Unit Plan - Physics of Music and Sound **Elise McCarren**

Table of Contents

Big Ideas

- What is sound?
- How do humans perceive sound?
- What are waves?
- How do changes in the nature of sound waves affect the sound?
- How fast does sound travel?
- How do we hear?
- How do instruments work?

Goal

Design a unit and series of activities on sound and music that:

- Involve interactivity
- Involves as many senses as possible
- Uses free software
- Increases student understanding of music as it relates to sound
- Is accessible for students of many ages and ability levels

Goals for students:

- Help them to understand their bodies & their relationships to the physical world
- Continue to instill mathematical principles and dimensional analysis
- Provide experiences for students to analyze and create data and to make scientific arguments
- Create an appreciation for the complexity of music and sound

Intended Audience

11-12 grade students, experienced in algebra and algebra II, in physics as a third year course after completing chemistry, or with similar experience in dimensional analysis

Associated Next Generation Science Standards

HS-PS4-1: Use mathematical representations to support a claim regarding relationships among frequency, wavelength, and speed of waves traveling in various media.

Accompanying Textbooks

Active Physics Medicine, It's About Time, Inc. Armonk, NY, 2000.

Active Physics Core Select, It's Amount Time, Inc. Armonk, NY, 2005.

Kramer, Craig. Merill Physics, Glencoe, Burbank, IL, 1995.

Software Used

- Visual Analyzer 2011
- Android Apps:
    - FrequenSee
    - SoundForm
    - Decibel Meter
- PhET Sound simulation: http://phet.colorado.edu/en/simulation/sound

Common Student Misconceptions

1. Sounds can be produced without using any material objects.
2. Hitting an object harder changes the pitch of the sound produced.
3. Human voice sounds are produced by a large number of vocal cords that all produce different sounds.
4. Loudness and pitch of sounds are the same things.
5. You can see and hear a distinct event at the same moment.
6. Sounds can travel through empty space (a vacuum).
7. Sounds cannot travel through liquids and solids.
8. Sounds made by vehicles (like the whistle of a train) change as the vehicles move past the listener because something (like the train engineer) purposely changes the pitch of the sound.
9. In wind instruments, the instrument itself vibrates (not the internal air column).
10. Music is strictly an art form; it has nothing to do with science.
11. Sound waves are transverse waves (like water and light waves).
12. Matter moves along with water waves as the waves move through a body of water.
13. When waves interact with a solid surface, the waves are destroyed.
14. In actual telephones, sounds (rather than electrical impulses) are carried through the wires.
15. Ultrasounds are extremely loud sounds.
16. Megaphones create sounds.
17. Noise pollution is annoying, but it is essentially harmless.

Hapkiewicz, A. (1992). Finding a List of Science Misconceptions. MSTA Newsletter, 38(Winterí92), pp.11-14.

Lecture Notes and Activities

Major Topic 0: Producing Sound

Demo: Can Telephone Activity

Materials Needed: Can Telephone

Activity: Take students into hallway, have them talk on the telephone when it is loose and when it is taut.

Notes/Discussion:

How could you hear the person on the other end, even whispers?

- Sound was created by causing a vibration in the can, which traveled down the string, which then transferred to the other can to your ear.

Why did it work when the string was not taut?

- The string has to be tight in order for a pressure variation to occur in the air.
- The string needs to vibrate which will cause regular variations in air pressure on the other end.
- When it's loose, it cannot continue the vibrations from your voice and will "fizzle out" before reaching the other end.

When we look at sound, we're going to be looking at how sound is produced, how it may travel, and how we perceive it. All of the principles of sound are rooted in the idea that sound must travel through a vibrating medium, such as the string in the can telephone, to be heard. When we are done, you will be able to better describe how sound behaves as a wave, how sound is produced by instruments, and the capabilities that humans have to hear it.

Major Topic 1: The Decibel Scale

Lecture Notes:

To measure the sound pressure level hitting your ears, we generally use the decibel scale. The scale measures the sound intensity in Watts per meter squared, and they are converted to decibels (dB) using the equation below:

$$\beta = 10 \log (I/I_o)$$

β represents the number of decibels, and this is determined on a logarithmic scale by comparing I to I_o,, the intensity for the threshold of hearing (softest possible sound that you can hear.) The threshold of hearing, $I_o = 10^{-12}$ W/m^2.

The table below shows the relationship between some common I/I_o values and the decibel scale.. Notice a pattern? This is a logarithmic scale. So this means that for when $I/I_o = 100 = 10^2$(or the pressure of a particular sound is 100 times that of the threshold of hearing), it means that the sound has an intensity level of 20 dB.

Table 14-1 Intensity and Intensity Level of Some Common Sounds ($I_0 = 10^{-12}$ W/m^2)

Source	I/I_0	dB	Description
	10^0	0	Hearing threshold
Normal breathing	10^1	10	Barely audible
Rustling leaves	10^2	20	
Soft whisper (at 5 m)	10^3	30	Very quiet
Library	10^4	40	
Quiet office	10^5	50	Quiet
Normal conversation (at 1 m)	10^6	60	
Busy traffic	10^7	70	
Noisy office with machines; average factory	10^8	80	
Heavy truck (at 15 m); Niagara Falls	10^9	90	Constant exposure endangers hearing
Old subway train	10^{10}	100	
Construction noise (at 3 m)	10^{11}	110	
Rock concert with amplifiers (at 2 m); jet takeoff (at 60 m)	10^{12}	120	Pain threshold
Pneumatic riveter; machine gun	10^{13}	130	
Jet takeoff (nearby)	10^{15}	150	
Large rocket engine (nearby)	10^{18}	180	

Continued Notes:

What are some situations where you have heard a sound that is so loud that it hurts your ears? How many decibels do you think that sound was.

To give you some ideas of how the decibel scale works, here are some examples of common decibel levels from the previous table that we have:

Softest sound you can hear – 0 decibels
Whisper – 20 decibels
Inside a bus – 90 decibels
Rocket launch - 170 decibels

Mini-Lab: In-Class Decibel Calculation – What is the sound level of everyday life?

Materials Needed:

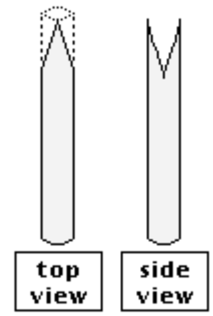
- Cell phone decibel meter app
- Students willing to be loud (should not be hard to find)

Have students use microphone to measure decibel level of various activities, have student volunteer record decibel level on table

- Singing
- Humming
- Whispering
- Talking
- Yelling
- Screaming
- Radio far away
- iPod Earbuds

Any surprises?

Demo: What happens when we measure multiple sounds for the same source?



Materials Needed:

- Enough drinking straws cut into "reed" instruments for everyone in class
- Decibel meter app for iPhone or Android

Activity:

Have everyone practice playing their "instruments" for the rest of the class. Then, take measurements of decibel levels using one instrument, then two, then the whole class.

Should conclude that each additional person playing (doubling the sound intensity) increases the number of decibels by approximately 3 dB.

**Suggestions for learning to play reed instruments: Students will need to apply pressure with their mouth (but not too much pressure so that it doesn't vibrate) to the straw slightly past the point of the "V." Once they get it, they get it. If they are having trouble, suggest that they experiment with moving their mouth forward and backward on the straw.

Discussion Questions

- What do you notice about the data?
- Does anything surprise you?
- Why do you think we have a decibel scale?
- If we had an increase of 3 dB for each additional instrument, by what factor do you think the sound intensity changed?
- Do you think you have experienced hearing loss due to sounds at a dangerous level?

Decibels - Data Tables/Handouts

1. In the table below, record the activity you participated in (whispering, talking, yelling, etc, and the recorded decibel level.)

Activity	**Decibel Level**

2. In the table below record the number of people playing straws and their decibel level.

Number of People Playing	**Decibel Level**

Accompanying Reading: Active Physics – Medicine pg. 13, 18

FOR YOU TO READ

Sound Levels

The decibel scale is unusual. You probably noticed that doubling the sound intensity increased the sound level by about 3 dB. If the previous activity was done very precisely, in a special room with hardly any sound reflection, the increase would be very close to 3 dB. Because you are in the classroom, you can't get rid of sound reflections. Therefore these decibel changes will be only approximately 3 dB.

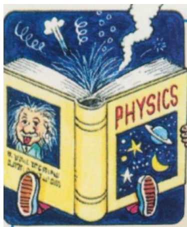
Notice that it doesn't matter what the initial sound intensity is. If you double that intensity, the sound level increases by 3 dB. If one person whispering is measured at 20 dB, two people whispering would be 23 dB. A person playing an electric guitar may be measured at 95 dB. Two people playing identical electric guitars in the same way would be 98 dB.

The table compares sound intensity with decibel levels for a wide range of sound intensities. Don't worry about the unfamiliar units of intensity. It's the changes that count. In this table, the softest sound the human ear can detect is set at zero decibels.

Do you think the human ear is a sensitive sound detector? Look at the range of sound intensity that the ear can detect. The peak sound level at a rock concert is about ten million million (10^1 W/m^2 ÷ 10^{-12} W/m^2 = 10^{13}) times stronger than the softest sound you can hear. That's what your ears can do!

