

## *Experiment #3, Measurement of the Speed of Sound in Air*

### **1 Purpose**

The purpose of this experiment is to measure the speed of sound in air. In addition, you will learn to measure time and distance, to plot and analyze a graph (by hand and Excel) and to use a scientific calculator to do linear regression.

$$Speed = \frac{\text{distance traveled}}{\text{time elapsed}}$$

### **2 Introduction**

To determine the speed of an object moving in one direction, it is necessary to measure the position of an object as a function of time, and make a plot of position vs. time. If the speed is a constant, the position vs. time graph will be linear, i.e., its slope is constant, otherwise the graph will be a curve indicating that the speed is changing, i.e., the object is accelerating.

When a medium such as air is disturbed, a pressure wave propagates through it. When a pressure wave hits the ear drum, it produces a sensation of sound and therefore a pressure wave is referred as a sound wave. Just like a physical object, a wave also takes a finite amount of time to travel between two points.

Normally we use our eyes and a meter stick to determine the position of an object and hands to operate a stopwatch to determine the time. The determination of the speed of sound requires production and detection of a sound pulse in a controlled fashion as well as the use of a very fast clock to measure time. Sound takes about 2.88 ms ( $1 \text{ ms} = 10^{-3}$  seconds) to travel a distance of 1.00 meter. Speakers are used to produce and detect sound and an oscilloscope is used as a stopwatch of very high precision.

Students should study the summary of error analysis in the supplementary material entitled "**Error Analysis**" which is located at [www.physics.umb.edu](http://www.physics.umb.edu).

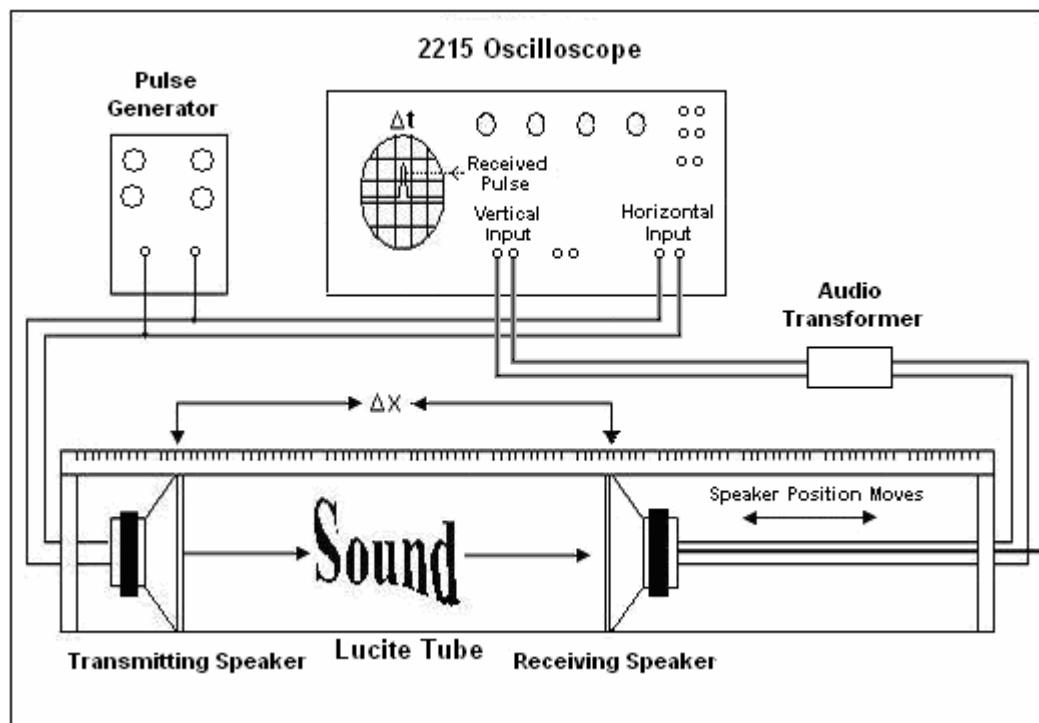
### **3 Experimental Apparatus and Procedure**

#### **3.1 Experimental Apparatus**

**A Lucite tube** is fitted with two speakers. 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 receiver of the sound pulse.

