Introduction

The purpose of this experiment is to measure the speed of sound in air. You will do this by measuring how long it takes for a sound pulse to travel a measured distance. To determine the speed of sound you will plot the distance traveled as a function of time and determine the slope of the resulting line.

Theory

The speed of an object may be determined by measuring its position as a function of time. If the speed, v, is constant then the position, x, will increase linearly in time, t:

$$x = vt + x_0$$

where x_0 is the initial position. So, by plotting position as a function of time and determining the slope of the resulting line we measure the speed of the object.

Sound is a wave of pressure change that propagates. For example, a loudspeaker pushes air producing an increase in the pressure right in front of the speaker. This increase in pressure moves away from the speaker, decreasing in amplitude as it travels along. When the increase in pressure reaches your eardrum it pushes on it and your ear detects the displacement of the eardrum as sound.

A change in pressure moves through the air with a characteristic speed which depends primarily on the density and temperature of the air through which it is moving. At typical pressures inhabited by people the speed of sound (at the frequency of sound used in this experiment, approximately 20 Hz) has the following temperature dependence,

$$v = 332.12\,\frac{m}{s}\sqrt{1 + \frac{T}{273.15\ ℃}}$$

where the temperature, T, is measured in degrees Celsius. So, in a room at 22°C, normal atmospheric pressure, and 50% relative humidity, sound will propagate at

$$v_{acc} = 345.25\,\frac{m}{s}$$

In our experiment we will be creating a pulse of sound, allowing it to travel a measured distance down a Lucite tube, and measuring the time at which it reaches a detector. By changing the distance traveled and measuring the change in time it take for the sound to travel that distance we will build up a data set with which we can plot distance as a function of time.

The time measurement will be made with an oscilloscope. An oscilloscope has a raster which moves across its screen at a speed which can be determined by the operator. The raster has a vertical deflection proportional to a voltage signal applied to the input of the oscilloscope. If our oscilloscope screen is ten centimeters wide and the raster is moving at one centimeter per millisecond (1 millisecond = 10^{-3} seconds) then if our detector converts a pressure wave into a voltage 5 milliseconds after it is released from the loudspeaker you will see a blip on the screen 5 centimeters from the origin. If we adjust the position of our detector so that the pulse is detected after 6 milliseconds we will see the blip 6 cm across the screen. In this way we can convert the oscilloscope trace into a time measurement that corresponds to the distance between our loudspeaker and our detector.

Materials and Equipment

- **Lucite tube with speaker assembly**
  A Lucite tube is fitted with two speakers, see figure 1. One of the speakers is fixed at one end of the tube; and the second speaker is moveable inside the tube. Its distance from the first can be measured using the metric tape glued to the Lucite tube. The first speaker is used as the transmitter of a sound pulse and the second speaker is used as a detector of the sound pulse.

- **Electric pulse generator**
  Pulse Generator provides voltage pulses of short duration to the transmitting speaker at a constant interval of time and concurrently turns on our electronic clock (it starts the raster moving across the screen of the oscilloscope).

- **Oscilloscope**
  The electron beam in an oscilloscope can be swept horizontally at various speeds. The screen of an oscilloscope has a grid consisting of vertical and horizontal lines. The spacing between lines is 1.00 cm. The speed at which the electron beam is swept determines the time scale. The time scale on the oscilloscope in this lab can be set for various values of time ranging from 0.5 sec to 0.05 μs per centimeter.

