fference A measure of the relative positions of two ; objects at a given time; also the relative positions, ation cycle, of a vibrating object and a driving force.

rameter that denotes the sharpness of a resonance; $/\Delta f$, where f_0 is the resonance frequency and Δf ewidth.

ce When a vibrator is driven by a force that oscil- a frequency at or near the natural frequency of the a relatively large amplitude results.

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

n A recipe for vibratory motion (or sound) that spec- relative amplitudes of the partials.

ıetic vibration One vibrator causing another to vi- the same frequency (which may or may not be a res- requency). An example is a piano string causing the nd soundboard to vibrate at the string's frequency.

ıipe with one open and one closed end has its lowest ınance at 200 Hz. What are the frequencies of its next ı resonances?

ıat is acoustic impedance?

ırder to lower the Helmholtz resonances of a guitar, ıld you make the sound hole larger or smaller?

excite a singing rod in its fundamental mode, where ıld you hold it? Where should you stroke it?

ı a singer break a wineglass by singing loudly?

ıat is the main function of a piano soundboard?

top of the spring up and down by hand. Then move it requencies below and above resonance, and carefully cribe the force exerted on your hand in each case.

es the end correction given in Section 4.5 lower all monics of a pipe proportionally, or does it result in overtones going out of tune? An exact expression the end correction shows that it varies slightly with velength. 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.