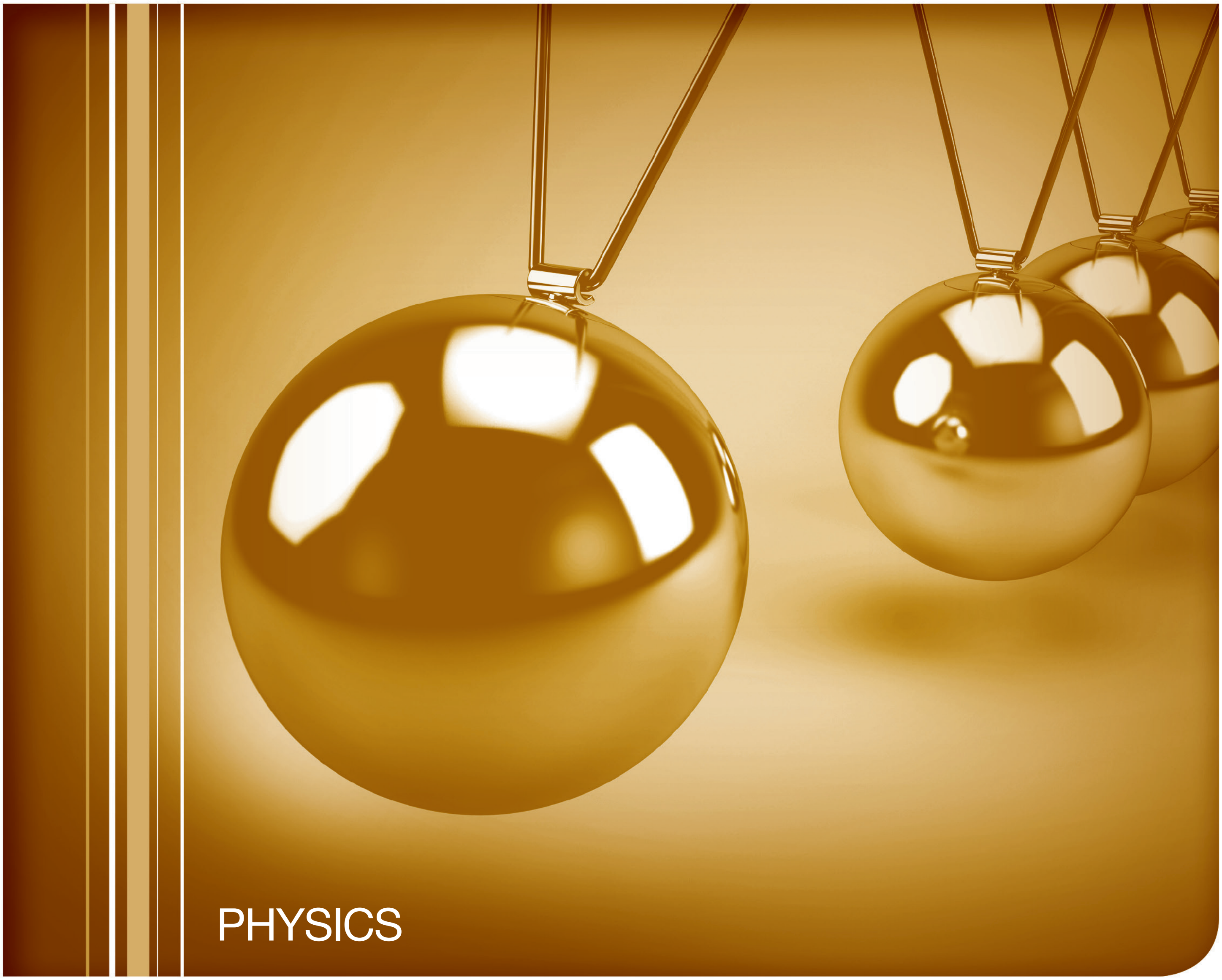
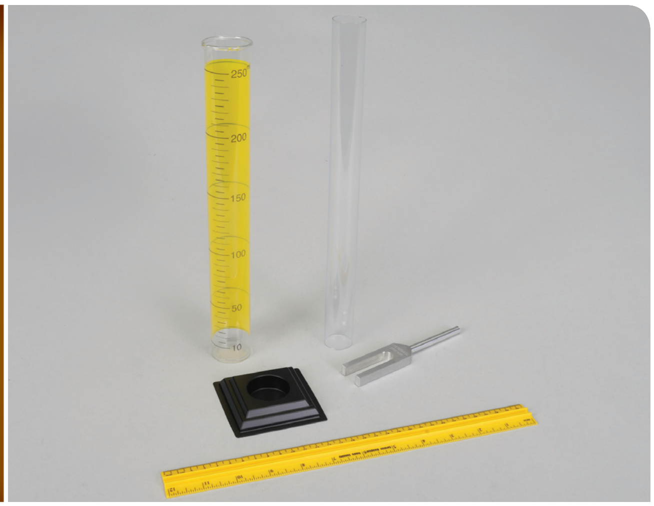


