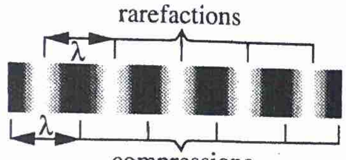
6.4.3 Determining the Wavelength of Sound

Concepts to Investigate: Wavelength of sound, resonance, fundamental mode, harmonics, speed of sound.

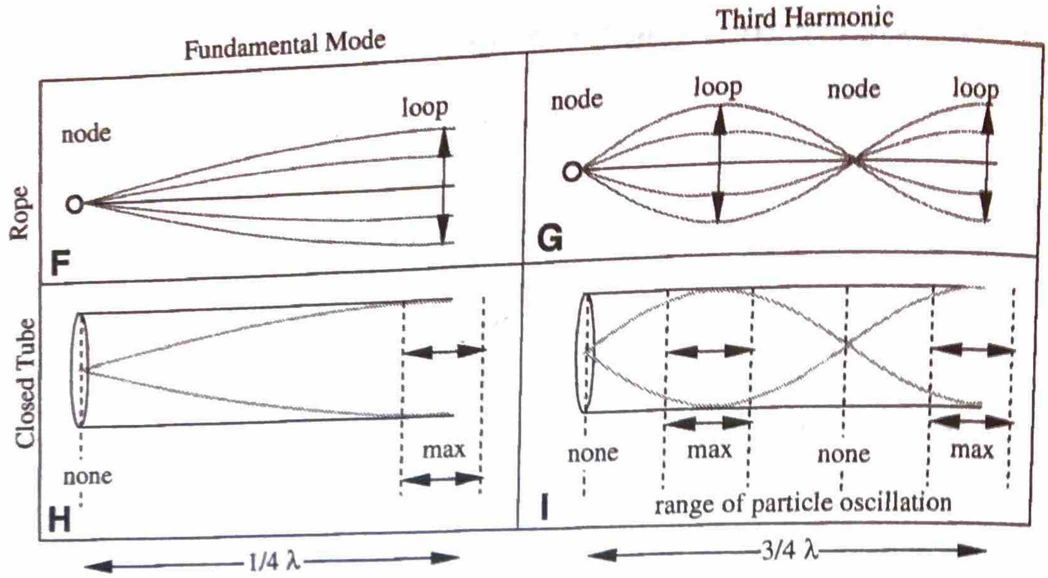
Materials: Tuning forks, 1-liter graduated cylinder or equally deep sink or container, 1"- or 2"-diameter PVC or glass pipe, hacksaw, demonstration spring or rope.

Principles and Procedures: The length of an ocean wave is defined as the distance between the crests or troughs of two successive breakers. In a similar fashion, the length of a sound wave λ is defined as the distance between two compression or rarefaction pulses (Figure E). Although it is possible to measure the wavelength of ocean waves as they approach the shore, it is impractical to measure sound waves because they travel fast (340 m/s at 20°C) and are invisible. When, however, two waves of the same amplitude and wavelength travel in opposite directions, a "standing wave" is established providing the opportunity to make measurements. Standing longitudinal waves may be understood by analogy to standing transverse waves as occur in vibrating springs or ropes. In Part 1 we will examine standing transverse waves, and in Part 2 we will determine the wavelength of sound using standing longitudinal waves in an open pipe.