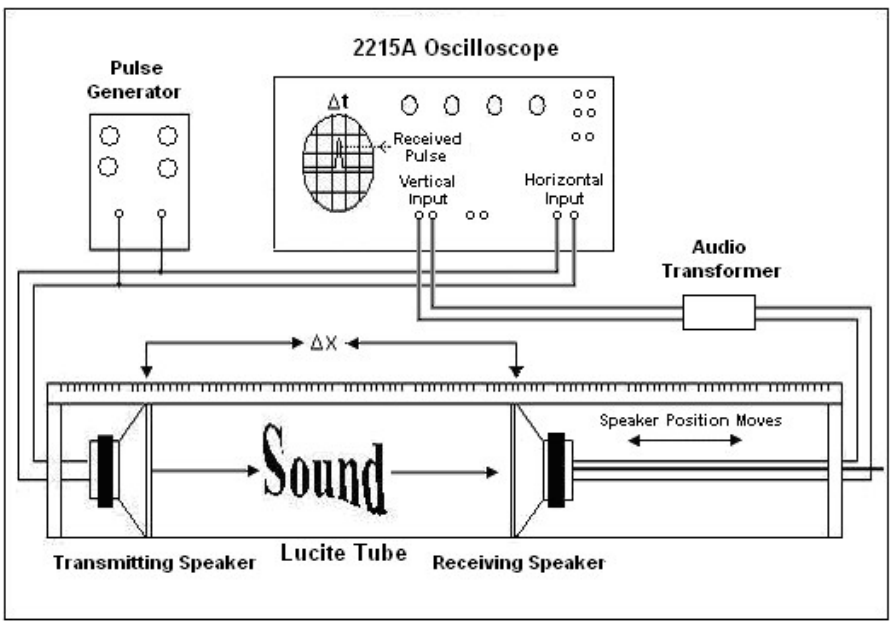

Figure 1: Schematic of the speed of sound setup

Procedure

The experimental equipment will be set up for you and you need not tamper with it. If there is no image on the oscilloscope, inform the instructor or teaching assistant. Check that the sweep dial is set at 0.5 ms/cm. Use the horizontal position knob to make sure the beginning of the trace is close to the zero time (the first vertical line on the oscilloscope).

1. Move the second speaker until the first large sharp peak of the voltage trace displayed on the oscilloscope screen coincides with the 0.5 ms vertical line corresponding to the time, *t*, equal

to 0.5 ms. Measure and record the position, *x*, of the detector in a table consisting of two columns, one for the time *t*, and the other for the position, *x*.

2. Slowly move the detector until the same peak is at the 1 ms line on the oscilloscope. Be aware: The size of this peak may change! Our goal is *not* to measure the highest peak at every distance, but the *same* peak at each distance.
3. Repeat step 1 above for additional values of *t* [1.5, 2, 2.5, and 3 ms] corresponding to other vertical lines on the oscilloscope screen.
4. **REMEMBER:** Each reading of both *time* and *distance* is a measured value! Be sure to record these values to the correct precision!

Calculations and Analysis

1. Subtract your initial position value from each of your position measurements. Subtract your initial time value from each of your time measurements. Your position and time data should now start at (t_0, x_0) = (0.0 ms, 0.00 cm)
2. Plot a graph of *x* (cm) versus *t* (ms). In class, you plot this graph using Excel. **You are required to plot, and submit, this graph by hand using cm-mm graph paper for your lab report.)**
3. Since the speed of sound is constant, the graph of *x* vs. *t* should be a straight line. Using two-dimensional statistics, linear regression, **the slope of this graph should be your experimental speed of sound, v_{exp}.**
4. Properly report your experimental result for the speed of sound in air.
5. Perform a precision versus accuracy test.
6. Calculate the percent difference calculation using the accepted value:

$$v_{acc} = 345.25\,\frac{m}{s}$$

Hand-drawn graph

On a sheet of 25mm graph paper (available in the lab classroom) plot your mass, volume data points.

1. Data must use at least 75% of the graph area. This means you must determine how to scale both the horizontal and vertical axes so that the area used to display your data covers most of the available space.
2. Display the scale on the graph area.
3. Include a descriptive title.
4. Axes must contain labels and appropriate units.
5. Precisely plot data points as a small dot.
6. Good points should be surrounded by a small circle, any bad points should be surrounded by a small square or explicit label.
7. Draw a line of best fit. This is a line that best represents the plotted data, it may pass through more, some, or none of your data points. The line should extend beyond your plotted data points.

8. Calculate slope and intercept using two **non-data points** on the best-fit line. Display the two points chosen, and the algebra used to calculate slope and intercept.
9. Include the equation of the best fit line including appropriate variables and units.
10. Example hand-drawn graphs are available on the course webpage.

Questions

1. (4 points) On your position vs. time graph, what does a straight line indicate about the speed of sound in air?
2. (4 points) What shape would the graph take if an object had a constant, non-zero, acceleration?
3. (4 points) Use Excel to calculate the speed of sound in air at temperature $T = 100$ °C and normal pressure.
4. (4 points) Using your v_{exp}, calculate the distance in centimeters, a sound pulse will travel in a time period of 0.5 ms.
5. (4 points) Calculate how many **miles** a light pulse in a vacuum will travel in 0.5 ms. (Use the speed of light's value as $c = 3.00 \times 10^8$ m/s and 1 km = 0.621 mi)
6. (10 points)

   a) What does your squared linear correlation coefficient, R^2 tell you about the relationship between your t and x values?

   b) After setting each t value, describe a different set of measurements you could make that would result in your R^2 tending toward zero. (At each time measurement, t, what other data might you measure that does *not* have a linear relationship with time?)