Sound and Resonance



Investigation Manual

CAROLINA DISTANCE LEARNING

SOUND AND RESONANCE

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Overview

In this activity, students will use a tuning fork to generate standing waves in a tube that is open at one end. Students will identify the length of tube necessary for the sound of the tuning fork to be amplified through resonance, which is an increase in the amplitude of a wave at a specific frequency. Through an understanding of the properties of waves and the conditions necessary to establish standing waves in this scenario, students will calculate the speed of sound in air at room temperature, and the wavelength of sound generated by the tuning fork.

Outcomes

- Develop an understanding of the properties of waves
- Calculate the speed of sound in air at room temperature
- Generate a standing wave and demonstrate the property of resonance

Time Requirements

Preparation .... 5 minutes
Activity 1 .... 10 minutes

Key

Personal protective equipment (PPE)

goggles gloves apron

follow link to video

photograph results and submit

stopwatch required

warning corrosion flammable toxic environment health hazard

Background

Whenever someone sings or strums a guitar, waves are formed. If you have ever seen a doctor for an ultrasound, they are using technology built upon a scientific understanding of waves to look inside your body. When ships use SONAR (SOund NAvigation Ranging) to detect objects under the waves or to measure the water's depth, this is another example of how we use waves in our everyday lives. Animals use waves, too. Bats, whales and dolphins, for example, all use a form of sonar, called echolocation, to locate object by reflected sound.

Earthquakes are a form of traveling waves that many people are familiar with. These seismic waves are waves of energy that travel through Earth and arrive at the surface and are a mix of wave types.

Waves can transmit energy over great distances. Seismic waves generated by earthquakes can cause extensive damage; scientists use their knowledge of seismic waves to locate the epicenter of an earthquake. Sound and light are transmitted through waves. Waves can also carry complex information over a long distance; for example, radio waves. Some radios can send and receive complex signals and broadcast them over great distances. In this activity, you will calculate the speed of sound in air and apply some basic knowledge of waves to determine the wavelength of sound generated by a tuning fork.

A **wave** is a propagation of energy due to a rhythmic disturbance in a medium or through space. A **medium** is the material through which a wave travels. **Mechanical waves**, such as waves in water, can only travel through a medium composed of some form of matter. Sound waves are mechanical and can travel through a gas, such as the air in earth's atmosphere, liquid, and solid matter, but not through a vacuum.

A mechanical wave is transmitted when the molecules of a medium, such as air or water, move or vibrate in a repeating or oscillating motion. The particles of the medium generally remain in their original positions and vibrate back and forth, but the energy of the wave travels outward from the wave source.

Mechanical waves can be classified as **transverse** or **longitudinal**. In a **transverse** wave, the particles of the medium move or vibrate in a direction that is perpendicular to the direction of the wave. A group of people performing "the wave" in a stadium is a good example of a transverse wave. People move their arms up and down (vertically), and the wave travels horizontally around the stadium. When a string on a musical instrument, such as a guitar or piano, is plucked or struck, the molecules in the strings vibrate in one direction, whereas the energy in the wave travels along the length of the string.

