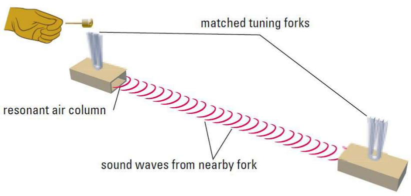
SPH3U UNIVERSITY PHYSICS

WAVES & SOUND

☞ Resonance in Air Columns (P.424)

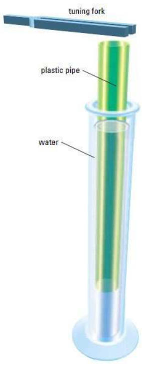
Resonance

As you learned earlier, sound waves from one source can cause an identical source to vibrate in resonance. But why is the tuning fork mounted to a wooden box? Why is the box open at one end and closed at the other and why is the box designed to be of a specific length?



Resonance in a Closed Air Column

An air column that is closed at one end and open at the other is called a ***closed air column****. When a vibrating tuning fork is held over the open end of such a column and the length of the column is increased, the loudness increases sharply at very specific lengths (i.e. points of resonance). If a different tuning fork is used, the same phenomenon is observed except the maxima occur at different lengths.*



Activity: Resonance in a Closed Air Column

INSTRUCTIONS

A. Set up a data table like the one below.

resonant point	fork #1 (f = 512 Hz)		
	column length L (cm)	wavelength λ (cm)	$\frac{L}{\lambda}$
first			
second			
third			

temperature of air =

speed of sound = ☜ recall v = 331 + 0.60T

λ = v/f

Activity: Resonance in a Closed Air Column

INSTRUCTIONS

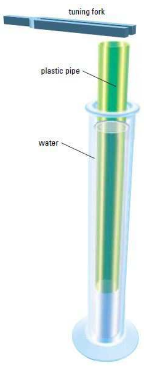
B. Place the plastic pipe in the graduated cylinder as shown. Fill the graduated cylinder with water as close to the top as possible.

C. Sound the tuning fork and hold it over the mouth of the plastic pipe. Move the pipe slowly out of the water and listen for the intensity of the sound to increase dramatically. This is the first resonant point.

D. Use the metre stick to measure the length of the air column for the first resonant length. Record your measurement.

E. Continue to raise the pipe, finding, measuring, and recording other resonant points.

F. Record the air temperature in the room.



Activity: Resonance in a Closed Air Column

QUESTIONS

1. What is the speed of sound at the air temperature you recorded?
2. What is the wavelength of the sound wave emitted by the tuning fork?
3. What is the relationship between the length of the closed air column for each resonant point and the wavelength of the tuning fork? Express your answer as a fraction to the nearest ¼ .
4. As a general rule, what are the resonant lengths, expressed in wavelengths, for a closed air column? Explain.

Activity: Resonance in a Closed Air Column

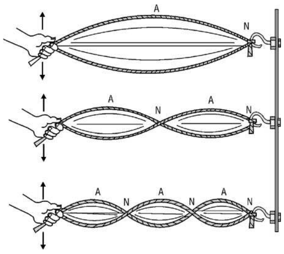
SAMPLE DATA

resonant point	fork #1 (f = 512 Hz)		
	column length L (cm)	wavelength λ (cm)	L/λ
first	17	67	0.25 ~ 1/4
second	51		0.76 ~ 3/4
third	84		1.25 ~ 5/4

temperature of air = 22°C
speed of sound = 344 m/s ☜ recall v = 331 + 0.60T
λ = v/f

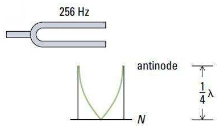
Resonance in Closed Air Columns

As you saw when we studied standing waves, when a series of transverse waves was sent down a rope to a fixed end, the wave was reflected back and interfered with the incident waves. A node always formed at the fixed end where the reflection occurred.



Resonance in Closed Air Columns

In a similar fashion, when longitudinal sound waves are emitted by a tuning fork, some of them travel down the closed air column. The end of the tube reflects the sound waves back in the same way that the waves in a rope are reflected from the fixed end. A node is formed at the bottom of the column. Resonance first occurs when the column is ¼ λ in length (i.e. L_1 = ¼λ). This is because that is the location of the first maxima (i.e. an antinode).

