LENS OPTICS

You may find the complete, interactive guide sheet of this experiment at http://faraday.physics.utoronto.ca/IYearLab/Intros/LensOptics/LensOptics.html

ABSTRACT

You may at some time have used a magnifying glass to set small pieces of paper or leaves on fire with sunlight. The sun is so far away that essentially all of its rays are parallel. The lens of the magnifying glass focuses all incoming light rays that are parallel with its axis at a single point, called the *focal point* of the lens. So what you were doing was concentrating all the sun's rays that entered the magnifying glass at one of the focal points of the lens. It turns out that lenses have two focal points, each a distance called the *focal length* f away from the centre of the lens.

The focal length of a lens depends on the radii of curvature of its surfaces and on the index of refraction of the material the lens is made from. This can be expressed, with some effort, by the *lens-maker's equation:*

$$\frac{1}{f}=(n-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right),$$

where n is the index of refraction of the glass of the lens, and R_1 and R_2 are the radii of curvature of the front and back lens surfaces respectively.

We shall supply a scenario for the *Lens Optics* experiment. We imagine that you are working for the *XYZ Organisation* and the apparatus that you are using will be used in a production environment of the organisation by a technician to make measurements of the focal length of a large number of lenses. The focal lengths will all have values fairly close to the one supplied with your apparatus. Your job is to design a procedure that provides the best measurement of the focal lengths of these lenses with the minimum effort by the technician.

PHYSICS OF SOUND

NON
CORE

☞You may find the complete guide sheet at
http://faraday.physics.utoronto.ca/IYearLab/sound.pdf

This is a six part package on the physics of sound, music, and sound reproduction. You may attempt whichever parts of the experiment that you wish, including parts that are not described here but which interest you. Successful completion of Experiments 1 through 3 constitutes **two** weights. Completion of all six experiments would constitute **four** weights.

The six sections for which guide sheets are prepared are:

●*Experiment 1: Frequency, Pitch, and Decibels*: An investigation of some basic concepts of the Physics of Sound and an introduction to the apparatus. We strongly recommend that at least the basic concepts discussed in this section are familiar to you before attempting further experimentation.
●*Experiment 2: Addition of Waves I - Two Waves:* Topics include beats, amplitude modulation, and frequency modulation. There is no prerequisite, but we expect familiarity with the concepts discussed in Experiment 1.
●*Experiment 3: Addition of Waves II - Fourier Analysis:* Fourier's Theorem, overtones, harmonic analysis, phase shift, and non-linear circuits are discussed. We expect you to have spent a few hours doing Experiment 1 and/or Experiment 2.
●*Experiment 4: Harmonic Analysis and Synthesis:* A direct extension of Experiment 3 which is a prerequisite. Musical and other sources are analysed for harmonic structure and then synthesized.
●*Experiment 5: Loudspeaker Principles:* Loudspeaker design is more “art” than “science”. In this experiment some of the parameters of this art are investigated. Topics include frequency response, dispersion, impedance, and tone-burst response. The prerequisite is a few hours doing Experiment 1 and/or Experiment 2. You may bring in your own loudspeakers to study if you wish at your own risk!
●*Experiment 6: Sound Levels:* Measuring sound levels found in the environment. We expect you to be familiar with the concepts discussed in Experiment 1.

Each of these experiments is open-ended, and can lead you into a variety of topics including wave theory, electronics, psycho-acoustics, and a great deal else. Thus, you may find this package more challenging than the usual First Year Lab experiment. Also, the equipment in the package is quite versatile, and a great deal more than these six experiments may be investigated in consultation with your demonstrator.

THE ACOUSTIC INTERFEROMETER

NON CORE

☞You may find the complete guide sheet at
http://faraday.physics.utoronto.ca/IYearLab/acinterf.pdf

The apparatus is the acoustic analogue of the Michelson optical interferometer. In our case, the beam splitter is a sheet of paper. The source is a “tweeter” (loud speaker) driven by an oscillator; it has a range from ~ 3 kHz to10 kHz. Each time the movable reflector is displaced through ½λ, so that the path length changes by the wavelength λ, the interference in the recombined beam going to the receiver is the same. Thus locating the points of minimum signal allows a measurement of λ, and hence the speed of sound in air.

A simple way to locate the minima in the received signal is to make a plot of the amplitude of this signal as a function of the position of the moveable reflector. The velocity of sound in air can be determined to about 1% at the lower frequencies. Some second harmonics may be detected, but should be disregarded and will not interfere with the experiment.