Sound travels in a **longitudinal** wave, also called a **compression** wave. When a sound wave is generated, the molecules of the medium vibrate in a direction parallel to the direction of the wave, but do not travel with the wave, remaining in the same location. When a sound is generated, e.g., by the tuning fork in this activity,

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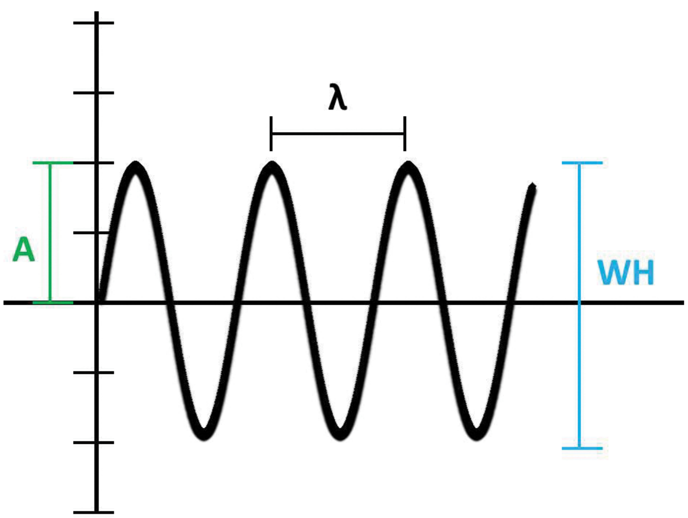
Background continued

the air near the source vibrates, causing a disturbance in the surrounding air molecules that travels outward in all directions. However, the air molecules near the source and along the wave generally remain in their original locations.

Longitudinal mechanical waves travel through solids, liquids, and gases; however, transverse waves only travel through solid or liquid matter.

The intensity and frequency of a wave are functions of the wave source, whereas the speed of the wave is determined by the medium through which the wave travels. To better understand waves, consider the diagram in Figure 1.

Figure 1.

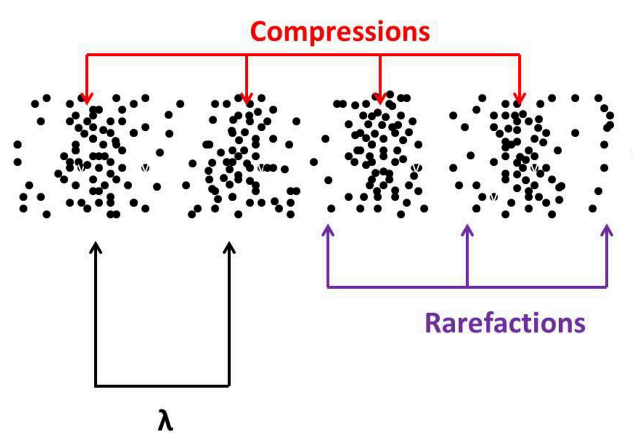


The horizontal line is called the rest position. This is where the particles in the medium rest until disturbed by the energy from the wave. The distance labeled "A" is the amplitude of the wave. The amplitude of the wave is directly related to the intensity, or acoustic energy, of the sound. For a sound wave, greater amplitude means louder sound. The amplitude is the distance from the rest position to the position of greatest displacement. The position of greatest displacement above the rest position, or the highest point on the wave, is the **crest**. The position of greatest displacement below the rest position is the **trough**. The wave height (WH) is twice the amplitude. The distance between any two identical points (i.e., two crests or two troughs) on a waveform is the **wavelength** and is represented by the Greek letter lambda (λ). In depictions of waveforms, the wavelength is usually depicted between two crests, as shown in Figure 1.

The waveform in Figure 1 can represent any kind of wave. The amplitude and wavelength provide enough information to analyze the wave. You may have seen sound waves represented by this type of waveform on an oscilloscope or computer screen.

In a sound wave, which is a compression wave, the air molecules move together in regions called **compressions**, and spread apart in regions called **rarefactions** (Figure 2).

Figure 2.



