**SOUN
D**

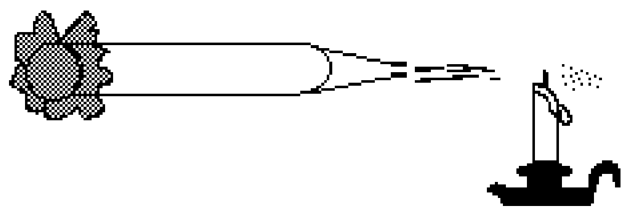
PROBLEM PRESENTATION / EXPLORATION

A. Can You "See" Sound?

1. If you were deaf, how could you see sound? You have all seen receivers in a stereo system that have meters that indicate the various sounds that are being produced by the speakers. In this case as the tape, record, or CD is activated, a current is sent to the meters at the same time it is sent to the speakers. In this way you can "see" the sound as well as hear it.
2. Lets build a non-electronic device to observe sound. You will need an oatmeal box or coffee can. Remove both the top and bottom of the box or can. Stretch a balloon or rubber sheet over one end of the box/can and secure with a rubber band or string. Be sure the balloon is stretched tight.
3. Attach a small mirror to the center of the surface of the balloon with some glue. Place the device on its side on a flat on a table. After darkening the room shine a flashlight at about a 45° with the flat surface of the balloon. Direct the reflection at a white wall or movie projection screen.
4. Have a student yell into the open end of the tube and watch the reflection. Can you explain what you see? Try different degrees of loudness.

B. Can You Put Out a Fire With Sound?

1. Obtain a mailing tube or large cardboard tube having a diameter of seven to ten centimeters. Both ends should be open. To one end stretch a balloon or rubber sheet and secure it with a rubber band or string.
2. Make a paper cone and fasten it to the other end of the mailing tube. The hole at the bottom of the cone should be between 0.5 and 1 cm in diameter.



3.. Light a candle and place it in front of the mailing tube/cone device. Secure the candle so that it will not tip over. Now clap your hands near the stretched balloon. Notice what happens Whistle or play a small radio near the stretched balloon. Finally flick your finger at the balloon surface. The flame should go out. Explain what happened in each of these cases.

C. Can You Hear a Bell in a Bottle?

1. Obtain a large Florence flask and equip it with a solid rubber stopper. Find a small hand bell (jingle bell) that will fit through the mouth of the flask. Push a thumbtack into the bottom of the rubber stopper. Finally, attach the bell by means of a short piece of iron wire to the thumbtack so that when the rubber stopper is lowered into the flask it will hang at about the center of the flask.
2. Shake the flask. Can you hear the bell? [Yes]
3. After removing the stopper pour about 20 mL of water into the flask and heat it to boiling. Let it boil for at least one minute.
4. Immediately insert the stopper with the bell into the flask. (Use a towel or other protection from the steam and hot glass.)
5. After letting the flask cool off for a minute shake it again. Can you hear the bell now? [Not very well.]

D. How Fast Does Sound Travel?

1. Take the class outside and face a large vertical brick wall.
2. Starting about 10 meters in front of the wall bang two sticks together and slowly walk backwards away from the wall.
3. As soon as an echo of the banging sticks can be heard by someone, move forward or backward A step at a time until the whole class can hear the echo.
4. Measure the perpendicular distance from the position where the echo was

heard to the wall.

5. The minimum time interval that the human ear can detect between two claps of the stick is 0.1 second. When this interval between the clap and the echo is shorter than 0.1 second, no echo is heard. This is why no echo was heard when standing only 10 meters in front of the wall. The time it took the echo to come back at this distance must be 0.1 second.
6. Can you find out from the information collected how fast the sound was traveling through the air? [The echo should be heard at about 17 m in front of the wall. This would mean that the sound traveled to the wall and back (2 x 17m) in 0.1 second. This means that the speed of sound is about 34m/0.1 second or about 340 m/second.]

