UNIVERSITY OF WATERLOO
DEPARTMENT OF PHYSICS

PHYSICS 132L
EXPERIMENT #1

THE OSCILLOSCOPE

INTRODUCTION

A beam of electrons is directed at the screen of the cathode ray tube (CRT) in a conventional analogue oscilloscope to produce a visible spot on the screen. In normal use, i.e., in the time display mode, the spot is made to move from left to right (positive x direction) at a constant speed controlled by a "time base" circuit. At the end of its left to right sweep, the spot is blanked out and returned to the left- hand side of the screen to repeat its left to right motion.

The vertical (Y) position of the spot is proportional to the voltage applied across the input terminals of the oscilloscope. Thus the pattern on the screen is a graph of Y (input voltage) versus X (time).

A "trigger" circuit ensures that the spot starts each left to right excursion at the same Y-deflection every time, so that a periodic input signal is reproduced exactly time after time, to produce a "steady picture" on the screen.

An oscilloscope set to the X-Y mode displays the net effect of the Y-input voltage as a function of the X-input voltage. Such displays are referred to as Lissajous Patterns.

The ability of the oscilloscope to measure voltage and time and thus determine frequency and phase is based on the fact that the displacement of the spot on the face of the CRT, D, is directly proportional to the voltage, V, placed across the deflection plates within the tube. This is summarized in the **CRT equation:**

$$\mathbf{V = K \times D}$$

where **K** is a constant of proportionality based on geometrical tube constants and a constant accelerating potential voltage which gives rise to the constant speed of the electrons comprising the beam. This direct proportionality relation allows us to justify a series of relations, which will be referred to as "The Oscilloscope Equations", and are the relations which explain how traces are manipulated and measurements made.

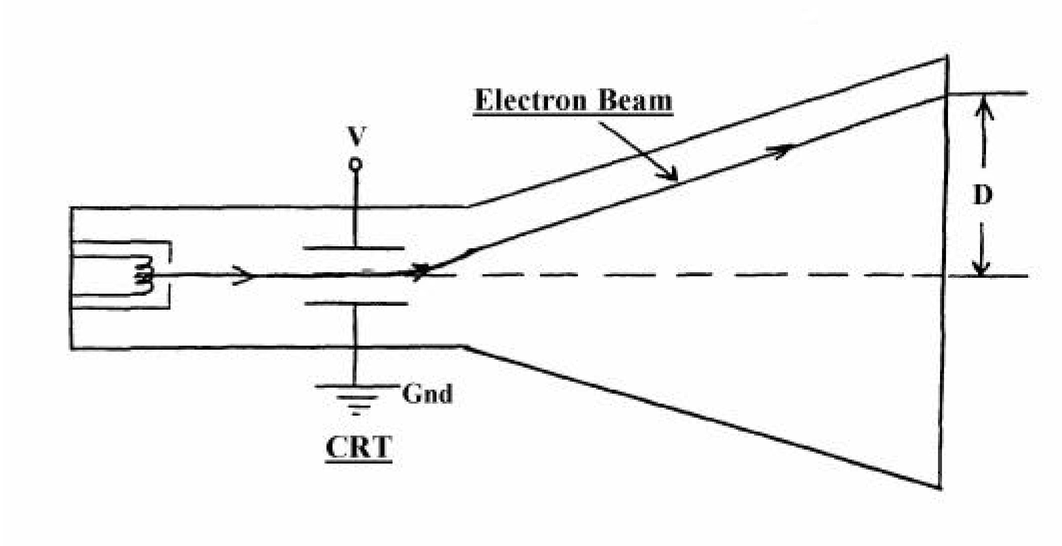


Fig. 1

THE OSCILLOSCOPE EQUATIONS

Measurement of Voltage

(1) $Vi = Dc \times D$ (y = mx form)

As with the CRT equation the direct proportionality between voltage and spot displacement is retained. However, here Vi refers to the input voltage to the oscilloscope and not to the voltage applied directly to the CRT deflection plates. As well, equation (1) applies equally to the vertical or horizontal inputs when under Lissajous (V_y vs. V_x) display. Dc is the constant of proportionality called the **Deflection Coefficient**. Its origin is in the amplifier system that exists between the input Vi and the V that is applied directly to the deflection plates. The Deflection Coefficient has units of Volts/Division and is represented by the Volts/Div dial on the oscilloscope. When this dial is properly calibrated it provides the voltage equivalent per unit vertical (or horizontal if in the X-Y mode) displacement, which is usually a centimeter distance. In other words, it gives the magnitude of input voltage (X or Y input) required to displace the spot 1 unit division (1 cm) distance on the tube face. Or, equivalently, it can be seen as the scale factor that converts the y (or x) unit distances to their equivalent voltage values.

Equation (1) suggests that the vertical (or horizontal) size of a display, D, can be changed by either changing the input voltage magnitude or by changing the Deflection Coefficient setting. Always, the product of the calibrated Dc and D equals the input voltage which gives rise to the spot deflection D.

Experimental Verification of Equation (1)

