REVIEW QUESTIONS

1. What are two different meanings of the word *sound*?
2. What is the science of sound generally called?
3. What is the difference between a longitudinal and a transverse wave? Give an example of each.
4. What are four different processes that can produce sound? Give an example of each.
5. What is the difference between *speed* and *velocity*?
6. The slope of a graph of position versus time is equal to what quantity?
7. What three quantities are related by Newton's second law of motion?
8. Describe the motion of an object when no net force is applied.
9. Arrange the following in order from largest to smallest: 0.004 m, 0.4 mm, 4×10^{-5} km, 4×10^{-5} μm.
10. What is the difference between *pressure* and *force*?
11. Compare the pressure on the top and the bottom sides of a thin plate immersed in water.
12. What is the pressure of the atmosphere on our bodies?
13. What is a waveform of a sound?
14. What unit is used to express energy? work?
15. What is *kinetic energy*? *potential energy*?
16. Give a formula for the potential energy of a displaced guitar string and explain each symbol.
17. What is the difference between *power* and *energy*?
18. When you pay your electricity bill, are you paying for power used or for energy used?

QUESTIONS FOR THOUGHT AND DISCUSSION

1. At the same time a rifle is fired in an exactly horizontal position over level ground, a bullet is dropped from the same height. Both bullets strike the ground at the same time. Can you explain why?
2. What are some advantages of using the metric (SI) system of units rather than the English system?
3. In the sixteenth century, Galileo is said to have dropped objects of various weights from the Leaning Tower of Pisa. Since all objects in *free fall* accelerate at 9.8 m/s^2, one would expect them to reach the ground at the same time. Careful observation, however, indicates that an iron ball will strike the ground sooner than a baseball of the same diameter. Can you explain why? Would the same be true on the moon? (The Apollo astronauts actually photographed a free-fall experiment on the moon using a hammer and a feather.)
4. Think of an object comparable in size to each of the following:
   (a) 10^7 m; **(b)** 10^3 m; **(c)** 1 m; **(d)** 10^{-3} m; **(e)** 10^{10} m.
5. Does shifting to a lower gear increase the power of an automobile? Explain.
6. Draw a diagram, similar to Fig. 1.10, showing how pressure acts on a floating object.

XERCISES

1. Letting your classroom serve as the "origin" ($x = 0, y = 0$), express the approximate coordinates (x, y) of your place of residence. Let $x =$ the distance east and $y =$ the distance north, as on a map. Use any convenient unit of distance.
2. The speed of a bicycle increases from 5 mi/h to 10 mi/h in the same time that a car increases its speed from 50 mi/h to 55 mi/h. Compare their accelerations.
3. The density of water is 1.00 g/cm^3 and that of ice is 0.92 g/cm^3. What are the corresponding densities in SI units (kg/m^3)?
4. If the speed limit is posted as 55 mi/h, express this in km/h and in m/s (1 mi = 1.61 km).
5. A car accelerates from rest to 50 mi/h in 12 s. Calculate its average acceleration in m/s^2. Compare this to the acceleration of an object in free fall (1 mi/h = 0.447 m/s).
6. An object weighing 1 lb (English units) has a mass of 0.455 kg. Express its weight in newtons and thereby express a conversion factor for pounds to newtons.
7. Express your own mass in kilograms and your weight in newtons.
8. Calculate average speed in each of the following cases:

(a) An object moves a distance of 25 m in 3 s.

(b) A train travels 2 km, the first at an average speed of 50 km/h and the second at an average speed of 100 km/h. (*Note:* The average speed is not 75 km/h.)

(c) A runner runs 1 km in 3 min and a second kilometer in 4 min.

(d) An object dropped from a height of 75 m strikes the ground in 4 s.

9. Estimate the total force on the surface of your body due to the pressure of the atmosphere.

10. Calculate the kinetic energy of a 1500-kg automobile with a speed of 30 m/s. If it accelerates to this speed in 20 s, what average power has been developed?