CLASS RESPONSE / CONCEPT INVENTION

A. What Causes Sound?

1. Every sound starts with energy being imparted to an object. This sets up a vibration in the object. Vibrating your vocal chords when you speak, or beating on a drum, or blowing into a trumpet are examples. The first EXPLORATION activity illustrates the idea of vibration. The energy was supplied by clapping your hands which caused the air molecules to vibrate which in turn caused the balloon to vibrate which caused the mirror to move back and forth so that you could visibly see the sound.
2. Notice how important the air was in this process. Could the energy disturbance (the hand clapping) have reached the balloon without the air providing a means of transferring the energy disturbance? [No] In addition to having an energy disturbance there must be a medium through which the disturbance can travel.
3. Notice what happened in the bell in the flask case. Shaking the bell was the energy disturbance. This then caused the air in the flask to vibrate and was transmitted to the glass, to the air on the outside of the flask, and to our ears. But in the case where the water was boiled, the air was forced out of the flask and replaced by water vapor. Upon the cooling of the water vapor the water molecules suddenly condensed into liquid water leaving most of the volume void of molecules. Shaking the bell now produced only a faint sound. The same energy disturbance occurred, but there was very little medium through which it could be transmitted to reach our ears. If a perfect vacuum could be produced, no sound would be heard.

B. How Would the Nature of the Medium Affect Sound?

1. Does sound travel better through gases, liquids, or solids?
2. Have you ever put your ear down to a railroad track and heard the train coming from miles down the track? Have you ever been swimming under water and heard somebody hit two rocks together? How does that compare with sticking your head out of the water and having the two rocks banged together above the water?
3. Position an ordinary coat hanger upside down (hook end pointing down). Tie a piece of string to each end (the curved parts making up the corners of the hanger "triangle.") Wind the string two or three times around the end of your first finger on each hand. Now stick these fingers in your ears. Either swing the hanger into a stationary, solid object or have someone else hit the coat hanger with a pencil. How does the sound you hear differ from hitting a normal coat hanger with a pencil?
4. The original vibration was set up by hitting the hanger with the pencil. This caused the hanger to vibrate which caused the string to vibrate, which was transmitted through your fingers to your ears. The resulting sound was a gong-like one, much richer and louder than the vibrations that normally travel through the air to your ears.
5. The idea of sound being a disturbance from one molecule to another can be illustrated by the following demonstration. Line up four students side by side and shoulder to shoulder. Place a chalkboard eraser on the head of the last

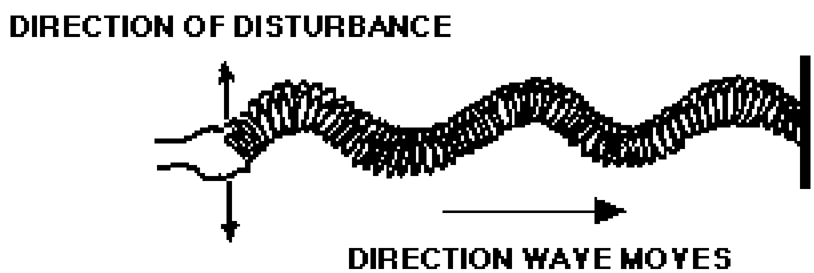
student. Each student should gently push against his or her neighbor, thereby showing the transmission of the movement along the line. The eraser falling from the head of the end student is evidence that the disturbance that began on the opposite end of the line has reached the one wearing the eraser. Did the first student push on the end student wearing the eraser? No. This is a very simple analogy of how an energy disturbance is transmitted through a medium.

C. How Would the Speed of Sound Be Affected Through Different Media?

1. We will investigate this more experimentally later, but a simple analogy might be helpful to start with. (See the lesson on Dominoes, average speed, p. 43.)
2. Line up dominoes at evenly spaced intervals (approximately 2 cm apart stretching out over a 100 cm length. Push over the first one and watch this disturbance transmitted to the next domino, and to the next, etc. Measure the amount of time it takes until the last domino topples. Lets say this setup represents sound being transmitted through a solid. Now line up the dominoes at evenly spaced intervals (approximately 4 cm apart.) stretching out over a 100 cm length Push the first domino and predict whether the time required for the last domino to topple will be greater or smaller than in the first case. [Longer] This might represent a liquid where the molecules are farther apart. Setting up both the solid and liquid situations and applying the disturbance at the same time may more graphically illustrate the comparison. Sound travels slower through substances where the particles making up the medium are farther apart. **The general rule is that the speed of sound is directly proportional to the density of the medium**.

