# 11 PHYSICS

## Unit 5: Light + Sound

## Booklet I

## June 2nd - June 9th

NAME: Filled

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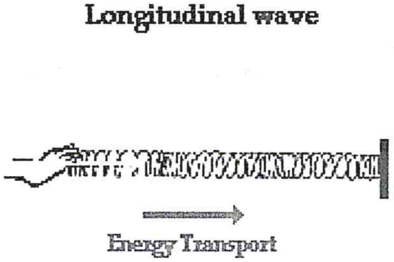
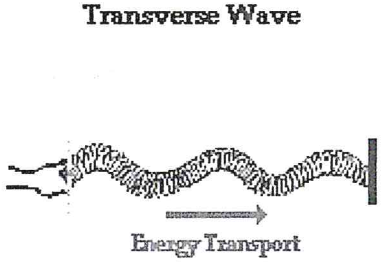
# U5:L1 Intro to Sound

Sound waves are longitudinal.



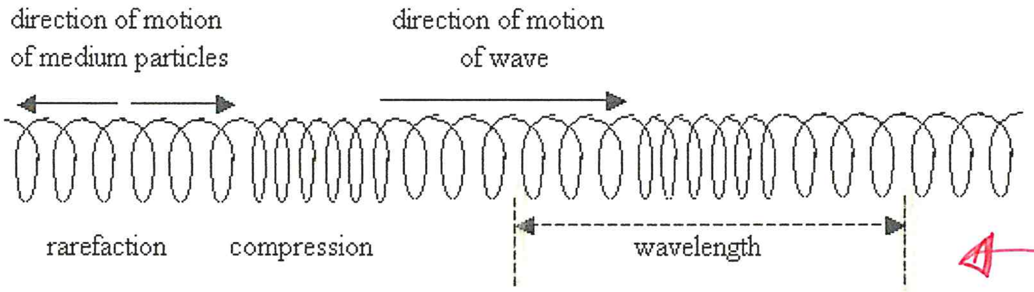


Recall that in a longitudinal wave, the vibration of the particles of the medium is along the same direction as the motion of the wave. A series of compressions and expansions move along the spring.

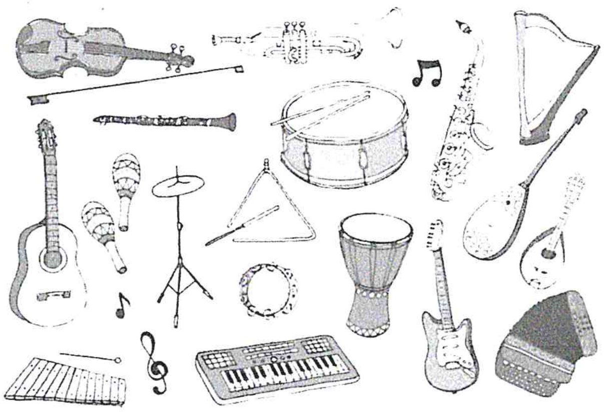
The **compressions** are those areas in a longitudinal wave that are momentarily **close together**.

**Rarefactions** (also called **expansions**) are regions where the coils are momentarily **far apart**.

Compressions and rarefactions correspond to the crests and troughs of a transverse wave.



One way to illustrate the wavelength of a longitudinal wave is as shown above, the distance between the centre of one rarefaction to the centre of another rarefaction.

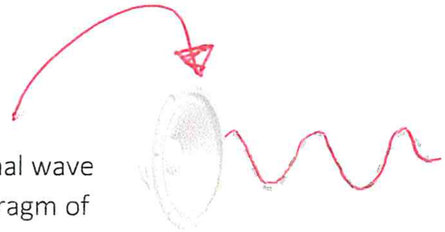


The longitudinal waves that make up sound are created by vibrating objects such as drums, guitar strings, vocal cords in animals or the diaphragms in a loudspeaker.

The sounds can be created or transmitted only in a medium such as a gas, liquid, or solid. The particles of the medium must be present for the disturbance to move from one place to another.

