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.

... The rope (in Experiment 1) is ... 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. *Reflection at an interface* Wave machines generally

sections together, and show the difference when a pulse originates in the slower medium and the faster medium.

6. *Waves in a ripple tank* Wave images can be projected onto a screen by means of an overhead projector or a large mirror. In a small class, projection onto the ceiling or a white paper on the floor may be satisfactory. The class should be shown how single pulses, plane waves, and circular waves propagate, reflect (at straight and curved reflectors), and refract. Diffraction at a slit and two-source interference should also be demonstrated. More complex phenomena may be demonstrated by means of film or videotape.

7. *Standing waves in a room* A three-dimensional pattern of standing waves can be demonstrated by driving a loudspeaker with a sine wave of about 1000 Hz and having the students move their heads. Ask them to estimate the distance between adjacent maxima (these will be only approximately a half-wavelength apart in a three-dimensional standing wave). Repeat the experiment at other frequencies. They may be surprised to discover a maximum (of sound pressure) in each corner of the room.

Little is to be gained by using two loudspeakers. Two-source interference should probably not be demonstrated in a classroom.*

8. *Diffraction by a slit* Diffraction can best be demonstrated with light waves. A vertical line source (straight-filament lamp or fluorescent tube) is viewed through a slit formed by two fingers; as the spacing is narrowed a diffraction pattern appears. Slits of varying size can be ruled on smoked glass or an old photographic negative and passed around. Best of all are photographic negative slits made by photographing black lines of various widths.

Laboratory Experiments

Sinusoidal motion: The oscilloscope (Experiment 3 in *Acoustics Laboratory Experiments*)

Wave propagation: The ripple tank (Experiment 6 in *Acoustics Laboratory Experiments*)

*See T. D. Rossing, "Acoustic demonstra