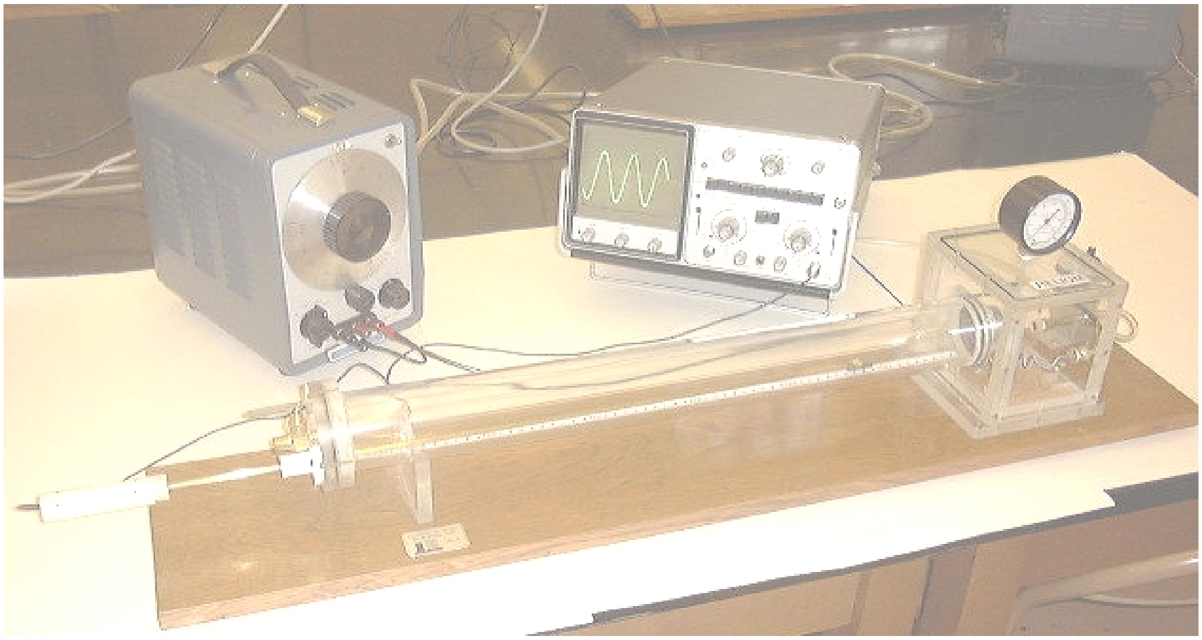
# VELOCITY OF SOUND IN A PURE GAS

## REFERENCES

*Statistical Physics*, Reif (Berkeley Physics Course, Vol. 5). p.279.
*Mechanics, Waves and Thermal Physics*, Armstrong and King. p.497, p.359.
*Introduction to Acoustics*, Randall.
This **Laboratory Manual**: The experiment on *Standing waves and Acoustic Resonance*:
*Commonly Used Instruments*; *the Oscilloscope*.

## INTRODUCTION



This experiment is very similar to the *Standing Waves* experiment, except that this is performed in a pure gas (Nitrogen). Consequently an accurate value of the constant $\gamma$ can be determined.

Sound waves in a gas are longitudinal excitations of the medium in which the waves are propagating. The gas undergoes alternate compressions and rarefactions locally as the wave travels through it. These local pressure changes are adiabatic *i.e.*, the separate parts of the gas are thermally isolated from each other. The relationship between pressure $p$, and volume $V$ for an adiabatic process in an ideal gas is

$$pV^{\gamma} = \text{constant} \tag{1}$$

where $\gamma$ is the ratio of the specific heat of the gas at constant pressure $c_p$, to the specific heat at constant volume $c_v$. $\gamma$ is therefore a dimensionless constant whose value depends on the structure of the gas molecule. $\gamma$ is a quantity of intrinsic interest to physicists, entering into the description of numerous thermodynamic processes.

The velocity v of longitudinal waves propagating in a gas can be shown to be v = $\sqrt{(\gamma p/\rho)}$ ......(2) where ρ is the density of the gas. Since $pV = nRT$ for an ideal gas, equation (2) can be written in the

form $$v = \sqrt{\frac{\gamma RT}{M}} \quad \text{............... (3),}$$ where $M$ = molecular weight of the gas.

Theoretical values of $\gamma = c_p/c_v$ are 5/3 for a monatomic gas, 7/5 for a diatomic gas of freely rotating molecules, 9/7 for a diatomic gas of rotating and vibrating molecules.

A very convenient way to determine γ is by measuring v and using equation (3).

Notice that equation (3) shows v to be independent of pressure. This is true so long as the gas obeys the ideal gas laws. The apparatus provided contains a gas at a pressure slightly greater than atmospheric. Thus any gas leak will immediately show up as a lowering of the pressure registered on the gauge. **Note: Do not attempt to change the pressure of the gas in the tube.**

See the figure and the apparatus description in the *Standing Waves and Acoustic Resonance* experiment for details of the apparatus arrangement.

Velocity v can be measured to better than ±1% with the apparatus provided. The simplest way to determine v is to measure frequency and wavelength.

a) Wavelength: when a standing wave is set up in the tube the wavelength is twice the distance between successive nodes (or antinodes).

b) Frequency: measure a few frequencies using the oscilloscope, and compare these values to those read on the scale of the frequency generator; once you have thus determined that the frequency generator has been well calibrated, you can use the scale reading on the frequency generator as your measure of frequency. The reading error is then determined by how well you can read this scale (note: this error depends on the portion of the scale being used).

Study your values for the speed of sound. Do you observe any dispersion (i.e. a change in the speed of sound with frequency)? Does your value of γ agree with your expectation for Nitrogen?

**Note: Best results will be obtained if you use frequencies between around 1000 & 3000 Hz.**

This apparatus also permits a study of acoustic resonances in a closed tube as described in the *Standing Waves and Acoustic Resonance* experiment. The standing wave patterns corresponding to the first few successive resonances should be investigated by setting the frequency as nearly on-resonance as possible. You would expect a regular relationship between the frequency of each resonance and the next. What do you predict this relationship to be, and is it approximately verified?

(efm - 1977, tk - 1995,97.98)

**Preparatory Questions.**

**Note:** We hope that the following questions will guide you in your preparation for the experiment you are about to perform. They are not meant to be particularly testing, nor do they contain any “tricks”. Once you have answered them, you should be in a good position to embark on the experiment.

1. What is the relationship between the wavelength and the frequency of a sound wave?

2. How would you use the oscilloscope to measure the period of the sound waves, $T$, coming out of the generator? How is that related to the frequency, $f$ ?

3. After you have used the oscilloscope readings to confirm the calibration of the oscillator, you can use the readings of frequency directly off the oscillator scale to determine your frequency. Is the reading error on this scale independent of the value of frequency?

4. The sound waves will set up standing waves in the closed tube. How will you measure the wavelength of these sound waves?

5. The microphone you will be using indicates a *maximum* signal when the amplitude of the standing wave in the tube is a *minimum* (i.e. an amplitude node). Why is this so? (*Hint: read about the microphone in the guide sheet on* ***Standing Waves and Acoustic Resonance.***).