15160 Resonance Tube Set

STUDENT NAME_______________________________

CONTENTS

- *Included*
  - (1) Long Tube
  - (1) Short Tube
  - (1) Styrene Plug
  - (1) Tuning Fork, 512 Hz
  - (1) Rubber Mat, 3" diameter
- *Suggested Accessories*
  - Tuning Forks (other frequencies)
  - (1) Oscilloscope
  - (1) Microphone Setup

SAFETY

- After use, store this apparatus in a closet or cabinet; do not leave this apparatus on the floor, where it may present a slipping hazard.
- Before using an oscilloscope, inspect the oscilloscope for any sources of electric shock (bare wiring, short circuitry, etc.). Never use an oscilloscope that is open or that has any exposed circuitry.
- When using the tuning forks, strike them ONLY on the rubber mat that is provided. Do not hit the tuning forks on a solid surface, such as the table top, as this may damage the tuning fork or the table.
- Wear appropriate eye protection while performing these experiments.

PURPOSE

- To study resonance of sound waves in an open or closed column of air by making adjustments to the length of the column.

ASSEMBLY

- To construct the resonance tube needed in Procedure A, leave the styrene stopper out of the long resonance tube. Place the smaller tube inside the longer tube. To adjust the total length of the tube, pull the smaller tube out of the longer tube slowly, or push the smaller tube into the longer tube slowly.
- To construct the resonance tube needed in Procedure B, place the styrene stopper in one end of the long resonance tube. Follow the instructions above to adjust the length of the tube.
- To conduct Procedure C, allow an instructor to connect a microphone to an oscilloscope. Follow the instructions above to create an open resonance tube and a closed resonance tube.

SUGGESTIONS FOR USE

- Strike any tuning forks on a table or lab bench, using the included rubber mat to protect tuning forks from bending or warping.

INTRODUCTION

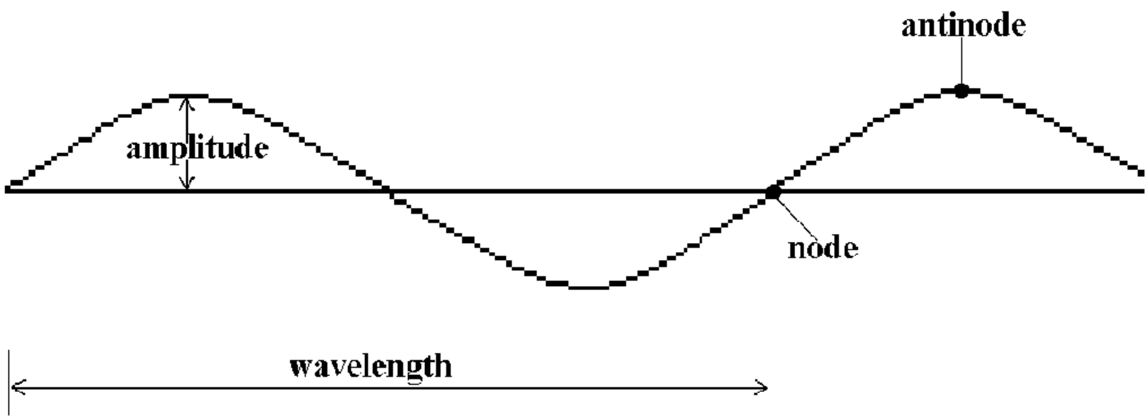
We hear sound waves every day, and sound waves are formed in many different ways. Many objects that create sound waves depend on a property of sound waves known as resonance. Resonating sound waves allow instruments to produce notes of different pitches, allow our voices to reach different pitches when we form different words, and cause certain pitches to ring in our ears. This apparatus allows examination of the conditions under which resonating sound waves occur.

Resonance occurs in many different kinds of waves. Tidal resonance in the Bay of Fundy, which lies between New Brunswick and Nova Scotia, results in some of the most extreme tides in the world. The difference between high tide and low tide in the Bay of Fundy is around 17 meters, and the highest difference between tides recorded in that bay is around 21 meters. Circuits consisting of an inductor, a capacitor, and a resistor will resonate at particular frequencies, depending on their inductance and their capacitance. The resonant properties of these circuits makes them useful in radiofrequency receivers and transmitters, as filters or variable frequency oscillators.

CONCEPTS

Parts of a Wave.