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Another important property of waves is **frequency**. The frequency is the rate at which the particles in the medium vibrate. Frequency is measured in Hertz (Hz; cycles per second, cycles/s, cycles × s^{-1}). Try tapping an object, such as a pencil, on a surface, such as a table, at a rate of one tap per second. That is a frequency of 1 Hz. The inverse of wave frequency is the **period** of the wave. If you tap the pencil at a frequency of 2 Hz or two taps per second, the period, or time between taps is 0.5 seconds. What is the highest frequency at which you can tap the pencil? The tuning fork in this kit has a frequency of 2,048 Hz. Humans can hear sounds in a frequency range of 20–20,000 Hz. Anything above the range of human hearing is called **ultrasound**, and anything below is called **infrasound**. A dog whistle makes an ultrasonic sound that is too high for humans to hear, but within the audible range for dogs. As people age, the ability to hear the higher frequencies diminishes.

The velocity, or speed, of a wave is related to the wavelength and frequency as described in the equation:

$$\boldsymbol{v} = f\lambda$$

where $\boldsymbol{v}$ is velocity in meters/s; f is frequency in Hz, and λ is wavelength, measured in meters.

For example, consider a wave with a wavelength of 0.5 m and a frequency of 27 Hz.

$$\boldsymbol{v} = (0.5\text{ m})(27\text{ Hz})$$
$$\boldsymbol{v} = 13.5\text{ m/}s$$

Waves exhibit many phenomena:

- **Echo waves**: Waves that reflect off solid objects.
- **Diffraction waves**: These waves diffract, or bend, around solid objects. An example of this is waves bending when passing through a gap, such as ocean waves passing between barrier islands.
- **Interference waves**: These waves interact with other waves. Imagine two instruments, such as trumpets, that are slightly out of tune, or have a slightly different pitch. Both trumpets play the same note, but the wave forms leaving each instrument are out of sync. The result is an oscillation in the intensity or loudness of the sound. Two sound waves result in a tone that has “beats” of higher and lower volume.
- **Standing waves**: At certain frequencies, a wave source may create waves that reflect back from one end of a medium and interfere with waves emanating from the source. A wave pattern is established where every point on the wave has a constant amplitude. A simple demonstration of a standing wave can be created with a rope or string. Tie a rope to a post or other immovable object. Pull the rope tight and then move it rhythmically up and down. Vary the speed of movement until the rope generates a constant wave form like the one shown in Figure 4. The wave pulses travel from the wave source (your hand) to the post and reflect back. At a particular frequency, the wave appears to stand still. In this example, the frequency depends on the linear density of the rope (mass per unit length; g/cm) and the

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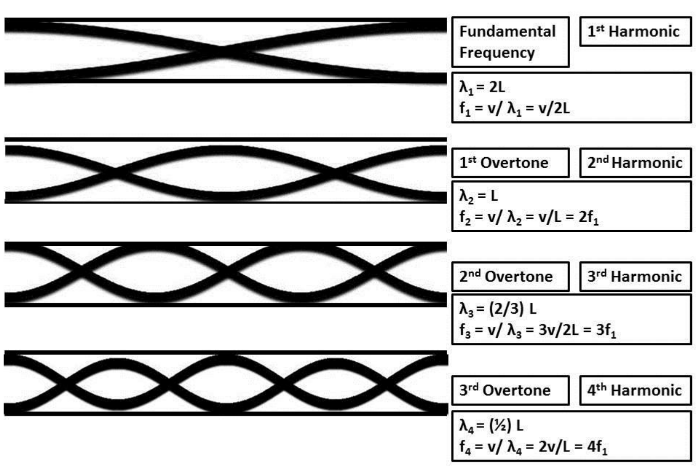
Background continued

tension. If you are having trouble setting up a standing wave with a rope, try adjusting the tension.

Where the wave forms cross, there is no displacement of the rope. These points are called **nodes**. The rope is maximally displaced halfway between two nodes. These points are called **antinodes**. Because you are moving the rope at one end, that end is an antinode. The end at which the rope is anchored is a node. Try changing the frequency of the wave. Each new frequency will be associated with a different standing wave pattern, with different numbers of nodes and antinodes. These frequencies and the associated wave patterns are called **harmonics**.