**Sound cannot exist in a vacuum.**

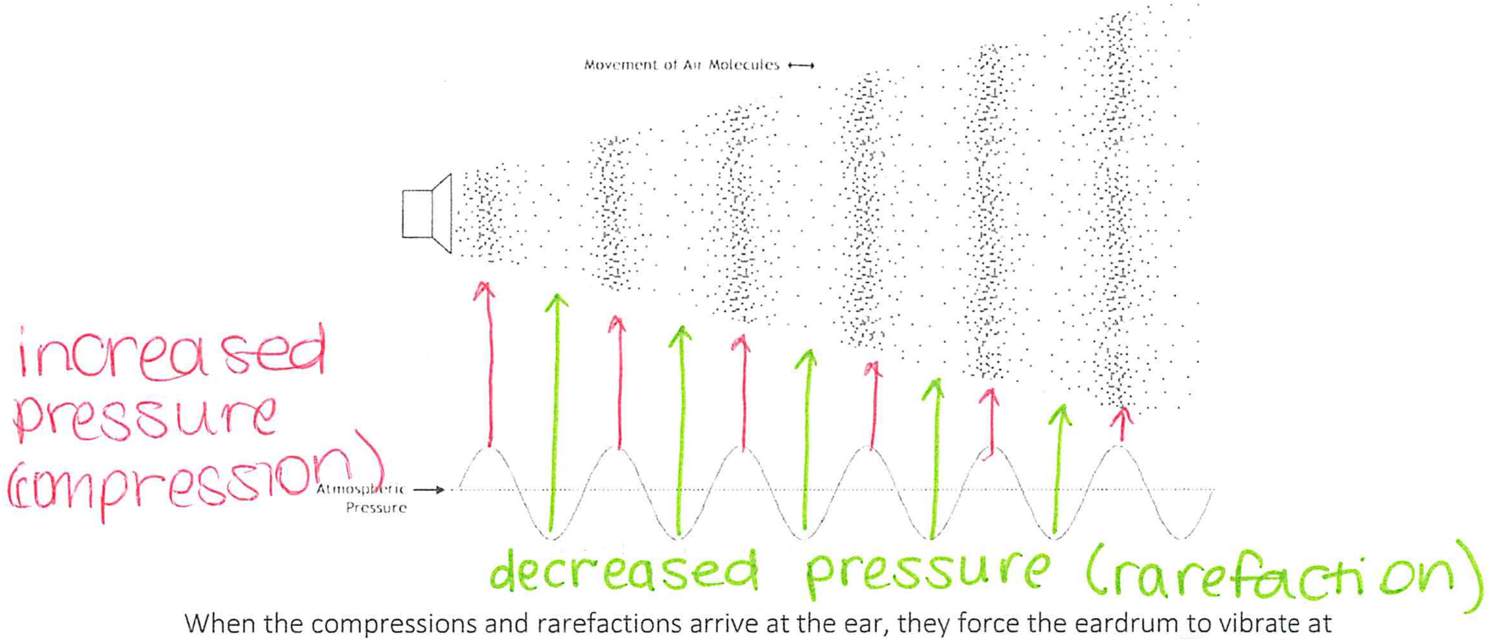
# Sound Propagation



To better understand how a vibrating object creates a longitudinal wave and why a medium is important, think about the vibrating diaphragm of a loudspeaker. When the diaphragm moves outward, it compresses the air directly in front of it.

This **compression causes the air pressure to rise slightly.** The region of increased air pressure is the compression part of the wave. The compression travels away from the speaker at the speed of sound. This compression is like the compressed region of coils in a slinky.

After producing the compression, the diaphragm reverses its motion and moves inward. The air **pressure is now slightly less than normal and produces the rarefaction** part of the wave. This is like the stretched region of coils in a slinky. This rarefaction follows immediately behind the compression and also travels away from the speaker at the speed of sound.



When the compressions and rarefactions arrive at the ear, they force the eardrum to vibrate at the same frequency as the vibrating source that produced the sound. The vibratory motion of the eardrum is interpreted by the brain as sound.

different eardrums hear different frequencies (ie: animals)

# Frequency

**Frequency** for any wave can be defined as the number of cycles of the wave that pass by a given point every second.

The sound wave is a longitudinal wave. Each cycle of the sound wave includes one compression and one rarefaction. If, for example, a speaker vibrates back and forth at a frequency of 500 Hz, then 500 compressions, each followed by a rarefaction, is generated every second.

A sound with a single frequency is called a **pure tone.**

A healthy young person hears all sound frequencies from 20 Hz to 20 000 Hz (20 kHz). This audible range of frequencies is called the **audio spectrum**. As a person ages the ability to hear high frequencies decreases. A normal middle-aged adult hears frequencies only up to 12-14 kHz.

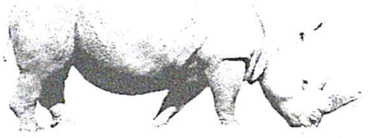
**Test how healthy your ears are! Watch the YouTube video "How Old are Your Ears (Hearing Test)" by ASAPScience (1 min 38 secs).**

An example of where pure tones are used is in push-button telephones. When a button is pressed, these phones simultaneously produce two pure tones. A different pair of tones is produced for each different button. The tones are transmitted electronically to a central telephone office where they activate switching circuits hat complete a call. If the number 3 is pressed on this type of phone, the frequencies 1477 Hz and 697 Hz are produced simultaneously. The number 7 produces the frequencies 1209 Hz and 852 Hz.