Approximate Intensities of Various Sounds

Sound	Intensity W/m^2 (Watts per meter squared)	Level dB
Rocket launch	100,000 (10^5)	170
Peak sound level at a rock concert	10 (10^1)	130
Sound that produces pain	1 (10^0)	120
Woodworking shop	0.1 (10^{-1})	110
Near a pneumatic drill (jack hammer)	0.01 (10^{-2})	100
Inside a bus	0.001 (10^{-3})	90
Speech at 1 meter	0.000,001 (10^{-6})	60
Inside a typical house	0.000,000,01 (10^{-8})	40
Whisper	0.000,000,000,1 (10^{-10})	20
Softest sound you can hear	0.000,000,000,001 (10^{-12})	0

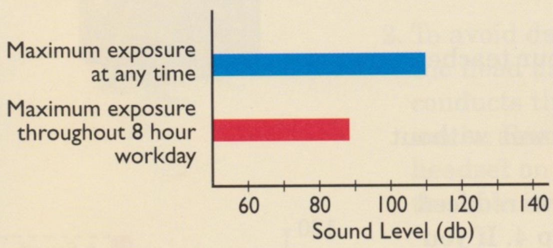


FOR YOU TO READ

Sound Levels in the Environment

Many measurements have been made of environmental sound levels. The table to the right shows sound levels from various household appliances and leisure activities.

Many workers are exposed to loud sounds on the job. What protection do these workers have? There are two federal regulations regarding noise exposure in the United States. Both say that no worker should ever be exposed to more than 115 dB. One regulation says that workers should be exposed to no more than 90 dB for an 8-hour day; the other says no more than 85 dB for an 8-hour day. In Europe, the maximum allowed is 75–80 dB for an 8-hour day.



Sound Levels from Household Appliances and Leisure Activities (dB)	
Jackhammer	116
Average gun (hunting)	115
Chain saw	106
Stereo, extremely loud party	102
Average home power tools	100
Electric drill	95
Lawn mower	92
Hair dryer	88
Food mixer in liquid	85
Inside an automobile	84
Vacuum cleaner	80
Stereo, loud	79
Piano, average	76
Shower stall	73
TV, average	64

Source: *Acquired Hearing Impairment in the Adult.* Minister of National Health and Welfare. Ottawa, Canada (January 1988), pp. 35–36.

Unsafe Listening - http://www.lasvegassun.com/community/press-releases/1610/

Optional Homework Activities for Students

Active Physics – Medicine pg. 14 – 15 "Physics to Go" Section

Merrill Physics, Chapter 14., pg. 325 #7, 8

REFLECTING ON THE ACTIVITY AND THE CHALLENGE

In this activity you measured sound intensity. Using your voice or other musical instruments, you discovered how the decibel scale works. You found that when you double the sound intensity, you increase the sound level by 3 dB. This knowledge will be important when you try to explain to your principal the importance of sound intensity levels of the rock band you were planning to invite to the school dance.

You also read about the large range of intensities that the ear can sense and how the decibel scale organizes these sounds from loudest to softest. You can now compare the loudest sounds in rock music with other loud sounds.

PHYSICS TO GO

1. Doubling the sound intensity increases the decibel level by 3. Suppose two singers together made a sound level of 70 dB. If two more joined in, the sound level would be 70 dB + 3 dB = 73 dB. If four more joined in, making a total of eight, the decibel level would again increase by 3 dB to 76 dB.
   a) What would be the level for a chorus of 16 singers?
   b) What would be the decibel level for 32 singers?
   c) Estimate the decibel level for 24 singers. Tell how you found your estimate.
   d) If the decibel level is 85, how many singers are singing?
   e) If the decibel level is 67, how many singers are singing?

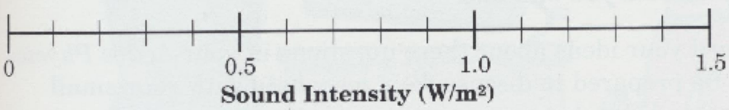
2. Suppose you measure the sound level of a jackhammer to be 100 dB.
   a) You back away until the level is reduced to 90 dB. By how much did the sound intensity go down?
   b) Suppose you back away again until the level is reduced to 70 dB. By how much did the sound intensity go down from your first measurement?

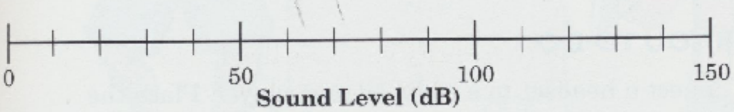
3. Suppose one musical instrument produces sound at 75 dB and another produces sound at 80 dB. Estimate the decibel level if both instruments are playing together. Explain how you made your estimate.

4. How would the measurement in For You to Do have been different if the singers' voices had been amplified?

5. How can the same sound level meter be used to measure such different sound levels as a quiet street or a noisy woodworking shop?

6. To help answer how the decibel scale is helpful, plot just a few of the values from the table in For You to Read. Use number lines like the ones shown below. Each number line is already labeled with the units you will use.





Go back to the table to get the values for the following sounds and plot each one on both number lines.

Sound that produces pain
Woodworking shop
Inside a bus
Inside a typical house

Which units were easier to use? Why?

STRETCHING EXERCISE

If you can borrow the sound level meter overnight, measure sound levels on a bus, a subway, a busy street and various places at home. Present your results to the class.

REVIEWING CONCEPTS

1. A firecracker is set off at the same level as a set of hanging ribbons. Describe how they might vibrate.
2. When a ringing bell is placed inside a jar connected to a vacuum pump and the air is removed, no sound is heard. Explain.
3. In the last century, people put their ears to a railroad track to get an early warning of an approaching train. Why did this work?
4. When timing the 100-m run, officials at the finish line are instructed to start their stopwatches at the sight of smoke from the starter's pistol and not on the sound of its firing. Explain. What would happen to the times for the runners if the timing started when sound was heard?
5. Does the Doppler shift occur for only some types of waves or all types of waves?
6. Sound waves with frequencies higher than can be heard by humans, called ultrasound, can be transmitted through the human body. How could ultrasound be used to measure the speed of blood flowing in veins or arteries?
7. How can a certain note sung by an opera singer cause a crystal glass to shatter?
8. In the military, as marching soldiers approach a bridge, the command "route step" is given. The soldiers then walk out-of-step with each other as they cross the bridge. Explain.
9. How must the length of an open tube compare to the wavelength of the sound to produce the strongest resonance?
10. Explain how the slide of a trombone changes the pitch of the sound using the idea of a trombone as a resonance tube.
11. What property distinguishes notes played on both a trumpet and a clarinet if they have the same pitch and loudness?

APPLYING CONCEPTS

1. A common method of estimating how far a lightning flash is from you is to count the seconds between the flash and the thunder, and divide by three. The result is the distance in kilometers. Explain how this rule works.
2. The speed of sound increases when the air temperature increases. For a given sound, as the temperature rises, what happens to
   a. the frequency?
   b. the wavelength?
3. In a science fiction movie, when a spaceship explodes, the vibrations from the sound nearly destroy a nearby spaceship. If you were the science consultant for the movie, what would your advice be for the producer?
4. Suppose the horns of all cars emitted sound to the same pitch or frequency. What would be the change in the frequency of the horn of a car moving
   a. toward you?
   b. away from you?
5. A bat emits short pulses of high-frequency sound and detects the echoes.
   a. In what way would the echoes from large and small insects compare if they were the same distance from the bat?
   b. In what way would the echo from an insect flying toward the bat differ from that of an insect flying away from the bat?
6. If the pitch of sound is increased, what are the changes in
   a. the frequency?
   b. the wavelength?
   c. the wave velocity?
   d. the amplitude of the wave?
7. Does a sound of 40 dB have a factor of 100 (10^2) times greater pressure variations than the threshold of hearing, or a factor of 40 times greater?
8. Simon lit a firecracker, and the firecracker produced a sound level of 90 dB. How many identical firecrackers would have to be exploded simultaneously at the same location to produce a 100-dB sound level?
9. The speed of sound increases with temperature. Would the pitch of a closed pipe increase or decrease when the temperature rises? Assume the length of the pipe does not change.
10. Two flutes are tuning up. If the conductor hears the beat frequency increasing, are the two flute frequencies getting closer together or farther apart?
11. A covered organ pipe plays a certain note. If the cover is removed to make it an open pipe, is the pitch increased or decreased?

