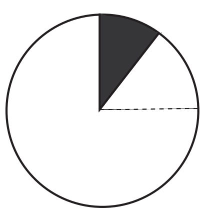
Shapes of Sound

Students observe the sound-producing modes of vibration of an object.

SCIENCE TOPICS	PROCESS SKILLS	GRADE LEVEL
Waves	Observing	5-9
Vibrations	Controlling Variables	
Sound	Inferring	
Sense of Hearing	Questioning	
	Hypothesizing	

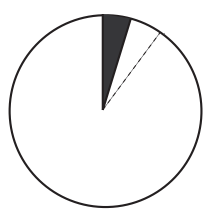
TIME REQUIRED

Advance Preparations



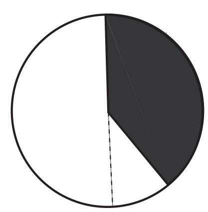
5-15 minutes

Set-Up



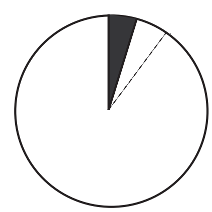
2-5 minutes

Activity



20-30 minutes

Clean-Up



2-5 minutes

MATERIALS

- Earplugs, one pair for each student, teacher, and other person in the room
- Glass or metal cooking pot lids at least 20 cm (8 in.) in diameter and with a central handle (one per group)
- A cup of fine sand or salt
- Rosin (as used for violin bows, available from any musical instrument shop or through the music teacher at your school)
- A violin bow
  —OR— large hack-saw and ball of cotton string, nylon cord, or dental floss (one per group is optional)

ADVANCE PREPARATIONS

❑ **STEP 1: PREPARING THE BOW:**

- Utilize an available violin bow (not from a fine instrument, but a spare bow) – one per group is optional. - OR - If you have no violin bow, remove the blade from a large hacksaw. Leave the adjustment screw loose. Unwind some cotton string, nylon string, or floss and tie it where you removed the hacksaw blade. You should be able to tighten the string or use the adjustment screw on the hacksaw.
- Rub rosin along the length of the bow or the tightened string on the hacksaw.

❑ **STEP 2: GATHER FOR EACH TABLE GROUP –**
if you do not have enough supplies for multiple groups, have student groups rotate through one “station.”

- pot lid
- violin bow or hacksaw bow
- sand or salt (about 1/8 cup per group)

INTRODUCING THE ACTIVITY

Ask the students the questions in **bold.** Possible answers are shown unbold in *italics.*

What is sound?
Some students will give examples. Some students will talk about waves or vibrations. Some will talk in terms of the ear and our ability to hear. If students know a great deal about sound vibrations and waves, ask them how sound waves might be the same or different than radio, microwaves, or ocean waves. If no one is sure, assign homework research, asking students to research sound waves for future discussion.

Can you sense sound other than through your ears?
We may see the vibration of a drum, the waves of a recording device or on an oscilloscope, etc. Beethoven was deaf and sawed off the legs of his piano so that he could feel vibrations through the floor.

Is sound dangerous?
Research indicates between 15% and 20% of American teens have already suffered hearing damage due to noise exposure by the time they leave high school. Although they may not be aware of their hearing loss (because early effects of hearing damage are often subtle), Noise-Induced Hearing Loss causes significant changes in both the quantity and quality of the sound one is able to hear.

In the experiment today, we will look at the ability of sound to actually move matter and how objects vibrate. The “power” of sound vibrations will become obvious.

CLASSROOM ACTIVITY

Students should work in groups of at least three.

Caution: This experiment may produce loud, high-pitched sounds. Always have students wear earplugs when working with loud noise or music.

Student Procedure:

1. Assign roles for the experiment. In each group there should be a "Holder," a "Bower" and an "Observer/Recorder."

2. Sprinkle a sparse dusting of fine sand or salt evenly over the entire surface into the upside-down pot lid or Chladni Plate (Optional Extension A).

3. Hold the base of the Chladni Plate assembly or handle of the pot lid firmly on a desktop without touching the Chladni Plate or pot lid.

4. Make sure the bow has rosin on it and draw it slowly down along the edge of the plate or lid. (If you have made a Chladni Plate in optional extension A, draw the bow along the middle of one edge of a rectangular plate.)