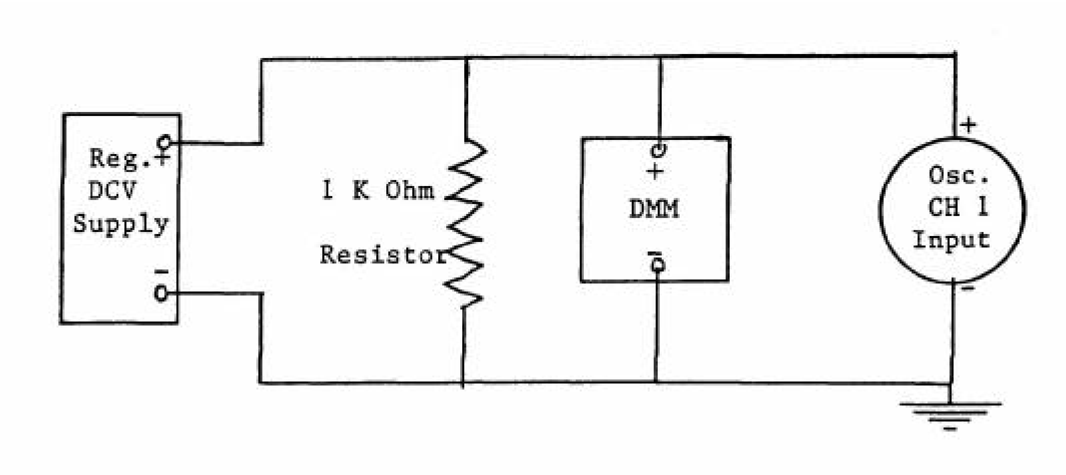


Fig. 2

Set up the circuit as shown in Fig. 2 that consists of a DC regulated voltage supply, a Digital Multimeter (DMM), an oscilloscope and a 1000 ohm resistor. Select a sweep speed of 1 ms/div using the Tc control on the horizontal control section of the oscilloscope. Check the lower left corner of the display to verify that the input for channel 1 is DC coupled, and seek assistance from the instructor if it is not. Use the ⬍ (y-position) control knob below the channel 1 button to position the oscilloscope trace on the bottom line of the graticule display with the regulated supply (HP 6532A) switched off. Choose a Deflection Coefficient setting, Dc of 500 mV/div. Switch on the 34401A DMM, press the DC V button, and then switch on the power supply and increase the voltage output (+6V knob on the 6532A) and record the voltages from the DMM as the trace is raised in major (1 cm) unit division displacements over the total height of the graticule (8 divisions). Tabulate your results and plot Voltage versus Displacement (y vs. x) on a sheet of linear graph paper. Repeat this procedure for a Dc value of 1 V/div. Tabulate and plot your results on the same graph paper. Relate your graphical results to the expectations of equation (1). What is the significance of the slopes of these plots?

The current, I, through the resistor can be obtained from **<u>Ohm's Law</u>** which relates the voltage "V" (in volts) across the resistor to the current "I" through the resistor (in amperes) and the resistance "R" to this current (in ohms) according to the relation

$$\mathbf{V = I \times R}$$

Using this relation how would you convert the voltage scale in your plots to the appropriate current scale? How would you change the <u>voltage</u> Dc to that of <u>current</u> i.e., from Volts/Div to Amperes/Div?

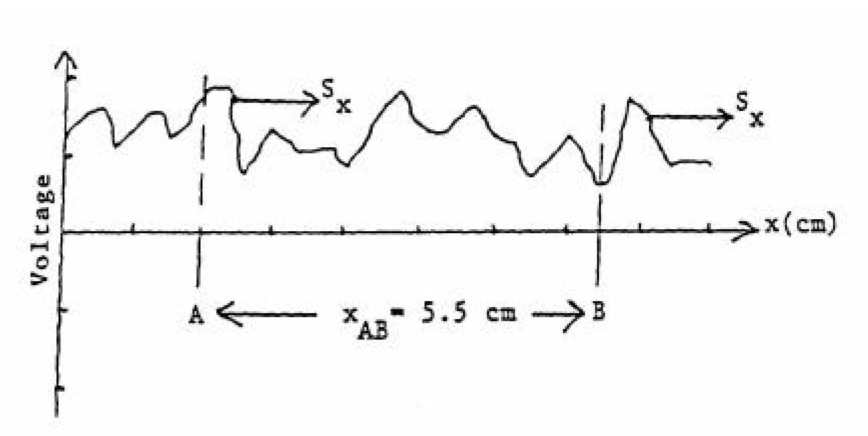
Measurement of Time

(2) Time, **$t = Tc \cdot x$** (y = mx form)

Circuitry exists that will make the voltage, V_x, across the X-deflection plates vary linearly with time. According to the CRT equation, this will cause the spot to move in the x-direction at a constant speed, S_x.

$$S_x = \dot{D}_x = K \cdot \dot{V}_x = \text{constant} \quad (\text{for } \dot{V}_x = \text{constant})$$

Time measurements from a scope display of V_y (t) vs. X are made by measuring the horizontal distance, x, in divisions (cm) between two points of interest and dividing this by the known constant speed of the horizontal component of the trace. For example, regarding Fig. 3 below,



Example:

Time/div = 50 msec/cm

t_{AB} = 50 msec/cm x 5.5cm

= 275 msec.

Fig. 3

$$t_{AB} = \frac{x_{AB}}{S_x} = \frac{x_{AB}}{(\text{Div/Time})}$$

$$= (\text{Time/Div}) \cdot x_{AB}$$

$t_{AB} = Tc \cdot x_{AB}$ or $t = Tc \cdot x$ (y = mx form)

This shows the linear proportionality between time and distance along the x-axis where the constant of proportionality, Tc, called the **Time Coefficient** is seen to be equal to the reciprocal of the speed, S_x. This constant, which can be changed in a controlled manner, is found in the Time/Div. dial which gives an accurate measure of the time equivalence in seconds per unit horizontal distance in divisions (cm). Hence, one can now see the justification for referring to the Y vs. X plot as a **graph** of voltage vs. time where the scale unit in volts for the Y-axis comes from the Dc (Volts/Div.) dial and the scale unit in seconds comes from the Tc (Time/Div.) dial.