**Infrasonic** sound waves are those below the range of normal human hearing. These frequencies occur below 20 Hz.

**Ultrasonic** frequencies occur above the range of normal human hearing and therefore are above 20 kHz.

- A rhinoceros uses frequencies as low as 5 Hz to communicate.
- Bats use ultrasonic frequencies up to 100 kHz for locating their food sources and navigating.



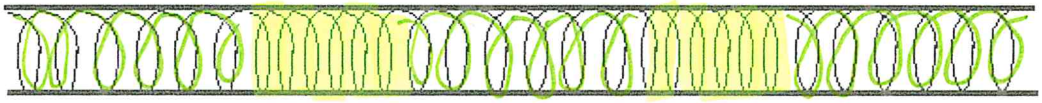
# Pitch and Loudness

Frequency is an objective physical property of a sound wave and can be measured using an electronic frequency counter.

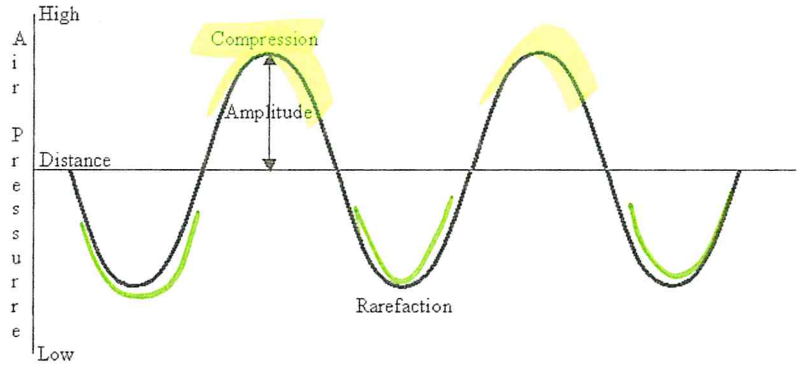
The listener's perception of sound is subjective. The brain interprets the frequency detected by the ear as a subjective or perceived quality called **pitch**. can be different between people!

A pure tone with a high frequency is interpreted as a high-pitched sound. A pure tone with a low frequency is interpreted as a low-pitched sound.

The diagram below shows a pure-tone sound wave travelling down a tube.



In the areas of rarefaction, the air pressure of the sound wave is low. In the areas of compression, the air pressure is high. An air pressure versus distance graph has the appearance of a transverse wave even though sound itself is a longitudinal wave.



The **pressure amplitude** shown in the graph above is the magnitude of the **maximum change in pressure** measured relative to undisturbed or atmospheric pressure.

**Loudness** is a characteristic of sound that depends primarily on the amplitude of the wave. The larger the amplitude, the louder the sound.

The pressure amplitude is an objective property of the sound wave since it can be measured with an instrument. Loudness, on the other hand, is subjective. Each individual determines what is loud, depending on their hearing.

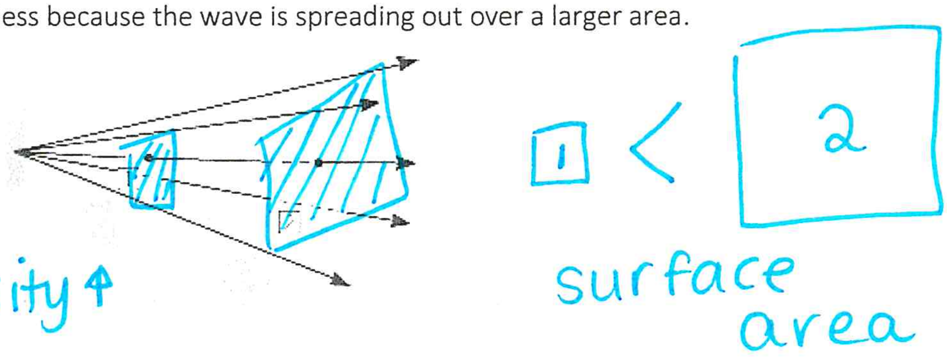
Sound waves  energy with them as they move from one place to another. This energy forces an eardrum to vibrate. In extreme cases such as a sonic boom, the energy can be sufficient to cause damage to windows and buildings. The amount of energy that is carried depends on the amplitude of the wave. So for example, if a guitar string is plucked with a greater force, then more energy is done to displace the string. It vibrates with a larger amplitude. The sound is louder and it carries more energy.