5. After several passes with the bow, record the pattern made by the sand or salt. The pattern may be sketched or photographed.

6. Spread out the sand or salt again and repeat by bowing in the same spot. Record the resulting pattern.

7. Spread out the sand or salt again and try bowing in a different spot or touching the surface edge of the plate or lid with a knitting needle (or tip of a scissors) and bowing.

DISCUSSION

Ask for student observations.
Observed patterns will vary depending on the shape and material of the plate or pot lid. It may take some practice to generate a pattern using a knitting needle or scissors to force a node. Check for understanding as to why the sand or salt formed a pattern. Remember that the sand or salt is moved by the energy of motion of the sound vibrations and collects or piles up where there is no vibration.

Can we actually see sound waves? No, but we can see what they do.
The sound produced by the vibrating Chladni Plates (or pan lids) resulted from the vibration patterns revealed by the sand or salt. We can also see sound waves with the aid of an oscilloscope, which turns sound waves into electrical energy.

Can we see things move as a result of sound waves?
The sand or salt was moved into the Chladni patterns by the energy of the vibrating object that also produced a sound. This sound energy is what is collected by the outer ear and transferred by the middle ear to the cochlea in the inner ear. The energy moves through the fluid-filled cochlea causing the tiny stereocilia on the hair cells to move. Those movements are responsible for hearing.

Discuss the fact that in our inner ear, sound waves actually move small hair-like structures (called stereocilia) that are attached to the tops of the specialized sensory cells (called hair cells). This action is similar to the way in which sound vibration caused the salt or sand to move on the Chladni Plate. These hairs are "tuned" to different frequencies of vibrations making different parts of the cochlea more or less sensitive to different frequencies of sound. The inner-ear stereocilia are much smaller than grains of sand. If incoming sound is intense enough, the sound waves cause some of the stereocilia to bend over or even break. The stereocilia may be able to straighten out and return to their normal position if the sound exposure was not too intense. However, with repeated exposure to loud sounds over time, or if sound is made sufficiently intense, more and more hair cells will suffer damage. Some stereocilia will break, for which there is no repair (unless you're a bird or a frog!). The result will be a permanent decrease in the ability to hear. This often occurs as a gradual loss of hearing which may not be noticeable at first. Most musicians, especially rock musicians suffer hearing loss even in early adulthood. This is known as “Noise-Induced Hearing Loss” (NIHL).

Ask students to give examples of some loud sounds they are exposed to in their environment.
Noise is not the only cause of hearing loss, but it is the most common cause in America (and in other industrialized nations). Loud noises (at or above 85 dB) can hurt your ears by damaging the sensitive hair cells of the inner ear. It makes no difference whether you like the loud sounds or not – if they are at or over 85 dB, they can begin to damage hair cells in your inner ear.

Because there is currently no treatment to repair hair cells that have been damaged by loud sound, it is important for people to protect themselves from such damage. Fortunately, there are several actions a person can take to prevent Noise-Induced Hearing Loss.

Following are three major ways to protect hearing:

- **Turn down the volume**
- **Walk away (put as much distance as possible between your ears and the sound source)**
- **Wear hearing protection such as ear plugs or “ear muffs”**

Revisit the “QUESTIONS TO DETERMINE WHETHER YOU ARE BEING EXPOSED TO EXCESSIVE SOUND THAT MAY DAMAGE YOUR HEARING” in the Balloon Drum Activity, page 26.

If you answer YES to any of the questions, you have been exposed to damaging sound levels.

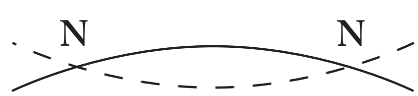
Remember: A concert can be just as damaging as noise from firearms or sirens or noisy engines. Also, growing accustomed to loud noise does not diminish its ability to damage our hearing or to cause other physiologic effects.

EXPLANATION

In-depth background information for teachers and interested students.

The rectangular or circular plate assemblies are usually called “Chladni Plates” in honor of 18th century scientist Ernest Chladni. Chladni conducted extensive work on fixed circular plates and developed Chladni’s Law which states that modal frequencies of fixed circular plates varies according to f~(m+2n)^2, where n is the number of circular nodes and m is the number of diametric nodes.