Figure 3 shows how standing waves are established in an air column in a tube that is open at both ends. Each harmonic is an integral multiple of the first harmonic, or fundamental frequency. If the velocity of air is known and the length of the column can be measured, the frequency of each harmonic can be calculated.

Figure 3.

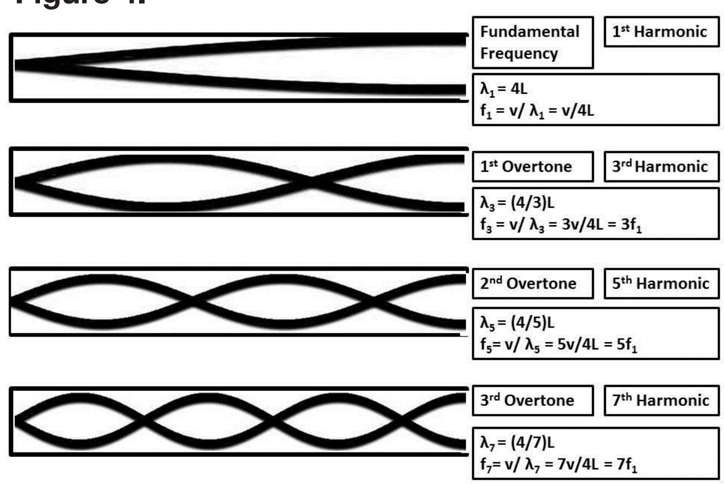


The variables in the equations here are:

f = frequency
L = length of the column
v = velocity of air in column
λ = wavelength

Figure 4 shows how standing waves are established in a tube that is closed at one end. There will be a node at the closed end of the tube and an antinode at the open end. Whenever the frequency of the wave is an odd-numbered integer of the fundamental frequency, a standing wave will be established in the tube.

Figure 4.



In the following activity, you will measure the speed of sound in air. Using the tuning fork as a sound source and a tube, one end of which is submerged in water in a graduate cylinder, you will adjust the length of the air column in the tube until a standing wave is established. When the standing wave is set up, the tube will resonate, which amplifies the sound slightly. You will then be able to calculate the wavelength of the standing wave.

Materials

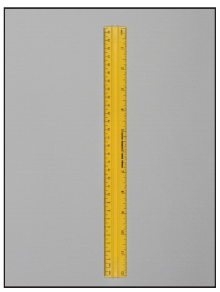
Included in the materials kit:

Tuning fork, 2048 Hz

Clear plastic tube

Needed from the equipment kit:

Graduated cylinder



Ruler, metric

Needed but not supplied:

- Calculator
- Permanent marker
- Twine or string
- Post or railing (something to tie twine to)

Reorder Information: Replacement supplies for the Sound and Resonance investigation (item 580406) can be ordered from Carolina Biological Supply Company.

Call: 800.334.5551 to order.

Safety

Wear safety goggles while performing this activity.

Read all instructions for this laboratory activity before beginning. Follow the instructions closely and observe established laboratory safety practices, including the use of appropriate personal protective equipment.

Do not eat, drink, or chew gum while performing this activity. Wash your hands with soap and water before and after performing the activity.

Preparation

1. Read through the activities.
2. Obtain all materials
3. Clean the work space.
4. Go to a quiet location with enough work space to place the graduated cylinder on a flat surface. Strike the tuning fork against your hand and hold it at arm's length. If you cannot hear the tuning fork, move to a quieter location.
5. Use your ruler and permanent marker to mark the entire length of the clear plastic tube at 1–cm intervals. Allow time to dry.

ACTIVITY

ACTIVITY 1

A Standing Wave in a Tube Open at One End

1. Calculate the speed of sound in the surrounding atmosphere. Measure the temperature of the room using the thermometer, and use the following equation:

$$v_s = 331.4 + 0.6T_c$$

where

v_s = the speed of sound in meters per second (m/s)

331.4 m/s = the speed of sound in air at freezing temperatures

0.6 is a constant with dimensions of m/s/°C

and T_c = the temperature of the room in degrees Celsius.