Major Topic 2: Frequency, Pitch, Sound as Waves

Essential Vocabulary			
Wave	Crest	Trough	Amplitude
Frequency	Wavelength	Pitch	Constructive interference
Destructive interference	Transverse wave	Standing wave	Volume
Period	Node		

Section A: Waves

Demo & Lecture Notes

Materials needed:

- Slinky
- Handwritten wave handout

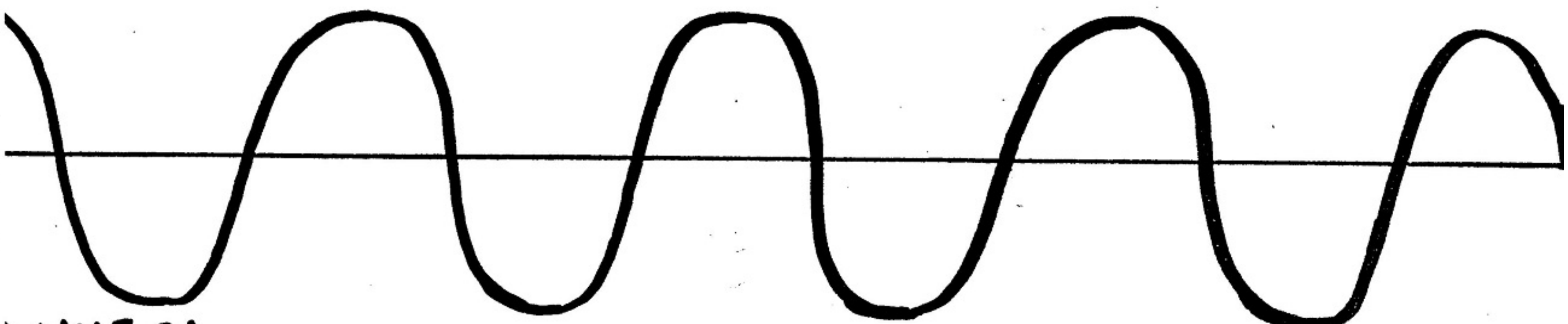
Students take notes and fill in written wave handout as we go along.

1. Demonstrate waves moving quickly, slowly, transverse waves, longitudinal waves, and standing waves.
   a. Transverse waves – particles of medium moving perpendicularly to the direction of the wave
   b. Standing waves – wave appears to be standing still
   c. Longitudinal waves – particles move parallel to the direction of a wave
2. On worksheet have students identify crest, trough, and wavelength of wave.
   a. Wavelength – shortest distance between points where the wave pattern repeats itself (ex. crest to crest or trough to trough
   b. Amplitude – maximum distance from rest or equilibrium position
   c. Trough – low point of each wave motion
   d. Crest – high point of each wave motion
3. Define wave motion
   a. Frequency - # of waves that pass through a point per second. Hz or s^{-1} or 1/s
   b. Period – time it takes for one complete wave to pass by (seconds) Equation: $T = 1/f$
   c. Velocity – distance wave moves over time. Equation: $v = d/t$
4. Wave interaction:
   a. Constructive interference
   b. Destructive interference
   c. Two pulses sent down at same time

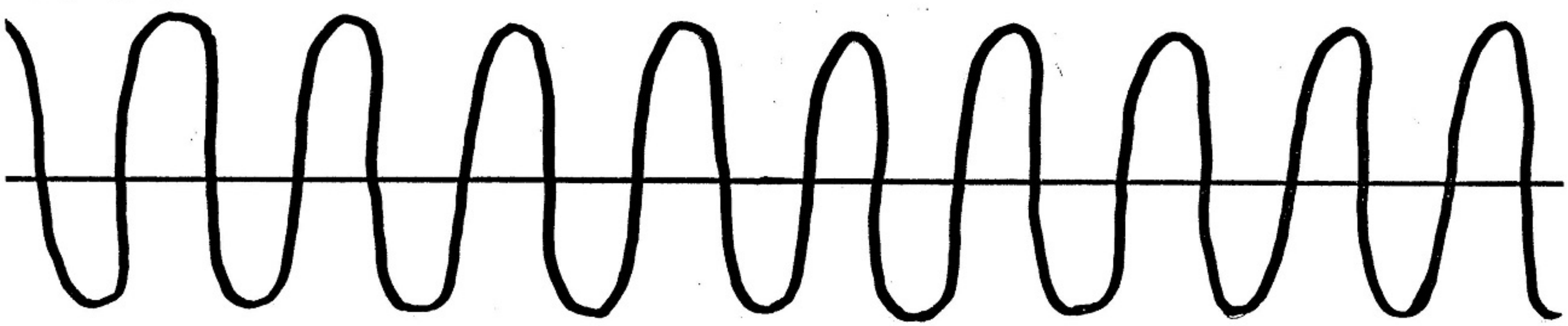
Physics-Chapter 14

WAVES

WAVE 1:



WAVE 2:



Lab – Waves on a Snakey pg. 292 Merill Physics

Materials Needed

- Slinkies for each group
- Meter sticks
- Stopwatches

Students do lab in groups of 2-3, go over results as a class.

Focus particularly on the speed of a wave changing as it travels, applications to sound question, let them play in general.

PHYSICS LAB

Waves on a Snakey

Purpose

To investigate properties of waves using a snakey as a model.

Materials

- a long coil spring (snakey)
- stopwatch
- meter stick

Procedure

1. You will need a clear path of about 6 meters for this activity.
2. Slowly stretch the snakey to the length suggested by your instructor.
3. Grip the snakey firmly with one hand for the entire activity.
4. It is easier to see the motion of the snakey if you are near one end. Don't watch from the side.
5. As the pulses die out, they can still be felt. Trust your feelings!
6. This activity is a sensory experience. Each student in the group should take some time on the end of the snakey.
7. Make a quick sideways snap with your wrist to produce a transverse pulse in the snakey.
8. Notice how many times the pulse will move back and forth on the snakey.
9. Look closely at the questions in the observation section. Try to design and conduct an experiment to answer each question.

Observations and Data

1. What happens to
   a. the amplitude of a wave as it travels?
   b. the speed of a wave as it travels?
2. Does the speed depend on the amplitude?
3. Put 2 quick pulses into the snakey. The distance between pulses is called λ. Does λ change as the pulses move?
4. What can you do to decrease the value of λ?
5. Do pulses bounce off each other or pass through?

Analysis

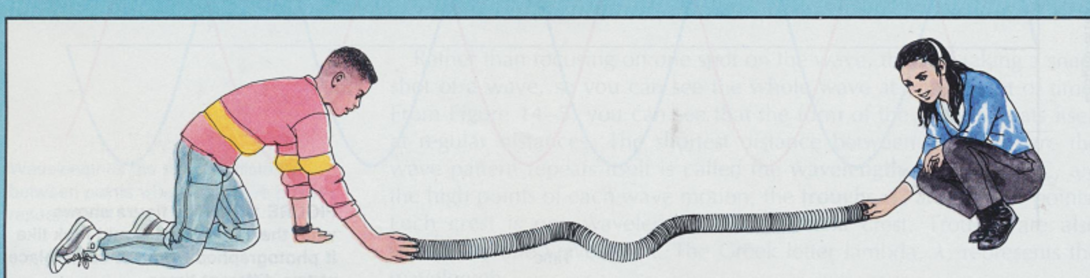
1. You probably used transverse waves for this activity. Should your answers be accurate for pressure (longitudinal) waves? Why?
2. Check your answers for steps 1-3 with *pressure* waves.
3. Use the snakey to find out if pressure waves go through each other. Describe your results.

Applications

Sound waves are pressure waves. Make your predictions consistent with your snakey results.

1. Does the speed of the sound depend on the loudness? (Do louder sounds travel *faster* than quiet sounds?)
2. Compare the speed of high frequency (short wavelength) sounds to low frequency (long wavelength) sounds.

* NOTE * Snakeys are *NOT SOCIAL*. Do not allow the snakeys to get tangled together! Each snakey should be stored in its own personal container!



Waves Mathematically Lecture Notes:

Review equations:

1. Relating period to frequency: $T = 1/f$ (units of T typically in seconds)
2. Relating calculating velocity $v = d/t$ (units of V typically in meters/sec, or m/s)

Now that we have looked qualitatively at the behavior of sound waves, we need to be able to describe them mathematically. We will use a fairly simple equation to relate the frequency of a wave to its velocity.

This equation is:

$$v = \lambda \cdot f$$

Where

V = velocity in m/s

λ = wavelength in m

f = frequency in Hz or s^{-1}

Can also rearrange the equation:

$f = v/\lambda$ $\lambda = v/f$

Examples of problems:

Merrill Physics pg. 293 Example (See attached on next page)

Homework/ Practice Problems:

Merrill Physics pg. 293 – Practice problems #1-4

Active Physics to go pg. 337-339

Example Problem

Velocity of a Traveling Wave

A sound wave with frequency 262 Hz has a wavelength of 1.29 m. What is the velocity of the sound wave?

Given: frequency, $f = 262$ Hz
wavelength, $\lambda = 1.29$ m

Unknown: velocity, v
Basic equation: $v = \lambda f$

Solution: $v = \lambda f = (1.29 \text{ m})(262 \text{ Hz}) = 338 \text{ m/s}$

Practice Problems

1. A sound wave produced by a clock chime 515 m away is heard 1.50 s later.
  a. What is the speed of sound in air?
  b. The sound wave has a frequency of 436 Hz. What is its period?
  c. What is its wavelength?

2. A hiker shouts toward a vertical cliff 685 m away. The echo is heard 4.00 s later.
  a. What is the speed of sound in air?
  b. The wavelength of the sound is 0.750 m. What is its frequency?
  c. What is the period of the wave?

3. A radio wave, a form of electromagnetic wave, has a frequency of 99.5 MHz (99.5×10^6 Hz). What is its wavelength?

4. A typical light wave has a wavelength of 580 nm.
  a. What is the wavelength of the light in meters?
  b. What is the frequency of the wave?