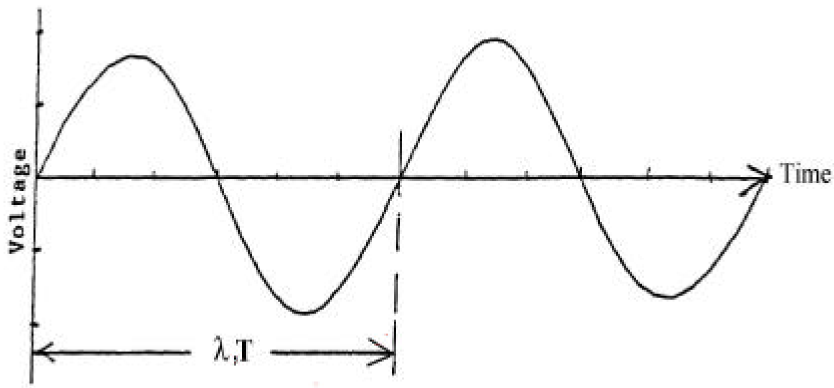
Experimental Verification of Equation (2)

Replace the DC regulated voltage supply of Fig. 2 with the Agilent 33120A Function Generator set to a sine wave output. Set the amplitude of the waveform to 5.0 $V_{p\text{-}p}$ by pressing the Ampl button and using the rotary dial to increase the value. Set the frequency, f, of the generator to 1000 Hz by pressing the Freq button and rotating the rotary dial (if necessary). Set the Tc of the oscilloscope to 1 msec/Div. (10^{-3} seconds/Div.). The period time of oscillation of the generator waveform is obtained according to T = 1/f.
Using the ◀ ▶ (x-position) control located in the Horizontal section of the scope control, adjust the position of the waveform so that it conveniently starts at the leftmost intersection point of the x-axis of the graticule. Tabulate the intersection of the waveform in integer multiples of the period time against the corresponding distance of intersection of the waveform with the x-axis in divisions. Plot the results on linear graph paper. Repeat this procedure for a Tc of 50 μsec/Div. and any arbitrary generator frequency (press the Freq button, and rotate the rotary dial) which gives at least five intersections with the x-axis. Tabulate and plot your results on the same graph as before.
Relate your graphical results to the expectations of equation (2). Obtain the speed, S_x, of the of the left to right motion of the trace from the graph for each case.

“Measurement” of Frequency

(3) Frequency, f = 1/T = 1/(Tc$\times$l)

Frequency “measurements “ on an oscilloscope are obtained by calculating the reciprocal of the period of one complete oscillation. For example, consider the sine wave display of Fig.4.



Example:

λ = 6.0 cm
time/div = .2msec/cm

$\therefore$ T = 1.2 msec

and

f = 1/T = 833 Hz.

Fig. 4

$$T = T_c \cdot \lambda \rightarrow f = 1/T$$

Equation (3) suggests the display of the horizontal wavelength distance, λ, can be changed by either changing the frequency of the source or changing the time-base, Tc. For example, for a fixed source frequency, λ will be reduced in length if the Tc setting is increased and vice-versa. Similarly, if the Tc is kept fixed, increasing the source frequency will reduce the λ display and vice-versa.

Qualitative Validation of Equations (1), (2) and (3)

With the function generator in place outputting a sine wave, increase and decrease the frequency noting the effect on the waveform. Then, keeping the frequency constant, adjust the Tc dial up and down in magnitude again noting the effect on the waveform. Increase and decrease the amplitude control on the generator noting the effect on the vertical size of the waveform. Then, keeping the amplitude control on the generator fixed, adjust the Dc magnitude up and down noting the effect on the vertical size of the waveform. Record these responses and relate them to the predictions of equations (1) to (3).

Voltage, Time and Frequency Measurements

Measurement of Time and Frequency

Set the function generator to 1000 Hz. Adjust the Tc to maximize the wavelength distance. Measure the period time, T, according to equation (2) then calculate the frequency. Compare this value to that of the generator. Repeat this procedure for two other frequencies from the generator chosen at random.

Measurement of Voltage

For a sine wave the DMM measures what is called a root-mean-square (RMS) voltage which relates to the amplitude Vo of the waveform according to the following relation:

$$V_{RMS} = \frac{Vo}{\sqrt{2}} = \frac{Vo_{p\text{-}p}}{2\sqrt{2}}$$

where $Vo_{p\text{-}p}$ refers to the peak-to-peak voltage amplitude, which is equal to twice the amplitude value Vo. To check out this equation and to validate equation (1) adjust the amplitude output of the generator to some arbitrary value for a low generator frequency (i.e. under 1000 Hz). Adjust the Dc, to maximize the vertical size of the waveform. Employing the y-position control adjust the waveform to accurately measure Vo or $Vo_{p\text{-}p}$ according to equation (1) and calculate V_{RMS} according to the above equation. Place the input leads to the DMM across the 1K load resistor, press the AC V button and measure V_{RMS}. Compare these two values. Repeat this type of measurement for two other amplitude settings within the same frequency range.

Measurement of Phase Angle

(4a) Dual Beam Phase Angle Measurements ➔ $Dq = (Dt/T) \times 360^o = (Dx/l) \times 360^o$

In the above equation $\Delta\theta$ is the phase angle to be measured, Δt refers to the separation in time between equivalent points on the two different waves, and Δx from equation (2) is the corresponding measure of the horizontal distance of their separation. T and λ are the period and wavelength equivalents of either of the waves (assuming they have the same frequency). The 360^o is the angular equivalence associated with T (orλ).

To understand the origin of this equation consider the two voltage equations

$$v_A = V_A \sin \omega t$$

and

$$v_B = V_B \sin (\omega t - \Delta\theta)$$

Schematically they can be represented by two **rotor vectors** V_A and V_B with a common angular frequency ω and separated by a phase angle $\Delta\theta$ as shown below.