All waves have particular quantities in common. These quantities are shown in the following sketch, and defined below:



Amplitude is the maximum displacement of the wave from the resting position of the medium. A node is a location on the wave where the displacement from the undisturbed medium is zero. An antinode is the location on a wave where maximum amplitude is reached. Frequency is the rate at which waves are produced, usually expressed in Hertz (Hz) or vibrations per second. A wavelength is the length of the wave when it has completed one full vibration.

Sound Waves.

Sound waves consist of pressure variations that occur periodically in a particular medium. A sound wave traveling through any particular medium has a wave speed that depends on the individual properties of that medium. These properties include density, elasticity or compressibility, temperature, pressure, and many others. Altering a medium also alters the properties of sound waves which travel in that medium, such as their intensity and wave speed.

A brief table giving estimated values for the speed of sound for some basic materials is given below. These measurements are for materials at 20º C and a pressure of 1 atmosphere. Notice that sound will travel much more quickly in materials which are more dense and difficult to compress.

Material	*Speed of Sound (m/s)*
Air	343
Helium	1005
Water	1440
Glass	≈ 4500
Aluminum	≈ 5100

The wavelength of any sound wave is given by the formula

$$\lambda = v/f$$

where ‘λ’ (Greek letter ‘lambda’) is the wavelength of the sound wave, ‘v’ is the speed of the sound wave, and ‘f’ is the frequency of the sound wave. The tuning fork included in this apparatus, for example, gives off sound waves at a frequency of 512 cycles per second. Sound travels at 343 meters per second in air at 20° C, so the wavelength of the sound waves from this tuning fork is around 0.67 meters. The speed of sound in air and the temperature of air are linearly related by the following formula:

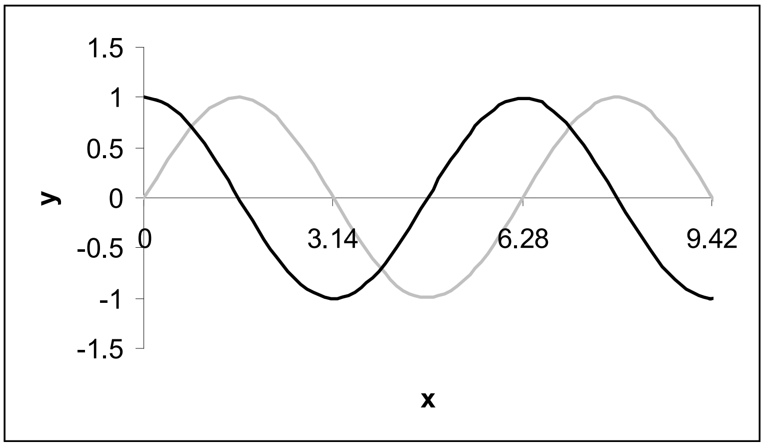
$$v_{sound} = (331 + 0.60T) \text{ m/s}$$

where ‘v_{sound}’ is the speed of sound in air, and ‘T’ is the temperature of the outside air. The table on the next page gives some speeds of sound in air.

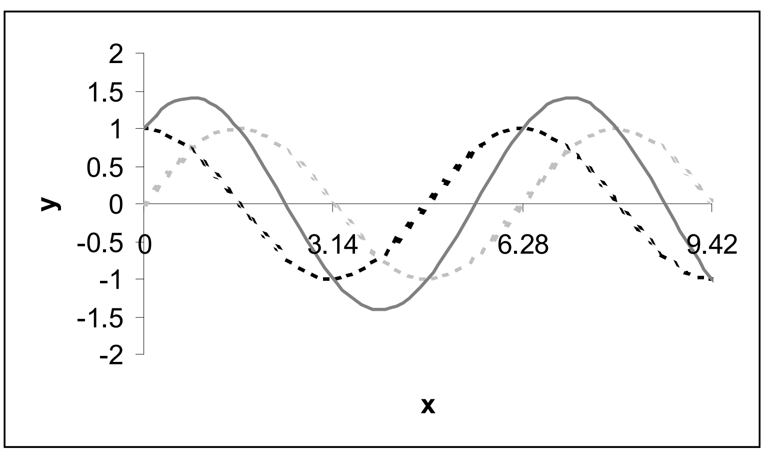
Temperature of Air (°C)	*Speed of Sound (m/s)*
-10	325
0	331
10	337
30	349

Principle of Linear Superposition.