# Intensity and Decibels

The **intensity** of a sound wave is the energy that is transported past a given area per unit of time.

When the amplitude of a sound wave increases, the energy of the wave increases and therefore the intensity is also larger.

As the sound wave travels away from its source, the surface area is larger and the intensity of the wave is less. The intensity is less because the wave is spreading out over a larger area.



amplitude ↑ = e ↑ = intensity ↑

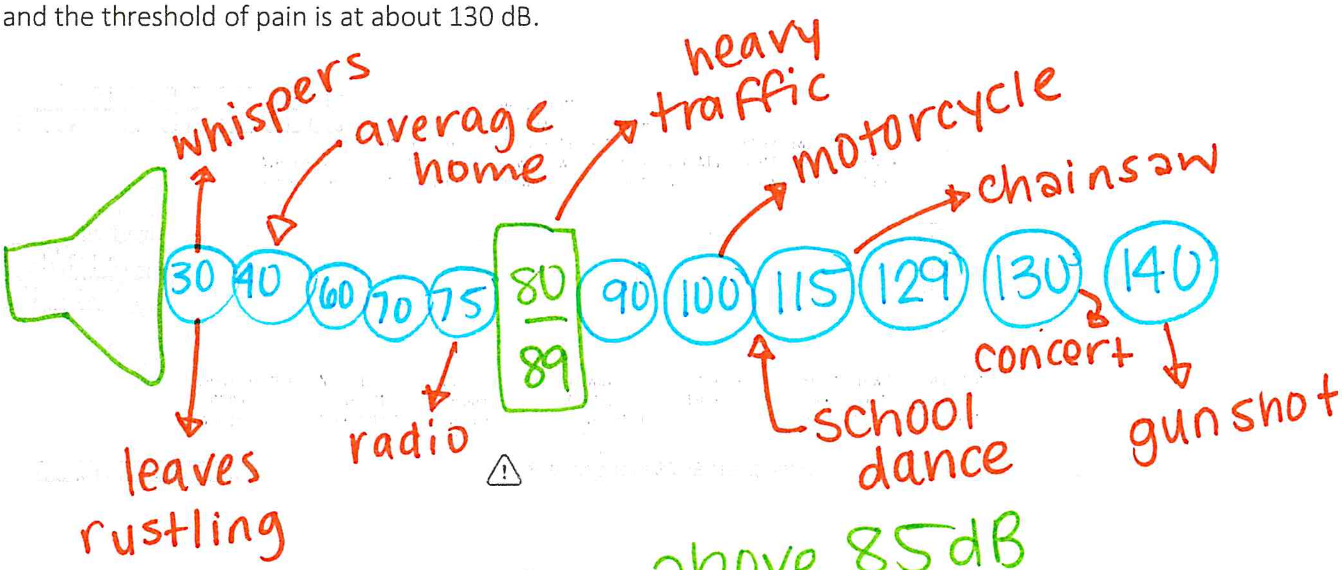
The **decibel** (dB) is a measurement that is used to compare two sound intensities.

The threshold of hearing is assigned a decibel level of 0 dB. A sound that is 10 ($10^1$) times more intense than the threshold is assigned a sound level of 10 dB. Rustling leaves would have a level of 10 dB.

A sound that is 100 ($10^2$) times more intense than the threshold is assigned a sound level of 20 dB. This is the sound of a whisper.

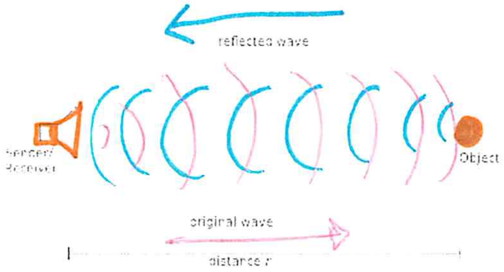
A sound that is 100 000 ($10^5$) times more intense than the threshold has a sound level of 50 dB. This is the sound of an average classroom with students actively working with each other.

Other examples of sound levels are a car without a muffler at 100 dB, a live rock concert at 120 dB, and the threshold of pain is at about 130 dB.



sounds above 85dB are harmful

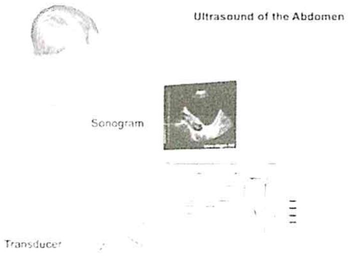
# Ultrasound



Ultrasonic waves can be used for diagnostic purposes in medicine. High-frequency sound pulses are produced by a transmitter and directed into the body.