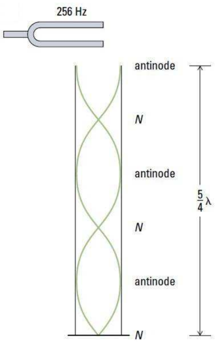


Resonance in Closed Air Columns

PRACTICE

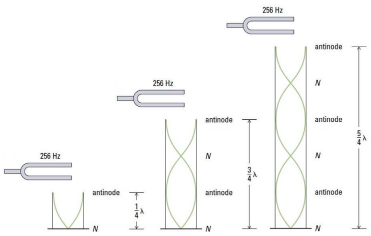
1. What are the next two resonant lengths for a closed air column (that is, where do the next two antinodes occur)?

   $L_2 = 3/4\ \lambda$
   $L_3 = 5/4\ \lambda$



Resonance in Closed Air Columns

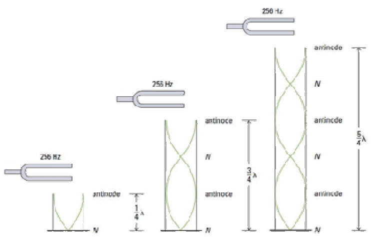
NOTE!
Resonant lengths in a closed air column start at ¼ λ and increase by ½ λ after that.



Resonance in Closed Air Columns

CLOSED AIR COLUMN

- column of air closed at one end
- first resonant length is ¼λ and lengths increase by ½λ after this
- resonant lengths are 1/4 λ, 3/4 λ, 5/4 λ, ...



Resonance in Closed Air Columns

PRACTICE

2. A vibrating tuning fork is held near the mouth of a column filled with water. The water level is lowered, and the first loud sound is heard when the air column is 9.0 cm long. Calculate the following:
   (a) the wavelength of the sound from the tuning fork
   (b) the length of the air column for the second resonance

   (a) λ = 36 cm
   (b) L_2 = 3/4 λ or 27 cm

Resonance in Closed Air Columns

PRACTICE

3. The first resonant length of a closed air column occurs when the length is 16 cm.
   (a) What is the wavelength of the sound?
   (b) If the frequency of the source is 512 Hz, what is the speed of sound?

   (a) λ = 0.64 m
   (b) f = 330 m/s (328 m/s)

Resonance in Closed Air Columns

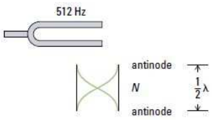
PRACTICE

4. When water is added to a bottle, what happens to the pitch of the sound as the water is added? Explain why.

   As the length of the air column decreases, the wavelength also decreases. As such, the frequency increases since $v = f\lambda$.

Resonance in Open Air Columns

*Resonance may also be produced in an **open air column**, that is, a column that is open at both ends. Since the column is open at both ends, antinodes occur at both ends. The first length at which resonance occurs is ½ λ (i.e. L_1 = ½λ).*

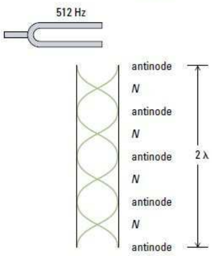


Resonance in Open Air Columns

PRACTICE

5. What are the next three resonant lengths for an open air column (that is, where do the next three antinodes occur)?

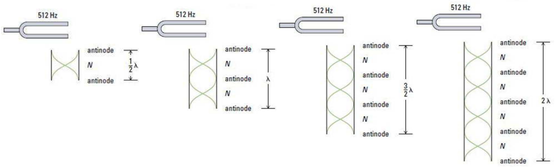
   L_2 = 1 λ
   L_3 = 3/2 λ
   L_4 = 2 λ



Resonance in Open Air Columns

NOTE!

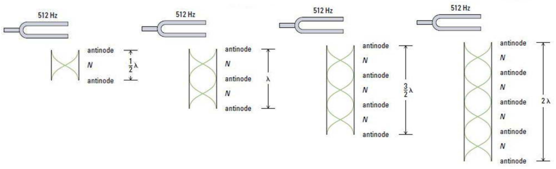
Resonant lengths in a open air column start at ½ λ and increase by ½ λ after that.



Resonance in Open Air Columns

OPEN AIR COLUMN

- column of air open at both ends
- first resonant length is ½λ and lengths increase by ½λ after this
- resonant lengths are 1/2 λ, 1 λ, 3/2 λ, ...



Resonance in Open Air Columns

PRACTICE

6. An organ pipe, 3.6 m long and open at both ends, produces a musical note at its fundamental frequency.
   (a) What is the wavelength of the note produced?
   (b) What is the frequency of the pipe if the speed of sound in air is 346 m/s?