11. An electric motor, rated at $\frac{1}{2}$ horsepower, requires 450 W of electrical power. Calculate its efficiency (power out divided by power in). What happens to the rest of the power?

12. Calculate the potential energy of:

(a) A 3-kg block of iron held 2 m above the ground;

(b) A spring with a spring constant $K = 10^3$ N/m stretched 10 cm from its equilibrium length;

(c) A 1-L bottle ($V = 1000\ \text{cm}^3$) with a pressure 10^4 N/m^2 above atmospheric pressure ($P = 10^5$ N/m^2).

EXPERIMENTS FOR HOME, LABORATORY, AND CLASSROOM DEMONSTRATION

Home and Classroom Demonstration

1. *Longitudinal waves on a coiled spring (Slinky)* For best results, suspend a Slinky from a long horizontal stick or rod by attaching several strings (about a meter in length). However, a giant Slinky will work satisfactorily on a smooth polished floor in spite of a small amount of friction. Jerk one end of the Slinky in the direction to increase its length and observe the pulse wave that propagates. Produce a small pulse and a large pulse in rapid succession. Does the distance between the two pulses change as they travel down the spring? What does this indicate about the relationship between amplitude (pulse size) and wave speed? Generate a series of waves by smoothly increasing and decreasing its length.

Repeat the experiment with transverse rather than longitudinal pulses and waves.

2. *Siren disk* Blow air through a siren disk. If none is available, you can construct one by drilling regularly spaced holes in a wooden disk attached to a rotator. Note that the pitch of the tone depends upon the speed of rotation of the disk, whereas the loudness is determined by the rate of airflow.

3. *Moving object stroboscopically observed* In a partially or totally dark room, observe a white ball in stroboscopic light. (If none is available, a hand stroboscope can be constructed by cutting slots around the circumference of a disc mounted on a dowel rod with a finger hole for rotating it). Roll the ball on a table or other horizontal surface and compare what you see to Fig. 1.3(a). Roll the ball down an incline and compare what you see to Fig. 1.3(b).

Observe a mass oscillating on the end of a spring, and see if you can make it appear to stand still by adjusting the rate of your stroboscope (either the flashing light or the hand stroboscope).

4. *Moving-object video capture* Make a video recording of a moving object. Use a VCR with a single-frame player or a "frame grabber" to transfer single frames to a computer. Measure the distance the object has moved between successive frames.

5. *Falling object stroboscopically observed* Observe a falling object in stroboscopic light (or with video capture) and compare what you see to Fig. 1.8(a). Toss a ball upward at an angle and compare what you see to Fig. 1.8(b).

6. *U-tube manometer* Attach a length of rubber tubing to a U-shaped glass tube filled with colored water placed in front of a meter stick. The difference in heights of the water in the two sides of the U-tube represents the pressure in cm of water (a unit commonly used by organ builders). To convert cm of water to newtons/meter^2 or pascals (Pa), multiply by 100. Calibrate your lungs by blowing and sucking to obtain 100 cm of water (10^4 Pa) above and below atmospheric pressure. Which is easier to do?

7. *Deciding if pressure in a container depends upon the amount of water in the container* Place the end of the tubing attached to a manometer at various depths in a cylinder of water and show that the pressure (in cm of water) is equal to the depth of the tube below the surface. Repeat with containers of varying size and shape to show that the pressure depends only of the depth below the surface, regardless of the shape of the container or how much water it holds.

8. *Force on a container wall* Blowing a collapsed varnish can back to shape demonstrates the relationship of force to pressure. Measure the area of the large side of the can and multiply by the pressure difference inside and outside (indi-

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GLOSSARY

amplitude Maximum displacement from rest.

damping Loss of energy of a vibrator, usually through friction.

envelope Time variation of the amplitude (or energy) of a vibration.

frequency The number of vibrations per second; expressed in hertz (Hz).

fundamental mode The mode of lowest frequency.

harmonics Modes of vibration whose frequencies are whole-number multiples of the frequency of the fundamental mode.

