Stationary waves in open air columns

Many musical instruments have tubes with two ends open. A standing wave is still produced as the longitudinal sound wave is reflected at the open ends too.

Harmonics of an open tube:

A tube must have an antinode (for displacement) at both ends of the tube when it is open in order to form a stationary wave. Unlike a tube with one close end, harmonics are all integer multiples of the fundamental frequency
(f_0 , $2f_0$, $3f_0$, $4f_0$,…….)

Harmonic	Frequency as a multiple of f_0	Length of tube	Wavelength of the progressive wave (where L is the length of the tube)
Fundamental frequency	f_0	L = $\frac{1}{2}\lambda$	2L
Second harmonic	$2f_0$	L = 1λ	L
Third harmonic	$3f_0$	L = $\frac{3}{2}\lambda$	2/3 L
Forth harmonic	$4f_0$	L = 2λ	½ L
Fith harmonic	$5f_0$	L = $\frac{5}{2}\lambda$	2/5 L

Note that this is identical to a standing wave on a length of string and the formulas are the same

(e.g. **L = k(λ/2)**). The only difference is that antinodes (of displacement) must be at the ends as they are open. Whereas on a string nodes are present at the ends.

The following diagram shows the displacement against distance along the pipe . The positions of nodes and antinodes (for displacement) are also shown. The wave shown is not transverse, it is longitudinal in nature, so the greater the amplitude of the wave shown, the greater the horizontal oscillation of the particles.

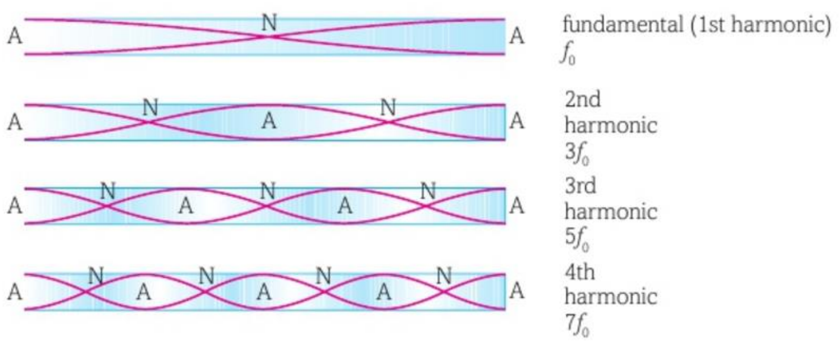

Figure 4 Stationary longitudinal waves can also be produced in pipes that are open at both ends.

Measuring the speed of sound in air

A simple but effective way of determining the speed of sound in air is to use a tuning fork and a tube of water, as shown in Figure 5.

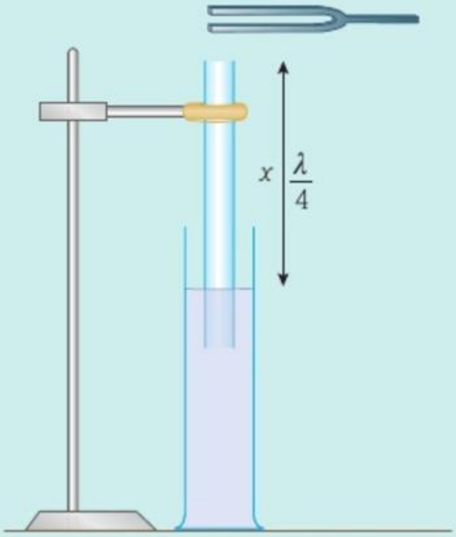

Figure 5 This apparatus can be used for setting up a stationary wave in a closed tube.

The tube is held by a clamp and is moveable so that its length can be altered. Because of the water in the measuring cylinder, the tube is effectively closed at one end.

When a tuning fork of known frequency is struck and held at the open end, the air molecules in the tube will vibrate and a stationary wave will be set up in the tube. By listening carefully, the fundamental frequency can be obtained, when the sound is loudest for at the minimum length. This is achieved when the length of the tube is equal to $\frac{1}{4}\lambda$, as shown in Figure 6.

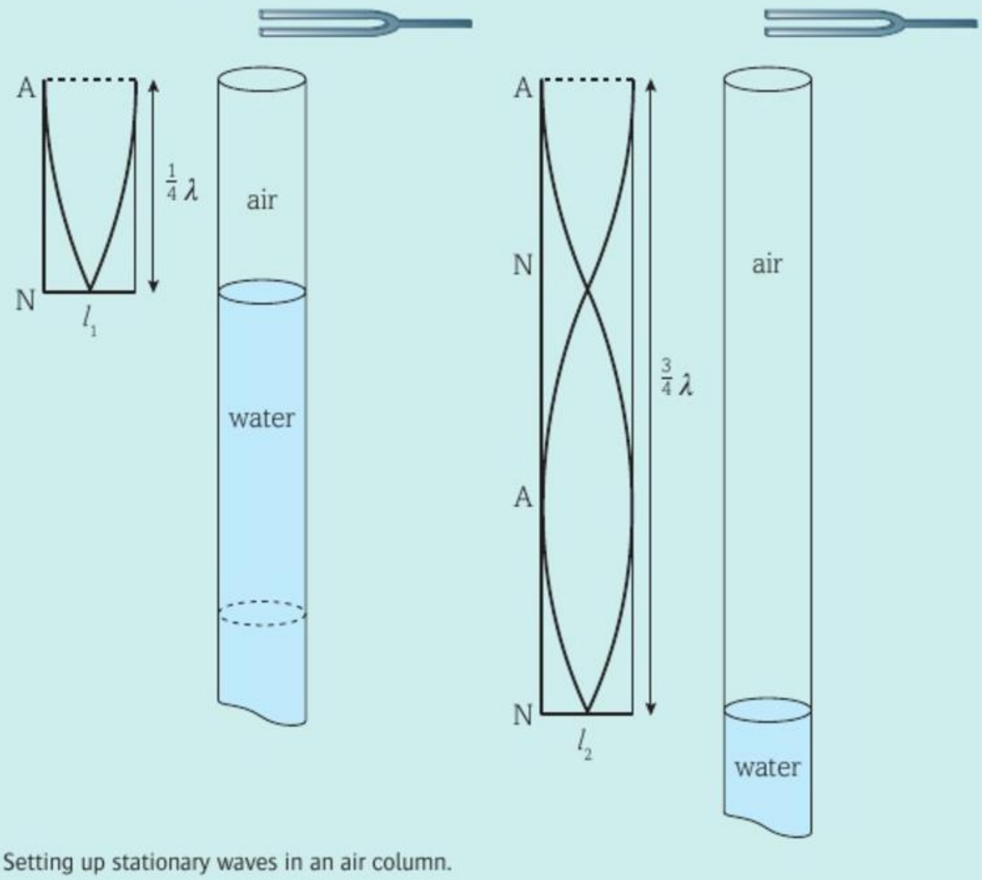

Figure 6 Setting up stationary waves in an air column.

The tube can then be lengthened by loosening the clamp, and the loudness of the sound will reduce initially before increasing again to a second maximum loudness when the length of the tube is equal to $\frac{3}{4}\lambda$. The difference between these two lengths is equal to half the wavelength of the sound, $\frac{1}{2}\lambda$, and the speed of sound can be determined by multiplying this value by 2 and then by the frequency of the tuning fork in Hz.