D. Transverse and Longitudinal Waves

1. A wave can be classified by the direction in which it disturbs the medium. A bobber on the end of your fishing line will float calmly on the lake until a fish pulls it down. In response the bobber will bounce up and down vertically, but the water waves generated will move horizontally out from the original disturbance. A **Transverse Wave** is a disturbance that moves the medium at right angles to the direction in which the wave travels. As the disturbance moves horizontally outward the medium is disturbed for an instant in a vertical plane.



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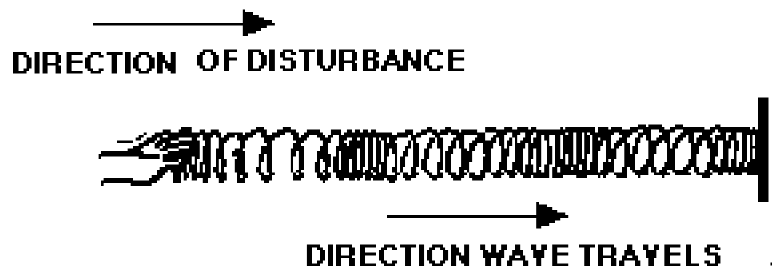
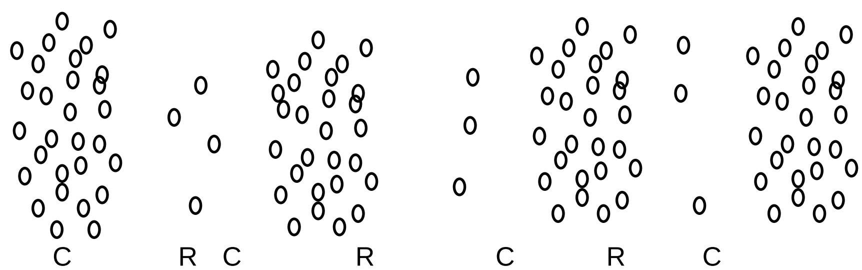
2. Place a large Slinky® on a smooth level surface. Have a partner hold the opposite end firmly. Stretch the spring until the coils are no more than 1 cm apart.
3. Suddenly move your end of the spring sideways about 20 cm, then quickly return it to its original position. A pulse should travel along it length and reach your partner. Compare the direction that the medium (Slinky®) moved compared to the direction of the pulse. This is an example of a transverse wave. If you rhythmically move your hand back and forth you will see a continual waveform traveling down the spring.
4. Bring the Slinky® back to its initial starting position. Reach a short distance down the spring and gather the coils toward you. Quickly release them. Observe the direction in which the pulse move and the direction in which the

coils of the medium move. Is this a transverse wave. [No]

5. In this case the spring did not move at right angles to the direction of the disturbance. It bunches up in some areas and spreads out in others. The spring moves back and forth rather than up and down. When the disturbance moves the medium back and forth parallel to the direction in which the wave travels we have a **Longitudinal Wave**. Sometimes these are called compressional waves.



6. By which type of waves does sound travel? [Longitudinal]
7. Sound is produced by the vibration (rapid back-and-fort motion) of an object which then pushes again and again on the surrounding medium. An example of a longitudinal wave traveling through air can be seen when you quickly push a door to your room inward. The door pushes against the air molecules next to the door, these molecules bump into other air molecules, etc. until the curtain hanging in your open window will swing out the window. Pulling the door shut will cause a rarefaction of the air next to where the door started and air molecules will rush into this near the door. The air molecules in the room will successively move toward the door and finally the curtains will be pulled toward the door.
8. Consider what happens when the tines of a tuning fork are struck with a rubber mallet. A series of compressions and rarefactions is set up and moves through the air. The air molecules move together and spread apart with respect to the frequency of the tines moving back and forth