Helmholtz resonator A vibrator consisting of a volume of enclosed air with an open neck or port.

longitudinal vibration Vibration in which the principal motion is in the direction of the longest dimension.

node, or nodal line A point or line where minimal motion takes place.

normal modes Independent ways in which a system can vibrate.

period The time duration of one vibration; the minimum time necessary for the motion to repeat.

simple harmonic motion Smooth, regular vibrational motion at a single frequency such as that of a mass supported by a string.

spectrum A "recipe" that gives the frequency and amplitude of each component of a complex vibration.

spring constant ("stiffness") The strength of a spring; restoring force divided by displacement.

transverse vibration Vibration in which the principal motion is at right angles to the longest dimension.

waveform Graph of some variable (e.g., position of an oscillating mass or sound pressure) versus time.

REVIEW QUESTIONS

1. What is meant by the period of a vibration? How is it related to the frequency?
2. In what units is the spring constant of a spring expressed?
3. What is meant by simple harmonic motion?
4. Doubling the distance a spring is stretched increases the restoring force by what factor?
5. Doubling the distance a spring is stretched increases its potential energy by what factor?
6. How does the frequency of a simple pendulum change when its mass is doubled?
7. How does the frequency of a Helmholtz resonator change when its volume is doubled? when the radius of its neck is doubled?
8. How many modes of longitudinal vibration does a two-mass system have? how many modes of transverse vibration?
9. How many modes of longitudinal vibration does a four-mass system have? how many modes of transverse vibration?
10. Describe the lowest mode of vibration in a vibrating string.
11. What is a node? Describe a node in a vibrating string. Describe a node in a vibrating membrane.
12. How many nodes are there in the lowest mode of a bar with free ends?
13. Describe the first two vibrational modes of a tuning fork.
14. What is a spectrum of vibration? In what sense is it a recipe?

QUESTIONS FOR THOUGHT AND DISCUSSION

1. Present an argument to show that the maximum kinetic energy of a mass-spring vibrator is equal to the maximum potential energy. Does the total mechanical energy remain constant throughout a cycle?
2. A damped vibrator is found to decrease its amplitude by one-half every 30 s. What is its amplitude at the end of 5 min? In theory will it every stop vibrating? Will it in practice? Explain. (*Hint:* $(\frac{1}{2})^{10} = \frac{1}{1024} \simeq 0.001$.)
3. With the help of Figs. 2.10 and 2.12, make a diagram of the four independent longitudinal modes of vibration for a four-mass vibrator.
4. To excite a tuning fork in its principal mode of vibration with a minimum of "clang" sound, where should you strike it? Of the four microphone positions A, B, C, and D in Fig. 2.23, which will best pick up the sound of the fork? Why?

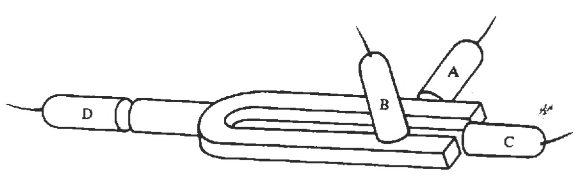

FIGURE 2.23

5. Why is the center arrow in Fig. 2.10(a) larger than the other two arrows?
6. Which Chladni patterns in Fig. 2.19 most nearly correspond to the second and fourth diagrams in Fig. 2.15? In what way are they different?