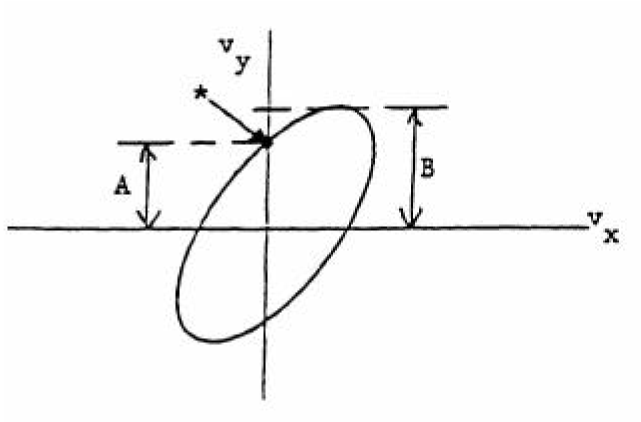


Fig. 5

The instantaneous values of v_A and v_B can be represented by the projections of these rotor vectors onto a common axis. We know that $\theta = \omega \cdot t$. Therefore, $\Delta\theta = \omega \cdot \Delta t$ where $\Delta\theta$ is the phase angle separating V_A and V_B. Δt is the time required for rotor vector V_B to take up the position formally occupied by rotor vector V_A when both are rotating with the common angular frequency of ω, i.e., the time for either rotor vector to rotate through angle $\Delta\theta$. Dividing one equation by the other gives

$$\frac{\Delta\theta}{\theta} = \frac{\Delta t}{t}$$

or

$$\Delta\theta = \frac{\Delta t}{t} \cdot \theta$$

If we make t the time for which we know the angular equivalent, say, for convenience, t = T for which $\theta = 360^{\circ}$, then the equation now becomes

$$\Delta\theta = \frac{\Delta t}{T} \cdot 360^{\circ}$$

When the instantaneous projections of these rotor vector voltages are displayed as a function of time the following display would appear on an oscilloscope.

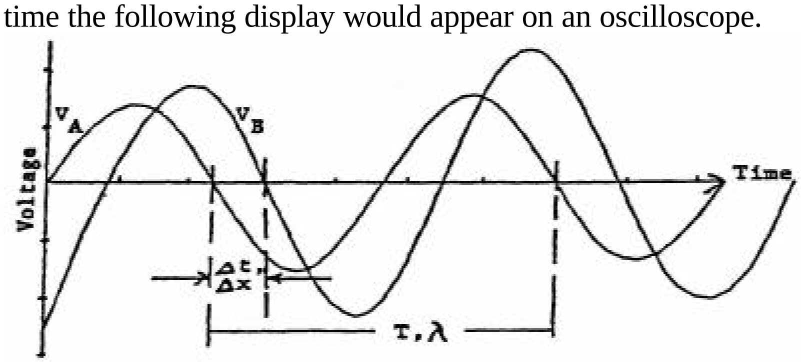


Fig 6

Example:

$\Delta t = 0.6$ cm

$T = 5.0$ cm

$\therefore \; \Delta\theta = (0.6/5.0) \times 360^{\circ}$
$= 43.2^{\circ}$.

Employing the time measurement relation, equation (2), we can set

$$\Delta t = Tc \cdot \Delta x$$

and

$$T = Tc \cdot \lambda$$

This then gives,

$$\Delta\theta = \frac{\Delta t}{T} \cdot 360^{o} = \frac{\Delta x}{\lambda} \cdot 360^{o}$$

which is equation (4a). Trace B, since it maximizes in a positive sense later in time than that of trace A, trace B is said to **lag** trace A and the phase angle of B relative to A is said to be negative. Trace A by the same logic **leads** trace B and is thought of as having a positive phase angle relative to B since it maximizes in a positive sense earlier in time than B.

Dual Beam Mode Phase Angle Measurements

To generate measurable phase angles you will employ a series connected resistor-capacitor (RC) circuit as shown below in Fig. 7. Hook up the circuit as indicated and set **both** inputs of the oscilloscope to be active. (i.e. make sure both the 1 and 2 buttons are illuminated)

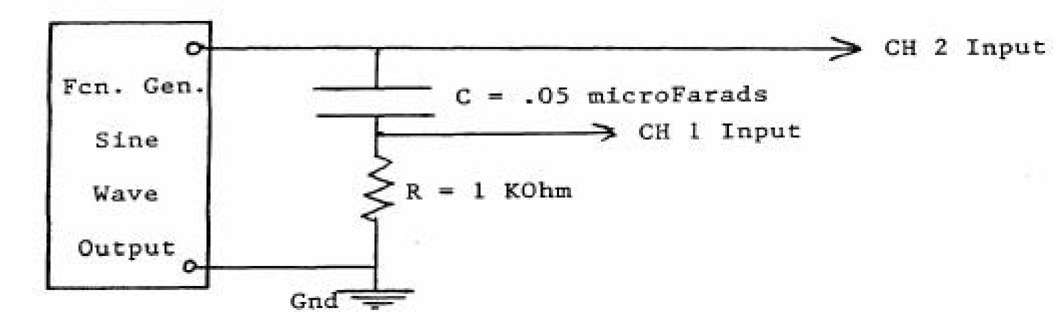


Fig. 7

Here V_B will be the applied voltage V_{RC} which is fed into CH 2. Voltage V_A will be V_R and fed into CH 1. The function generator is to be set to the sine wave output and changing its frequency will change the phase angle between V_R (which is proportional to the current I) and V_{RC}. The equation that describes the phase angle as a function of frequency is given by

$$\mathrm{Tan}\,(\Delta\theta) = \frac{-1}{2\pi fRC}$$

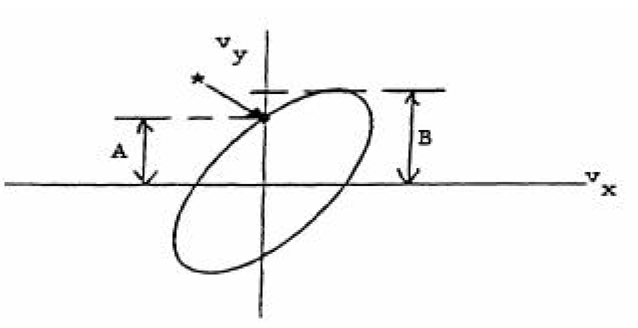
where $\Delta\theta$ is the phase angle of V_{RC} relative to V_R and the negative sign implies that V_{RC} lags V_R. Calculate the expected phase angle for component values of R = 1k Ω (ohm) and C = 0.047 μFarads ($\mu = 10^{-6}$) for frequencies 2kHz, 3kHz and 5kHz respectively. Set the generator to these frequencies and measure the phase angles on the oscilloscope for comparison. Make sure you use the y-position controls to make the two waveforms <u>symmetrical</u> about the X-axis of the CRT graticule.