E. Frequency, Wavelength, and Speed

1. The distance from one compression to the next compression in a sound wave is called its wavelength. Therefore, the diagram above shows a portion of the wave three wavelengths long.
2. If you stand at a fixed spot and count how many wavelengths of the sound reach you, you will determine the frequency of the sound.
3. If the wavelength above measures 4 cm and the portion of the wave pattern above represents a total of 1.0 seconds, the frequency would be 3 cycle/second. (When dealing with sound we use the term Hertz, so the frequency of this wave would be 3 Hertz.)
4. At what speed was this sound traveling through the air? Common sense tells you that the wave was traveling 12 cm/second. This involves using nothing more than the formula for finding average speed

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{12\text{ cm}}{1\text{ sec}} = 12\text{ cm/sec}$$

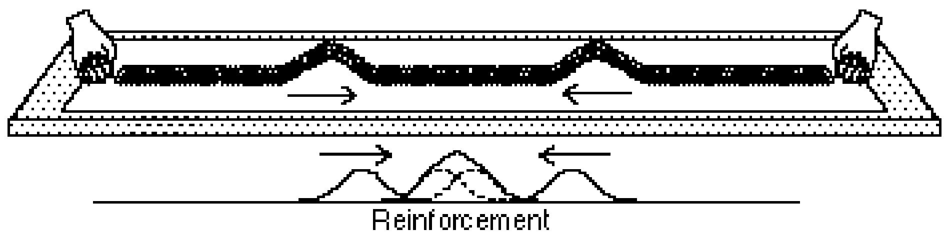
However, when dealing with wave movement we can use the following relationship: wave speed = wavelength x frequency, where we use **v** for wave speed, λ (lambda) for wavelength, and **f** for frequency.

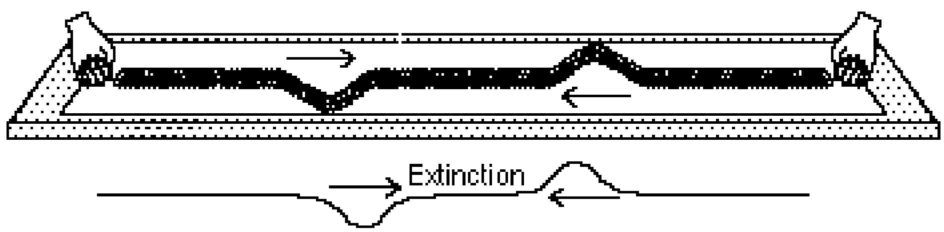
wave speed = wavelength x frequency

$$v = \lambda f = (4\text{ cm}) \times (3/\text{sec}) = 12\text{ cm/sec}$$

F. Constructive and Destructive Interference

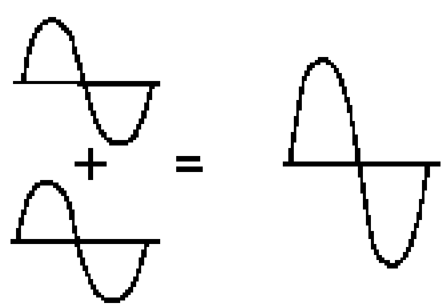
1. A very interesting demonstration can be done with either a rope or a Slinky®. Have two students hold the rope at opposite ends. Have student #1 start a pulse going down the rope in one direction and have student #2 start a pulse going in the other direction. What do you think will happen when they meet? This could be done with the Slinky® just as easily.





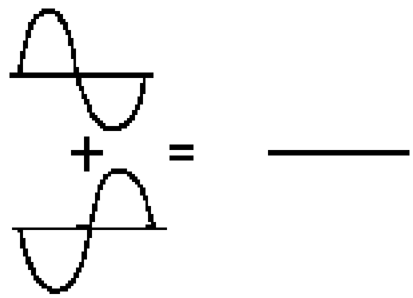
2. The answer is as can be seen above, "It depends." If the two waves hit at the same point "in phase" they will add together positively or reinforce the displacement. If they hit out of phase they will add together negatively and destroy the displacement. The positive reinforcement will make the wave pulse bigger (greater amplitude) and the negative reinforcement will completely level out the wave pulses. These two possibilities are examples of wave interference. In most cases when waves meet they are not perfectly in or out of phase and there is both positive and negative reinforcement