GEOLOGY CONNECTION

Waves through a solid can be either transverse or longitudinal. An earthquake produces both transverse and longitudinal waves that travel through Earth. Geologists studying the waves with seismographs found that longitudinal waves could pass through Earth's core, transverse waves could not. From this evidence, they concluded that Earth's core is liquid. From its density, it is most likely molten iron.

When a wave passes through a medium, the particles move, but they are not carried along with the wave. For example, as a transverse wave passes through a spring, Figure 14–2a, each coil is in the same position as before the wave arrived. Even though huge waves may crash on a beach as the result of a distant storm, the water in the waves remains near the beach.

Reflecting on the Activity and the Challenge

Slinky waves are easy to observe. You have created transverse and compressional slinky waves and have measured their speed, wavelength, and frequency. For the **Chapter Challenge**, you may want to create musical instruments. You will receive more guidance in doing this in the next activities. Your instruments will probably not be made of Slinkies. You may, however, use strings that behave just like Slinkies. When you have to explain how your instrument works, you can relate its production of sound in terms of the Slinky waves that you observed in this activity.

Physics To Go

1. a) Four characteristics of waves are amplitude, wavelength, frequency, and speed. For each characteristic, tell how you measured it when you worked with the Slinky.
   b) For each characteristic, give the units you used in your measurement.
   c) Which wave characteristics are related to each other? Tell how they are related.

2. a) Suppose you shake a long Slinky slowly back and forth. Then you shake it rapidly. Describe how the waves change when you shake the Slinky more rapidly.
   b) What wave properties change?
   c) What wave properties do not change?

3. Suppose you took a photograph of a wave on a Slinky. How can you measure wavelength by looking at the photograph?

4. Suppose you mount a video camera on a tripod and aim the camera at one point on a Slinky. You also place a clock next to the Slinky, so the video camera records the time. When you look at the video of a wave going by on the Slinky, how could you measure the frequency?

5. a) What are the units of wavelength?
   b) What are the units of frequency?
   c) What are the units of speed?
   d) Tell how you find the wave speed from the frequency and the wavelength.

e) Using your answer to **Part (d)**, show how the units of speed are related to the units of wavelength and frequency.

6. a) What is a standing wave?
   b) Draw a standing wave.
   c) Add labels to your drawing to show how the Slinky moves.
   d) Tell how to find the wavelength by observing a standing wave.

7. a) Explain the difference between transverse waves and compressional waves.
   b) Slinky waves can be either transverse or compressional. Describe how the Slinky moves in each case.

8. a) When you made standing waves, how did you shake the spring (change the frequency) to make the wavelength shorter?
   b) When you made standing waves, how did you shake the spring (change the frequency) to make the wavelength longer?

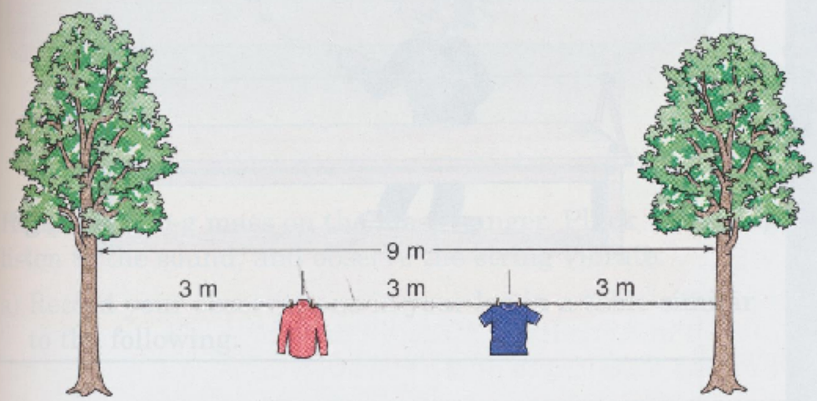
9. Use the wave viewer and adding machine tape to investigate what happens if the speed of the wave increases. Pull the tape at different speeds and report your results.

10. A Slinky is stretched out to 5.0 m in length between you and your partner. By shaking the Slinky at different frequencies, you are able to produce waves with one loop, two loops, three loops, four loops, and even five loops.
    a) What are the wavelengths of each of the wave patterns you have produced?
    b) How will the frequencies of the wave patterns be related to each other?

11. A tightrope walker stands in the middle of a high wire that is stretched 10 m between the two platforms at the ends of the wire. He is bouncing up and down, creating a standing wave with a single loop and a period of 2.0 s.

a) What is the wavelength of the wave he is producing?
b) What is the frequency of this wave?
c) What is the speed of the wave?

12. A clothesline is stretched 9 m between two trees. Clothes are hung on the line as shown in the diagram. When a particular standing wave is created in the line, the clothes remain stationary.



a) What is the term for the positions occupied by the clothes?
b) What is the wavelength of this standing wave?
c) What additional wavelengths could exist in the line such that the clothes remain stationary?

13. During the Slinky lab, your partner generates a wave pulse that takes 2.64 s to go back and forth along the Slinky. The Slinky stretches 4.5 m along the floor. What is the speed of the wave pulse on the Slinky?

14. A drum corps can be heard practicing at a distance of 1.6 km from the field. What is the time delay between the sound the drummer hears ($d = 0$ m) and the sound heard by an individual 1.6 km away? (Assume the speed of sound in air to be 340.0 m/s.)

Determining the Speed of Sound - Whole Class Lab

Materials needed:

- Computer with Sound PhET simulation
- Two students to measure

Predictions: Write down on a piece of paper what you think.

1. Does all sound move at the same speed?

2. Does sound or light travel faster?

Discuss with a partner before moving on.

Lecture notes:

(Demonstrate simulation with wave and time measurement)

http://phet.colorado.edu/en/simulation/sound

Using what we learned & a computer simulation, we are going to measure the speed of sound and see how close we are to the actual value.

This simulation shows a sound wave moving over time and possible ways to measure it.

Directions for determining speed of sound (explain to students).

Method 1: $v = \lambda \cdot f$

1. We want to determine the velocity. We have an equation that can help us with velocity.

$$v = \lambda \cdot f$$

2. We will need to measure the wavelength of the wave and the frequency to be able to determine the velocity. One person will look at wavelength and one person will look at frequency.
3. To measure the wavelength: Use the ruler, measure crest to crest (lightest part to lightest part) or trough to trough (darkest part to darkest part). Then, since velocity is most often given in meters per second, calculate the wavelength in meters by converting from centimeters to meters.
4. To measure the frequency, we need to find how many cycles we have per second. Measure in cycles per 0.10 second (since otherwise it would take forever.) Then take cycles/.10 to get frequency. You can also just look up frequency on the simulation…. ☺
5. Rotate through so that different students get to measure each trial. Take turns being the person who times and the person who counts.

6. Use data given to calculate the overall wave velocity.
7. Change the frequency of the wave and repeat for up to five trials.

Method 2: Using v = d/t

1. Using the ruler tool, choose a given distance to measure on the simulation. (5 meters is a good distance to choose.)
2. Line up the zero point of the ruler with the middle of the speaker.
3. You are going to determine the time it takes one part of the wave to travel five meters. Press "start" and time how long it takes the wave to travel five meters. Stop timing as soon as the wave reaches the five-meter mark.
4. Use the distance and the time to determine the velocity given the equation above.
5. Repeat for up to five trials.

Method 3: Using T = 1/f and $v = \lambda \cdot f$

1. In this case, you are going to measure the period of the wave, or the number of waves that pass through a given point in time. Typically, we would look at waves that pass through per second, but in this case, we are going to look at how many waves pass through the point in 0.10 seconds.
2. Choose a particular point to watch. Have one partner time for 0.10 seconds, and have the other partner count the number of waves (either crest to crest or trough to trough) that pass through the particular point.
3. To find the period (T), take the seconds/number of waves.
4. Use this to find the frequency by solving the equation T = 1/f for frequency.
5. Use the equation $v = \lambda \cdot f$ to find the velocity.

Data Tables:

Method 1:

Trial #	Wavelength	# of Cycles	# Seconds	Frequency (cycles/sec)	Velocity
1					
2					
3					
4					
5					

Sample Calculation:

Method 2:

Trial #	Distance	Time	Velocity (d/t)
1			
2			
3			
4			
5			

Sample Calculation:

Method 3:

Trial #	Wavelength	# of Cycles	# Seconds	Period (sec/cycle)	Frequency (cycles/sec)	Velocity
1						
2						
3						
4						
5						

Questions for Discussion

1. The actual speed of sound is calculated to be 343 seconds in air. Which of these methods comes closest to determining that speed of sound?
2. What are some sources of error in this experiment, and do you think they caused the results to be too high, or too low? Why?
3. Which method did you most prefer for determining the speed? Why?
4. Do you believe that this simulation is reliable and accurate? Why or why not, and what are some of its limitations?

Demo – How do we describe sound using waves?

Materials Needed:

- Computer to play music

Play a few examples of music and ask student to describe sounds in it (High, low, loud, soft, etc.)