(4b) <u>Single Beam Phase Angle Measurements</u> ® Sine (Dq) = $\frac{A}{B} = \frac{2A}{2B}$

When one displays the net result of one voltage versus another on an oscilloscope in a X-Y plot format one obtains what is referred to as a **Lissajous Pattern.** Suppose two voltages of the form

$$v_x = Vx \sin \omega t \quad \text{and} \quad v_y = Vy \sin(\omega t + \Delta\theta)$$

are applied to the X and Y inputs of an oscilloscope set to the **X-Y mode**. To do this, press the Main/Delayed key in the horizontal control section and then press the XY softkey below the oscilloscope trace. What will be produced on the screen is an elliptical lissajous pattern as shown below in Fig. 8.



<u>Example:</u>

A = 3.0 cm
B = 3.5 cm

Sin ($\Delta\theta$) = 0.86, or $\Delta\theta$ = 59°

Fig. 8

To establish the phase angle from such a display consider the useful Y-axis intersection point indicated by *. Here, $v_x = 0$ thus $\sin \omega t = 0$ or $\omega t = 0$. Hence, at this point,

$$v_y = Vy \sin(\Delta\theta)$$

giving

$$\sin(\Delta\theta) = \frac{v_y}{Vy} = \frac{A}{B} = \frac{2A}{2B}$$

where A and B are measured distances off the screen scale which are directly proportional to v_y and Vy respectively. Thus directly measuring A and B allows one to determine $\Delta\theta$ but <u>not</u> its sign unless the direction of rotation of the spot forming the ellipse can be determined at a low frequency. In practise, the ellipse **must be centered** about the origin of the X, Y screen display.

This is done employing the X and Y position controls. Repeat the above measurements in the X-Y mode and compare your resultant $\Delta\theta$ values with the dual beam results and theory.

SUMMARY

As **a rule of thumb**, when taking measurements from an oscilloscope display it is best to adjust the appropriate dials to **maximize its size** subject to the constraint of the calibrated settings if accurate results are to be achieved. In summary, the **Oscilloscope Equations** that you will apply in your trace manipulations and measurements are as follows:

THE OSCILLOSCOPE EQUATIONS

(1) Voltage Measurements $\rightarrow$ $Vi = Dc \cdot D$

(2) Time Measurements $\rightarrow$ $t = Tc \cdot x$

(3) Frequency "Measurements" $\rightarrow$ $f = 1/T = 1/(Tc \cdot \lambda)$

(4) Phase Angle Measurements

(a) Dual Beam Mode $\rightarrow$ $\Delta\theta = \dfrac{\Delta t}{T} \cdot 360^o = \dfrac{\Delta x}{\lambda} \cdot 360^o$

(b) Single Beam Mode $\rightarrow$ $\sin(\Delta\theta) = A/B$

The above set of relations are of a general applicability and it is wise to memorize them!!

ADDENDUM

The Digital Oscilloscope

The above equations apply to any oscilloscope be it the "conventional" analogue type or the newer "digital". The conventional analogue scope displays the input signal in a continuous manner. It lacks the ability to store and manipulate the input signal unless some sort of facility such as a magnetic tape storage device is incorporated into the scope. The digital oscilloscope, such as your Agilent 54621A Mixed-Signal Oscilloscope, circumvents these limitations by employing digital technology. It is, in effect, a computer with a CRT display.
The digital scope works by sampling the input signal voltage in a continuous succession of discrete time intervals. Over one of these brief time intervals it employs what is known as an **analogue to digital (A/D) converter chip**. This chip measures of the "average" value of the voltage over this time interval and expresses this magnitude in binary form (a number expressed as a series of powers of 2). This number can then stored in its memory for immediate display or later retrieval if it possesses storage capability or transferred to other digital systems such as a computer for signal processing. The aim of the digital technology is shrink the time interval of sampling and expand the accuracy of the measurement of voltage within this interval to

approach, as close as possible, the instantaneous input voltage value on which the analogue oscilloscope operates.

List of Apparatus

1 Agilent 54621A Mixed-Signal Oscilloscope

1 Agilent 33120A Function Generator/Arbitrary Waveform Generator

1 Agilent 34401A 6 1/2 Digital Multimeter (DMM)

1 Hewlett Packard 6532A Triple Output Power Supply

1 1K Ohm Resistor

1 .047 μFarad Capacitor

1 Circuit Board

1 Set of Connecting Wires and Instrument Leads

Biophysics of the Heart

The goal of this experiment is to learn how the principles of physics are used in a simple biological application, namely the study of the cardiovascular system. In particular, electric fields generated by the heart will be studied and the response to exercise will be measured.

