Lab Sim 02: Speed of Sound

Introduction

Wave speed is a relatively simple calculation: $v = \lambda f$. For sound waves, a difference in frequency is perceived as a difference in pitch—you can hear frequency changes. But how can you measure the wavelength if you can't see the wave? Lighting the wave on fire is a fairly dramatic technique, but you can't argue that it's ineffective!

Objectives

- Observe a standing wave in a closed column of propane gas
- Measure the wavelength for multiple wave frequencies
- Use these observations to calculate the speed of sound
- Determine the amount of error in an experimental value
- Evaluate the effect of the experimental technique on the accuracy of your results

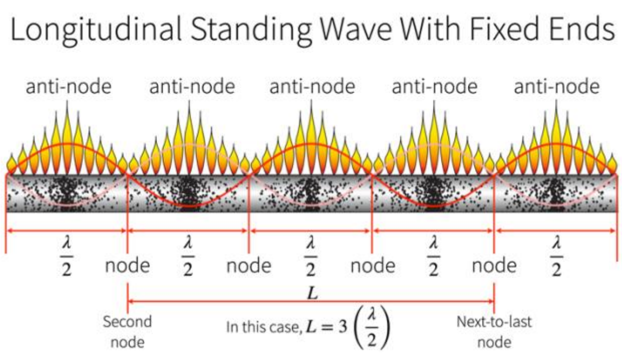
Pivot Interactives

This exercise requires the online simulation (Lab 02: Speed of Sound). You should sign in to your Pivot account and choose the correct Interactive from the PHYS 1420 selection.

Measuring the Wavelength

The second video shows a series of standing wave patterns in the Ruben's Flame Tube. The frequency is given for each standing wave, and you can see the resulting wave pattern. By measuring the wavelength, we can apply the wave equation $v = \lambda f$ and calculate the speed of the sound wave through the propane-filled tube.

The sound wave is a pressure wave, and the flames are highest where the pressure is maximum and lowest where the pressure is minimum. We know that sound waves are longitudinal, but visualizing them with a transverse sketch makes it easy to identify the wavelength. Node–to–node, or min–to–min, is exactly one half a wavelength, $\frac{\lambda}{2}$. Because the tube is closed at both ends, each end is also a node.



To measure the wavelength, pause the video and click on the tool icon to activate the ruler. Measure the total distance from the second left-most node to the next-to-last right node or the furthest node that you can pinpoint clearly. Notice that you are not using the very ends of the tube, which gives you a more accurate measurement!

Also, be sure to count and record the number of half-wavelengths (n) that you have measured (this will change as you adjust the frequency: higher f, more nodes).

1) (10 points) You should measure the wavelength for **at least 15** different frequencies. **You will need to add two columns** to the data table: one for calculating the wavelength λ and another for calculating the period T.

Frequency f (Hz)	Half-Wavelengths n (count)	Tube Length L (m)

To calculate the wavelength: $\lambda = \frac{L}{n/2}$

where L is the measured length of tube and $\frac{n}{2}$ is the number of complete wavelengths measured (i.e., $n = 4$ means four *half*-wavelengths, which corresponds to $\frac{n}{2} = \frac{4}{2} = 2$ *full* wavelengths!).

And we are already familiar with the relationship between frequency and period: $T = \frac{1}{f}$.

Measuring the Wave Speed

The simplest way to extract the wave speed will be graphically. Of course, we could calculate the speed for each individual trial, then take an average. But that's precisely what graphing the data and finding the best-fit line accomplishes in considerably fewer steps.

Start with the wave equation: $v = \lambda f$, which has the form of a line ($y = mx$), but we need to re-arrange the terms. We want the slope to be the wave speed v:

$$\lambda = \frac{v}{f} = vT$$

2) (5 points) Within the interactive, plot the appropriate graph and perform the linear regression.

Interpreting the Results

How accurate is your slope?

We really have no way to know how precise or how accurate the frequency generator is. For simplicity, let's assume $f \pm 1\%$. This means the actual frequency might be up to 1% higher or lower than the value reported to us.

We can calculate the uncertainty in our wavelength measurements. We know that measuring uncertainty is $\pm\frac{l}{2}$, where l is the smallest division on the measurement scale. In our case, the meter stick is $\pm 1\text{cm} = \pm 0.01\text{m}$, which translates as $\lambda \pm 1\%$, if the wavelength was 1m—which it was not!

Ok, then, let's make an estimate: the values of L were all in the *vicinity* of 1.5m: $L = 1.50 \pm 0.01\text{m}$, which translates as $L \pm 0.67\%$. The relative (percent) error on the length will then be the same percentage for the wavelength: $\lambda \pm 0.67\%$.

3) (3 points) So, based strictly on our estimates for measuring uncertainty, how accurate is the slope?
   A. $v \pm 0.67\%$
   B. $v \pm 1\%$
   C. $v \pm 1.67\%$

According to "Handbook of the Speed of Sound in Real Gases," by A. J. Zuckerwar (Academic Press, 2002). the speed of sound in propane at STP is $v_{STP} = 258\frac{\text{m}}{\text{s}}$.

4) (3 points) Compare the prediction to the value you obtained by calculating the percent error.
5) (3 points) Wow, right? Your value is nowhere close to the prediction! Why?
   A. The graph shows that there is considerable scatter in the data, which means that there is a lot more random error in the measurements than we have estimated. A *lot* more.
   B. The correlation coefficient (r) is very high, which indicates that the data are very linear. This implies that the effect of random error has been minimized—so there must be something *systematic* affecting our results.
   C. There is simply not enough information for us to figure out whether random or systematic effects are responsible for our results.

Your experimental value is *much* higher than the prediction. Why?

What if I told you it was the *prediction*?

Ok, I'm telling you: it's the prediction.

6) (4 points) Explain clearly (but briefly) two reasons why the experimental value ***must*** be greater than the predicted value.

The speed of sound in air has a temperature dependence:

$$v = 331\frac{\text{m}}{\text{s}} + \left(0.6\frac{\text{m/s}}{°\text{C}}\right)T$$

where T is the air temperature in °C.

7) (4 points) Explain why you think that the speed of sound through propane does (or does not) have a similar temperature dependence (we are not suggesting that the temperature coefficient has the same numeric value for propane as for air). What about other gases? Is the temperature dependence a general property?

When you have completed this lab exercise in Pivot, please be sure to submit your responses. This lab is due no later than Thursday, 14 July 2022 at 11:59PM CDT.