It has been found theoretically and experimentally that thin plates or membranes resonate at certain “modes.” A **mode** is just a term for one of the many ways an object can vibrate. This concept can be demonstrated with a vibrating string: tie one end of a string to a fixed object and smoothly vibrate the other end of the string. If vibrated fast enough, there will be a point or points in the middle that seem to be still while the rest of the string vibrates wildly. These points are the nodes. Imagine what happens when you strike a xylophone bar in the middle or a cymbal on the edge and set it vibrating. The bar is supported at two points towards the ends. The simplest mode of vibration is this: when the middle of the bar goes up (as shown by the solid lines in the figure) the ends of the bar go down. When the middle goes down (dashed lines), the ends go up. For the circular cymbal, the clamp in the middle forces a place where there is no motion. The points that do not move are called **nodes** and are marked N in the diagram of the xylophone bar below. (A good way to keep the terms “mode” and “node” from getting mixed up is to remember that the **no**de has **no** motion.)



Due to initial conditions imposed upon the plate (i.e. fixed edges, shape, distribution of mass) the plate and other objects can vibrate only at certain allowable frequencies and will demonstrate predictable “node” patterns. The patterns of vibration can be very complex and may also depend on where the energy causing the vibration is applied. Nodes are points on the plate that vibrate with zero amplitude (are motionless), while other surrounding points have non-zero amplitude (vibrate some distance). On a two-dimensional vibrating plate, the nodes are not points, but curves. With the circular plate, the most commonly observed pattern is concentric circular nodes and diametric modes, while with the rectangular plate commonly produces nodes parallel with the boundaries. In an object that is not firmly clamped, a vibration cannot easily move the center of mass of the object. It follows that, if some part is going up, another part is going down. In the simple motion at resonance, the point(s) that divide(s) these regions are nodes. When a violin or an isolated part is vibrating, the center of mass doesn't move much, so once again it can be divided into parts that are going up and others that are going down.

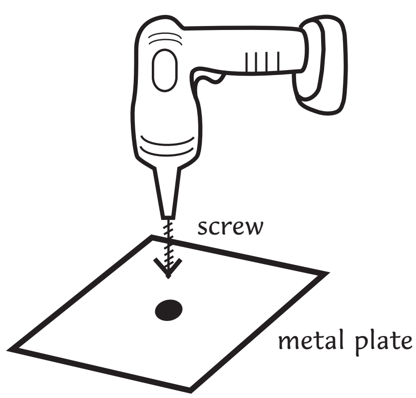
OPTIONAL EXTENSIONS

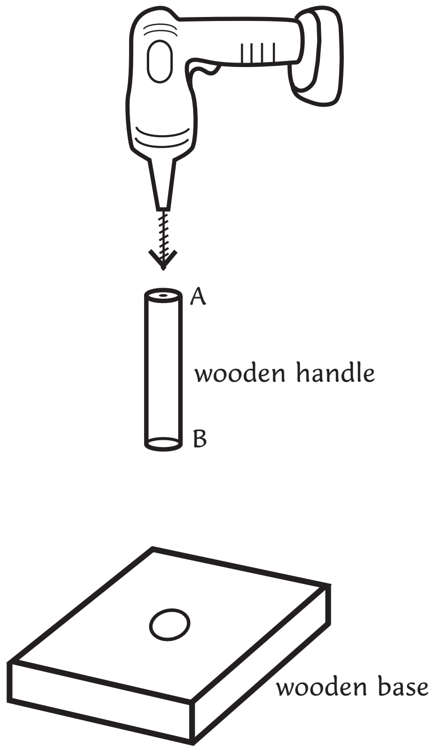
A. Make Your Own Chladni Plate Standing Display
See labeled picture on page 78 for supplies.

1. Your plate can be any size and any thickness—however, remember that the plate will be fixed in the middle at one point. If your metal is thin, make the plate small. A 1 mm-thick metal plate should be 10 to 15 cm (4 to 6 inches) square. If the plate is not perfectly shaped—no matter. Try to file the edges as flat as possible. Don't dent or scratch the surface if you can avoid it.