CONSTRUCTIVE INTERFERENCE



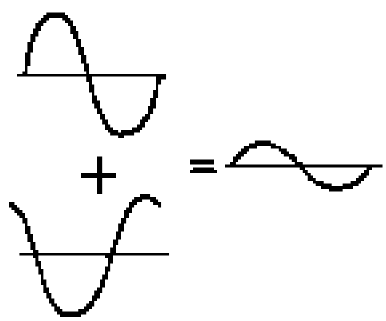
3. Total destructive interference can produce "dead" spots in which no sound can be heard. An example is in a large new concert hall. Dead spots are created due to the fact that sound coming from the stage radiates out in all directions. Some of the sound comes directly to your ears from the stage. Some of the sound, however, may hit a wall or ceiling and bounce off and then come to your ears. Now if the rarefactions from the direct sound arrive at your ears at the same time the compressions from the reflected sound, you will hear nothing. They cancel each other out, just like in the rope above. This is why there often are odd shaped panels hanging from the ceiling or panels affixed to the sides of the auditorium to keep the sound waves from being reflected in a manner that destructive interference occurs.

DESTRUCTIVE INTERFERENCE



4. If two instruments sound the same note and they arrive at your ear at the same time, you will not hear the separate tones they produced but instead you will hear the wave pattern produced due to the addition of the waves from the two instruments.

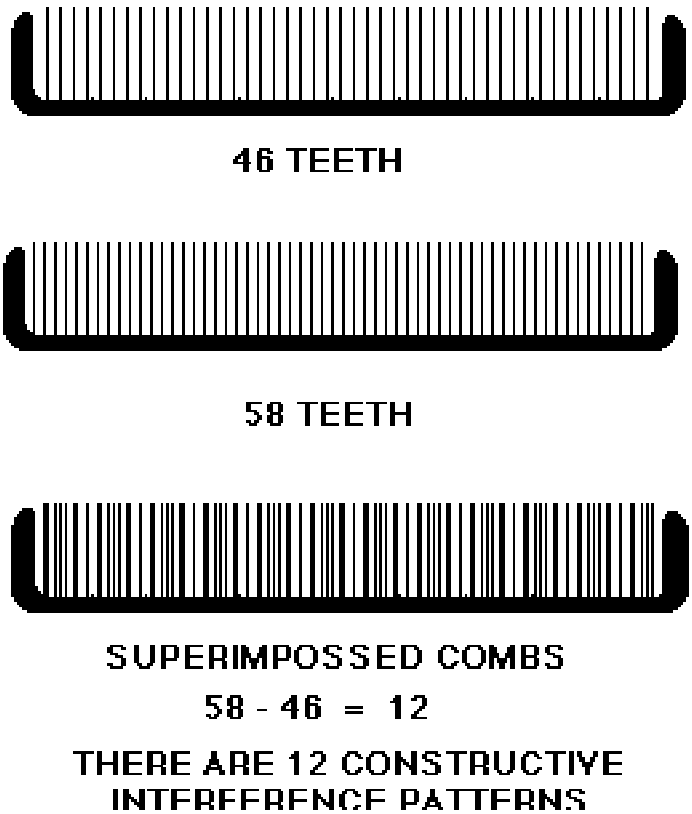
BOTH CONSTRUCTIVE AND DESTRUCTIVE INTERFERENCE



5. What would happen if two identical instruments played the same note, say middle C (512 Hertz) ? What would happen if one of the instruments was a little out of tune and it sounded 516 Hertz instead of 512 Hertz; what would you hear? Lets try it.
6. Get two tuning forks having the same frequency. Tie a rubber band around the one tine of one of the tuning forks. It now will not sound the same frequency as the other tuning fork. Hit both of the tuning forks with a rubber mallet at the same time. What do you hear? [The loudness of the sound you hear will vary in a regular way. This is a feature of interference and is known as Beats. Beats are the result of compressions and rarefactions of two slightly different waves reaching your ears together. If the compressions come together they result in a greater compression. If a rarefaction from one instrument arrives at the same time as a compression from the other instrument there will be a partial cancellation and a smaller sound intensity results. This alternating loudness and softness is called beats. The

frequency of these beats can be found by counting how many periods of loudness occur in a given time. It turns out that the difference in the frequencies of the two tuning forks is equal to the number of beats heard.

