PHY/ENS 119 EXPERIMENT NO. 9
THE VELOCITY OF SOUND

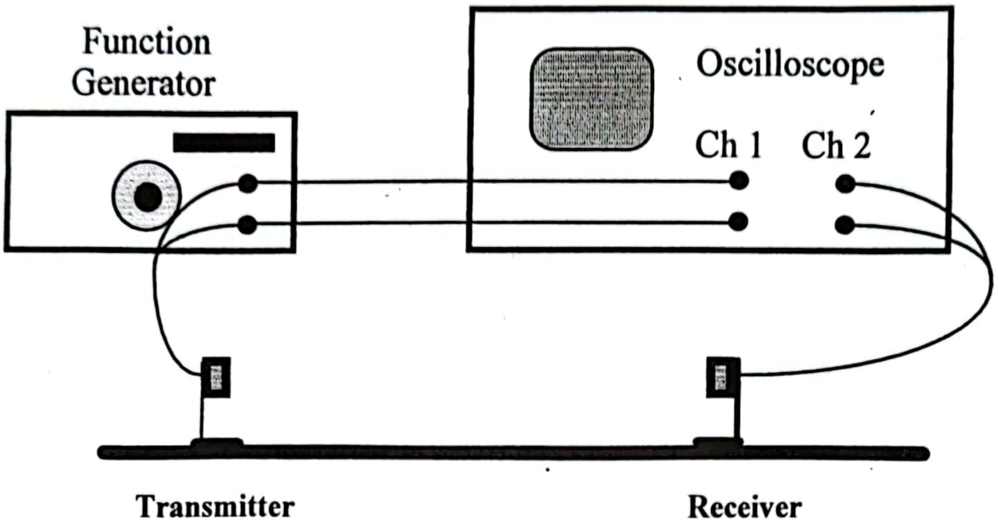
In this experiment we will determine the velocity of sound in air by studying the propagation of 40 kHz ultrasonic waves between two piezoelectric crystal transducers, one acting as a transmitter, the other as a receiver. An oscilloscope will be used to measure the time difference between the sending of a short sound pulse and its subsequent arrival at the receiver, a known distance away.

A. Equipment

1 Dual Trace Oscilloscope, 1 Function Generator, 2 Piezoelectric Crystal Transducers, 1 Meter Stick, 1 DC Power Supply.

B. Method

Sound waves are created by local variations in air pressure above and below ambient pressure. These waves travel through the air at a swift but finite speed. We will measure the speed of sound waves in air by measuring the time required for a short sound pulse or "chirp" to travel from its source to a receiver. This time interval is short and is measured with the help of an oscilloscope, whose operation you have already studied. The experimental setup is shown in the figure below:



The function generator will be set to produce a square wave. Each rising or falling edge of the square wave will cause the piezoelectric transmitter crystal to "chirp" ultrasonically (in much the same way a hammer blow will make a bell ring). The function generator is wired to both the crystal and to the oscilloscope. The sound is received at a second crystal. A small amplifier is mounted to the receiver to make its signal large enough to be easily visible on the 'scope.

As you have already learned, the oscilloscope is essentially a voltmeter in which a spot on a screen can be displaced up or down or left or right by a distance proportional to an applied voltage. The spot can also be made to move from left to right at a uniform speed (sweep rate) to display the time variation of a voltage that deflects the spot up and down. The latter of these two modes is used in our experiment. The oscilloscope sweep is triggered (started) by the function generator when it "chirps" the transmitter crystal. The screen then shows two traces, one for the square wave whose rising edge initiates the transmitted pulse (always to be positioned at the left edge of the display), and one for the received pulse (delayed). By knowing the time calibration of the horizontal trace, we can measure the delay of the received signal and hence the velocity of sound.

The oscilloscopes used here are expensive high-quality instruments and should be handled carefully. **Do not have the intensity control set too high, and never allow a small very bright spot to remain stationary on the cathode-ray tube face. The screen can be damaged if the intensity is too high.**

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C. Procedure

1. Set the function generator to produce maximum amplitude square waves at a frequency of 100 Hz.
2. The oscilloscope should be set to trigger from channel 1 in the AUTO mode and the VERT MODE switch should be set to DUAL, so that two traces are visible. Your TA will lend assistance if the oscilloscope is adjusted improperly.
3. The receiver transducer has a small amplifier built onto its holder because the received signal is quite weak. The power supply for the receiver amplifier should be set to 12 volts and turned on. Then adjust the 'scope sensitivity and time base until you can clearly observe the elapsed time between the edge of the square wave and the arrival of the sound pulse at the receiver.
4. Move the receiver back and forth along the meter stick and observe the motion of the received pulse on the screen. If the pulse appears to move in proportion to the distance between the transmitter and receiver, then your device is adjusted properly.