EXERCISES

1. Hanging a mass of 1 kg on a certain spring causes its length to increase 0.2 m.
   (a) What is the spring constant K of that spring?
   (b) At what frequency will this mass-spring system oscillate?
2. Copy the graphs of displacement and velocity shown in Fig. 2.2, and draw graphs of kinetic energy and potential to the same scale of time.
3. Most grandfather clocks have a pendulum that ticks (makes half a vibration) each second. What length of pendulum is required? (The value of g was given in Chapter 1 as 9.8 m/s^2.)
4. A bass-reflex loudspeaker enclosure (see Fig. 19.12) is essentially a Helmholtz resonator. Given the following parameters, what resonance frequency might be expected? $V = 0.5 \text{ m}^3$, $a = 0.02 \text{ m}^2$, $l = 0.05$ m, speed of sound $v = 343$ m/s at $T = 20°$C.
5. Calculate the maximum potential energy of the mass-spring system described in Problem 1 if its maximum displacement is 5 cm.
6. In the two-mass system shown in Fig. 2.7, each mass is 2 kg and each spring constant $K = 100$ N/m. Calculate the frequencies of modes (a) and (b).
7. Equation (2.3) for the frequency of a simple mass-spring vibrator assumes that the mass of the spring is much smaller than that of the load and thus can be neglected. This will not always be the case. The formula can be refined by letting m be the mass of the load plus one-third the mass of the spring. Suppose that the spring in the example in Section 2.1 has a mass of 100 g (K was found to be 196 N/m). Calculate the vibration frequencies with loads of 0.5 kg and 2 kg, and compare them to those given in the example.

EXPERIMENTS FOR HOME, LABORATORY, AND CLASSROOM DEMONSTRATION

Home and Classroom Demonstration

1. *Simple vibrating system: dependence of frequency on mass* Load a spring with several different masses and determine its frequency by counting oscillations during some appropriate time interval (such as a half-minute). What happens to the frequency when the mass is doubled? What happens when it is quadrupled?

2. *Simple vibrating system: dependence of frequency on spring constant* Determine the frequency of the simple vibrating system using several different spring constants. The spring constant can be determined by loading the spring with different masses and noting its static deflection, but this may not be necessary. Connecting two identical springs in series reduces the spring constant by half, whereas connecting them in parallel doubles the spring constant. What happens to the frequency when the spring constant is doubled? What happens when it is halved?

refraction A bending of waves when the speed of propagation changes, either abruptly (at a change of medium) or gradually (e.g., sound waves in a wind of varying speed).

standing wave A wavelike pattern that results from the interference of two or more waves; a standing wave has regions of minimum and maximum amplitude called nodes and antinodes.

superposition The motion at one point in a medium is the sum of the individual motions that would occur if each wave were present by itself without the others.

transverse wave A wave in which the vibrations are at right angles to the direction of propagation of the wave; *example:* waves on a rope.

waveform The graph of some variable (e.g., wave displacement, sound pressure) versus time.

wavelength The distance between corresponding points on two successive waves.

Young's modulus An elastic modulus of a solid; the ratio of force per unit area to the stretch it produces.

REVIEW QUESTIONS

1. How many times faster do light waves travel as compared to sound waves?
2. Compare the speed of longitudinal (sound) waves in an aluminum rod 10 mm in diameter with a similar rod 5 mm in diameter.
3. Doubling the frequency of a sound wave multiplies the wavelength by what factor?
4. Compare the phases of an incident and reflected pulse on a rope with a fixed end and then with a free end.
5. What must be true of the sizes and shapes of two pulses that meet on a rope in order for them to cancel each other (interfere destructively)?
6. Compare the speed of sound in air, water, and steel.
7. How does the speed of sound in air change with temperature?
8. How does the speed of sound in air change with atmospheric pressure?
9. Describe the sound of a car horn as the moving car passes an observer standing at roadside.
10. What is the cause of the "red shift" observed in the spectra of distant stars?
11. Why are curved walls sometimes detrimental to concert hall acoustics?
12. Why is it difficult to be heard when you shout into a strong wind?
13. Why is it possible to hear around a corner but not to see around a corner?
14. Why do you see a flash of lightning seconds before you hear the thunder associated with it?
15. Why do low frequency sound waves from a subwoofer spread out in all directions, but high-frequency sound waves from a tweeter travel pretty much straight ahead?