URL Music Examples:

http://www.youtube.com/watch?v=U6tV11acSRk (Here comes the sun.)

http://www.youtube.com/watch?v=Dlr90NLDp-0 (Gregorian chant.)

http://www.youtube.com/watch?v=LXO-jKksQkM (Pumped up Kicks Dubstep.)

Notes:

The sounds that you hear are all in the forms of waves coming towards your ears, and they are all different from each other because the waves vary.

Pitch & Waves

Notes: We use sound to make waves. When we do this, we make changes to the various parts of the waves.

Wave components:

- Amplitude
- Frequency
- Speed
- Wavelength

Pitch Intro Lab:

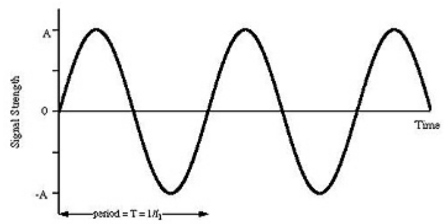
Materials needed – computers with Visual Analyzer 2011 software or Smartphone with SoundForm app or similar

Pitch Intro Lab

Part 1: Prelab and Predictions

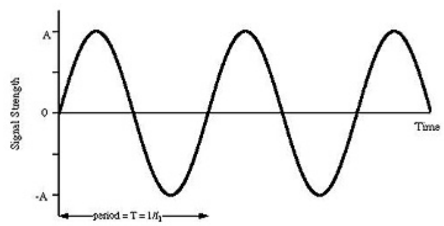
There is a sound wave drawn in on the axes below. The axes display signal strength over time. Modify the drawing of the wave on the axes to predict how the sound wave will change with pitch and volume.

1. Draw how the wave above will change when the volume of the wave goes up.



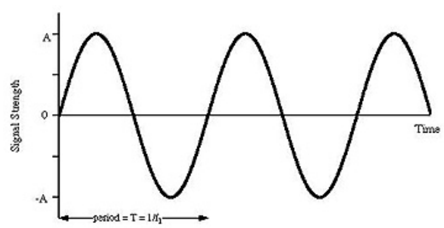
(a) Sine Wave

2. Draw how the wave below will change when the volume of the wave decreases.



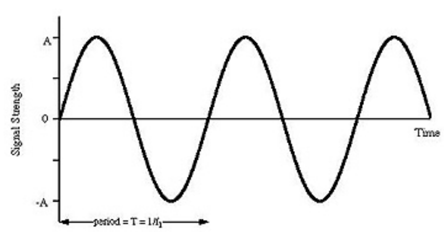
(a) Sine Wave

3. Draw how the wave below will change when the pitch of the wave goes up.



(a) Sine Wave

4. Draw how the wave below will change when the pitch goes down.



(a) Sine Wave

Name ________________________________

Pitch Lab

Objective: Make a connection between the appearance of a wave including amplitude, wavelength, and frequency, both quantitatively and qualitatively and the pitch and volume of a wave.

Materials:

- Visual analyzer software & computer with microphone OR smartphone with a similar application such as SoundForm for the Android
- Reliable source of sound: ex. pitch pipe, human voice, recorder, synthesizer, etc.

Directions for Students:

Our goal is to qualitatively look at waves and make connections between the appearance of a wave on the Visual analyzer software (or your phone) and the volume and pitch of the wave. When doing this activity, you should think about how changing the quality of the sound you are producing affects what appears on the screen.

Instructions

1. Practice making sounds on the visual analyzer. Try to make sounds as consistently as possible and make them look as close to a sine wave as possible. You will not get *exactly* there because every way of making sounds does not have just one pitch; there are various harmonics involved in making each pitch.
2. Choose a particular pitch, observe the form of the wave, and draw it below:

3. Now experiment with making the pitch ***lower.*** Draw or describe how the wave has changed. Use some or all of the following words: amplitude, wavelength, frequency, speed.

4. Experiment with making the pitch higher**.** Now, draw or describe how the wave has changed. Use some or all of the following words: amplitude, wavelength, frequency, speed.

5. Experiment with making the pitch louder. Draw or describe how the wave has changed. Use some or all of the following words: amplitude, wavelength, frequency, speed.

Summary/Verbal Quiz:

1. What is frequency of a wave?

2. What is amplitude of wave?

3. Draw two waves with different pitches. Identify which corresponds to the higher pitch and which corresponds to the lower pitch.

True or false:

1. A higher volume changes the frequency of the wave.
2. A higher pitch makes the wavelength shorter and the frequency faster.
3. A higher volume reduces the amplitude of the wave.

Doppler Effect

Lecture Notes:

Have you ever noticed a change in pitch of a police siren or a train as it moves past you? This is due to an effect know as the Doppler shift. This means that there is a sudden change in frequency (we hear as pitch) of a moving object.

Materials needed:

Car with horn

Demo:

Have someone drive by while honking the horn and listen for changes in pitch

Explanation:

What happened to the pitch?

- As the car approaches, the horn pitch is higher than normal. (Sound waves approach you more frequently.)
- As the car moves away from you, the pitch lowers. (Sound waves are encountered less frequently.)

The Doppler shift occurs in all wave motion – sound, light, etc.

Examples: radar detectors, bats use to detect and catch flying insects, it is used to measure the speed of a pitched baseball, motion detectors use CBL's for this principle

Accompanying Reading:

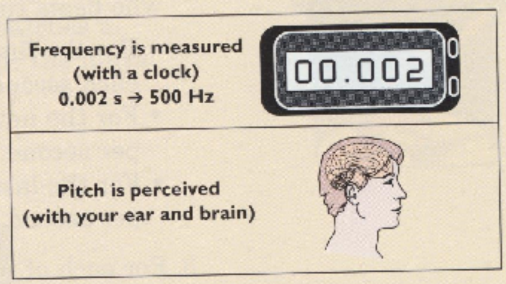
Active Physics – Medicine pg. 25

FOR YOU TO READ

The world is filled with objects that vibrate. Some examples are guitar strings, trees swaying, and springs. All sorts of things vibrate. They move back and forth in a regular way. We can describe vibration by finding its frequency. As the tree swings back and forth one time, it goes through a whole cycle of its movement. Look at the illustration of the palm tree. First the tree moves to one side, then back through the center, then to the other side, back to the center, and then to the first side again. The movement from one position through the back-and-forth motion and back to that position is one cycle.

If the tree swings back and forth once in one second, its frequency is one cycle per second. The cycle per second is a unit of frequency. It is also called the *hertz* (Hz).

The vibrating meter stick produced a sound that you could hear. As you change the length of the stick that extends out over the end of the table, you change the stick's frequency of vibration. You can observe the frequency by looking at the stick. The frequency is a characteristic of the motion. What you hear is quite different. As you change the length that sticks out over the table, you change the pitch of the tone that you hear. Pitch is a sense perception. The ear and the brain create pitch. As the frequency of the vibration goes up, so does the pitch you hear.



Optional Homework Activities for Students:

Active Physics Medicine – Physics to go pg. 26-27

REFLECTING ON THE ACTIVITY AND THE CHALLENGE

In this activity you have learned what frequency is and how to measure it. You have seen from the vibrating meter stick experiment how different frequencies of sound produce different pitches. That means frequency is important in hearing. You will learn more in later activities of this chapter about the role of frequency in hearing loss.

PHYSICS TO GO

1. Explain the difference between frequency and period.
2. In your log, sketch a graph of drumbeats for a drummer who beats time like this:
   - For the first three seconds she strikes the table once each second.
   - For the next three seconds she strikes the table four times per second.
   - For the last four seconds she strikes the table two times per second.
3. For each of the three parts of your graph above:
   a) Calculate the frequency and the period of the drumming. Write your answers on each part of the graph.
   b) Multiply the frequency by the period. What do you get?
4. Calculate the period for the following frequencies:
   a) 2 Hz (cycles per second)
   b) 5 Hz
   c) 10 Hz
   d) 100 Hz
5. Calculate the frequency for the following periods:
   a) 2 s
   b) 0.5 s
   c) 0.1 s
   d) 0.001 s

6. Explain the difference between frequency and pitch.

7. a) Make a list of as many string instruments as you can.
   b) Think about the pitch you hear when these instruments play. Now order your list from the instrument that has the lowest pitch to the one that has the highest pitch.
   c) Think about the size of these instruments. How is the length of the strings related to the pitch you hear? How is the length of their strings related to the frequency of sound they produce?

8. What is the frequency of your heartbeat? What is the period?

STRETCHING EXERCISE

Musicians are very good at singing a note that matches a note they have just heard. Find someone (perhaps the music teacher) who can demonstrate this ability.

Major Topic 3 – Hearing

Notes: How Our Ears Perceive Sound

Youtube video on Hearing:

https://www.youtube.com/watch?v=PeTriGTENoc

Reading as a Class: Active Physics pg. 7,42-43, 49

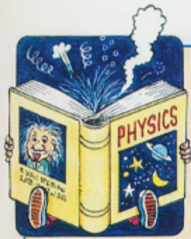
Demo: Hearing Loss with Age

Materials Needed: Computer, people of various ages

http://www.noiseaddicts.com/2009/03/can-you-hear-this-hearing-test/

Notes/Discussion:

As we age, over time our hearing becomes impaired, particularly at higher frequency levels. It can be caused by job related hearing loss (overexposure for example), or it can be caused by listening to music at an excessively high level. There is a fairly direct correlation between age and the frequencies at which people can hear. Today we are going to use people of various ages to test the fundamentals of hearing loss. This web page will play various pitches at increasingly high frequencies. Keep your hand raised until you can no longer hear the pitch being played. Notice anything interesting?



