In a pipe open at both ends, the first possible wavelength is 2*L;* in a pipe closed at one end, the first possible wavelength is 4*L.* Because frequency and wavelength are inversely proportional, the fundamental frequency of the open pipe should be twice that of the closed pipe, that is, 70.4 = (2)(35.2).

PRACTICE B

Harmonics

1. What is the fundamental frequency of a 0.20 m long organ pipe that is closed at one end, when the speed of sound in the pipe is 352 m/s?

2. A flute is essentially a pipe open at both ends. The length of a flute is approximately 66.0 cm. What are the first three harmonics of a flute when all keys are closed, making the vibrating air column approximately equal to the length of the flute? The speed of sound in the flute is 340 m/s.

3. What is the fundamental frequency of a guitar string when the speed of waves on the string is 115 m/s and the effective string lengths are as follows?

    a. 70.0 cm   **b.** 50.0 cm   **c.** 40.0 cm

4. A violin string that is 50.0 cm long has a fundamental frequency of 440 Hz. What is the speed of the waves on this string?

Trumpets, saxophones, and clarinets are similar to a pipe closed at one end. For example, although the trumpet shown in **Figure 17** has two open ends, the player's mouth effectively closes one end of the instrument. In a saxophone or a clarinet, the reed closes one end.

Despite the similarity between these instruments and a pipe closed at one end, our equation for the harmonic series of pipes does not directly apply to such instruments. One reason the equation does not apply is that any deviation from the cylindrical shape of a pipe affects the harmonic series of an instrument. Another reason is that the open holes in many instruments affect the harmonics. For example, a clarinet is primarily cylindrical, but there are some even harmonics in a clarinet's tone at relatively small intensities. The shape of a saxophone is such that the harmonic series in a saxophone is similar to that in a cylindrical pipe open at both ends even though only one end of the saxophone is open. These deviations are in part responsible for the variety of sounds that can be produced by different instruments.

Figure 17
Variations in shape give each instrument a different harmonic series.