The Principle of Linear Superposition states that when two waves are superimposed, those waves will add to create a new wave. For example, two waves (the cosine function in black and the sine function in gray) are displayed below:



Now, suppose that these two superimposed waves are added together to create one wave. Notice that some points are particularly easy to add: on the y-axis, the cosine function is equal to 1, and the sine function is equal to zero. Their sum at the axis is 1. When ‘x’ is equal to 3.14, the cosine function is equal to –1, and the sine function is equal to zero. Their sum at this value for ‘x’ is –1. These summations can be conducted for each and every point along the two functions. When these additions are performed, the result is the following function, shown with a solid line in darker gray:

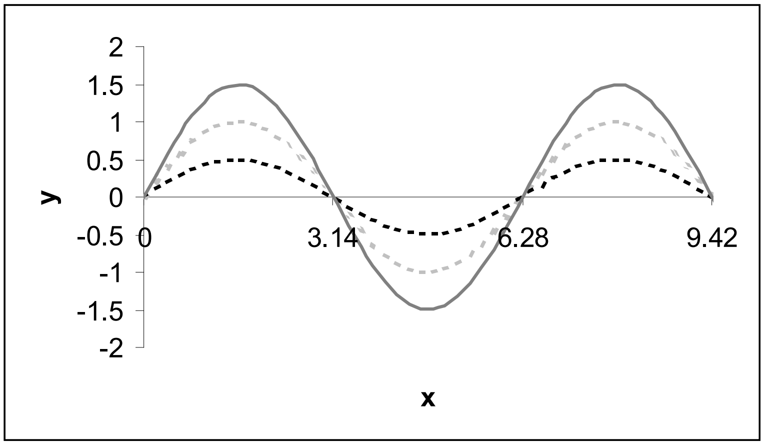


Notice that the resulting wave has larger maximum values than the other two functions, and each point on the new wave is a sum of the two previous functions (now shown as dotted lines).

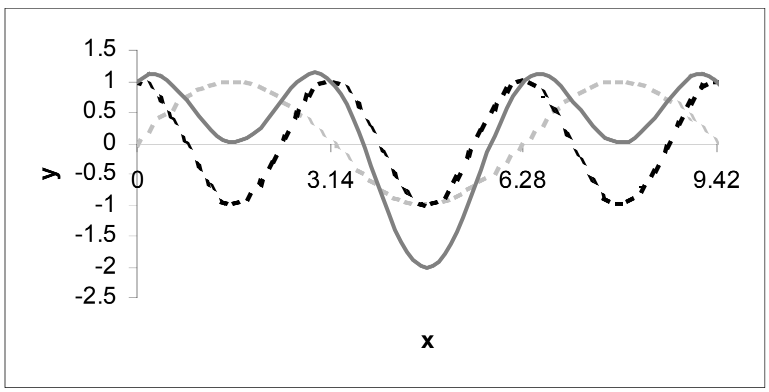
Constructive and Destructive Interference.

Constructive and destructive interference are effects that occur as a result of the Principle of Linear Superposition. Constructive interference occurs when two functions are added, and the sum of the two functions at any point is greater than the value of one of the individual functions at that point. Destructive interference occurs when two functions are added, and the sum of the two functions at any point is less than the value of one of the individual functions at that point. Constructive interference is often described as a 'building' or 'adding' effect, and destructive interference is often described as one function 'canceling' another function.

The graph below is an example of two waves that result in constructive interference. Notice that the solid line (the sum of the two functions) is greater in magnitude than any particular point on either of the two original functions. The function shown by the gray dotted line is y = sin (x), and the function shown by the black dotted line is y = ½ sin (x).

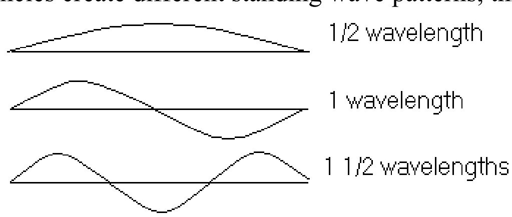


The next graph is an example of two waves that result in destructive interference. Notice that the solid line is of lower value in some places, and higher in others. This is a result of both constructive and destructive interference; destructive interference occurs in places where one function is positive, and the other is negative. The function shown by the gray dotted line is y = sin (x), and the function shown by the black dotted line is y = sin (2x).



Standing Waves and Resonance.

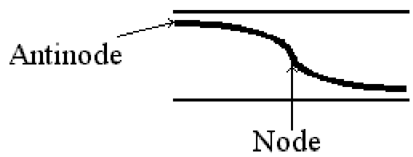
Standing waves are waves created in a medium that keep a set pattern. These waves appear to be either standing still or vibrating in place. Standing wave patterns are created when the medium is displaced at specific frequencies. These specific frequencies, called harmonic frequencies, produce reflected waves which reinforce the incident waves, building larger and larger wave amplitudes. The tendency of waves to reflect and constructively interfere with one another upon reflection is called resonance. Different harmonic frequencies create different standing wave patterns, three of which are shown below.