7. A very crude representation of beats can be illustrated by using two pocket combs having a different number of teeth for the same length of comb. If you overlap them you'll see a moiré pattern. The number of beats per length will equal the difference in the number of teeth per length for the two combs. Try it!



G. Resonance

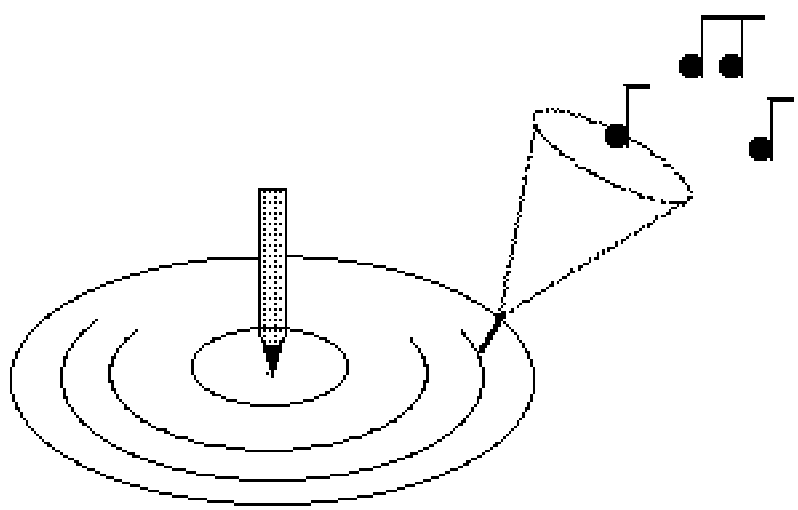
1. Get two identical pop bottles. Place one with its opening near your ear.
2. Have another student a few feet away blow across the other bottle to make a sound.
3. What do you hear every time he does this?
4. When two objects can vibrate at the same frequency, if one is set into vibration it will cause the other one to also start vibrating. This phenomenon is known as **Resonance**. It is the explanation for what happens in the famous commercial for Memorex where an opera singer can sound a note and cause a glass across the room to crack and break. The natural vibrational frequency of the glass is the same as the note sung. This causes the glass to vibrate so vigorously that it breaks.
5. Give two identical tuning forks to two students. Place them about 30 cm apart. Hit one of the tuning forks with a rubber mallet. Wait a couple of seconds and have the first student silence her tuning fork by putting her hand on it. What will happen to the other tuning fork? [It will be vibrating.] If tuning forks of different frequencies are used, the second one will not start to vibrate.
6. You are applying the principle of resonance every time you turn on your radio. Each radio station broadcasts at a specific frequency. When you turn the dial and tune in to a station, you are matching the frequency of your radio

with the frequency of the broadcasting station.

CONCEPT EXTENSION

A. Homemade Phonograph

1. A simple phonograph can be made with materials from around the house. The first thing that is needed is an old 78 rpm or 33 rpm record, one with the little hole in the middle. Find a pencil that will fit in the little hole snugly. Insert the pointed end of the pencil to a depth of about one centimeter. You have essentially made a top so that if you spin the pencil with your fingers the whole record/pencil contraption will remind you of a spinning top.
2. A straight pin will serve as our needle. Our amplifier will be made out of a piece of paper. Roll the paper up into a cone. Tape the straight pin to the cone so that it is pointing down when the wide opening of the cone is pointing up.
3. To play your record, spin your "top." Then carefully move the "needle" so that it makes contact with spinning record. Lightly make contact with the record, and immediately you will hear what is recorded on the record.
4. What would happen if the paper amplifier cone was not attached to the straight pin? Would you hear the sound? What would happened if you used a larger sheet of paper to make a bigger cone, would the sound be louder? What other modifications could you make to improve the quality of your record phonograph?