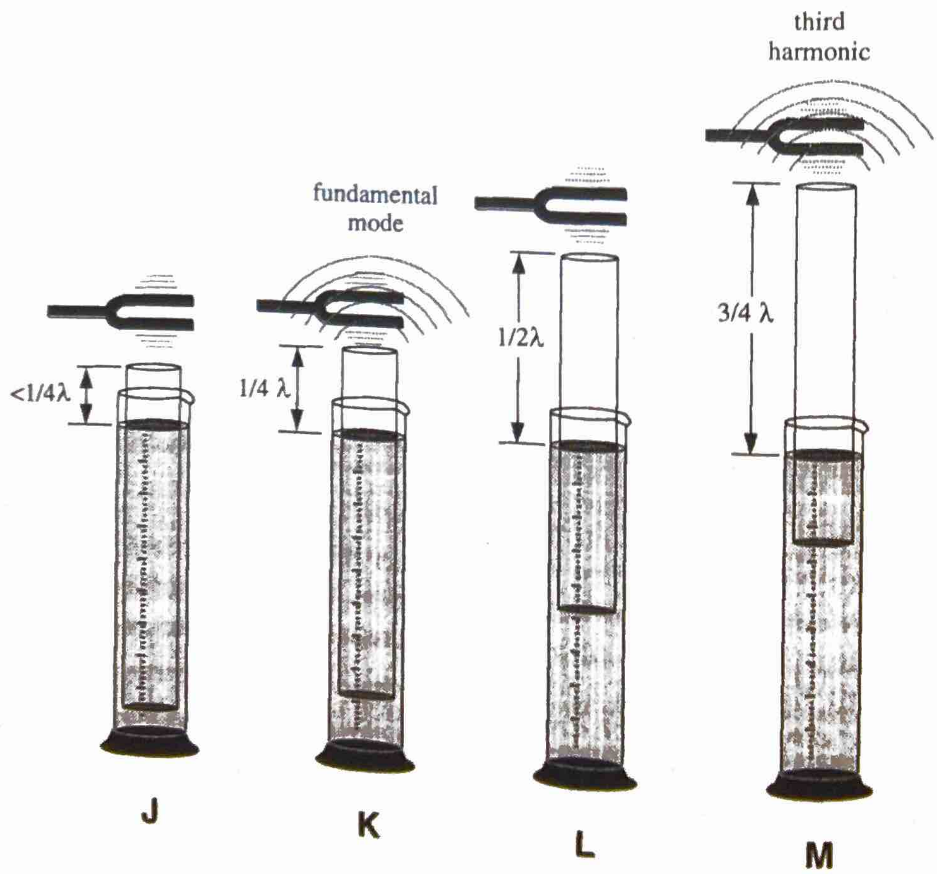
E

Part 1. Standing transverse waves: Secure one end of a wave demonstration spring or rope to an immovable object and move the other end in an oscillating fashion, as illustrated in Figure F. Some portions of the rope will appear to stand still (nodes), while other portions move rapidly back and forth (loops). In an open pipe such as a trumpet or trombone (Figure G), air molecules oscillate (move back and forth) rapidly at the loops, but not at all at the nodes. The fundamental mode is defined as the mode in which only one node exists (Figures F and G) and represents the lowest frequency, or tone, the instrument can produce. Move the free end of the rope more rapidly. When two nodes appear, the third harmonic has been established (Figures H and I). A "harmonic" is a whole number multiple of the fundamental frequency and can be generated given the same string or tube length as that producing the fundamental frequency. The pitch produced by a nonelectronic instrument is never pure, but contains one or more harmonics. These harmonics are responsible for the "quality" or "timbre" of a sound. Increase the frequency of the rope or spring again until first the fifth and then the seventh harmonics are produced. Listen carefully and notice that the loops in the rope generate a "whooshing" sound while the nodes remain silent. Draw pictures of both the fifth and seventh harmonics for a spring and an open pipe, identifying the nodes and loops in each.



F - I

Part 2. Standing longitudinal waves: Like the transverse waves in Part 1, standing sound waves also develop quiet nodes and noisy loops. The closed end of a tube acts like the fixed end of a rope, reflecting waves back toward their source. If the length of the tube is one quarter the wavelength (1/4 λ) of the sound, a loop will appear at the mouth of the tube, just as a loop appears in your hand in the fundamental mode of an oscillating rope or spring (Figures F and G). At this loop, there will be a maximum oscillation of particles, just as there was a maximum transverse oscillation of



the rope. Consequently, the sound will reach a maximum volume and the tube is said to resonate or reverberate.

Use a hacksaw to cut a section (length ≥ 50 cm) of Plexiglas, PVC, or ABS pipe (diameter ≥ 2.5 cm) and immerse in an upright position in a large graduated cylinder or other deep container. Hold a vibrating middle-C (261.6 Hz) tuning fork above the cylinder (Figure J) and slowly raise the pipe until it resonates and the amplitude of the sound increases significantly (Figure K). The shortest length at which the pipe resonates is known as the fundamental mode and is one quarter the length of the sound wave. Measure the length of the air-filled pipe (l) and multiply by four to determine the wavelength λ of sound generated by the tuning fork. Continue raising the pipe and note that the volume decreases (Figure L) before it increases again at the third harmonic (Figure M). Record the length of the third harmonic. Is it three times the length of the first harmonic? Repeat this process, using other tuning forks in the octave scale and record your results in the table provided. Determine the relationship between frequency and wavelength by plotting your data. The wave equation states that $v = f\lambda$. Knowing this, calculate the speed of sound for each tuning fork. Is the speed of sound dependent upon its frequency?

Note	f (1/s)	l	λ $(4 \times L)$	$v_{(sound)}$ $(f \times \lambda)$
C	261.6			
D	293.7			
E	329.6			
F	349.2			
G	392.0			
A	440.0			
B	493.9			
C	523.3			

Questions

(1) The speed v of sound is equal to its wavelength multiplied by its frequency $v = f\lambda$. Calculate the speed of sound produced by three tuning forks. Is the speed of sound dependent upon its wavelength ? Explain.

(2) How can one determine the fundamental mode?

(3) Does the pitch increase, decrease, or remain the same as the wavelength increases?

(4) If you have ever hummed while standing in a stairwell or shower, you may have noticed that certain frequencies cause the walls to vibrate. Explain why and when this will occur.