Similar patterns of waves are used to create sound waves from the strings of a guitar, violin, or piano. Standing waves also develop in mechanical systems such as cables, airplane wings, and even bridges. The collapse of the Tacoma Narrows Bridge is a dramatic example of the destructive results of uncontrollable standing waves.

Open-Tube Resonance.

Suppose a sound wave originates at one end of a tube that is open at both ends, and that tube has a length of half of the wavelength of the sound wave. At the end of the tube where the source of the sound waves is located, air molecules will vibrate at a maximum speed, creating an antinode of the sound wave at this point. At the center of the tube, air molecules do not vibrate; this results in a node at the center of the tube. At the second open end of the tube, air molecules once again vibrate with maximum speed, creating another antinode. This behavior of sound waves is illustrated in the graphic below.



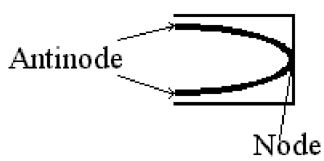
Open-tube resonance will occur whenever the length of the tube is equal to a half-wavelength of the incoming sound wave, or a whole number multiple; mathematically, the following formula relates the length of an open-tube to the wavelength of a sound wave when the sound resonates:

$$L = \frac{1}{2}(n\lambda)$$

where 'L' is the length of the tube, 'λ' (Greek letter 'lambda') is the wavelength of the sound wave, and 'n' is an arbitrary, positive integer. 'n' can take on any value; sound will resonate in an open tube for any value of 'n'.

Closed-Tube Resonance.

Now, suppose a sound wave originates at the open end of a tube where the other end is blocked. In this case, air molecules located at the end of the tube are unable to move; this forces a node to be located at the end of the tube. If an antinode is located at the open end of the tube, where the source of the sound wave is located, then only a quarter of a wavelength will fit inside the tube (or odd multiples of the wavelength). This is illustrated in the graphic below.



Mathematically, the length of a closed tube that will result in the resonance of a sound wave is

$$L = \frac{1}{4}(n\lambda)$$

where 'L' is the length of the closed tube, 'λ' is the wavelength of the sound wave, and 'n' is an arbitrary, positive, odd integer. Only odd integers will work, since even integers will constitute multiples of half-wavelengths; half-wavelengths will not work, since they would have antinodes at both ends of the tube, which is not possible in the closed tube.

PROCEDURE A (OPEN-TUBE RESONANCE)

Follow the instructions in the Assembly section for constructing an open resonance tube for this procedure. Before beginning this experiment, measure both the large resonance tube and the short extension tube, and use the formula for the wavelength of sound in the Concepts section to calculate the wavelength of the sound that comes from each tuning fork in this experiment. To sound one of your tuning forks, strike the tuning fork once on the rubber mat. *Practice sounding the tuning forks, and familiarize yourself with the sound of each tuning fork.*

Place the assembled open resonance tube on a flat surface, such as a table or a lab bench. Place the smaller tube inside the larger tube, so that it does not protrude. Lay the included rubber mat on the table. After laying the rubber mat on the table, give the 512 Hz tuning fork a quick strike and hold the tines of the tuning fork at one end of the open tube.

Q1. What does the tuning fork sound like when it is held close to the open tube? Is its sound made louder or softer by the tube?

While holding the sounding tuning fork at one end of the resonance tube, adjust the length of the tube as the tuning fork is sounding by pulling the smaller tube out of the larger tube, or by pushing the smaller tube into the larger tube. (*Note: you may have to adjust the tube slowly to notice any differences in sound, and you also may have to strike the tuning fork periodically to keep it vibrating.*)

Q2. Is there one tube length where the tuning fork sounds the loudest?

Q3. Is there one tube length where the tuning fork is quietest, or doesn't sound at all?

Repeat this procedure for tuning forks of different frequencies.

Q4. Do the other tuning forks that you used for this experiment resonate at the same tube lengths, or different tube lengths?

Q5. How does the wavelength of the sound waves emitted by the tuning forks compare to the resonant lengths of the tube?

ASSESSMENT A
For all questions, assume the air temperature is 20° C, and that the speed of sound is 343 m/s.