Theory

Electricity in the body

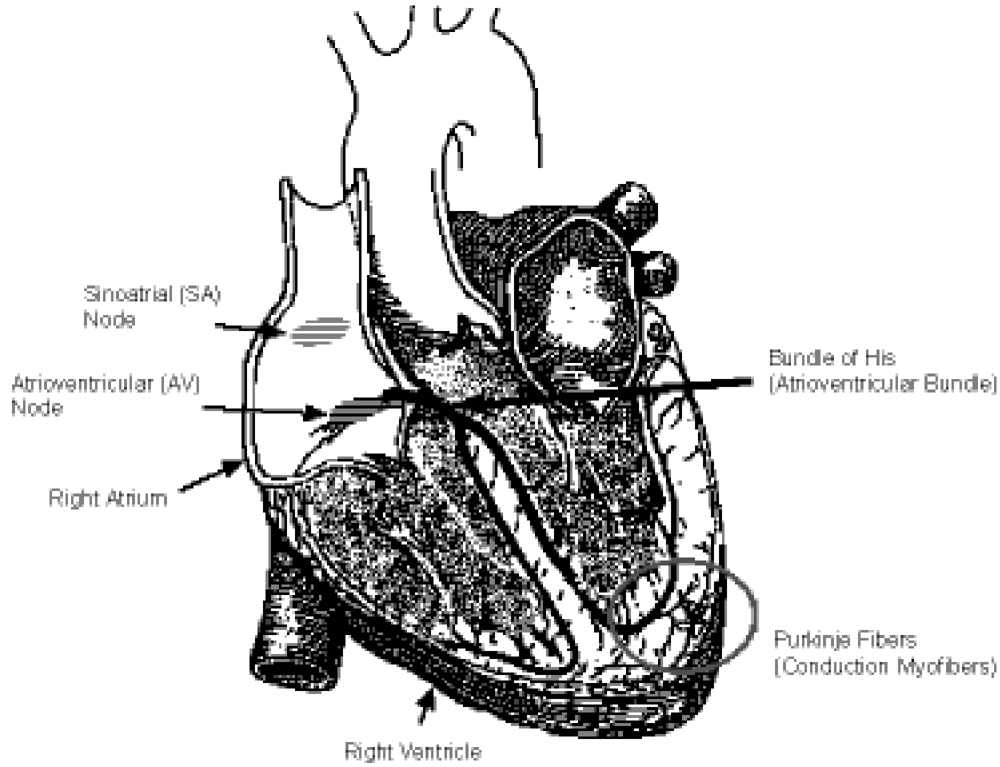
Most bodily functions have electrical activity associated with them. These bioelectric signals may be studied in order to gain further under- standing of the internal operation of the body. Here we shall be concerned first of all with a display of the electrical signals associated with heart activity - an electrocardiogram, abbreviated as EKG or ECG, and secondly with a display of the electrical signals associated with muscle contraction - an electromyogram, abbreviated as EMG.

Heart muscle cells are polarized at rest. This means the cells have slightly unequal concentrations of ions across their cell membranes. An excess of positive sodium ions on the outside of the membrane causes the outside of the membrane to have a positive charge relative to the inside of the membrane. The inside of the cell is at a potential that is about 90 millivolts (mV) less than the outside of the cell membrane. The 90 mV difference is called the resting potential.

The typical cell membrane is relatively impermeable to the entry of sodium. However, the stimulation of a muscle cell causes an increase in its permeability to sodium. Some sodium ions migrate into the cell. This causes a change (depolarization) in the electrical field around the cell. This change in cell potential from negative to positive and back is a voltage pulse called the action potential. In muscle cells the action potential causes a muscle contraction. Other ions and charged molecules are involved in the depolarization and the recovery back to the polarized state. These include potassium, calcium, chlorine and charged protein molecules. The effect of this depolarization and repolarization for the entire heart can be measured on the skin surface. This is an electrocardiogram (EKG). The depolarization of the heart also leads to the contraction of the heart muscles and therefore the EKG is also an indicator of heart muscle contraction (although this is an indirect measurement).

The cells of the heart will depolarize without an outside stimulus; that is, they will depolarize spontaneously. The group of cells that depolarize the fastest is called the pacemaker (also known as the sinoatrial or SA node). These cell are located in the right atrium. The cells of the atria are all connected physically and thus the depolarization of the cells of the pacemaker cause all the cells of both atria to depolarize and contract almost simultaneously. The atria and the ventricles are isolated from each other electrically by connective tissue that acts like the insulation on an electric wire. The depolarization of the atria does not directly affect the ventricles.

There is another group of cells in the right atria, called the atrioventricular or AV node, that will conduct the depolarization of the atria down a special bundle of conducting fibers (called the Bundle of His) to the ventricles. In the muscle wall of the ventricles are the Purkinje fibers, which are a special system of muscle fibers that bring depolarization to all parts of the ventricles almost simultaneously. This process causes a small time delay and so there is a short pause after the atria contract before the ventricles contract. Because the cells of the heart muscle are interconnected, this wave of depolarization, contraction and repolarization spreads across all the connected muscle of the heart.



When a portion of the heart is polarized and the adjacent portion is depolarized this creates an electrical current that moves through the body. This current is greatest when one half of the connected portion of the heart is polarized and the adjacent half is not polarized. The current decreases when the ratio of polarized tissue to non-polarized tissue is less than one-to-one. The changes in these currents can be measured, amplified, and plotted over time. The EKG represents the summation of all the actions potentials from the heart as detected on the surface of the body and does not measure the mechanical contractions of the heart directly.

