

SOLUTION We can write, for the fundamental frequencies of each string, the ratio

$$\frac{L_L}{L_H} = \frac{f_H}{f_L},$$

where the subscripts L and H refer to the lowest and highest notes, respectively. Thus $L_L = L_H(f_H/f_L) = (5.0 \text{ cm})(150) = 750 \text{ cm}$, or 7.5 m. This would be ridiculously long ($\approx 25 \text{ ft}$) for a piano.

NOTE The longer strings of lower frequency are made heavier, so even on grand pianos the strings are less than 3 m long.

EXAMPLE 12-8 **Frequencies and wavelengths in the violin.** A 0.32-m-long violin string is tuned to play A above middle C at 440 Hz. (a) What is the wavelength of the fundamental string vibration, and (b) what are the frequency and wavelength of the sound wave produced? (c) Why is there a difference?

APPROACH The wavelength of the fundamental string vibration equals twice the length of the string (Fig. 12-7). As the string vibrates, it pushes on the air, which is thus forced to oscillate at the same frequency as the string.

SOLUTION (a) From Fig. 12-7 the wavelength of the fundamental is

$$\lambda = 2L = 2(0.32 \text{ m}) = 0.64 \text{ m} = 64 \text{ cm}.$$

This is the wavelength of the standing wave on the string.

(b) The sound wave that travels outward in the air (to reach our ears) has the same frequency, 440 Hz. Its wavelength is

$$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{440 \text{ Hz}} = 0.78 \text{ m} = 78 \text{ cm},$$

where v is the speed of sound in air (assumed at 20°C), Section 12-1.

(c) The wavelength of the sound wave is different from that of the standing wave on the string because the speed of sound in air (343 m/s at 20°C) is different from the speed of the wave on the string ($= f\lambda = 440 \text{ Hz} \times 0.64 \text{ m} = 280 \text{ m/s}$) which depends on the tension in the string and its mass per unit length.

NOTE The frequencies on the string and in the air are the same; the string and air are in contact, and the string “forces” the air to vibrate at the same frequency. But the wavelengths are different because the wave speed on the string is different than that in air.

Stringed instruments would not be very loud if they relied on their vibrating strings to produce the sound waves since the strings are too thin to compress and expand much air. Stringed instruments therefore make use of a kind of mechanical amplifier known as a *sounding board* (piano) or *sounding box* (guitar, violin), which acts to amplify the sound by putting a greater surface area in contact with the air (Fig. 12-9). When the strings are set into vibration, the sounding board or box is set into vibration as well. Since it has much greater area in contact with the air, it can produce a more intense sound wave. On an electric guitar, the sounding box is not so important since the vibrations of the strings are amplified electronically.

Wind Instruments

Instruments such as woodwinds, the brasses, and the pipe organ produce sound from the vibrations of standing waves in a column of air within a tube or pipe (Fig. 12-10). Standing waves can occur in the air of any cavity, but the frequencies present are complicated for any but very simple shapes such as the uniform, narrow tube of a flute or an organ pipe. In some instruments, a vibrating reed or the vibrating lip of the player helps to set up vibrations of the air column. In others, a stream of air is directed against one edge of the opening or mouthpiece, leading to turbulence which sets up the vibrations. Because of the disturbance, whatever its source, the air within the tube vibrates with a variety of frequencies, but only frequencies that correspond to standing waves will persist.



(a)



(b)

FIGURE 12-9 (a) Piano, showing sounding board to which the strings are attached; (b) sounding box (guitar).

CAUTION

Speed of standing wave on string \neq speed of sound wave in air

FIGURE 12-10 Wind instruments: clarinet (left) and flute.