1. Suppose you have a 440 Hz tuning fork and an open tube that is 50 centimeters long.

a) Calculate the wavelength of the 440 Hz tuning fork.

b) Will the open tube cause the sound from the tuning fork to resonate? If it will not, find the amount of the tube you would need to remove in order to achieve resonance.

c) What other tuning forks will resonate with the adjusted open tube?

d) What tuning forks will resonate in the original open tube?

PROCEDURE B (CLOSED-TUBE RESONANCE)

Follow the instructions in the Assembly section for constructing a closed resonance tube for this procedure. Before beginning this experiment, measure both the large resonance tube and the short extension tube, and use the formula for the wavelength of sound in the Concepts section to calculate the wavelength of the sound that comes from each tuning fork in this experiment. To sound one of your tuning forks, strike the tuning fork once on the rubber mat. *Practice sounding the tuning forks, and familiarize yourself with the sound of each tuning fork.*

Place the assembled closed resonance tube on a flat surface, such as a table or lab bench. Situate the stopper at the very end of the closed tube, and place the smaller tube inside the larger tube, so that it does not protrude. Lay the included rubber mat on the table. After laying the rubber mat on the table, give the 512 Hz tuning fork a quick strike on the mat and hold the tines of the tuning fork at the open end of the tube.

Q1. What does the tuning fork sound like when it is held close to the open end of the tube? Is its sound made louder or softer by the tube?

While holding the sounding tuning fork at one end of the resonance tube, adjust the length of the tube as the tuning fork is sounding by pulling the smaller tube out of the larger tube, or by pushing the smaller tube into the larger tube. (*Note: you may have to adjust the tube slowly to notice any differences in sound, and you also may have to strike the tuning fork periodically to keep it vibrating.*)

After adjusting the length of the tube by moving the smaller tube in and out of the larger tube, remove the smaller tube from the larger tube. Use a meter stick to push the styrene stopper further into the larger tube. This should create a tube with two open ends. Hold the tuning fork to either end of the tube. Use the meter stick to adjust the stopper in the tube, as well as measure the length of the tube when the styrene stopper divides the tube.

Q2. Is there one tube length where the tuning fork sounds the loudest?

Q3. Is there one tube length where the tuning fork is quietest, or doesn't sound at all?

Repeat this procedure for tuning forks of different frequencies.

Q4. Do the other tuning forks that you used for this experiment resonate at the same tube lengths, or different tube lengths?

Q5. How does the wavelength of the sound waves emitted by the tuning forks compare to the resonant lengths of the tube?

b) Will the closed tube cause the sound from the tuning fork to resonate? If it will not, how far into the tube would you need to move the stopper to make the sound from the tuning fork resonate?

c) What other tuning forks will resonate with the adjusted closed tube?

d) What tuning forks will resonate in the original closed tube?

PROCEDURE C (RESONANCE WITH AN OSCILLOSCOPE)

This procedure will require the use of an open resonance tube, several different tuning forks, as well as an oscilloscope with a microphone setup. Allow your instructor to set up an oscilloscope for this experiment.

After setting up an oscilloscope with a microphone, turn on the oscilloscope and microphone. Strike a tuning fork and hold it close to the microphone.

Q1. What is displayed on the screen of the oscilloscope when the tuning fork is held close to the microphone?

Observe and record the general shape of the wave that is displayed on the oscilloscope; also, record the wavelength of the sound wave that is displayed on the oscilloscope.

Q2. What happens to the wave as the sound dies down?

Strike a different tuning fork and hold it close to the microphone.

Q3. How did the wavelength of the wave on the oscilloscope change when you changed tuning forks? Why did it change?

Set the resonating tube to the length that caused maximum resonance for the 512 Hz tuning fork in Procedure A. Place the tube on your table or lab bench, and set the microphone next to one opening in the tube while the oscilloscope is running. Strike the tuning fork and hold it up to the other end of the tube. Continue to strike the tuning fork, so that you may continue to see wave pulses.

Q4. How does the height of the wave pulses for the resonating wave pulses compare to the height of the wave pulses for the tuning fork on its own?

Set the resonating tube to a length that is 2 to 3 centimeters less than the length of maximum resonance.

Q5. How does the height of the wave pulses for the non-resonating wave pulses compare to the height of the wave pulses for the tuning fork on its own?

ASSESSMENT B

For all questions, assume the air temperature is 20° C, and that the speed of sound is 343 m/s.

1. Suppose you have a 256 Hz tuning fork and a closed tube that is 24 centimeters long. The tube has a thin foam stopper at its closed end.

a) Calculate the wavelength of the 256 Hz tuning fork.