5. To understand why this crude phonograph works, examine the record under a magnifying glass. You should see a continuous V-like groove cut in the plastic. When the record was cut the sounds caused a stylus to vibrate side to side with a frequency and amplitude determined by the pitch and loudness of the sound being recorded. As a result the walls of the groove wiggle from side to side. What happens when the needle runs into these groves. How does this create sound? [The process is reversed when the record is played. The needle follows these same wiggly paths causing the cone of paper to vibrate with the same pitch and amplitude as the original sound. On a modern phonograph a minute electrical signal is generated in response to the wiggles. It is then amplified and sent through loudspeakers to reproduce the recorded sound. In the arm is a transducer that converts the groove undulations into the electrical signal by means of the stylus, a jewel-tipped needle.]

B. Tuning Forks, Pianos, and Pendula

1. Strike a tuning fork with a rubber mallet and touch its stem to a piano. Wait a few seconds and kill the vibration of the tuning fork by grabbing it in your

hand. What do you think will happen? [The string of the piano that is tuned to that same frequency will begin to vibrate all by itself. This is another example of resonance.]

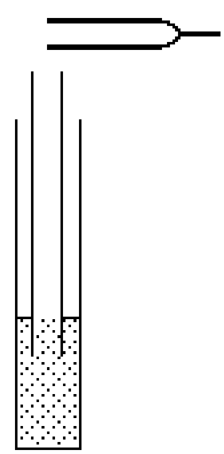
2. Stretch a light string or thread about 50 cm long between two supports. The string should be stretched tight so that it is parallel to the table or floor.
3. Tie short lengths of string to seven washers and then hang them on the horizontal string. The lengths of string should be:

#1	#2	#3	#4	#5	#6	#7
20 cm	15 cm	20 cm	15 cm	5 cm	10 cm	15 cm

4. Before carrying out this next step, have the students predict what they think will happen. Start to swing washer #7 and observe the other washers. [The natural vibration rate of washers 7, 4, and 2 are the same and washers 2 and 4 will start to swing along with washer 7. The others should remain motionless. Any of the washers hung at the same height will start to resonate when a washer of its same vibrational frequency starts to swing.]

C. A Mini Pipe Organ and the Speed of Sound in Air

1. We have seen instances of strings, glasses, and tuning forks resonating. Gases can resonate as well. This is the principle of how flutes, clarinets, and the pipes in a pipe organ work.
2. Place some water in a tall cylinder of at least 50 cm. Cut in half a plastic golf club protector tube. These may be purchased at Wal Mart, K-Mart, etc. for under a dollar. Place the plastic tube in the cylinder holding the water.
3. Strike the tuning fork with a rubber mallet and hold it horizontally about 1 cm above the open end of the plastic tube. You should hear a sound made by the vibrating of the column of air. If you move the tube and tuning fork up and down, you will find a point where the air column gives the very loudest sound. (There will be more than one loud spot.) With a grease pencil mark on the plastic tube the level to which the water came when this point of loudest sound was found.



4. Measure the distance from the water level mark on the plastic tube to the top of the tube. If a physics book is consulted, you will see that for a open-ended tube that the first resonance point comes at one fourth of the wavelength of the resonating column of air. The column of air is vibrating at the same frequency as the tuning fork.
5. With the information that has been gathered have the students figure out first the wavelength of the vibrating air column and the speed of sound in air. [The wavelength will depend on the frequency of the tuning fork used. It should roughly be 4 times the length determined in #4 above. The speed of sound can be calculated by using $\mathbf{v} = \lambda \mathbf{f}$. The accepted value for the

speed of sound in air is 332 m/sec at 0°C. The speed of sound in air increases by 0.6 m/sec for each °C above zero. If room temperature is around 20°C, the speed of sound will be 344 m/sec. There will be some error in this method. If your students really want to determine a more accurate value, they will need to correct the length measured on the plastic tube. If they measure the diameter of the tube and multiply by .4 of this diameter and add this correction factor to the length determined, they will get a more accurate value for the wavelength and speed of sound.]

