Resonance Apparatus

P7-7450

INSTRUCTIONAL GUIDE

Contents

Resonance Apparatus:

- Acrylic Tube (39.5" long x 1.5" dia)
- Cast Iron Support Stand with Base
- Water Canister
- Rubber Tubing
- 1 Tuning Fork (512Hz High C)
- 2 Clamps

Recommended for Activity:

- Complete Set of Tuning Forks (P7-5000)

Background

Resonance is the phenomenon in which the forced vibration of one object produces a frequency that matches the natural frequency of another object. When this occurs, the one object drives the other and a dramatic increase in amplitude occurs. A common example occurs when pushing a child on a swing. The swing, acting like a pendulum, has a natural back and forth frequency. When the person pushing adjusts the frequency of his or her pushes to be in sync with and matching that of the swing, larger and larger amplitudes of the swing. The Resonance Apparatus uses this principle to measure the speed of sound.

In the experiment, described below, you will use the wave equation ($v = \lambda f$) to measure the speed (v) of sound; here (f) is the frequency and (λ) is the wavelength. A vibrating tuning fork held over the top of the graduated water cylinder will begin to resonate with the air column above the water in the cylinder. After taking the measurements of the air column and the tuning fork, the speed of sound can be calculated

Assembly

1. Stand the support stand with base upright
2. Slide the water canister onto the support stand and secure around the middle of the stand.
3. Locate both clamps. Attach one clamp at the top of the support stand and attach the other clamp near the base of the support stand.
4. Open both clamps. Place the acrylic tube inside both clamps and tighten. Make sure the measurements on the cylinder are clearly visible.
5. Locate the plastic tubing. Attach one end of the tubing on the nozzle at the bottom of the graduated cylinder.

Measuring the Speed of Sound in Air

Objective:

The purpose of this experiment is to measure the speed of sound in air by exploring standing wave and resonance effects in longitudinal waves

Physics Theory:

You may have already examined the theory of standing waves and resonance in transverse waves (standing waves on a string). In transverse waves, the displacement of the medium through which the wave propagates is perpendicular to the direction of wave travel. Electromagnetic waves and waves on strings are both examples of transverse waves. In longitudinal waves, the displacement of the medium through which the wave propagates is parallel to the direction of wave travel. Sound waves are a prominent example of longitudinal waves.

Recall that the condition for transverse standing wave formation on a string was $v = 2lf/n$ or $f = n\,v/2l$ ($n = 1, 2, 3, \ldots$) where 'f' is the frequency of vibration, 'l' is the length of the medium (string), 'n' is the number of half wave lengths, '$\lambda/2$' (loops), and 'v' is the propagation velocity of the wave. For sound waves, this relationship still holds. In this experiment 'f' is the frequency at which a column of air vibrates (driven by a tuning fork), 'l' is the length of the column of air, 'n' is the number of half wave lengths, '$\lambda/2$' and v is the speed of sound in air.

In this experiment, we will create longitudinal standing waves in a tube containing air in which the tube is open at the top. By adjusting the amount of water in the tube, one may lengthen or shorten the length, 'l' of the column of air in the tube. If a tuning fork is held over the open end of the tube and struck, it excites the air molecules in the tube and causes a sound wave to propagate down the length of the tube to the air-water boundary, where it is reflected back up the length of the tube to the open end. The end of the tube containing water constitutes a "closed" end. In tubes, pipes or columns open at one end and closed at the other creates a stable standing wave pattern requires that a displacement antinode exists at the open end and a displacement node at the closed end of the tube. This means that the fundamental (first harmonic) standing wave, such as a tube, occurs when the column of air is of length $\lambda/4$. The series of nodes and antinodes in a tube, open at one end and closed at the other, form an odd harmonic series. In tubes open at both ends, or closed at both ends, all harmonics are possible. Thus the condition for a standing wave to form in a tube closed at one end is $f = n\,v/4l$ or $\lambda = 4l/n$ ($n=1,3,5,\ldots$)

Experimental:

In this experiment, the resonant frequencies are determined by the tuning forks that you will use to produce standing waves in a column of air, within a tube that is open at one end. These are of known value. By adjusting the level of water at the other end of the tube you will be able to adjust 'l', the length of the tube. In doing so you will be able to adjust the length of the column of air so as to form standing waves in the tube. Once a standing wave of a given frequency has been established, by adjusting the tube to the appropriate value of 'l' for the fundamental of that particular frequency, it will be possible to locate the position of each successive antinode along the wave by lengthening the tube. By measuring the difference between successive nodes you will be able to compute the wavelength of the standing wave;

and from that, the speed of sound in the column of air by: $v = \lambda f$. Remember that the distance between successive antinodes is half a wavelength

Fill the reservoir of the resonance apparatus with water positioning it near the bottom of the tube before doing this to prevent overflow. Note how moving the reservoir up and down the attachment rod raises and lowers the level of water in the resonance tube. Use the 512 Hz tuning fork. Strike the fork on its tines; a great deal of force is not necessary. This will produce a 512 Hz (high C) tone audible to the ear. Hold the tuning fork over the mouth of the tube with the end of the tines vibrating perpendicularly to the mouth of the tube and adjust the level of water in the tube by moving the reservoir up. You will notice that the tube will emit loud tones of the same frequency, similar to the tuning fork for certain water levels. This indicates resonance and the presence of an antinode at the mouth of the tube. The first resonance will occur when the water level is λ beneath the mouth of the tube, the second when the water level is $3\lambda/4$ beneath the mouth of the tube, the third at $5\lambda/4$, etc. Note that the distance between successive antinodes is $\lambda/2$. Note, as well, that the number of resonances will increase with increasing frequency. Can you explain why?

Once you have located the approximate position of resonance for the tuning fork repeat the procedure again but, this time measure each position of resonance as carefully as possible. Record each measurement in your lab notebook along with a sketch of the standing wave in the tube at the position that you are measuring. Once you have measured the position of each resonance, repeat the experiment a few times and compute the mean "x". When you are finished with this procedure for a particular frequency, repeat the procedure with two more tuning forks of differing frequencies, if available. Record the frequency of these tuning forks on the data table below the 512 Hz fork.

Data Analysis:

1. Record the resonance positions for the tuning fork on the data table.

2. Using the distance for the resonance positions, determine the half wavelengths of the tuning fork.

3. Calculate the velocity of sound using $v = \lambda f$

4. The speed of sound in air at STP is about 330 m/s. Statistically speaking, how do your results compare with this?

Questions:

1. Is the speed of sound independent of frequency?

2. What factors could make the speed of sound in your lab different than the value given at STP?

3. Why are sound waves longitudinal waves that can't be transverse waves?

4. What limited the number of resonances you found in the tube in this experiment for a given frequency?

Tuning Fork (Hz)	1st Resonance Position (cm)	2nd Resonance Position (cm)	3rd Resonance Position (cm)
512 Hz			

Tuning Fork (Hz)	Half Wavelength 1st to 2nd Resonance	Half Wavelength 2nd to 3rd resonance	Average half Wavelength	Speed of Sound
512 Hz				

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