Reflections of the pulses occur each time a pulse encounters a boundary between two tissues that have different densities or a boundary between a tissue and the adjacent fluid.

By scanning ultrasonic waves across the body and detecting the echoes generated from various internal locations, it is possible to obtain an image or sonogram of the inner anatomy.



Ultrasonic waves are used extensively in obstetrics (childbirth medicine) to examine the developing fetus. The fetus, surrounded by the amniotic sac, can be distinguished from other anatomical features. This makes it possible to determine the size and position of the fetus, and possible abnormalities that it may have.

Ultrasound is also used in other medically related areas. For example, malignancies in the liver, kidney, brain, and pancreas can be detected with ultrasound.

It is also possible to use ultrasound to monitor the real-time movement of pulsating structures such as heart valves and large blood vessels.

Ultrasound also has other applications in medicine. Neurosurgeons use a device called a cavitron ultrasonic surgical aspirator (CUSA) to remove brain tumors that were once thought to be inoperable. Ultrasonic sound waves cause the slender tip of the CUSA probe to vibrate at approximately 23 kHz. The probe shatters any section of the tumor that it touches, and the fragments are flushed out of the brain with a saline solution. Because the tip of the probe is small, the surgeon can selectively remove small bits of malignant tissue without damaging the surrounding healthy tissue.

# U5:L2 Sound Beats

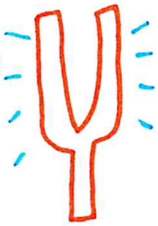
We learned in our work with waves that constructive and destructive interference occur when waves pass through each other.

Both transverse waves and longitudinal waves show this characteristic. Constructive and destructive interference occur when the waves are of the same frequency.

In this section we will study what happens when sound waves have slightly different frequencies.

This gives rise to a phenomenon called **beats.**

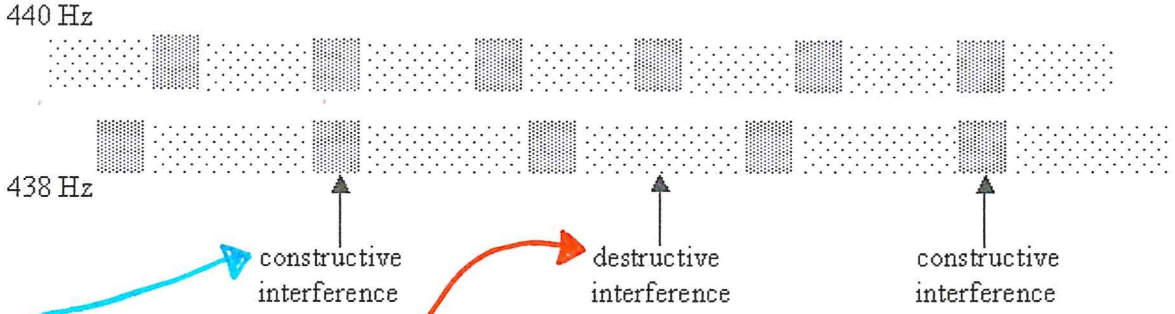
The diagram below shows sound coming from two tuning forks placed next to each other. A tuning fork produces a single-frequency sound wave when it is struck with a sharp blow.



One of the tuning forks produces a 440 Hz tone. The other tuning fork can also produce the same tone but a small mass added to the fork make it vibrate at a slightly smaller frequency of 438 Hz.

When the two forks are struck simultaneously, the loudness of the sound rises and falls periodically so that it is faint, then loud, then faint, then loud, and so on.

The periodic variations in loudness are balled **beats** and they result from the interference of sound waves with slightly different frequencies.



The diagram shows the condensations and rarefactions of the sound waves separately. In reality the waves spread out and overlap. The ear detects the combined total of the two.

Note that there are regions where the waves interfere constructively and places where they interfere destructively.

Two compressions add to form a larger compression according to the principle of linear superposition discussed earlier for waves. This constructive interference results in a loud sound.

When a compression and a rarefaction come together, destructive interference occurs and the sound intensity drops.

If the waves have the same amplitude, it will drop to zero.

The number of times that the loudness rises and falls every second is called the beat frequency. The beat frequency is the difference between the two sound frequencies. For the 440 Hz and 438 Hz waves discussed above, the beat frequency will be 2 Hz.

The following diagram helps to explain the difference between the frequencies of the sound producing the beats, and the beat frequency.

The graphs show the pressure patterns of a 10 Hz wave and a 12 Hz wave, along with the pressure pattern that results when the two overlap.