QUESTIONS FOR THOUGHT AND DISCUSSION

1. Although ocean waves are often described as transverse waves, the motion of a small bit of water is actually in a circle. Why could strictly transverse waves not exist on a water surface?
2. Mine operators carefully select the right atmospheric conditions for blasting operations in order to minimize community disturbance. What atmospheric conditions would be optimum?
3. (a) Will a larger pulse (with more energy) overtake a smaller pulse as they travel down a rope?
   (b) Will a baseball thrown with more energy overtake a baseball with less energy?
   (c) Does a loud sound travel faster than a softer sound?
4. A camera lens is made of glass in which light travels slower than it does in air. Could you construct a lens for sound by filling a balloon with carbon dioxide?
5. Would you expect interference effects from two loudspeakers in a room?
6. Compare the speed of sound at altitude of a jet airplane with the speed at ground level.
7. At some high altitude the density of air will equal the density of helium gas at sea level. What would you expect the speed of sound to be at this altitude?

EXERCISES

1. Electromagnetic waves travel through space at a speed of 3×10^8 m/s. Find the frequency of the following. (1 nm $= 10^{-9}$ m)
   (a) radio waves with $\lambda = 100$ m
   (b) waves of red light ($\lambda = 750$ nm)
   (c) waves of violet light ($\lambda = 500$ nm)
   (d) microwaves with $\lambda = 3$ cm (used in police radar)
2. Two trumpet players tune their instruments to exactly 440 Hz. Find the difference in the apparent frequencies due to the Doppler effect if one plays his or her instrument while marching away from an observer and the other plays while marching toward the observer. Is this enough to make them sound out of tune? (Assume 1 m/s as a reasonable marching speed.)
3. How much will the velocity of sound in a trumpet change as it warms up (from room temperature to body temperature, for example)? If the wavelength remains essentially the same (the expansion in length will be very small), by what percentage will the frequency change?
4. At what frequency does the wavelength of sound equal the diameter of the following? (1 in. $= 0.0254$ m)
   (a) a 15-in. woofer
   (b) a 3-in. tweeter
5. A nylon guitar string has a mass per unit length of 8.3×10^{-4} kg/m and the tension is 56 N. Find the speed of transverse waves on the string.
6. The audible range of frequencies extends from approximately 50 to 15,000 Hz. Determine the range of wavelengths of audible sound.
7. The distance from the bridge to the nut on a certain guitar is 63 cm. If the string is plucked at the center, how long will it take the pulse to propagate to either end and return to the center? (Use the speed calculated in Problem 5.)
8. Find the speed of sound in miles per hour at 0°C. This is called Mach 1. A supersonic airplane flying at Mach 1.5 is flying at 1.5 times this speed. Find its speed in miles per hour.
9. A thunderclap is heard 3 s after a lightning flash is seen. Assuming that they occurred simultaneously, how far away did they originate?
10. The density of aluminum is 2700 kg/m^3 and Young's elastic modulus is 7.1×10^{10} N/m^2 (Pa). Compare the speed of longitudinal waves in aluminum to those in steel (See Example 3.1).
11. Compare the speed of sound calculated from Eqs. (3.4) and (3.5) when $t = 30$°C.

EXPERIMENTS FOR HOME, LABORATORY, AND CLASSROOM DEMONSTRATION

Classroom Demonstrations

Waves in one dimension

1. *Waves on a rope* A rope is stretched across the front of the room and one end is fastened to a door handle or other fixed point. The other end is held in one hand, and the other hand strikes it quickly to create a pulse. The speed of this pulse is shown to increase as the tension increases. The phase of the reflected pulse on the rope is seen to be reversed (see Fig. 3.4(a)).

2. *Wave machine* A pulse is sent down a wave machine of the type developed at Bell Laboratories (see Fig. 3.8). Reflection at a fixed end again reverses the impulse, whereas reflection at a free end maintains the same orientation. When the wave machine is terminated with a dashpot, no reflection occurs.

