Figure 14
The harmonic series present in each of these organ pipes depends on whether the end of the pipe is open or closed.

STANDING WAVES IN AN AIR COLUMN

Standing waves can also be set up in a tube of air, such as the inside of a trumpet, the column of a saxophone, or the pipes of an organ like those shown in **Figure 14.** While some waves travel down the tube, others are reflected back upward. These waves traveling in opposite directions combine to produce standing waves. Many brass instruments and woodwinds produce sound by means of these vibrating air columns.

If both ends of a pipe are open, all harmonics are present

The harmonic series present in an organ pipe depends on whether the reflecting end of the pipe is open or closed. When the reflecting end of the pipe is open, as is illustrated in **Figure 15,** the air molecules have complete freedom of motion, so an antinode (of displacement) exists at this end. If a pipe is open at both ends, each end is an antinode. This situation is the exact opposite of a string fixed at both ends, where both ends are nodes.

Because the distance from one node to the next ($\frac{1}{2}\lambda$) equals the distance from one antinode to the next, the pattern of standing waves that can occur in a pipe open at both ends is the same as that of a vibrating string. Thus, the entire harmonic series is present in this case, as shown in **Figure 15,** and our earlier equation for the harmonic series of a vibrating string can be used.

HARMONIC SERIES OF A PIPE OPEN AT BOTH ENDS

$$f_n = n\frac{v}{2L} \qquad n = 1, 2, 3, \ldots$$

$$\text{frequency} = \text{harmonic number} \times \frac{\text{(speed of sound in the pipe)}}{\text{(2)(length of vibrating air column)}}$$

In this equation, L represents the length of the vibrating air column. Just as the fundamental frequency of a string instrument can be varied by changing the string length, the fundamental frequency of many woodwind and brass instruments can be varied by changing the length of the vibrating air column.

Did you know?

A flute is similar to a pipe open at both ends. When all keys of a flute are closed, the length of the vibrating air column is approximately equal to the length of the flute. As the keys are opened one by one, the length of the vibrating air column decreases, and the fundamental frequency increases.

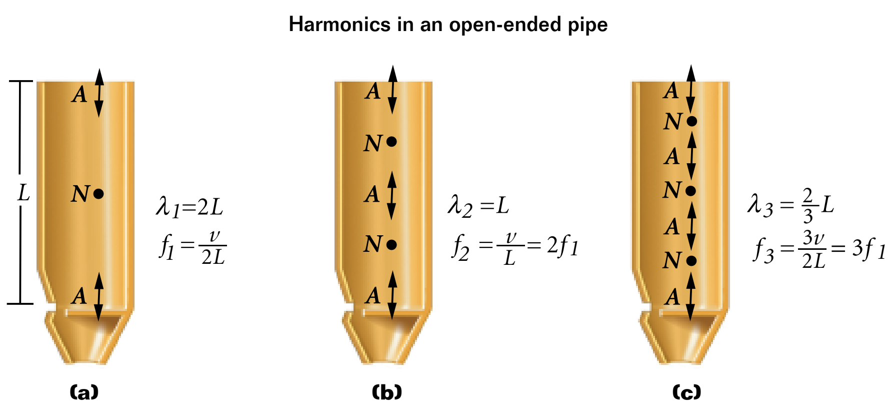

Figure 15
In a pipe open at both ends, each end is an antinode of displacement, and all harmonics are present. Shown here are the **(a)** first, **(b)** second, and **(c)** third harmonics.