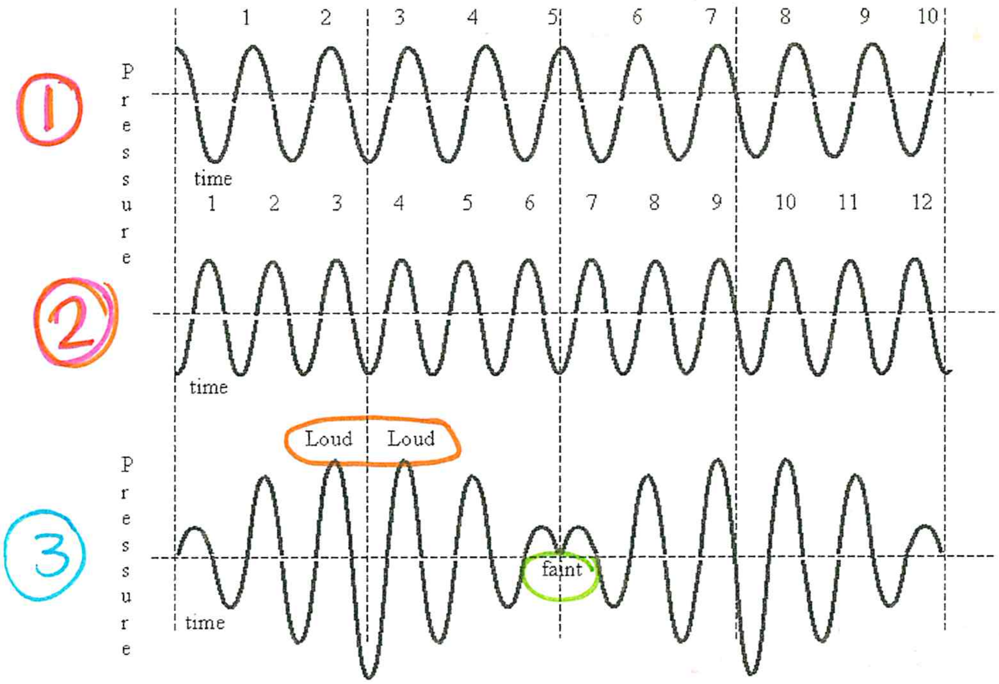
① ② The top two drawings show the pressure variations in one second for each wave.

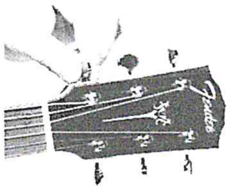
③ The third graph shows the result of adding together the first two patterns according to the principle of linear superposition.

Notice that in the third graph the amplitude is not constant. Instead the amplitude changes from a minimum to a maximum, back to a minimum an so on.

When such variations reach the ear and occur in the audible range, they produce a loud sound when the amplitude is a maximum and a faint sound when the amplitude is a minimum.

Two loud-faint cycles or beats occur in the one second interval shown in the drawing, corresponding to a beat frequency of 2 Hz. This is consistent with the earlier statement that the beat frequency is the difference between the frequencies of the individual waves, that is 12 Hz - 10 Hz = 2 Hz.



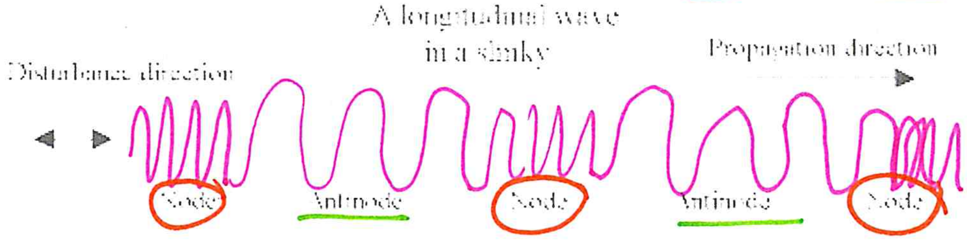


Musicians often tune their instruments by listening to beat frequency. For instance, a guitar player sounds an out-of-tune string along with a tone from a source known to have the correct frequency. The guitarist adjusts the tension in the string until the beats vanish, ensuring that the string is vibrating at the correct frequency.

In our study of waves in an earlier module, we observed that a standing wave pattern is formed when reflected waves interfere with incident waves to form a **standing wave** that appears to be standing in place.