3. *Standing waves on a rope* The rope (in Experiment 1) is moved up and down rhythmically to produce a standing wave pattern. Vary the frequency to produce one, two, and three loops. Have a student grab the rope at a nodal point to show that waves still propagate "through" his or her hand. An elastic rope attached to an electromagnetic wave driver (Pasco SE9409 and WA9753, for example) is particularly convenient for this demonstration. Projecting a transparency similar to Fig. 3.10 (preferably with the three waves in different colors) at the same time is a great help to the students in understanding standing waves.

4. *Standing waves on a wave machine* Standing waves are generated on the wave machine by moving the hand up and down rhythmically, by attaching a motorized driver, or by using an electromagnetic driver. Compare the standing waves that result from a fixed end and a free end.

5. *Wave reflection at an interface* Wave machines generally include two sections having different wave speeds. Attach two

damping Energy loss in a system that slows it down or leads to a decrease in amplitude.

electromagnetic force The force that results from the interaction of an alternating electric current with a magnetic field.

fundamental The mode of vibration (or component of sound) with the lowest frequency.

harmonic A mode of vibration (or a component of a sound) whose frequency is a whole-number multiple of the fundamental frequency.

Helmholtz resonator A vibrator consisting of a volume of enclosed air with an open neck or port.

linewidth The width Δf of a resonance curve, usually measured at 71% of its maximum height; a measure of the sharpness of a resonance (a sharp resonance is characterized by a small linewidth).

overtone A component of a sound with a frequency greater than the fundamental frequency.

partial A component of a sound; includes the fundamental plus the overtones.

phase difference A measure of the relative positions of two vibrating objects at a given time; also the relative positions, in a vibration cycle, of a vibrating object and a driving force.

Q A parameter that denotes the sharpness of a resonance; $Q = f_0/\Delta f$, where f_0 is the resonance frequency and Δf is the linewidth.

resonance When a vibrator is driven by a force that oscillates at a frequency at or near the natural frequency of the vibrator, a relatively large amplitude results.

soundboard A sheet of wood or other material that radiates a substantial amount of sound when it is driven in sympathetic vibration by a vibrating string or in some other manner.

spectrum A recipe for vibratory motion (or sound) that specifies the relative amplitudes of the partials.

sympathetic vibration One vibrator causing another to vibrate at the same frequency (which may or may not be a resonance frequency). An example is a piano string causing the bridge and soundboard to vibrate at the string's frequency.

REVIEW QUESTIONS

1. Write a definition of *resonance* and give several examples.
2. In Fig. 4.4, do the solid curves or the dashed curves represent a higher Q? Explain.
3. What does n equal in Fig. 4.5(d)? How many wavelengths equal L?
4. Distinguish between partials, harmonics, and overtones.
5. If you blow over the ends of two pipes, one with the other end closed and one with it open, which pipe will give the tone of lower pitch? approximately how much lower?
6. A pipe with one open and one closed end has its lowest resonance at 200 Hz. What are the frequencies of its next two resonances?
7. What is acoustic impedance?
8. In order to lower the Helmholtz resonances of a guitar would you make the sound hole larger or smaller?
9. To excite a singing rod in its fundamental mode, where should you hold it? Where should you stroke it?
10. Can a singer break a wineglass by singing loudly?
11. What is the main function of a piano soundboard?

QUESTIONS FOR THOUGHT AND DISCUSSION

1. If a child in a swing is pushed with the same impulsive force in each cycle, will the amplitude increase by the same amount in each cycle?
2. List as many examples of Helmholtz resonators as you can other than those given in Section 4.7. Are the resonances sharp or broad?
3. Attach a mass to a spring, as in Fig. 2.1 or 4.2, and determine the approximate resonance frequency by moving the top of the spring up and down by hand. Then move it at frequencies below and above resonance, and carefully describe the force exerted on your hand in each case.
4. Does the end correction given in Section 4.5 lower all harmonics of a pipe proportionally, or does it result in the overtones going out of tune? An exact expression for the end correction shows that it varies slightly with wavelength. Does that change your answer?