The velocity of sound in a gas is given by $v = \sqrt{\frac{\gamma R T}{M}}$

where R is the gas constant, T the absolute temperature, M is the molecular weight, and $\gamma = \frac{c_p}{c_v}$,

such that c_p is the specific heat of the gas at constant pressure and c_v is its specific heat at constant volume. Remembering that air is approximately 21% O_2, and 77% N_2, the rest being 0.9% each of argon and water vapour, traces of carbon dioxide and the other inert gases, you will determine the effective value of γ/M.

References

D. Halliday, R. Resnick, and J. Walker. Fundamentals of Physics, 6th edition. Wiley, 2003.
E. Hecht. Physics (Calculus). Brooks/Cole, 1996.

THE SPEED OF SOUND IN A SOLID

REFERENCES

The Signal Generator - Model 19 and **Commonly Used Instruments: The Oscilloscope** of this Lab Manual.

INTRODUCTION

Everyone knows the old trick of putting your ear to a train track to get early warning of an approaching train. Sound can travel great distances in many solid materials, and moreover, it travels quickly. The speed of sound in an iron rail is roughly ten times that in air!

In this experiment we measure the speed of sound in a plastic rod. The technique we use is straightforward. We "tap" the rod at one end, and measure the time, t, it takes for the tap to be "heard" a distance d along the rod. If this is done for several distances, a plot of d vs. t will yield a straight line. The slope of this line is the speed of sound in the rod. Figure 1 shows the equipment used in the experiment.