To convert from Fahrenheit to Celsius, use the formula ˚C = (˚F – 32) × 5/9.

Record T_C and v_s values in **Data Table 1**.

2. Assemble the graduated cylinder by placing the cylinder in the base.

3. Fill the graduated cylinder to the top with water.

4. Place the plastic tube in the cylinder. The submerged end is the closed end of the resonance tube, and the end above the surface of the water is the open end.

5. Strike the tuning fork on the palm of your hand or a book, and hold the vibrating tuning fork about 2 cm (~¾ in) above the mouth of the plastic tube.

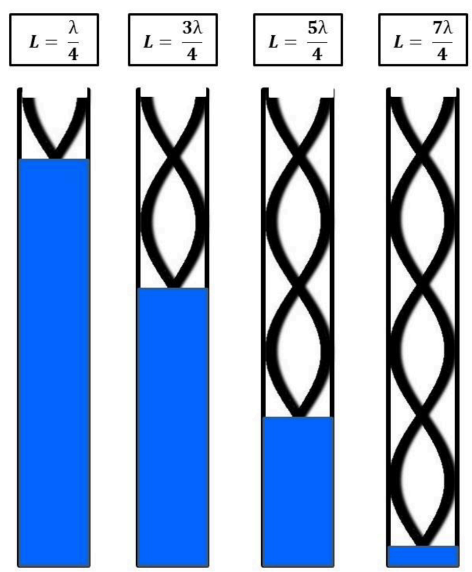
6. Raise the plastic tube, increasing the length of the air column in the tube, while keeping the tuning fork about 2 cm above the mouth of the tube.

7. Listen for the point at which the plastic tube amplifies the sound from the tuning fork. It may be necessary to strike the tuning fork again during the experiment if the sound becomes too faint, and it may be necessary to move the tube up and down to reach to find the exact point where the sound from the tuning fork is amplified.

8. Measure the distance from the open end of the tube to the water. This is the length of ¼ of one wavelength. Record this value (L_1) in **Data Table 1**.

9. Continue moving the tube upward, further extending the length of the air column, until you reach the next point where the sound from the tuning fork is amplified. This is the length of ¾ of one wavelength (see Figure 5). Record this value (L_2) in **Data Table 1**.

Figure 5.



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10. Move the tube upward again until you reach the next point where the sound from the tuning fork is amplified. This is the length of ⁵⁄₄ of one wavelength. Record this value (L_3) in **Data Table 1**.

11. Complete **Data Table 1**, using the speed of sound in the air ($\boldsymbol{v}_s$) to calculate the length of the wavelength, λ.

12. Calculate the percent difference between the values you calculated for the speed of sound using the closed tube and the equation from Step 1 using the following equation:

$$\boldsymbol{v}_s = 331.4 + 0.6T_c$$
$$\boldsymbol{v} = f\lambda$$

$$\text{percent difference} = \left| \frac{\text{first value} - \text{second value}}{\left(\frac{\text{first value} + \text{second value}}{2}\right)} \right| \times 100\%$$

Disposal and Cleanup

1. Dispose of the water.
2. Dry the tube, tuning fork, and the graduated cylinder.
3. Return all materials to the equipment kit.

Data Table 1.

Temperature (T_c) (°C)	$\boldsymbol{v}_s$* (m/s)	f (Hz)	Length (L) (m)¶	Calculate λ§ (m)	$\boldsymbol{v}_s$** (m/s)
			L_1 ($L_1=\lambda/4$ and $\lambda=4L_1$)		
		2048	L_2 ($L_2=3\lambda/4$ and $\lambda=4L_2/3$)		
			L_3 ($L_3=5\lambda/4$ and $\lambda=4L_3/5$)		

* Speed of sound in air ($\boldsymbol{v}_s$) = $331.4 + 0.6T_C$
** Speed of sound in air ($\boldsymbol{v}_s$) = $f\lambda$

¶ Convert cm measurements to m
§ Using equation $\boldsymbol{v}_s = f\lambda$ and/or $\lambda = \boldsymbol{v}_s/f$

NOTES

PHYSICS
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Investigation Manual

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