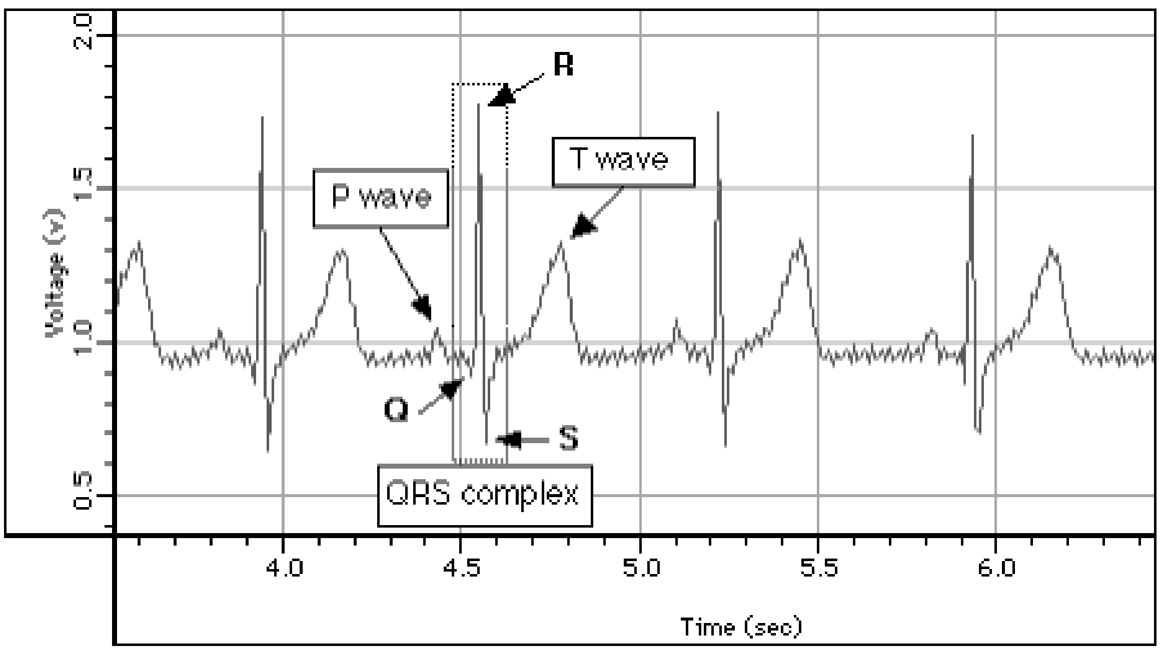
The two atria contract due to the pacemaker and force blood into the two ventricles. Shortly after this contraction the two ventricles contract due to the signal conducted to them from the atria. The blood leaves the two ventricles through pulmonary and aortic arteries. The heart muscle cells recover their polarity and in another second the cycle starts again.

The Electrocardiogram

One part of a typical EKG (electrocardiogram) is a 'flat line' or trace indicating no detectable electrical activity. This line is called the Isoelectric line. Deviation from this line indicates electrical activity of the heart muscles.

The first deviation from the Isoelectric line in a typical EKG is an upward pulse followed by a return to the Isoelectric line. This is called the P wave and it lasts about 0.04 seconds. This wave is caused by the depolarization of the atria and is associated with the contraction of the atria.

After a return to the Isoelectric line there is a short delay while the heart's AV node depolarizes and sends a signal along the atrioventricular bundle of conducting fibers (Bundle of His) to the Purkinje fibers, which bring depolarization to all parts of the ventricles almost simultaneously.



After the AV node depolarizes there is a downward pulse called the Q wave. Shortly after the Q wave there is a rapid upswing of the line called the R wave followed by a strong downswing of the line called the S wave and then a return to the Isoelectric line. These three waves together are called the QRS complex. This complex is caused by the depolarization of the ventricles and is associated with the contraction of the ventricles.

After a short period of time the sodium and calcium ions that have been involved in the contraction migrate back to their original location in a process that involves potassium ions and the sodium-potassium pump. The movement of these ions generates an upward wave that then returns to the Isoelectric line. This upward pulse is called the T wave and indicates repolarization of the ventricles. The atria repolarize during the QRS complex and therefore this repolarization is not separately detectable.

The sequence from P wave to T wave represents one heart cycle. The number of such cycles in a minute is called the heart rate and is typically 70-80 cycles (beats) per minute at rest. Some typical times for portions of the EKG follow.

P-R interval	120-200 milliseconds
QRS interval	under 100 milliseconds
Q-T interval	under 380 milliseconds

Note: If your EKG does not correspond to the above numbers, DO NOT BE ALARMED! These numbers represent typical averages and many healthy hearts have data that fall outside of these parameters. To read a EKG effectively takes considerable training and skill. This sensor is NOT intended for medical diagnoses.

The Sensors

About the EKG Sensor

The sensor consists of the EKG amplifier case and a cable for connecting to the interface. Three electrode leads are attached to the amplifier case. The circuitry isolates the user from the possibility of electrical shock in two ways. The sensor signal is transmitted through an opto-isolation circuit. Power for the sensor is transferred through a transformer. The circuitry protects against accidental over-voltages of up to 4,000 volts.

The sensor is designed to produce a signal between 0 and five volts with 1 volt being the Isoelectric line. Deviation from the Isoelectric line indicates electrical activity. The shape and periodicity of the signal is of primary importance, so the sensor does not need to be calibrated.

The bioamplifier has three input leads, one red, one white, and one black. If, at a certain instant, the potential difference between the red and black leads is e_1, and the potential difference between the white and black leads is e_2, then the potential difference appearing across the two output leads is proportional to the difference between the two input signals $e_1 - e_2$. The bioamplifier is thus called a differential amplifier.

The constant of proportionality between the differential input signal, $e_1 - e_2$, and the output signal, V_{out}, is called the gain of the amplifier, and is

$$A = \frac{V_{out}}{e_1 - e_2}$$

In addition to the electrical signals generated within the body, any detector coupled to the body will also observe electrical activity originating from outside the body and conveyed to it, just as radio signals are transmitted from their source to the receiver antenna. The most important source of this externally generated signal is the network of electrical wiring within any modern building, and the frequency of this signal in North America is 60 Hz. This 60 Hz signal is known as "hum", and may be much larger than the bioelectric signals generated within the body, thus making their observation difficult or impossible. The reason for using a differential amplifier to observe bioelectric signals now becomes apparent. The signal across one active terminal (red) and the common ground terminal (black) is e_1+ hum, where e_1 is generated within the body, and the signal across the other active terminal (white) and the common ground terminal is e_2+ hum, where again e_2 is generated within the body. The signal that is amplified and finally observed is thus $(e_1 + \text{hum}) - (e_2 + \text{hum}) = e_1 - e_2$. This electronic subtraction will never be perfect, but nevertheless an amplifier with good "common mode rejection" can reduce the hum to a level low enough that the internally generated electrical signal $e_1 - e_2$ is easily observable.