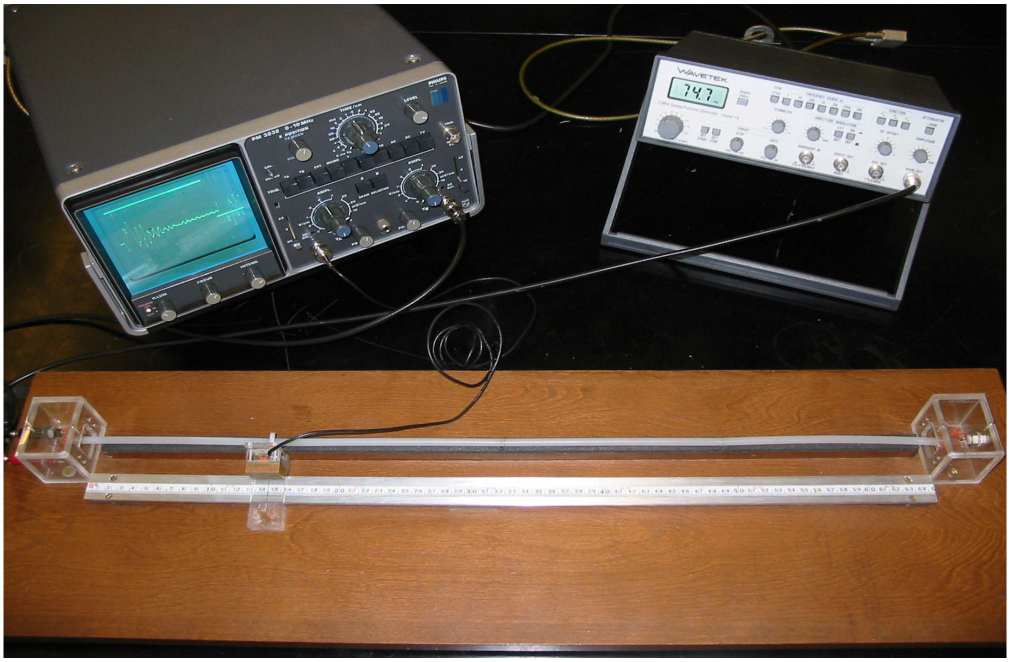


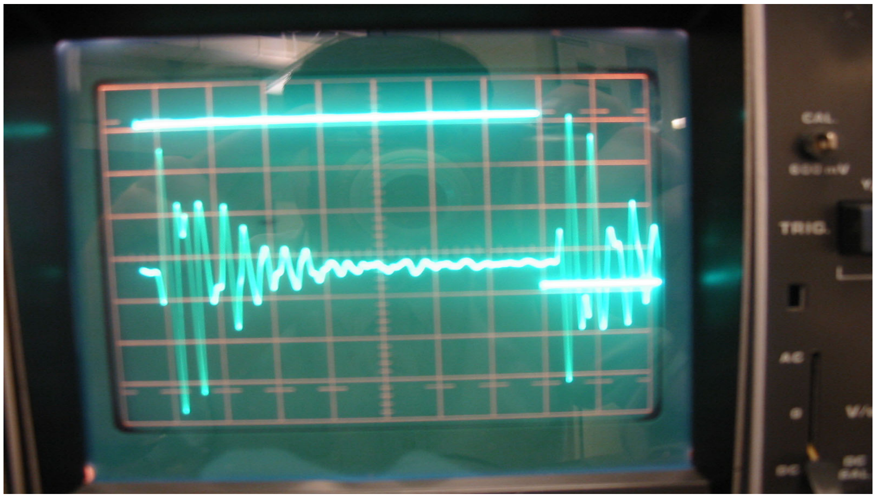
Figure 1: Equipment used to measure the speed of sound in a plastic rod. The signal generator supplies a voltage pulse to the driver transducer which converts the electrical pulse into a mechanical pulse. This mechanical pulse travels, as a sound wave, down the length of plastic rod and is detected by the pickup transducer. The pickup transducer converts the sound wave into an electrical signal. The oscilloscope is used to measure the time interval between the pulse supplied to the driver and the pulse detected by the pickup transducer.

THE EXPERIMENT

Connect the WAVETEK signal generator (Main Out) to the driver transducer. Use a cable with BNC connector at one end and split banana connectors at the other end. Select a square wave output. Turn up the signal generator amplitude, enough that you can start to hear a faint buzzing. The exact frequency you use is not important but it should be somewhere between 50 and 100Hz. Connect channel A of the scope to the driver transducer terminals (use the same type of cable as before), and adjust the scope so that 2 or 3 periods of the square wave are seen.

Now connect the pickup transducer to channel B of the scope, and adjust the channel B position and AMPL controls so that the pickup signal is also seen. Make a sketch of what you see in your notebook and try to explain the main features qualitatively.

Now increase the TIME/cm setting on the scope until the signal in channel B resembles that shown in Figure 2:



Make a sketch of the signal you observe.

Indicate on this sketch the point at which the pulse from the generator arrives at the driver, and the point at which the pickup transducer senses the sound wave. When the pickup receives the wave, it generates some sort of noise which is damped before the second half of the square wave arrives at the driver transducer.

The distance between these two events (pulse arriving at the driver transducer and signal being picked up by the pickup transducer), measured along the horizontal direction on the oscilloscope display will be proportional to the time interval.

To calculate the time, you multiply the distance read on the scope display by the conversion numerical factor from the TIME/cm knob.

Does the time interval depend on the frequency of the signal generator's square wave?

Could the time interval be measured accurately if this frequency was very large, say 1000Hz? Try it, and explain what happens.

Measure the time interval t, as a function of the separation d, between the driver and pickup transducers. Once you have 5 or 6 pairs of d and t values, plot ***d vs. t***, and calculate the speed of sound in the rod. It will be the slope of your plot. Compare the value you obtain with typical values for plastics. See the CRC handbook.

Actually, there is not only one type of sound wave that can propagate through solid materials. In fact, there are at least three different types of sound waves, each with its own unique speed of propagation. Longitudinal waves, based on compression and rarefaction, are the fastest. Transverse waves, based on bending, and torsion waves, based on twisting, travel considerably more slowly. Of what type of wave does the present experiment measure the velocity and how do you know?

RESONANCES

The apparatus for this experiment can also be used to study the phenomenon of resonance. Once the sound wave generated by the driver has traveled the length of the rod it will be reflected back towards the pickup transducer. The wave may bounce back and forth several times before finally dying out. If the length of the rod happens to be an integral number of half wavelengths, then a wave reflected from an end will add constructively to the wave incident on that end, and large amplitudes will result.

Apply a **continuous sine** wave input to the driver transducer and search for resonances. That is, find the frequencies for which the pickup transducer records especially large amplitudes; the signal from a cable attached to the ***end*** of the rod is often easier to see.

The wavelengths for which we expect a resonance are given by the condition

$$\ell = n\,\lambda/2, \qquad (1)$$

where n is an integer (n = 1, 2, 3, etc.) and ℓ is the length of the rod between two fixed points (the loudspeaker and the pickup). Make sure you understand how to derive this expression.

Since wavelength and frequency are interrelated, the resonance condition may also be written:

$$f = c/\lambda = n\cdot c/(2\ell), \qquad (2)$$

where f and c are the frequency and speed of sound respectively.

