Sound waves propagate (travel) through air at a velocity of approximately 340 m/s (1115 ft/sec). As a sound wave travels away from a small source of sound such as a vibrating speaker or tuning fork, its amplitude decreases as its energy is spread over larger and larger area. These waves also reflect from surfaces and in reflection lose amplitude through absorption. The purpose of these experiments is to explore these ideas by using short pulses of sound. We will generate these short pulses of sound by sending short voltage pulses to a speaker.

**Physics Concepts Involved:**

The velocity of sound in air depends on the temperature of the air. The formula:

\[ v = 331.5 \text{ m/s} + (0.6 \text{ m/s}) T \]  \hspace{1cm} (1)

gives the velocity in m/s (meters per second) when \( T \) is in degrees Celsius. Sound reflects from a flat surface much as light reflects from a mirror. In analogy to light one can draw rays of sound where the incoming and reflected angles are equal. From this view you can calculate the time it takes for a sound wave from the speaker to bounce from a flat surface and back to the mike. Assume the room temperature to be 20 degrees Celsius.

**A. Velocity of Sound:**

A convenient arrangement for these experiments is one where the directional speaker is mounted on a ring stand about 0.5 m above the lab table. The computer microphone must be mounted on a ring stand in fixed position for careful measurements. See the drawing.
1. Simple velocity measurement: Look at the “VARiable OUTput” of the 4001 Pulse Generator on channel 1 of your oscilloscope. (Convenient settings of the pulse generator are: power and run buttons pushed in, pulse spacing = 10ms, pulse width = 100μs, spacing vernier = 1, and width vernier = 1.) Adjust the amplitude of the pulse to approximately 0.5 volt. When you are happy with your pulse, attach your speaker in parallel with the oscilloscope. You should hear a (gentle) buzzing. Loud buzzing is unnecessary.

To measure the velocity of sound, you need only measure the distance the sound travels and the time it takes to get there.

2. To measure the time, record a series of clicks on your computer (?-0). Zoom in on the recorded signal so you can see a close pair of pulses (the first pulse represents the sound signal from the speaker passing the microphone, the second is the reflected sound). Point the cursor at the first pulse and click the mouse, then point it at the corresponding part of the reflected pulse and click again. The time (in seconds) and signal level (in volts) of each point you clicked are recorded in the bottom window. To find the time between the pulses, subtract the two times.

The distance (in meters) between the speaker and microphone is also needed. Calculate the velocity you get and compare it with the value you expect from equation (1). Be sure to measure both the time and distance as carefully as the instruments allow and record your labeled measurements and calculations:

\[
\text{pulse travel time} =
\]

\[
\text{distance traveled} \text{ (twice the distance between the mike and the board)}:
\]

\[
\text{expected velocity from equation (1)}:
\]

\[
\text{velocity from your measurements} \text{ (v = d/t)}:
\]

comments:
B. $\frac{1}{R^2}$ Decrease in Sound Intensity:

Since the energy of a sound wave from a source must spread over a larger and larger sphere as it moves away from the source and since the area of this sphere is $4\pi R^2$, one expects the energy of any wave to decrease as $1/R^2$ as the distance to the source, $R$, is increased. Similarly, since the energy (and the corresponding intensity or energy per second per square meter) is proportional to the square of the amplitude of the wave, the amplitude should decrease with distance as $1/R$. You can make a measurement of this effect by simply observing the amplitude of the mike pulse as you space the mike farther and farther from the speaker.

To measure the amplitude, turn the microphone towards the speaker, place it at the distance you want, and record the sound signal. Then zoom in on several pulses and use the mouse to click the most positive and negative peaks of each pulse. The difference between the signal levels (which are recorded in the lower window) represent the peak-to-peak amplitude of each pulse. Measure the peak-to-peak amplitudes of several pulses in each recording and average them.

Make a table of amplitude as a function of distance of the mike from the speaker. Start your measurements with the mike close to the speaker where the amplitude is largest (10 centimeters away) and then measure every 10 centimeters. Be careful to avoid saturation effects. The largest amplitude should never exceed 13-15 V.

<table>
<thead>
<tr>
<th>distance (cm) = R</th>
<th>amplitude (volts) = A</th>
<th>1/amplitude (1/volts) = 1/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4: Sound pulses: - 3
On a separate piece of graph paper plot your amplitudes as a function of distance from the speaker. Does the amplitude decrease with distance as $1/R$? Do you see any strange effects as you get very close to the speaker? These are called proximity effects.

When measuring the distance to the speaker it’s difficult to decide precisely where to take the position of the speaker. The speaker really isn’t a point source, so it’s hard to select the “center of the sphere”.

There is an easy way to replot your data to see if the amplitude decreases as $1/R$ and to determine the effective center of the sphere of radiating sound. The expected amplitude-distance relationship is $A = k/R$, where $k$ is a constant determined by the amplifier gain, speaker type, etc. Since the $R$ you measure from the front edge of the speaker is clearly not the center of the sphere, we can add an unknown distance, $R_o$, and write:

$$A(R) = \frac{k}{R + R_o}$$

This equation can be rearranged to read:

$$R = \frac{k}{A} - R_o$$

Plotting distance $R$ on the vertical axis against one over amplitude, $1/A$, on the horizontal axis should give a straight line with slope $k$ and intercept, $-R_o$. Make this plot. Use a ruler to draw a straight line through your data points. From the plot read the intercept of the line (the vertical coordinate where the line crosses the vertical axis ($1/A=0$)). Also calculate the slope $k$ of the straight line; To do this pick up two arbitrary points on the line, then the slope = (change in the vertical coordinates)/(change in horizontal the coordinates) for the two points. In this case, units of the intercept are cm, units for the slope are cm*V.

Comment on whether you believe your data fits this model. What values do you find for $R_o$ and $k$?

$$R_o =$$

$$k =$$
C. Early Sound

Early sound refers to the arrival of reflected sound from surfaces in a room (or concert hall). As mentioned in the physics section above, sound reflects from a flat surface much as light reflects from a mirror with equal incident and reflected angles. You can calculate the time it takes for a sound wave from the speaker to bounce from a flat surface and back to the mike. With the speaker and mike mounted on separated ring stands 50 cm or so above the lab table, you can observe the arrival of both the direct sound and the early sound reflected from the table. With the computer, we can measure the difference between the arrival times.

Place the mike and speaker about 1 meter apart facing each other. Record the sound signal and zoom in on a pulse (this is the direct pulse). About 1 ms later, you should see a much smaller pulse, which represents the early sound. Use the mouse to measure the time interval between the pulses. To make sure you have identified the early sound pulse, put a piece of acoustic foam on the table and record again. Check to make sure your reflected pulse disappears from its previous position (if the feature you measured did not disappear, you probably did not identify it correctly, call me over).

**Early Time - Direct Time =**

The difference between the direct time and the early time should reflect the difference in distances traveled by the sound in each case. Without moving your apparatus, use meter sticks to measure the direct sound distance and the reflected sound distance. In measuring the reflected sound distance how did you decide the path to measure? Make a sketch, approximately to scale, where you have labeled the two paths and the lengths of each. On your sketch be sure to show the two angles that are known to be equal.

............... Your Sketch ................

**Direct Distance =**

**Early Distance =**

**Early Distance - Direct Distance**

Using your best velocity determination from part A and your measured time difference calculate the expected path difference for the early and direct sounds. Does it agree with your estimate using a meter stick?