FOR YOU TO READ

Hearing Loss

Hearing loss can occur with advancing age. It was once thought that you could not avoid hearing loss as you grew older. However, there now is strong evidence that some of this hearing loss is due to damage by exposure to loud sounds. In a study in the United States, 40% of people over age 57 reported some degree of hearing difficulty; of those, one out of five attributed their hearing loss to noise exposure.

Noise on the job can lead to hearing loss. One ear may be exposed to greater noise than the other. For example, a study of male college freshmen from an agricultural area showed that those who drove tractors had hearing loss in their right ear. This happens because they look over their left shoulders as they drive, which aims their right ear at the engine and exhaust pipe. Those who were hunters showed sharp drops in hearing ability in the ear most exposed to the sound of the shotgun.

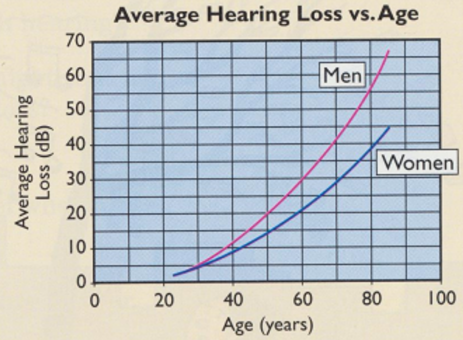
Performing rock music can cause hearing loss. Rockers tend to have a slightly greater hearing loss in the ear next to the drum and cymbal, or the ear next to the loudspeaker if they stand in front of it. To protect themselves, many musicians stand behind their loudspeakers.

Noise-induced hearing loss is usually temporary at first, but it becomes permanent after long exposure (or one very loud exposure). No treatment is known at present. Several devices can help the hearing-impaired. Those with a partial hearing loss can use a hearing aid, which can provide limited improvement. Hearing aids cost from $300 up to about $3,000. A newer device is the cochlear implant. It allows those who are completely deaf to detect sounds, but not to distinguish speech. This implant costs $10,000 or more.

There are clear differences between the hearing losses in men and women. The graph shows the average hearing loss for men and women of various ages. This graph is for a sound frequency that makes a very high pitch in the ear. You will learn about frequency in the next activity. The loss scale is measured in decibels (dB). Decibels are also the units of your sound level measurements.

Think back to your measurements with the sound level meter. The higher the sound level, the higher the decibel value that you measured. Instead of sound level, the graph below shows hearing loss. The higher the decibel value on the graph, the greater the hearing loss. At what age does the graph's data begin? Hearing loss can begin in the teenage years. In a Canadian study, more than half of those reporting hearing loss were between ages 16 and 64.

Average Hearing Loss vs. Age



Source: "Average Hearing Loss vs. Age for Men and Women at a High-Pitched Tone (4000 Hz)," *Acquired Hearing Impairment in the Adult.* Minister of National Health and Welfare. Ottawa, Canada (January 1988), p. 13.

FOR YOU TO READ

The Ear

The ear is an amazing organ. It can detect sounds from a tiny rustle of leaves to a large explosion. Go back and review the table in Activity Two on page M13. Look at the range of sound intensities. These sound levels can vary by as much as 130 dB. Remember that subtracting 10 dB means ten times less sound intensity. That means the softest sound the ear can sense is about ten million million times less intense than the loudest.

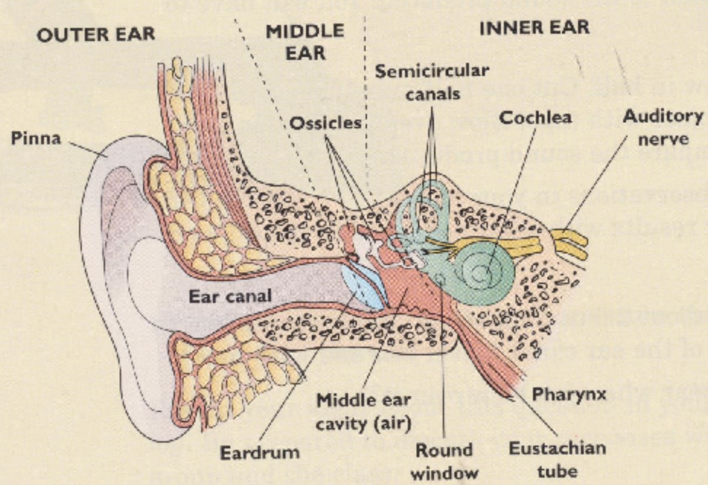
The ear can respond to sound over a wide frequency range. Have you ever been able to "feel the bass?" You can feel the music vibrating in your chest. You can hear from about that frequency—around 20 Hz—up to well above 20,000 Hz. That means the highest frequency you can hear is a thousand times greater than the lowest!

Take a look at the diagram that shows the inside of the ear. It is helpful to divide the ear into the outer ear, the middle ear, and the inner ear.

Suppose you are listening to someone playing a guitar. The strings, wood in the top, and the air enclosed vibrate. The back-and-forth motion of the guitar top makes the air move back and forth, too. That makes a wave of sound that travels from the guitar to your ear.

Here is how these three parts of your ear help you hear the sound of the guitar:

- The external ear gathers the sound.
- The middle ear contains three tiny bones. They amplify the vibrations so they can enter the liquid of the inner ear.
- The inner ear transforms the energy in the sound waves into nerve signals going to the brain.



The outer ear consists of two parts. One is what you see on the outside, which is called the pinna. The other is the ear canal. The ear canal is the part of the outer ear that leads to the middle ear. The outer ear is closed at one end by the eardrum and open to the pinna at the other end.

Resonance

You have heard several examples of tones produced by tubes. Sometimes you blew over the end of the tube. Sometimes you just listened to the tube. When the air in the tube is disturbed, sound waves are set up in the tube. For certain frequencies, the sound waves build up and the sound becomes loud. These frequencies are related to the length of the tube. The longer the tube, the lower the frequency. The lower the frequency, the lower the pitch of the sound you will hear. Making sound this way is called resonance.

You can observe many examples of resonance. You may have seen organs or heard organ music. The length of each organ pipe determines the note it makes. The shorter the length of the resonating air column, the higher the frequency of the note produced. A flute or trombone or clarinet produces a note in the same way.

Although it's much smaller than an organ pipe, the ear canal resonates too. Its resonant frequency is about 2,000 Hz. Sound waves with that frequency build up to a high level inside the ear canal.

REFLECTING ON THE ACTIVITY AND THE CHALLENGE

You have learned that when a tube resonates, the sound builds up inside. Also, you have learned that the ear canal is a tube. By using a model of the ear canal, you have found that it resonates at a frequency well within the range of human hearing. That resonance makes the sound in the ear canal louder and helps you hear better.

PHYSICS TO GO

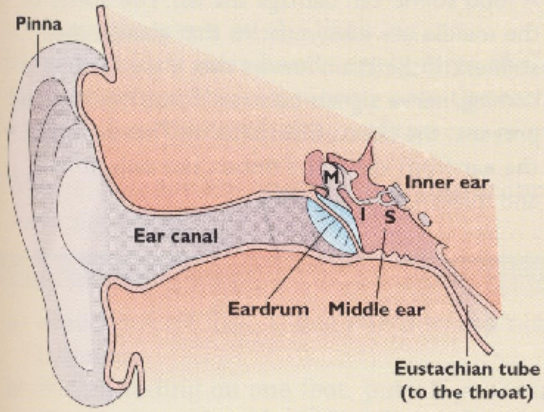
1. a) In the outer ear, what is the function of the pinna?
   b) Tell how an animal uses its pinna to hear better.

2. a) What is the frequency range of human hearing?
   b) Do you think the resonance inside the ear canal helps you hear better? Why?
   c) Can you wiggle your pinna?

FOR YOU TO READ

The Middle Ear

The middle ear passes the sound vibrations to the inner ear, which is filled with water. It is very difficult for sound to pass from air to water.



The three bones in the middle ear are among the smallest in the body. The bone in contact with the eardrum is called the *malleus* (it is shaped a bit like a mallet or hammer). The next bone is the *incus* (from the Latin for "anvil," which it resembles slightly). The third bone, which is in contact with the oval window, is the *stapes* (from the Latin for "stirrup").

Operation of the Middle Ear

Sound arrives at the ear as a vibration in the air. Sound energy must enter the inner ear in order to be converted into a nerve signal to the brain. But the inner ear is filled with liquid. If there were no middle ear, only about one-thousandth of the sound energy would reach the fluid of the inner ear. That would produce a 30 dB loss inside the ear. Imagine how difficult it would be to hear if sound levels were reduced this much.

To prevent this loss, the middle ear increases the sound vibrations in two ways. First, the bones are pivoted, as you observed on the model of the inner ear. They work as levers that increase the force of the vibrations by about 30%. That is the same as multiplying the force by 1.3 times.

