Discovering the Speed of Sound in Air

FLINN SCIENTIFIC PHYSICAL SCIENCE FAX!

Introduction

Have you ever observed a carpenter hammering in a nail off in the distance? If you are far enough away from the carpenter, you will observe the hammer hit the nail before you hear it hit. It seems as though there is a delay in the time it takes for the sound to reach your ears. Why does this happen? How fast does sound travel? Discover the speed of sound with this activity!

Concepts

- Anti-node and node
- Frequency and wavelength
- Mechanical wave
- Longitudinal wave
- Standing wave
- Velocity

Background

Sound is a mechanical, longitudinal wave created by the vibrations of material objects. A mechanical wave requires a medium in order to propagate. In other words, for sound to travel, some type of substance must be present (solid, liquid, or gas). A substance is needed because sound travels by pushing molecules back and forth. If there are no molecules to move, sound will not propagate. This is why sound can not travel in a vacuum. Sound is also considered to be a longitudinal wave because it vibrates the particles in the medium back and forth along the direction of the wave propagation.

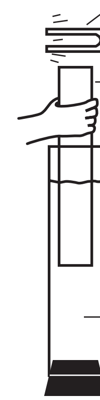


Figure 1.

The speed of sound is not a constant value and varies depending on the medium in which it travels. At 0 °C the accepted value for the speed of sound in air is 331 m/s. As the temperature of air increases, the speed of sound also increases because molecules in hot air move more rapidly and collide more often than molecules in cool air. The speed of sound also increases in substances having molecules that are packed tightly together. Therefore sound tends to have higher speeds in solids and slower speeds in liquids and gases. The reason for this is because molecules that are close together bump into each other more easily than molecules that are far apart.

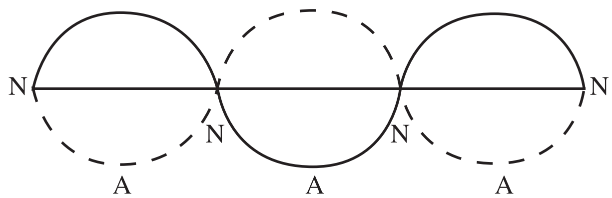
The speed of sound can be calculated using Equation 1 below. According to this formula, if the frequency (f) and wavelength (λ) of a wave are known, the speed (v) can easily be calculated by multiplying the two values together. In this activity you will be using various tuning forks to determine the speed (v) of sound. When a tuning fork is set into motion, the sound produced will have a specific frequency and wavelength. The frequency of a tuning fork is printed directly on it. The wavelength, on the other hand, is not listed on the tuning fork, and must be determined in order to calculate the speed of sound.

$$v = f\lambda \qquad \textit{Equation 1}$$

v = speed (m/s)
f = frequency (Hz)
λ = wavelength (m)

The wavelength of a sound wave can be determined using an air-filled tube that is closed at one end. In this experiment, the air-filled tube is a piece of white PVC tubing placed in water. The water is used to close off the tubing at one end. See Figure 1. A tuning fork will be used to generate a sound wave over the open end of the white PVC tube. The length of the white PVC tube is altered by slowly lifting it out of the water. As the PVC tube is lifted, the length of the air-filled portion increases. At the appropriate length (this length varies for tuning forks of different frequencies), the sound wave travels through the air in the tube and reflects off the water at the closed end. The reflected wave then interferes with the incident waves generated by the source (the tuning fork), and a standing wave forms.

A *standing wave* is a pattern that results when two waves of the same frequency, wavelength, and amplitude travel in opposite directions and interfere with each other. A *node* is a point in a standing wave that always undergoes complete destructive interference and therefore is stationary. An *anti-node* is a point in the standing wave, halfway between two nodes, at which the largest amplitude occurs. See Figure 2. Because the amplitude is largest at an anti-node, the sound will be the loudest at this point. Figure 3 represents various standing waves that can be created in a close-ended column of air. When an anti-node is present at the open end, the sound will resonate or hum loudly.



N = node
A = anti-node

Figure 2.

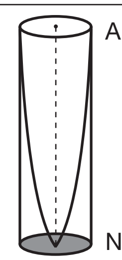
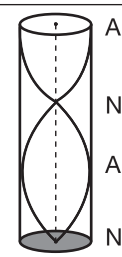
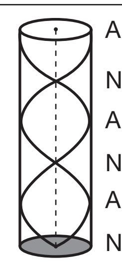
No. of Wavelengths Shown	Closed-end Air Column
¼ λ 1 quarter of a full wavelength	
¾ λ 3 quarters of a full wavelength	
5⁄4 λ 1 full wavelength plus 1 quarter of a wavelength	

Figure 3.

The *Procedure* section of this lab lists the steps necessary to create a standing wave having only one node and one anti-node, as shown in the top section of Figure 3. Creating a standing wave with one node and one anti-node will mean that only ¼ of a complete wavelength is present inside the air-filled PVC tube. If the length (L) of the air-filled portion of the PVC tube is measured in meters, this will be the length of ¼ of one complete wavelength. In order to calculate one complete wavelength, the tube length (L) must be multiplied by 4. See Equation 2 below.

$$\lambda = 4L \qquad \textit{Equation 2}$$

λ = wavelength (m)

L = tube length (m)

Materials

Clamps, universal extension, 2
Clamp holders, 2
Graduated cylinder, 250-mL
Plastic tube, clear, 1" diameter, 2 ft
PVC tube, white, 1/2" diameter, 2 ft
Rubber stopper, solid, #6
Ruler, metric
Support stand
Tuning forks, set of 8
Tuning fork activator
Water, 250 mL

Safety Precautions

This lab is considered to be nonhazardous. Please follow all laboratory safety guidelines.