Q1. Sketch both traces and explain clearly what is happening.

5. Record the setting of the "time base" of the oscilloscope. This setting tells you the time it takes the trace to move 1 cm horizontally. For example, if your time base setting were 10.0 milliseconds per centimeter, then a spacing of 3.6 centimeters between pulses would imply a 36 millisecond delay. **Be sure the time base is in the calibrated mode!**
6. Record the location of both the transmitter and receiver. Record the distance (in cm) between the transmitted pulse trace and the received pulse trace on the oscilloscope screen.
7. Calculate the time delay of the received pulse using the oscilloscope time base setting.

8. Repeat steps 5-7 for ten additional spacings between the transmitter and receiver.
9. Plot the distance of separation (vertical axis) vs. the time delay. Calculate the velocity of sound from your graph.
10. Record the temperature in the room.

Q2. Why did we not just use the distance between the transducers for this part? (HINT: What is the exact position of each transducer?)

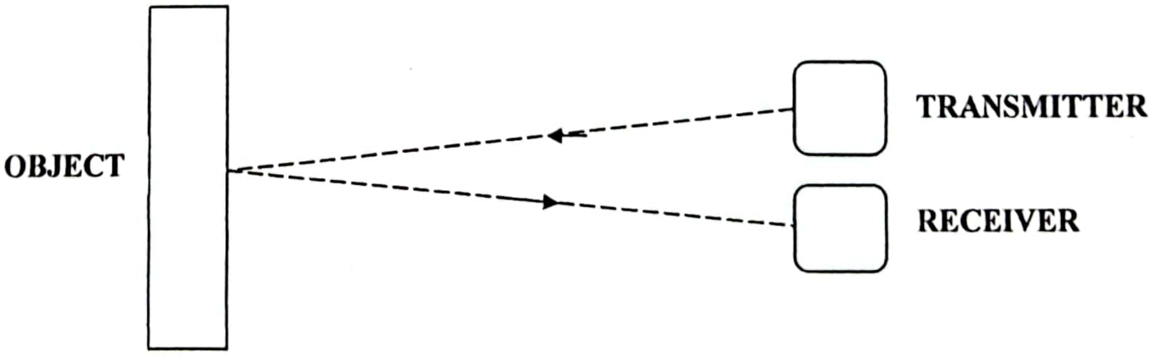
Q3. Compare your values with the theoretical value:

$$c_{sound} = \sqrt{\frac{\gamma_{air} RT}{M_{air}}}$$

Assume that air is 78% N_2, 21% O_2, and 1% Ar. A table of atomic weights can be found online or in the CRC Handbook of Chemistry and Physics, and the constant γ is 1.4 for air. M_{air} is the mass (in kg) of 1 mole of air. Determine M_{air} from the molecular weights and percentages of the constituent gases of air. R is the usual ideal gas constant (in joule/mole/K), and T is the absolute temperature.

D. A "Sounding" Measurement

Place the transmitter and receiver transducers side by side, facing in the same direction, at one end of the meter stick. Your TA will put an object an unknown distance away from the transducers. By using your velocity of sound data from your previous work and by measuring the "echo" delay time with the oscilloscope, determine the distance from the transducers to the object.



E. Determination of the sound velocity from the wavelength and period of the ultrasound

Again arrange the transmitter and receiver as shown in Part **B**. Change the signal generator to a 40 kHz sine wave by pressing the sine waveform button, the 10K multiplier button, and then carefully adjusting the frequency dial to about 4, until there is a maximum response from the receiver crystal. Adjust the two ‘scope channel sensitivities until the two sine waves are about equal in amplitude, and adjust the time base until there are about two complete periods of the waves visible on the screen.

1. Determine the period of the waves.
2. Now move the receiver crystal slowly along the meter stick. What do you observe? How can you determine the wavelength of the sound from your observations, and how can you make the measurement as accurate as possible?
3. Determine the sound velocity from your data using $v = \lambda/T$, and compare this result with your time-of-flight result.