**An Electric Pulse Generator** provides voltage pulses of short duration to the transmitting speaker at a constant interval of time and concurrently turns on an electronic clock (an oscilloscope). Whenever a voltage pulse is applied to the transmitting speaker, a pulse of sound is emitted. The sound pulse propagates through the air (or gas) in the Lucite tube and upon hitting the diaphragm of the receiving speaker; its diaphragm is set into vibrations inducing the appearance of a voltage pulse at the terminals of the receiving speaker. This voltage pulse is used to 'stop' the electronic clock (oscilloscope).

The time elapsing between the application of a voltage pulse to the transmitting speaker and the appearance of a voltage pulse across the terminals of the receiving speaker is equal to the time it takes for the pulse of sound to travel the distance between the two speakers. From a measurement of this time interval and the distance between the two speakers, the speed of sound can be determined.



**Figure 1. Experimental Setup**

**Oscilloscope as a stop watch** - 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 screen acts as a clock dial and the electron beam acts as a clock hand. 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 200 ms to 5  $\mu$ s. As previously mentioned the voltage pulse from the pulse generator emits a sound pulse and simultaneously starts the clock. In this instance the voltage pulse triggers the electron beam to begin its sweep (the hand of the clock starts to move) in the horizontal direction. The sweep rate, i.e., the

speed with which the electron beam moves across the oscilloscope screen, can be adjusted using the appropriate oscilloscope controls.

The voltage pulse from the receiving speaker is applied to the vertical input terminals of the oscilloscope, causing vertical deflection of the electron beam. In the absence of any voltage pulse across the vertical input terminals, the electron beam, once set in motion by the pulse from the pulse generator, will move horizontally across the screen. When the sound pulse produced by the first speaker reaches the second speaker, a voltage pulse will appear across the vertical input terminals causing a sharp vertical deflection of the electron beam (which up to that time was moving only horizontally).

The time which elapses between the start of the horizontal motion of the electron beam and the beginning of its vertical deflection is equal to the time it takes for the pulse of sound to travel the distance between the speakers. This time can be read on the oscilloscope screen since the horizontal sweeping rate of the electron beam is known from the setting of the horizontal display switch.

As is the case when using a normal stopwatch where one mechanically stops it to determine the time, it is not possible to stop an electron beam and read its position. Instead, the stopping is indicated by the vertical deflection of the electron beam.

### 3.2 Experimental Procedure

The experiment 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).

#### Data Collection:

1. Move the second speaker until the first large sharp peak of the voltage trace displayed on the oscilloscope screen coincides with the 0.50 ms vertical line corresponding to the time,  $t$ , equal to 0.50 ms. Measure and record the position,  $X$ , of the second speaker in a table consisting of two columns, one for the time  $t$ , and the other for the position,  $X$ . **This table is located at the end of this document.**
2. Repeat step 1 above for additional values of  $t$  [1.00, 1.50, 2.00, 2.50, and 3.00 (and possibly 3.50 ms)] corresponding to other vertical lines on the oscilloscope screen. Continue to use table one for this data.
3. **Determining the precision of the Measurements:** Once you have finished step 2, reset the speaker for the position where  $t$  equal to 2.00 ms on the screen and again note the value of  $X$ . Repeat this four additional times by moving the second speaker and returning it to a position corresponding to the same time  $t$  equal to 2.00 ms. You

will observe that the five values of the  $X$  will not be the same. This data on  $X$  reflects on how precisely you can measure time and distance. **Use table two for this data.**

#### 4 Calculations and Analysis of the Data

1. Plot a graph of  $X$  (cm) versus  $t$  (ms). In class, you plot this graph using Excel. **For your lab report, you are required to plot this graph by hand using cm-mm graph paper.** Since the speed of sound is constant, the graph of  $X$  vs.  $t$  should be a straight line. Draw on your graph a thin straight line which best accommodates the measured points and calculate its slope using 2 **non-data** points widely separated to minimize reading errors. This slope is equal to the speed of sound in air in **cm/ms**.
2. Use linear regression on your calculator to determine the slope, intercept and correlation coefficient  $R$  or  $R^2$ . **In your lab report, use this value of the slope for the experimental speed of sound,  $v_{exp}$ . Your graph should indicate the best linear data for you to enter into your calculator.**
3. Calculate the standard deviation  $s_x$  and SDM using the five values of  $X$  for  $t = 2.00$  ms. Estimate the random error (precision)  $\pm \Delta v$  in the speed of sound. **For your lab report, convert your value of the speed of sound to meters/second (m/s) before you do the following calculation.**

$$\pm \Delta v = v_{exp} \left( \frac{SDM}{X} \right)$$

4. The accepted value of the speed of sound in air at  $25.0^\circ\text{C}$  is  $v_{accepted} = 347.13$  m/sec.
  - a. Convert your value of the speed of sound to meters/second (m/s), and determine the absolute difference between the accepted and the experimental values of the speed of sound (note this will be a positive number due to the use of the absolute value  $|\cdot|$ ).

$$\text{Discrepancy} = \text{Absolute difference} = |v_{accepted} - v_{exp}|$$

A discrepancy much greater than  $\Delta v$  probably indicates that the experiment is not accurate and systematic errors should be suspected. Precision,  $\pm \Delta v$ , reflects random error.