2. Drill a hole in the middle of the metal plate (the diameter of the hole is dependent on the size of the screw you use to secure the plate).

3. Cut off a length of rod (broom handle or wooden dowel) approximately 15cm (6 in.) long. Mark one end of the dowel or broomstick "A" and the opposite end "B."





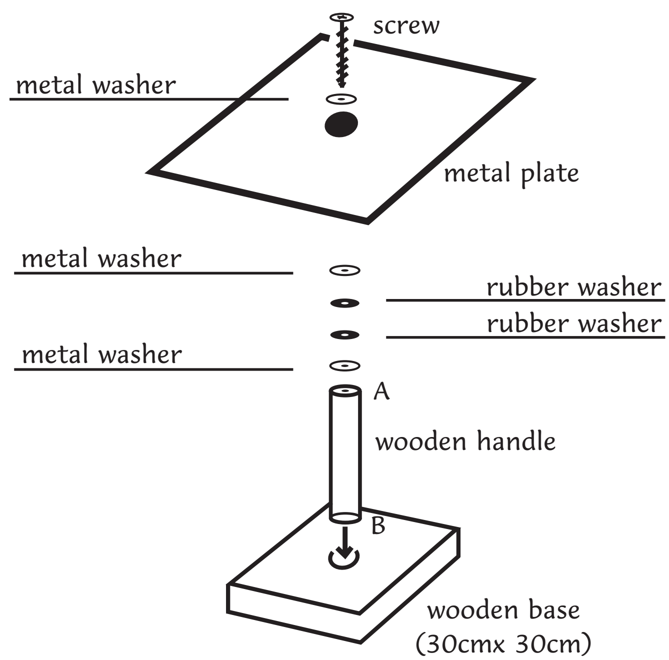
4. Carefully drill a small hole into end “A” of rod (broom handle or dowel). This hole should be smaller than the actual screw that will go into the dowel in step 7, below. (Drilling the smaller hole first will prevent the (dowel or broom handle) from splitting when you screw the plate on in step 7.

5. In this step you will be preparing the square piece of wood board, approximately 30 cm. by 30 cm. (1 ft. by 1 ft.) to serve as a base for a vertical rod (the broomstick or dowel) in much the way a Christmas tree stand might hold up a Christmas tree: Drill a hole the diameter of the broom handle or the dowel in the center of the board. To find the center you can draw a diagonal lines from opposite corners of the board. Where the two diagonal lines meet, at the center of an “X”, is the center of the board. This is where you will drill the hole.

The broom handle or dowel will need to wedge tightly into this hole. If you don't have a large enough drill bit, try filing a smaller hole to the appropriate size.

6. Insert the "B" end of the rod (dowel or broomstick) into the hole of the wooden base. This results in a horizontal wooden base with a vertical rod standing securely upright.

7. Finally place a metal washer on top of the "A" end of the upright rod (broom handle or dowel), followed by the two rubber washers, another metal washer, then the plate, the final metal washer on that and screw the assembly in place.



B. Experiencing Sound Energy

1. Carefully cut the neck off a balloon.
2. Stretch the remaining part of the balloon over the end of a cardboard tube (e.g., an empty toilet paper or paper towel tube.)
3. Secure the balloon with a small wide rubber band. Take turns talking softly and loudly into the tubes while you lightly touch the balloon end with your fingertips.
4. Can you feel the vibrations?
5. Do they change as your voice changes?

C. Bass and Treble

1. Use your balloon tube from optional extension B to feel sound vibrations from a speaker.
2. Hold the open end of the balloon tube right in front of, but not touching, the speaker.
3. If available, change the bass and treble settings on your stereo.
4. Can you feel a difference?
5. Can you also feel the vibrations within your body?
6. What do you feel the most, the vibrations from a high bass setting or a high treble setting?

D. Balloon Drum

Try the Dangerous Decibels Balloon Drum Activity from the Intermediate curriculum, page 19. Have students bring in their own music tapes to test.