Using your measured value for c, calculate the expected three lowest resonance frequencies. Do you actually find resonances close to these frequencies? You may notice more resonances than are predicted by Equation 2. From where might these additional resonances come? Would resonances for the three different types of waves all occur at the same frequencies? In fact, due to these effects, you can probably expect only an approximate agreement between calculated and observed values.

Please return wires to their proper location !

Revised: RMS 2003, TK 1998. Designed by RS, TK, MF in 1997.

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 algebraic relationship between the wavelength and the frequency of a sound wave?
2. The instructions for this experiment say to use a square wave to drive the transducer. Could a triangle or sine wave be used instead?
3. Should the time it takes for sound to travel from the driver to the pickup depend on the frequency of the signal generator? Explain.
4. How might you detect a resonant frequency of the plastic rod *without* using an oscilloscope?
5. What are the three lowest resonant frequencies in a rod of length 1 meter, if the speed of sound in the rod is 2000 m/s?

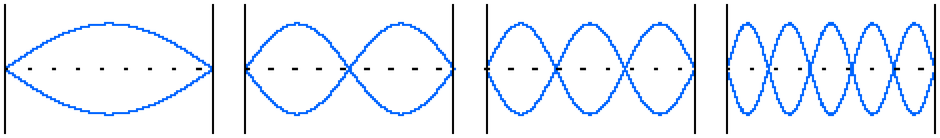
STANDING WAVES AND ACOUSTIC RESONANCE

You may find a complete, interactive guide sheet of this experiment at
http://faraday.physics.utoronto.ca/IYearLab/Intros/StandingWaves/StandingWaves.html

ABSTRACT

Consider a vibrating string that is fixed at both ends. Because it is fixed at the ends, the only stable vibrations of the string are those with "nodes" at the ends. Such a wave state is called a *standing wave*.

The positions where the string does not move are called nodes. The positions where the amplitude of vibration is a maximum are called antinodes; there are four antinodes above. Here are some standing wave states for a string fixed at both ends:



The distance from each node to the next, d, is related to the wavelength λ of the wave by:

$$\lambda = 2d \tag{1}$$

The reason why these standing waves occur is that when a sine wave traveling, say, to the right strikes the fixed end of the string, it is reflected back to the left. In the course of the reflection, the amplitude is reversed. The "standing wave" is actually the interference pattern between the incident wave and the reflected wave.

The formation of standing waves in a closed or open tube will be studied. Physical quantities such as the period, frequency, wavelength of the standing wave, as well as speed of sound in the air will be determined.

THE SPEED OF SOUND IN A PURE GAS

You may find a complete, interactive guide sheet of this experiment at
http://faraday.physics.utoronto.ca/IYearLab/Intros/SpeedPureGas/SpeedPureGas.html

ABSTRACT

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. 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

$$\mathbf{pV^{\gamma} = constant} \qquad \mathbf{(1)}$$

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

In this experiment, some characteristics of a standing wave such as the period, frequency, and wavelength will be determined. The speed of sound in helium will be calculated and used to determine the thermodynamic quantity γ

INTERFERENCE & DIFFRACTION (Using a Laser)

NON CORE

☞You may find the complete guide sheet at
http://faraday.physics.utoronto.ca/IYearLab/intdif.pdf

Light can be considered to be an electromagnetic wave and different rays of light can interfere with each other. If two waves are exactly “in phase”, they will reinforce each other. This is called *constructive interference.* In this case, the difference in phase angle is 360° (one full wavelength), or 720° (two wavelengths), etc.

If, however, they are exactly “out of phase”, they will cancel each other. This is *destructive interference.* If their phase relationship is somewhere between these two extremes, some intermediate result will be observed. In this case, the difference in phase angle is 180° (half a wavelength) or 540° (one and a half wavelengths), etc.

The well-known phenomena of diffraction and interference are easily demonstrated and measured using a laser light source. Laser light is much more coherent than light from conventional sources. Coherence, which is the extent in time and/or space to which the beam of light is in phase with itself, is necessary for the observation of interference.

Several experiments are suggested:

a) **Interference from a Double Slit system** (Thomas Young’s classic interference experiment)

b) **Diffraction from a Single Slit**

c) **Interference with Three or more Slit Systems** (When the number of slits intercepting the beam becomes large, the system is called a *diffraction grating.)*

D. Halliday, R. Resnick, and J. Walker. Fundamentals of Physics, 6th edition. Wiley, 2003.
E. Hecht. Physics (Calculus). Brooks/Cole, 1996.