   (a) λ = 7.2 m
   (b) f = 48 Hz

Resonance in Open Air Columns

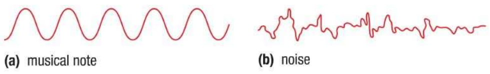
PRACTICE

7. An open air column is 60.0 cm long. If the speed of sound is 344 m/s, calculate the frequency of forks that will cause resonance at:
   (a) the first resonance length.
   (b) the third resonance length.

   (a) L_1 = 287 Hz
   (b) L_3 = 860 Hz

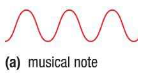
Music & Noise

*A musical note (**music**) originates from a source that vibrates in a uniform manner with one or more constant frequencies, and the waveform is constant. **Noise** originates from a source that vibrates in a non-uniform manner, and the waveform looks erratic in frequency and amplitude. In addition, the loudness and pitch of a note is determined by the amplitude and frequency of the waveform produced.*



Music & Noise

MUSIC
- sound that is pleasant to the ear
- waveform is constant



NOISE
- sound that is not pleasant to the ear
- waveform is erratic

WAVEFORM
- loudness = amplitude
- pitch = frequency

Musical Instruments – Applications of ...

All musical instruments can be grouped depending on how the vibrations are produced. Music may be produced by plucking, bowing, or striking stringed instruments; by blowing air across a hole or a reed, or through a special mouthpiece in wind instruments; or by striking various surfaces in percussion instruments.

Musical Instruments – Applications of ...

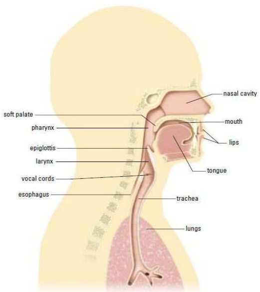
Wind instruments contain columns of vibrating air molecules. The frequency of vibration of the air molecules, and thus the fundamental frequency of the sound produced, depends on whether the column is open or closed at the ends. As is the case with all vibrating objects, large instruments create low-frequency sounds, and small instruments create high-frequency sounds.

Musical Instruments – Applications of ...

In some wind instruments such as the pipe organ, the length of each air column is fixed. However, in most wind instruments, such as the trombone, the length of the air column can be changed. In either case, to cause the air molecules to vibrate, something else must vibrate first. This initial vibration is created by a reed or by the player's lips.

Human Voice – Applications of ...

The human voice is a fascinating instrument; it is also the oldest and most versatile of all musical instruments. The human voice consists of three main parts: the source of air (the lungs); the vibrators (the vocal folds or vocal cords); and the resonators (the lower throat or pharynx, mouth, and nasal cavity). To create most sounds, air from the lungs passes by the vocal cords, causing them to vibrate. The vocal cords are two bands of skin that act like a double reed.



Resonance in Open Air Columns

PRACTICE

8. As the musicians in an orchestra warm up, do the frequencies of the following instruments rise or fall? Explain why.
   (a) wind instruments
   (b) string instruments

   (a) rise – as T increases, v increases, λ constant so f increases
   (b) fall – as T increases, strings become looser/longer, f decreases

Activity: Standing Waves (Inv.9.4.1/P.439)

INSTRUCTIONS

A. Follow procedure steps 1-11.
B. Create a data table similar to the one below. You will need enough rows for 3 different tuning forks. Recall the first 3 resonant lengths for a closed air column (i.e. 1/4λ, 3/4λ, and 5/4λ).

	theoretical (expected)			experimental (measured)			
tuning fork f (Hz)	speed of sound v (m/s)	wavelength λ (m)	resonant lengths L (cm)	resonant lengths L (cm)	wavelength λ (m)	speed of sound v (m/s)	% error
			L_1	L_1	λ_1		
			L_2	L_2	λ_2		
			L_3	L_3	λ_3		

Activity: Standing Waves (Inv.9.4.1/P.439)

INSTRUCTIONS

C. Once you have measured the resonant lengths, calculate and record the (i) wavelengths and (ii) speeds of the sound ($v=f\lambda$) for each resonant length.

NOTE!

① if $L_1 = 1/4\ \lambda$ then $\lambda_1 = 4\ L_1$
② if $L_2 = 3/4\ \lambda$ then $\lambda_2 = 4/3\ L_2$
③ if $L_3 = 5/4\ \lambda$ then $\lambda_3 = 4/5\ L_3$

Activity: Standing Waves (Inv.9.4.1/P.439)

QUESTIONS

1. Calculate and the % error between your theoretical and experimental speeds of sound. Record the values in your table.
2. Make a drawing of the standing waves in your resonance tube for each harmonic you detected. Be sure to label the nodes and antinodes of each harmonic.
3. Answer the following: Q.(a),(c),(e),(g)/P.439.