The inner ear is filled with liquid. In a liquid, forces are applied through pressure. You may have felt water pressure in your ears when you dive to the bottom of a swimming pool. Also, you probably have seen marks that high heels make on a floor. If the weight of a person is spread out on a flat, wide heel, the pressure is reduced and the floor is undamaged. But when the heel has only a small area, the force is concentrated. The pressure is very large, and the heel leaves a mark on the floor.

Pressure is equal to force divided by area.

$$P = \frac{F}{A}$$

That means the smaller the area, the bigger the pressure—just like what happens with high heels on a floor. This is the second way in which the middle ear increases the sound vibrations.

The ossicles transmit the force on the eardrum to the oval window. The oval window is much smaller than the eardrum. The area of the oval window is only about one-twentieth as large as the area of the eardrum. On the oval window, the force of the vibrations is concentrated into a much smaller area. That raises the pressure by about twenty times.

The inner ear increases the vibrations in two ways:

1. The pivoting bones multiply the force by about 1.3.
2. The difference in size of the eardrum and oval window increases the pressure by about 20 times.

→

The middle ear compensates for the energy lost in making the liquid of the inner ear vibrate.

The air pressure inside the inner ear is important. If the air pressure inside becomes different from the air pressure outside—on the eardrum—then the eardrum stretches. This stretching is painful and prevents the eardrum from vibrating easily. The inner ear has a tube, called the *eustachian tube*, which is shown in the diagram on the previous page. The eustachian tube leads from the middle ear to the mouth and throat. If you fly in an airplane, the air pressure changes. The eustachian tubes let air move in or out of the inner ear. That makes the pressure the same on both sides of the eardrum. Otherwise your eardrum would become painful and you would have a temporary hearing loss. Yawning helps open the eustachian tubes and equalize the pressure.

A loud sound can damage the ear. The bones of the middle ear have muscles that change their stiffness. If the brain knows that a loud sound is coming, nerve signals contract these muscles and prevent the bones from moving. That protects the ear from very loud noises, but only at low and midrange frequencies.

REFLECTING ON THE ACTIVITY AND THE CHALLENGE

You have learned how sound is transmitted from the outer ear to the inner ear. The inner ear is immersed in fluid and would be a poor transmitter of sound if there weren't some other compensations. One of these compensations is the lever system of the small bones in the middle ear. The other compensation is due to the difference in areas of the eardrum and the oval window. Learning about this fine-tuned machine called the human ear gives an appreciation of the gift of hearing. Going to a dance where you risk a loss of hearing is quite a price to pay. You may wish to discuss this risk in your letter to the school principal.

Major Topic 4 – Music and Instruments

Demo/Lecture Notes:

Materials Needed: Various Musical Instruments

Notes:

For a musical instrument to function, something in the instrument must vibrate to create a pressure variation. As each instrument is demonstrated, detect where the source of vibration in the instrument is coming from.

- Drum – surface (and barrel)
- Human voice – vocal chords (to change frequency, muscular tension is placed on chords)
- Brass – lips of person
- Reed instruments – air blown across reed
- Flute/whistle – air blown across opening in pipe sets column of air in pipe to vibration
- Guitar – strings being plucked

Let's return to the idea of pitch (with regards to the frequency of wave)

Pythagorus found that when two strings had frequencies that were in 2 small whole number ratios (2:1, 3:2, 4:3, etc.) pleasing sounds resulted!

- Two notes with frequencies that are related by the ratio 2:1 are said to differ by an octave. (demonstrate) Example: note #1 – 420 Hz, note #2 – 840 Hz (note 2 is an octave higher) and note #3 – 1680 Hz.
- The ratio of frequencies, not the actual size or amount, is what is important.
- These small whole number ratios are important to making music:

Instrument Labs:

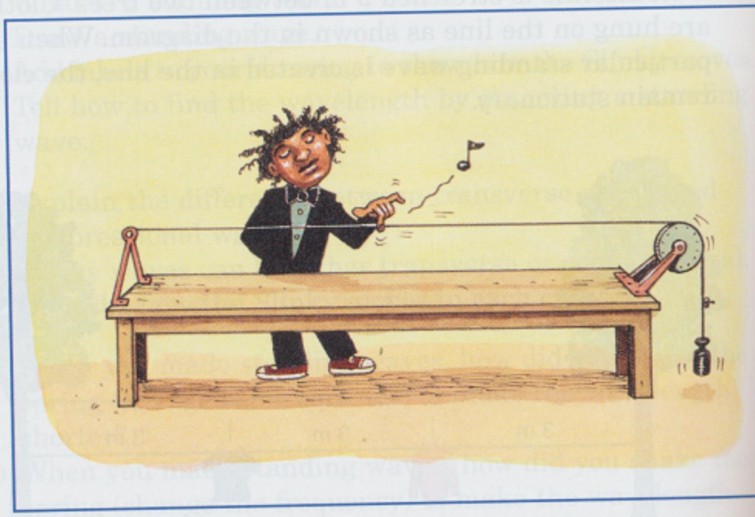
String Lab

Large Active Physics pg. 340 – 344

Wind Lab

Large Active Physics pg. 346-347

Activity 2 Sounds in Strings



GOALS

In this activity you will:

- Observe the effect of string length and tension upon pitch produced.
- Control the variables of tension and length.
- Summarize experimental results.
- Calculate wavelength of a standing wave.
- Organize data in a table.

What Do You Think?

When the ancient Greeks made stringed musical instruments, they discovered that cutting the length of the string by half or two-thirds produced other pleasing sounds.

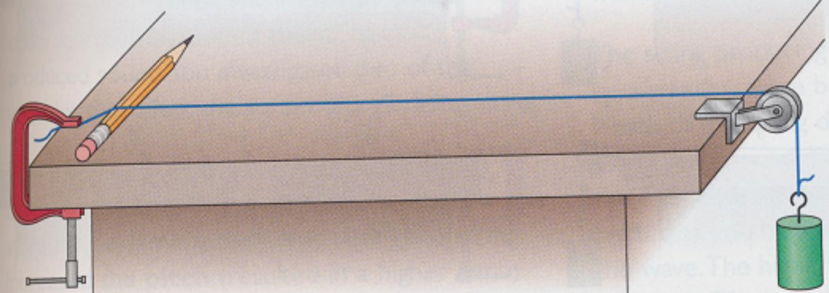
- **How do guitarists or violinists today make different sounds?**

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and with your class.

For You To Do

1. Carefully mount a pulley over one end of a table. Securely clamp one end of a string to the other end of the table.
2. Tie the other end of the string around a mass hanger. Lay the string over the pulley. Place a pencil under the

string near the clamp, so the string can vibrate without hitting the table, as shown in the drawing.



3. Hang one 500-g mass on the mass hanger. Pluck the string, listen to the sound, and observe the string vibrate.

Make sure the area under the hanging mass is clear (no feet, legs). Also monitor the string for fraying.

a) Record your observations in your log in a table similar to the following:

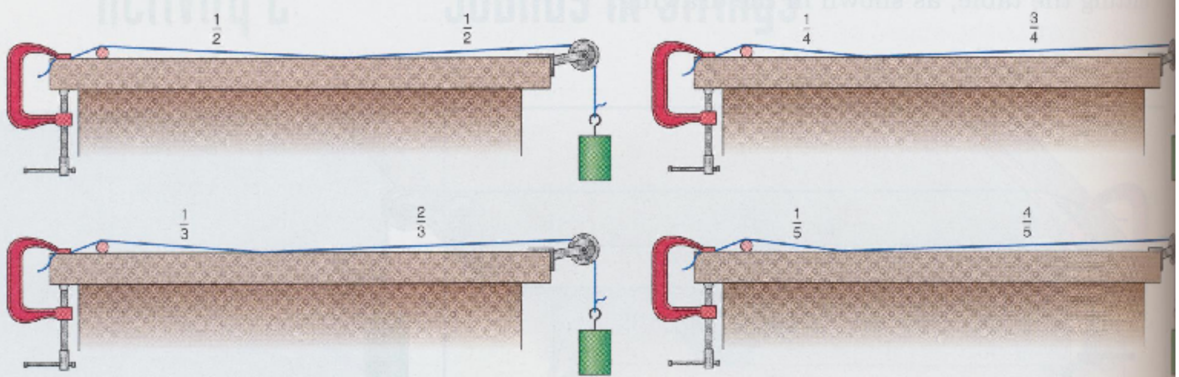
Length of vibrating string	Load on mass hanger	Pitch (high, medium, low)

4. Use a key or some other small metal object. Press this object down on the string right in the middle, to hold the string firmly against the table. Pluck each half of the string.

a) Record the result in your table.

5. To change the string length, press down with the key at the different places shown in the diagrams on the next page. Pluck each part of the string.

a) Record the results in your table.



6. When you pluck the string, it does not move at the ends. Look at the drawing under **Step 9** of the **For You To Do** section in **Activity 1**. Measure the length of your string, and find the wavelength of the vibration for each string length.

 a) Record the wavelength in your table.

 b) Look over the data in your table. Make a general statement about what happens to the pitch you hear as you change the length of the string.