E. Inquiry

Students develop an experiment to investigate whether noise affects concentration. For example, assign a poem to memorize or some math problems to do and have one group of students try to complete the assignment in a noisy environment (such as cafeteria) while the other group works in a very quiet environment. Document results and report to the class. Perhaps publish results in a school newspaper. Repeat the experiment changing roles of the two groups. (See further information about Noise Pollution in the "How Loud Is Too Loud" activity explanation on page 101, Appendix E.)

CROSS-CURRICULAR CONNECTIONS

MUSIC

A. Musical Comb

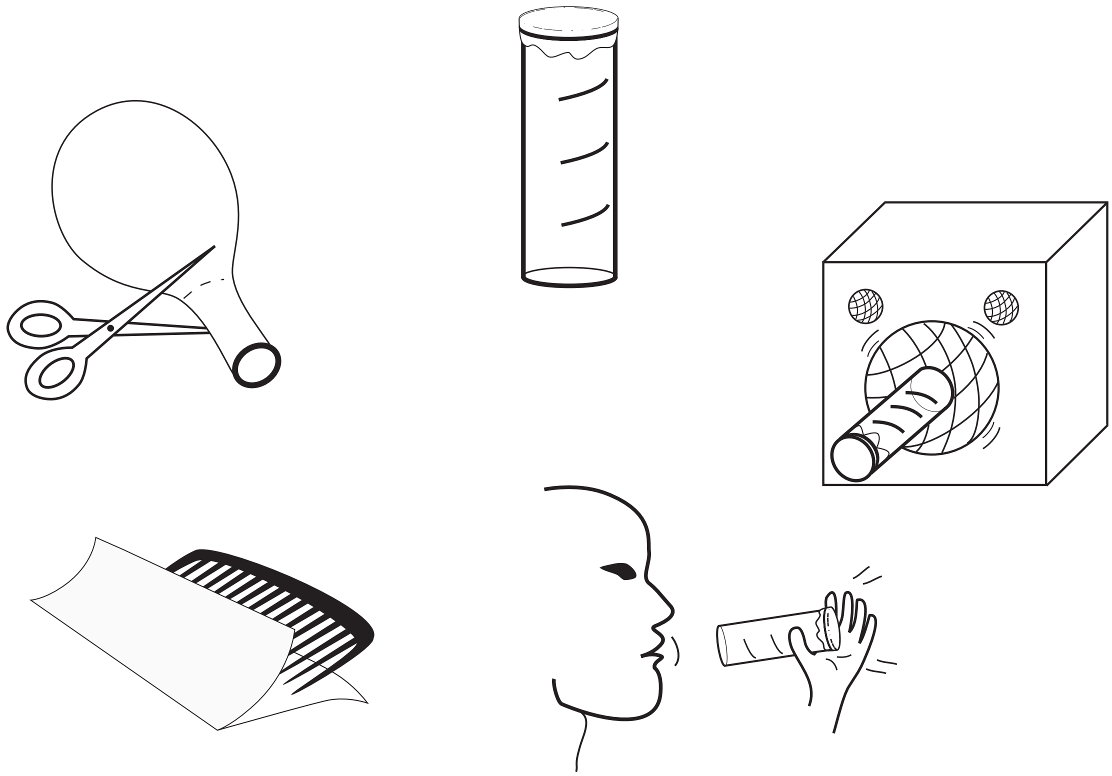
Fold a piece of wax paper in half and place a comb inside the fold.
Hold the comb at each end, pressing the paper against the teeth of the comb.
Gently press your lips against the paper and hum, keeping your lips slightly parted.

B. Kazoo

Take an empty cardboard tube and, using a paper punch, make a hole at one end of the tube about 1/2" from the end.

Cut a square of wax paper large enough to cover the end of a toilet paper tube (not smaller than 4”). Fold the wax paper down over one end of the toilet paper tube and rubber band it in firmly in place.

Explanation:
Humming causes the paper to vibrate and produce a buzzing sound. You can play a tune this way.



RESOURCES

Acoustic and Vibration Animations
http://www.kettering.edu/~drussell/Demos/MembraneCircle/Circle.html
This site by Dan Russel, Ph.D. Associate Professor of Applied Physics at Kettering University in Flint MI contains animations which visualize certain concepts concerning acoustics and vibration. In particular, this page shows various modes of vibration of a circular membrane. Go to the home page to select other examples.