Procedure

1. Set up a support stand and attach one universal extension clamp to the top of the rod, and a second universal extension clamp to the bottom of the rod.
2. Plug the bottom of the clear plastic tube with a #6 rubber stopper.
3. Attach the clear plastic tube to the support stand using the universal extension clamps. See Figure 4. The rubber stopper should be resting on the base of the support stand.
4. Place the white PVC tube inside of the clear plastic tube.
5. Fill a large graduated cylinder with 250 mL of water.
6. Make sure the end of the clear plastic tube is completely sealed by pouring a small amount of water into the tube and watch for leaking. Vaseline® can be put around the edge of the stopper if leaking does occur.
7. Pour the 250 mL of water into the sealed plastic tube. The water should be near the top but not overflowing.

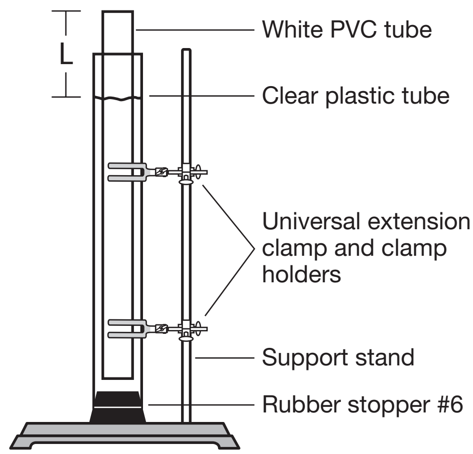


Figure 4.

8. Obtain a tuning fork that matches a frequency listed on the data table (see the next page).
9. Hit the tuning fork on a tuning fork activator.
10. Hold the tuning fork over the tube setup. Hold the white PVC tube with your free hand and slowly lift it out of the water while at the same time lifting the tuning fork. Make sure the tuning fork remains over the opening of the white PVC pipe (see Figure 1). Keep moving the tube and the tuning fork upward until a very loud humming noise is heard. The tube may hum the entire time, but at a certain point, it will get very loud.
11. Hold the tube in place at the spot where the sound resonates the loudest. Using a metric ruler, measure the length of the white PVC tube that is above the surface of the water. Measure the length (L) in centimeters, and record the length in both cm and meters on the data table.
12. Repeat steps 7–10 with the remaining tuning forks.
13. Using Equation 2 from the *Background* section, calculate the wavelength of sound for each tuning fork.
14. Using Equation 1 from the *Background* section, calculate the speed of sound in air for each tuning fork.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
- MS-PS1 Matter and Its Interactions
  - PS1.A: Structure and Properties of Matter
- MS-PS3 Energy
  - PS3.C: Relationship between Energy and Forces
- MS-PS4 Waves and Their Applications in Technologies for Information Transfer
  - PS4.A: Wave Properties

Disciplinary Core Ideas: High School
- HS-PS1 Matter and Its Interactions
  - PS1.A: Structure and Properties of Matter
- HS-PS3 Energy
  - PS3.A: Definitions of Energy
- HS-PS4 Waves and Their Applications in Technologies for Information Transfer
  - PS4.A: Wave Properties

Science and Engineering Practices
- Developing and using models
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions

Crosscutting Concepts
- Patterns
- Cause and effect
- System and system models
- Energy and matter in systems
- Structure and function

Tips

- This activity will only work for tuning forks with a frequency of 256 Hz or higher.
- If a clear plastic tube is not available, a large graduated cylinder may be used.
- Before the students do this activity, demonstrate how to properly lift the white PVC pipe out of the water while lifting the tuning fork. As this technique is demonstrated, have the students listen for the change in loudness of the sound. The students should be close during the demonstration because individuals who are far way commonly have trouble hearing the change in volume.
- PVC tubing of a different length and diameter may be used in place of the size suggested. If the length or diameter is changed, make sure to test it before the students perform the activity. Make sure that the tube length is longer than 0.35 m. This is because our sample data shows that the largest ¼ wavelength was 0.329 m from the tuning fork with a frequency of 256 Hz. If the tube is not longer than this amount, the 256 Hz tuning fork will not resonate when held over the tube.
- For further concept development, try the *Waves and Sound Student Laboratory Kit* (Flinn Catalog No. AP7014) and the *Open-Ended Resonance Tube Set* (Catalog No. 4616) available from Flinn Scientific.

Sample Data Table

Frequency (Hz)	Tube Length (cm)	Tube Length (m)	Wavelength (m)	Speed of Sound (m/s)	Average Speed of Sound (m/s)
256	32.9	0.329	1.316	336	334
288	29.5	0.295	1.180	339	
320	26.5	0.265	1.060	339	
341	24.7	0.247	0.988	337	
384	21.6	0.216	0.864	331	
427	19.4	0.194	0.776	331	
480	17.2	0.172	0.688	330	
512	16.2	0.162	0.648	331	

Materials for *Discovering the Speed of Sound* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP7260	Disocvering the Speed of Sound in Air—Classroom Set
AP1037	Clamp, Universal Extension Clamp
AP8219	Clamp Holder
AP2228	Rubber Stoppers, Solid, #6
AP4685	Ruler, Metric, 12"
AP4550	Support Stand, Economy Choice
AP9242	Tuning Forks, Set of 8
AP6422	Tuning Fork Activator

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.