D. A Mini Pipe Organ and the Speed of Sound in a Gas Other Than Air

1. Based on our discussion about the speed of sound in different media, students should be able to predict what the speed of sound would be in something other than air. [The greater the density of the medium, the faster sound will travel through it.]
2. Set up the water resonance apparatus as in the last exercise (part C). Only one change will be made this time. Before sounding the tuning fork and measuring the water level and determining the wavelength, replace the air in the cylinder/tube with something other than air. One of the simplest (and safest) gases to generate is CO_2. Drop a few Alka-Seltzer® tablets into the water and allow the CO_2 to be generated. Wait a few minutes so that the cylinder and tube can fill with CO_2 . Because CO_2 is more dense that air it will have to fill the tube from the bottom and may take a while before enough CO_2 will have been generated to force the air out the top of the tube. Now sound the tuning fork and carry out the measurements.
3. Predict what will happen this time. Will the wavelength be longer, shorter, or the same as when the tube was filled with air? Will this cause the speed of sound to be greater, smaller, or the same as in air? Try to get the students to relate their predictions back to the model of how sound travels that we developed in the Concept Invention stage. [The speed of sound should be faster in CO_2. The molecular weight of CO_2 is about 44 g/mole while the molecular weight of air is about 28 g/mole.
4. If you have gas jets in your classroom and if you are using methane to run your Bunsen burners from these gas jets, you can also test the other prediction of this theory. Since methane has a molecular weight of only about 16 g/mole, filling the cylinder and tube with it should make the speed of sound decrease. The easiest way to carry out this test would be to attach a rubber hose to the gas jet and stick it down to the bottom of the cylinder of water. Allow the gas to bubble up through the water and fill the cylinder and tube. Since it is lighter than air, it will easily rise out of the tube during the experiment. Allow it to keep bubbling throughout the whole experiment. As long a it is not bubbling too vigorously, it should not disturb the sound waves hitting the surface of the water and bouncing upward.

CAUTION: METHANE IS OBVIOUSLY FLAMMABLE. THERE SHOULD NOT BE ANY FLAMES IN THE CLASSROOM WHILE THIS DETERMINATION IS BEING MADE.

E. Using the Speed of Sound to Find the Frequency

1. Provide another tuning fork of unknown frequency and ask the students to find out its frequency by modifying the resonance experiment introduced in part C above. In other words use air in the tube rather than CO_2 or methane.
2. Obviously, all they must do is to use the speed of sound in air that they determined in part B and the wavelength that they determine in this setup to solve the equation $\mathbf{v} = \lambda \mathbf{f}$ for **f**.

F. Doppler Effect

1. We have all stood at a railroad crossing and heard the whistle of the approaching train. After the train passes you, you can still hear the whistle. How does what you heard when the train was approaching and when it was moving away differ? Would what you hear demonstrate beats? destructive interference? constructive interference? resonance?
2. Get a tape recorder and two students to make a tape for you. Have one student stand on the side walk with the tape recorder. Have the other student ride a bike toward the tape recorder. Attached to the bike should be a sound producing device that emits a constant frequency. Record the approaching sound. Continue to record as the bike and sound move away from the tape recorder. Finally, have the bike rider stop in front of the tape recorder and activate the constant frequency device. Tape a few seconds of this.
3. Bring the tape of the three situations to class and play it. Can the class determine when the sound was approaching the tape recorder, when it was receding from the tape recorder, and when it was not moving with respect to the tape recorder? What did their ears detect as being different about the three sounds?
4. In one case more sound waves were hitting the tape recorder per second than were produced by the sound generator per second. In another case fewer waves per second were hitting the tape recorder per second than were produced by the sound generator per second. And in the other case the same number of waves per second were hitting the tape recorder per second as were produced by the sound generator per second.
5. When the bike was approaching the tape recorder the waves were being all bunched together and pushed forward toward the recorder. When the bike was moving away from the tape recorder the waves get spread out. When the bike is standing still the tape recorder picks us the same frequency of waves hitting it as are produced by the sound generator.
6. A change in the frequency of a sound due to the motion of either the sound source or the observer is known as the **Doppler Effect**. Lets use a concrete example to illustrate this.
7. Get a large tub of water. Place a water bug in the center of the tub. If he moves up and down the water waves will radiate out from the center and hit the edge of the tub at the same frequency as he jumps up and down. What will happen to the frequency of waves hitting the side of the tub when he starts to move toward this side? [More waves will hit the side.] What will happen to the frequency of waves hitting the other side of the tube, the side he is moving away from? [Fewer waves will hit this side.]