Make sure the string is capable of holding 2 kg.

7. Remove the key, so the string is its original length. Pluck the string. To investigate the effect of tightening the string, add a second 500-g mass to the mass hanger. Pluck the string again, observe the vibration, and listen to the pitch of the sound.

 a) Make up a table to record your data in your log.

 b) Add a description of the pitch of the sound to your table. Continue adding weights and observing the sound until the total mass is 2000 g.

 c) Look over your data. As the mass increases, the string becomes tighter, and its tension increases. Make a general statement about what happens to the pitch you hear as you change the tension on the string.

FOR YOU TO READ

Changing the Pitch

Sound comes from vibration. You observed the vibration of the string as it produced sound. You investigated two of the variables that affect the sound of a vibrating string.

When you pushed the vibrating string down against the table, the length of the string that was vibrating became shorter. Shortening the string increased the **pitch** (resulted in a higher pitch). In the same way, a guitarist or violinist pushes the string against the instrument to shorten the length that vibrates and increases the pitch.

When you hung weights on the end of the string, that increased the pitch too. These weights tightened the string, so they created more tension in it. As the string tension increased, the pitch of the sound also increased. In tuning a guitar or violin, the performer changes the string tension by turning a peg attached to one end of a string. As the peg pulls the string tighter, the pitch goes up.

Combining these two results into one expression, you can say that increasing the tension or decreasing the length of the string will increase the pitch.

The string producing the pitch is actually setting up a standing wave between its endpoints. The length of the string determines the wavelength of this standing wave. Twice the distance between the endpoints is the wavelength of the sound. The pitch that you hear is related to the frequency of the wave. The higher the pitch, the higher the frequency. The speed of the wave is equal to its frequency multiplied by its wavelength.

$$v = f\lambda$$

where v = speed

f = frequency

λ = wavelength

If the speed of a wave is constant, a decrease in the wavelength will result in an increase in the frequency or a higher pitch. A shortened string produces a higher pitch.

Reflecting on the Activity and the Challenge

Part of the challenge is to create a sound show. In this activity you investigated the relationship of pitch to length of the string and tension of the string: the shorter the string, the higher the pitch; the greater the tension, the higher the pitch. You also learned that the string is setting up a standing wave between its two ends, just like the standing wave that you created in the Slinky in **Activity 1**. That's the physics of stringed instruments! If you wanted to create a stringed or multi-string instrument for your show, you would now know how to adjust the length and tension to produce the notes you want. If you were to make such a stringed instrument, you could explain how you change the pitch by referring to the results of this activity.

Physics Words

pitch: the quality of a sound dependent primarily on the frequency of the sound waves produced by its source.

Physics To Go

1. a) Explain how you can change the tension of a vibrating string.
   b) Tell how changing the tension changes the pitch.

2. a) Explain how you can change the length of a vibrating string.
   b) Tell how changing the length changes the sound produced by the string.

3. How would you change both the tension and the length and keep the pitch the same?

4. Suppose you changed both the length and the tension of the string at the same time. What would happen to the sound?

5. a) For the guitar and the piano, tell how a performer plays different notes.
   b) For the guitar and the piano, tell how a performer (or tuner) changes the pitch of the strings to tune the instrument.

6. a) Look at a guitar. Find the tuners (at the end of the neck). Why does a guitar need tuners?
   b) What is the purpose of the frets on a guitar?
   c) Does a violin or a cello have frets?
   d) Why do a violinist and a cellist require more accuracy in playing than a guitarist?

7. a) Using what you have learned in this activity, design a simple two-stringed instrument.
   b) Include references to wavelength, frequency, pitch, and standing waves in your description.
   c) Use the vocabulary of wavelength, frequency, and standing waves from **Activity 1** to describe how the instrument works.

Activity 3 Sounds from Vibrating Air

GOALS

In this activity you will:

- Identify resonance in different kinds of tubes.
- Observe how resonance pitch changes with length of tube.
- Observe the effect of closing one end of the tube.
- Summarize experimental results.
- Relate pitch observations to drawings of standing waves.
- Organize observations to find a pattern.

What Do You Think?

The longest organ pipes are about 11 m long. A flute, about 0.5 m long, makes musical sound in the same way.

- **How do a flute and organ pipes produce sound?**

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and with your class.

For You To Do

1. Carefully cut a drinking straw in half. Cut one of the halves into two quarters. Cut one of the quarters into two eighths. Pass one part of the straw out to one member of your group.

2. Gently blow into the top of the piece of straw.

   a) Describe what you hear.

   b) Listen as the members of your group blow into their straw pieces one at a time. Describe what you hear.

   c) Write a general statement about how changing the length of the straw changes the pitch you hear.

3. Now cover the bottom of your straw piece and blow into it again. Uncover the bottom and blow again.

   a) Compare the sound the straw makes when the bottom is covered and then uncovered.

   b) Listen as the members of your group blow into their straw pieces, with the bottom covered and then uncovered. Write a general statement about how changing the length of the straw changes the pitch you hear when one end is covered.

4. Obtain a set of four test tubes. Leave one empty. Fill the next halfway with water. Fill the next three-quarters of the way. Fill the last one seven-eighths of the way.

Make sure the outsides of the tubes are dry.

5. Give each test tube to one member of your group. Blow across your test tube.

   a) Describe what you hear.

   b) Listen as the members of your group blow, one at a time, across their test tubes. Record what you hear.

   c) What pattern do you find in your observations?

   d) Compare the results of blowing across the straws with blowing across the test tubes. How are the results consistent?

Intonation

Lecture Notes:

Most sounds are not simple sine waves made up of just one frequency like the ones that we have been seeing. Instead, most waves are a combination of various frequencies, that result in the sound having a particular **timbre** or "tone color." Two waves that have similar but not identical frequencies will result in waves that have an oscillating intensity. This oscillation is known as a **beat**. The frequency of the beat is the difference in the frequency of the two waves. It is possible to hear beats when instruments of similar frequency are played at the same time. The human ear can detect beat frequencies of up to 7 Hz.

Materials Needed:

Two of the same type of tunable instrument

Demonstration/Discussion:

Have two students play the instruments as in tune as possible. Then have one student dramatically adjust the intonation, either with their embouchure or by changing the tuning slides, length, etc. of their instrument. Observe the beats that are being produced.

Accompanying Reading:

Active Physics – Medicine pg. 31

Student Projects and Lab Reports

General

1. Measure the average hearing at high frequency of a variety of people you know. If possible, consider people with a variety of ages, and people of both genders. For a potential research question, consider either of the following:
    - Which gender tends to hear better?
    - How does hearing loss vary with age?

   In your report, fully explain who your subjects you tested were, give data, and explain any conclusions you drew and how you came to them.

2. Conduct a study of the physics of a particular instrument. Explain how it produces sound, its physical capabilities, and its history. You are encouraged to choose instruments with unique physical properties, such as bagpipes, Theremin, accordions, etc. Come up with an interesting way to present and share the information, preferably involving an example of how the instrument produces sound.

3. Design or build a musical instrument, and use it to play something for the class. Provide a detailed explanation of the materials you used and the purpose for each material. Please also be prepared to demonstrate a simple song on the instrument to the class. Explain how your instrument is similar to or varies from the "standard" version of your instrument.

4. Choose two genres of music and explain the differences between them. Differences may relate to tempo, instruments used, general pitch range, mood, etc. Does there appear to be common trends within a genre? Are there common trends between genres.

5. Free Choice. Please get it approved first! ☺

More Specific

If you need more specific ideas from the choices above, here are some that may get you started:

- Make a "glass bottle orchestra."
- Design a set of drinking straw instruments that will play a whole octave.
- Determine where the harmonics are on a guitar.
- Determine the average bpm (beats per minute) of several songs of a variety of different genres.
- Create and explain the physics behind singing wine glasses.

Part 6: Final Unit Test – Sound and Waves

Answer each question below as thoroughly as possible. Remember, no work, no credit. Good luck! ☺

1. For the following words, write the definition or draw a picture:
    a. Wavelength

    b. Diffraction

    c. Destructive interference

2. ________________ interference can result when two waves add together to create a wave with larger amplitude than any of the individual waves.

3. ________________ is the number of waves that pass through a point per second.

4. If you triple the frequency of a vibrating object, what will happen to its period?

5. What physical characteristic of wave would you change to increase the loudness of a sound? To change the pitch of a sound?

6. Find the wavelength of a 34000-Hz ultrasonic wave in air.

7. What is the relationship between frequency and pitch?

8. A sound absorber attenuates (increases) the sound level by 30 dB. By what factor is the sound intensity increased when comparing it to the threshold of hearing (0 dB)?

9. The sound of a soft whisper is about 30 decibels. When a second person starts talking at the same time, what will be the total sound level of the people talking together?

10. A sound with a frequency of 432 kHz is heard by Fido, the crazy dolphin. If the speed of sound is 150,000 cm/s in seawater, what is the wavelength of the wave?

11. While watching ocean waves at the dock of the bay, Steve notices that 10 wave pass beneath him in 30 seconds. He also notices that the crests of successive waves exactly coincide with the posts that are 5 meters apart. What are the period, frequency, wavelength, and speed of the ocean waves?