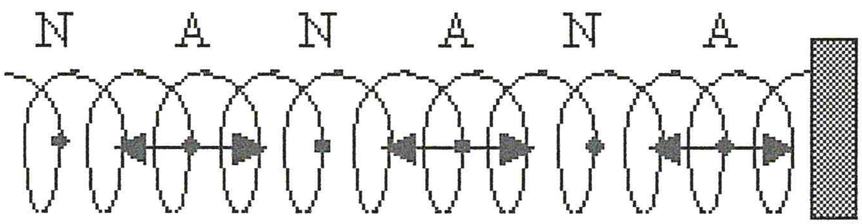
The frequency at which the standing wave exists is called the **resonant frequency**. Each resonant frequency is a whole-number multiple of the lowest resonant frequency called the fundamental frequency.

Sound waves are longitudinal waves, so to understand standing waves in sound let us look again at the Slinky. When the longitudinal waves reflect from a wall, the forward and backward waves can produce a standing wave. As in a transverse wave, there are nodes and antinodes.



At the nodes the coils of the Slinky do not vibrate at all, that is they do not have any displacement. At the antinodes the coils vibrate with maximum amplitude. This is indicated by the dots with the arrows indicating back and forth movement.

At an antinode, the coils have a maximum displacement. The vibration occurs along the line of travel of the individual waves. In a standing wave, the molecules and atoms of the medium behave as the dots in the diagram do.



N = Node

A = Anti Node

**Name:** Answers

## The Nature of Sound Waves

Read from **Lesson 1** of the **Sound and Music** chapter at **The Physics Classroom:**

**http://www.physicsclassroom.com/Class/sound/u11l1a.html**
**http://www.physicsclassroom.com/Class/sound/u11l1b.html**
**http://www.physicsclassroom.com/Class/sound/u11l1c.html**

**MOP Connection:** Sound and Music: sublevel 1

**TRUE or FALSE:** Identify the following statements as being either true (T) or false (F).

**T or F?**

T 1. Sound waves are longitudinal waves.

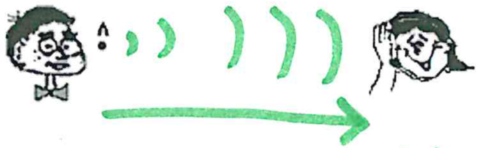
T 2. As the teacher talks, students hear the voice because particles of air move from the mouth of the teacher to the ear of the student.

T 3. Sound waves are mechanical waves.

T 4. All sound waves are produced by a vibrating object.

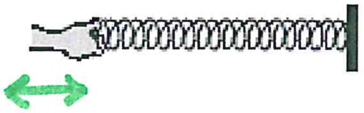
F 5. A sound wave does not consist of crests and troughs.

6. Mac is talking to Kate. The dot at A represents a particle of air. Describe the motion that this particle must undergo in order for Kate to hear Mac. Then show the motion by placing arrows on the diagram.



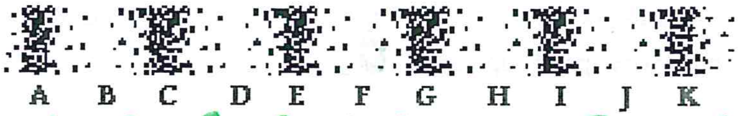
vibration sends air particles to Kate.

7. Tosh is holding one end of a slinky; the opposite end is attached to a wall. Tosh wishes to produce a longitudinal wave in the slinky. Describe how Tosh must move his hand in order to produce a longitudinal wave. Then place arrows on the diagram to show the way in which Tosh must move his hand.



Tosh must go back + forth for Longitudinal

8. A sound wave is moving through air. The diagram below represents a snapshot of the air particles at a given instant in time. Several regions are labeled with a letter. Use the letters to identify the compressions and rarefactions.



Compressions: A, C, E, G, I, K Rarefactions: B, D, F, H, J

9. A science fiction film depicts inhabitants of one spaceship (in outer space) hear the sound of a nearby spaceship as it zooms past at high speeds. Critique the physics of this film.

↓ air = similar to "vacuum"
Sound cannot travel without air particles.

## Properties of Sound Waves

Read from **Lesson 2** of the **Sound and Music** chapter at **The Physics Classroom:**

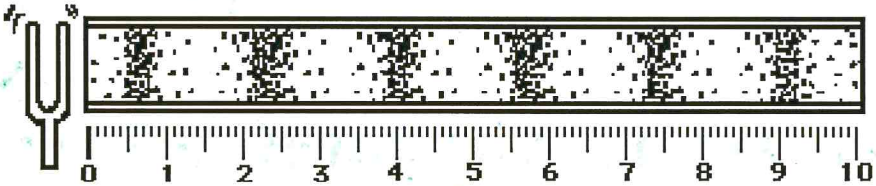
**http://www.physicsclassroom.com/Class/sound/u11l2a.html**
**http://www.physicsclassroom.com/Class/sound/u11l2b.html**
**http://www.physicsclassroom.com/Class/sound/u11l2c.html**

**MOP Connection:** Sound and Music: sublevel 2

**Review:**
Match the following wave quantities to the *mini-definition*. Place the letter in the blank.
A. Frequency B. Period C. Speed D. Wavelength E. Amplitude

C 1. **How fast** the wave moves through the medium.
D 2. **How long** the wave is.
A 3. **How often** the particles vibrate about their fixed position.
B 4. **How much time** it takes the particles to complete a vibrational cycle.
E 5. **How far** the particles vibrate away from their resting position.