- b. Determine the % difference between the accepted and the experimental value of speed of sound:

$$\% \text{ difference} = (|v_{accepted} - v_{exp}| / v_{accepted}) (100\%)$$

## 5 Questions

1. Does your data on the hand drawn graph fit that of a straight line? What does a straight line indicate in a graph of position vs. time?
2. Using your value of  $v_{exp}$  from linear regression, calculate the distance, in centimeters, a sound pulse will travel in a time period of 0.5 ms.
3. How many **miles** will a light pulse travel in a time period of .50 ms (ms = milliseconds). The speed of light is given as  $c = 3.00 \times 10^8 \text{ m/s}$  (meters/second).
4. Describe the difference between accuracy and precision. Refer to the supplemental material on Error Analysis at [www.physics.umb.edu](http://www.physics.umb.edu) to answer this question.
5. Does  $v_{accepted}$  fall within the interval determined by the limits of your experimental error (precision),  $\pm \Delta v$ , for  $v_{exp}$ , which was determined in part 4.3? We want to know if the following is true:

$$|v_{accepted} - v_{exp}| \leq \Delta v_{exp}$$

Do the above by comparing the calculation of the expression on the left (4.4a), to the expression on the right (4.3). **Be sure that all values are in meters/second.**

6. If question 5 is not true, what type of error may account for this?

## 6 Conclusion

This section should have a clear statement of the results of the experiment and the extent to which the results are in agreement with the theory being tested. Use percent difference to compare your experimental result to the accepted or theoretical value. If percent difference was done earlier in your report, you are still required to do it in this section.

To make this comparison meaningful, you should include the impact of the experimental error on your results. This includes errors in plotting and reading linear graphs when determining their slope and intercept. Possible systematic and procedural errors should be included. Please include a statement of what you have learned, a critique of the experiment, and any suggestions you have which you think could improve the experiment or the lab handout.

# Error Analysis of the Speed of Sound in Air

## Appendix 1

### 1 Important Formula:

#### 1.1 The speed of sound, $v$

The relationship between the speed,  $v$ , the distance,  $X$ , and the time,  $t$ , is given by:

$$v = \frac{\Delta X}{\Delta t} = \frac{\text{Rise}}{\text{Run}}$$

#### 1.2 Statistical Analysis

##### 1.21 Mean Value ( $\bar{X}$ )

If  $N$  measurements of the distance ( $X$ ) yield the values

$$X_1, X_2, X_3, X_4, \dots, X_N$$

the mean value of  $X$  is defined as:

$$\bar{X} \equiv \frac{X_1 + X_2 + X_3 + X_4 + \dots + X_N}{N} = \left(\frac{1}{N}\right) \sum X_i$$

##### 1.22 Standard Deviation ( $s$ )

The standard deviation of a sample consisting of  $N$  values of distance ( $X$ ) is given by:

$$s_x \equiv \sqrt{\frac{1}{N-1} \sum (X_i - \bar{X})^2}$$

##### 1.23 Standard Deviation of Mean (SDM)

The standard deviation of the mean (standard error) value of a sample consisting of  $N$  measurements of the distance  $X$  is related to its standard deviation by:

$$SDM_x = \frac{s}{\sqrt{N}}$$

## Measurement of the Speed of Sound in Air Data Sheet

*Table I: Time vs Position*

Time t (ms)	Position X (cm)

*Table II:*

*Position at t=2 ms*

Time t (ms)	Position X (cm)
2.00	
2.00	
2.00	
2.00	
2.00	

Estimated error in X from reading metric tape,  $\text{Error}_X = \pm \Delta X = \underline{\hspace{2cm}}$  cm

Use half of the smallest interval on the tape to determine this value. Error in any measurement you make should be entered into the data section of your lab report.

**The above tables must be generated for your data section of your lab report. You are not allowed to simply attach this sheet.**

**The Excel work which you did in class should be attached to the end of your computer generated lab report. This information is separate from what is required for your report.**