EXERCISES

1. A particular vibrator has a resonance frequency of 440 Hz and a Q of 30. What is the linewidth of its resonance curve?
2. Sketch a waveform that represents the displacement of the mass in Fig. 4.2 as a function of time. Then carefully sketch a second wave one-fourth cycle in advance of the first to represent the driving force at resonance. Label each curve correctly.
3. Determine the frequencies of the fundamental and first overtone (second partial) for the following. Neglect end corrections.
   (a) A 16-ft open organ pipe
   (b) a 16-ft stopped organ pipe (one open end, one closed end)
4. Extend Figs. 4.7 and 4.8 to include two more modes each.
5. Find the difference in the fundamental frequency, calculated with and without the end correction, of an open organ pipe 2 m long and 10 cm in diameter.
6. A nylon guitar string 65 cm long has a mass of 8.3×10^{-4} kg/m and the tension is 56 N. Find the frequencies of the first four partials.
7. A steel bar 1 m long is held at the center and tapped on one end. Because its ends are free to move, its modes of longitudinal vibration will be similar to those of the air in a pipe open at both ends. Using the speed of sound given in Table 3.1, calculate the frequencies of the first three longitudinal modes.
8. Determine the frequencies of the pipes in Problem 3 if helium is substituted for air. (The speed of sound in helium is given in Table 3.1.)

EXPERIMENTS FOR HOME, LABORATORY, AND CLASSROOM DEMONSTRATION

Home and Classroom Demonstration

1. *Resonance of hand-held oscillator* It is easy to demonstrate resonance by moving the top of a spring, to which a mass is attached, up and down at the correct frequency. When the hand is moved up and down slowly, the mass is seen to move in phase with the hand; when the hand is moved quite rapidly, it can be seen that the mass and the hand move in opposite phase, as shown in Fig. 4.3.

2. *Resonance of a driven oscillator* Quantitative data require a sinusoidal drive with variable frequency. Although it is easy to demonstrate that the amplitude of a mass-spring oscillator has maximum value at the resonance frequency (Fig. 4.2), it is more difficult to show the important phase change at resonance (Fig. 4.3). Attaching markers as shown at the right is fairly effective. In the Pasco ME9210A harmonic motion analyzer (now discontinued), a flashing LED showed the phase relationship between the driver and the oscillating mass.

3. *Resonance of a wire string* The resonances of a thin wire string should be demonstrated, preferably both by electromagnetic excitation and by bowing with a violin bow (see Fig. 4.6).

4. *Resonance of a closed tube* A tuning fork is held above one end of a glass tube whose other end is immersed in a large reservoir of water. The tube is raised or lowered in the water until resonance occurs.

Another way to change the length of a closed-end tube is to connect it to a reservoir by means of a hose. The water height in the tube is adjusted by raising or lowering the reservoir.

5. *Resonance of a tube by a loudspeaker* A loudspeaker L driven by an audio generator sets up standing waves in a large cardboard or Plexiglas tube. A small microphone M can be moved up and down to locate the pressure maxima for each resonance.

6. *Tubing fork resonator* The Ames tube, sold by Riverbank Laboratories, is a tuning fork and open-end resonance tube combined. Their Ames tube kit includes materials for several interesting demonstrations. Choirchimes, made by Malmark, Inc. (a handbell manufacturer), similarly combine a tuning fork with a closed-end resonator. Choirchimes, which are popular with handbell choirs in churches and schools, include a clapper with which to set the tuning fork into vibration.

7. *Smoke alarm vibrator* A vibrator of the type used in smoke alarms is attached to one end of a tube, which is adjustable in length. When powered by a battery, the vibrator generates a tone with several harmonics, and the tube can be adjusted to resonate with individual harmonics.