6. A sound wave with its characteristic pattern of compressions and rarefactions is shown below. A centimeter ruler is included below the pattern. The wavelength of this sound wave is 2 cm.



7. The pitch of a sound is directly related to the A of the sound wave.
a. frequency b. wavelength c. speed d. amplitude

8. High pitched sounds have relatively large ______ and small ______. C
a. period, wavelength b. speed, period
c. frequency, wavelength d. period, frequency
e. amplitude, wavelength f. amplitude, speed

9. As the frequency of a sound increases, the wavelength ______ and the period ______. B
a. increases, decreases b. decreases, increases
c. increases, increases d. decreases, decreases

10. A sound wave is described as being 384 waves/s. This quantity describes the wave's A.
a. frequency b. period c. speed d. wavelength

11. The speed of a sound wave depends upon the D.
a. frequency of the wave b. wavelength of the wave
c. amplitude of the wave d. properties of the medium through which it moves

12. If a person yells (as opposed to whispering), then it will cause C.
a. air molecules to vibrate more frequently
b. the sound wave to travel faster
c. air molecules to vibrate with greater amplitude

13. If a person yells (as opposed to whispering), then it will cause C.
a. the pitch of the sound to be higher
b. the speed of the sound to be faster
c. the loudness of the sound to be louder

**Name:** ______________________

## The Speed of Sound

Read from **Lesson 2** of the **Sound and Music** chapter at **The Physics Classroom:**

**http://www.physicsclassroom.com/Class/sound/u11l2c.html**

1. When the C4 key on a piano keyboard is pressed, a string inside the piano is struck by a *hammer* and begins vibrating back and forth at approximately 260 cycles per second.
   a. What is the frequency in Hertz of the sound wave?

$f = 1/T = \boxed{0.0038 \text{ Hz}}$

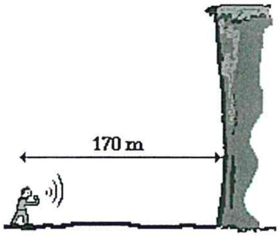
   b. Assuming the sound wave moves with a velocity of 345 m/s, what is the wavelength of the wave? **PSYW**

$\lambda = \frac{v}{f} = \frac{345}{0.0038} = \boxed{90789.47 \text{ m}}$

2. An automatic focus camera is able to focus on objects by use of an ultrasonic sound wave. The camera sends out sound waves that reflect off distant objects and return to the camera. A sensor detects the time it takes for the waves to return and then determines the distance an object is from the camera. If a sound wave (speed = 345 m/s) returns to the camera 0.115 seconds after leaving the camera, how far away is the object? **PSYW**

$v = \frac{d}{\Delta t} \therefore d = v(\Delta t) = 345(0.115) = \boxed{39.68 \text{ m}}$

3. Miles Tugo is camping in Glacier National Park. In the midst of a glacier canyon, he makes a loud holler. The sound (v = 345 m/s) bounces off the nearest canyon wall (which is located 170 meters away from Miles) and returns to Miles. Determine the time elapsed between when Miles makes the holler and the echo is heard. **PSYW**



$\Delta t = \frac{d}{v} = \frac{170}{345} = \boxed{0.49 \text{ s}}$

4. Suppose that sound travels at a speed of 345 m/s on the evening of a thunderstorm. There is a lightning strike some distance from your home. The light reaches you nearly immediately. Yet the thunder is heard 3.5 seconds later. How many miles from your home did the lightning strike? (1609 meters = 1 mile) **PSYW**

$d = v(\Delta t) = 345(3.5) = \boxed{1207.5 \text{ m}}$

5. A male vocalist with a bass voice can sing as low as 85 Hz. Given that the speed of sound is 345 m/s, what is the wavelength of the sound waves? **PSYW**

$\lambda = \frac{v}{f} = \frac{345}{85} = \boxed{4.06 \text{ m}}$

6. A female vocalist with a soprano voice can sing as high as 1000 Hz. Given that the speed of sound is 345 m/s, what is the wavelength of the sound waves? **PSYW**

$\lambda = \frac{345}{1000} = \boxed{0.345 \text{ m}}$