There is a second problem that must also be considered. Although in a relaxed body the EMG signal may be small enough that the EKG signal may be observed with little interference from the EMG signal, it is clearly impossible to "turn-off" the EKG signal so that the EMG signals may be observed undisturbed. Although a sensible separation of EMG and EKG signals may be achieved by correct positioning of the skin electrodes, we can improve the resolution between them by a correct choice of the amplifier bandwidth. The electrical signals associated with EKG are mainly low frequency, below 20 Hz, whereas the electrical activity associated with EMG is mainly of higher frequency, from 20 Hz to 1 kHz. Thus, with the amplifier bandwidth selected to be between f_{LO} = 0.05 Hz and f_{HI} = 100 Hz, the EKG signal will be strongly amplified, but the EMG signal will not be amplified nearly as much.

About the Heart rate sensor

You probably have experienced the sensation of your heart beating strongly when you participated in physical activity. Your nervous system monitors your entire body and signals your heart to beat faster in response to increased activity. **Pulse rate** measures how fast your heart is beating. **Recovery time** is how long it takes for the heart to return to its normal resting rate.

The PASCO Heart Rate Sensor works with a computer interface to monitor a person’s heart rate. Unlike an electro- cardiograph (EKG), which monitors the electrical signal of the heart, the Heart Rate Sensor monitors the flow of blood through a part of the body, such as an ear lobe, by shining a light through it and monitoring the change in intensity. As the heart beats and forces blood through the blood vessels in the ear lobe, the light transmittance through the ear lobe changes.

The sensor consists of a Heart Rate Sensor amplifier box and an ear clip. The ear clip can be attached to a part of the body such as an earlobe, a fingertip, toe, or the web of skin between the thumb and index finger. The sensor shines an infrared light through the earlobe and measures the change in light that is transmitted. The light source is a small infrared light emitting diode.

About the Respiration Sensor

The respiration sensor consists of two parts, the low pressure sensor and the respiration belt.

Low Pressure Sensor

The low pressure sensor consists of the electronics box and uses a 10 kiloPascal transducer. This type of transducer has two ports. The reference port of the transducer is inside the electronics box. It is always open to the atmosphere and not available to the user.

The other port is connected to the atmosphere via the pressure port connector at the front of the pressure sensor unit. It has a "quick-release" style connector for attaching accessories such as the PASCO Respiration Belt accessory. The pressure sensor gives a reading of "zero" when there is no pressure difference between the internal reference port and the external pressure port connector.

The range of the Low Pressure Sensor is between 0 and 10 kiloPascals. The resolution of the sensor is 0.005 kiloPascals (kPa). The output voltage from the sensor is +1.00 Volts when the pressure is 1 kiloPascal (kPa), and the output voltage is linear. Therefore, the output voltage should be +10.00 Volts at the top of the range (10 kPa). Atmospheric pressure is normally around 101.326 kiloPascals (kPa).

Respiration Belt

The respiration belt has the following features:

• hook-and-pile strips sewn onto opposite ends of the belt
• attached squeeze bulb for inflating the rubber bladder inside the belt

Connection of the Sensors

The sensors plug into the grey distribution box located on the desktop. There are three DIN plug sockets labeled "Pasco Sensors". The sensors should be connected (left to right) as follows: Heart rate sensor, EKG, Respiration Sensor. Make sure that the small HP power supply (6235A) next to the distribution box is switched on. Do not adjust any of the voltage settings.

The Respiration Rate Sensor

The Respiration Rate Sensor is a wide nylon belt that can be wrapped around a person's abdomen or chest region. The belt has a rubber bladder inside that can be inflated using the attached squeeze bulb. The squeeze bulb has a thumbscrew valve to allow air in the bladder to be released. The rubber bladder has a tube that can be connected to the "quick-release" connector of the Low Pressure Sensor.

The section of the Respiration Rate Sensor that contains the rubber bladder has a rectangular piece of "pile" material attached to one side. The other end of the nylon belt has strips of "hook" material attached to one side. The "hook" and "pile" materials can be used to fasten the sensor in place when it is wrapped around a person's chest or abdomen.

1. Place the belt of the Respiration Rate Sensor around the chest of the person whose breathing rate is going to be measured. Arrange the belt so that the rubber bladder is in front. Use the Velcro materials on the ends of the belt to fasten it snugly in place.
2. Connect the end of the tube that comes from the rubber bladder to the quick-release connector on the pressure port of the Low Pressure Sensor.
3. Close the thumbscrew valve (turn it clockwise) on the squeeze bulb of the Respiration belt. Use the squeeze bulb to inflate the rubber bladder (between twenty and thirty 'squeezes'). The belt should be snug but not too tight. DO NOT over inflate the bladder in the belt. .

The Heart Rate Sensor

1. Attach the clip to your ear lobe or finger. There is a small light bulb in the clip, so you may feel warmth on your ear lobe.

The EKG Sensor

Obtain three electrode patches from the presiding instructor. The electrodes can be reused but they tend to absorb moisture (they are very hygroscopic), and therefore, reuse is not recommended. The electrodes should be kept in an airtight, clean, dry container for storage. Because the electrical signal produced by the heart and detected at the body's surface is so small, it is very important that the electrode patch makes good contact with the skin. Scrub the areas of skin where the patches will be attached with a paper towel to remove dead skin and oil.

1. Peel three electrode patches from the backing paper. Firmly place the first electrode on the right wrist. Place a second electrode on the right elbow pit. Place the third electrode on the left elbow pit.
   - Place each electrode so it is on the inside part of the arm (closer to the body) and the tab on the edge of the electrode patch points down, so the wire of the sensor can hang freely without twisting the edge of the electrode patch.
2. Connect the micro alligator clips from the sensor to the tabs on the edges of the electrode patches.
   - Connect the black (or "reference") alligator clip to the wrist electrode patch. This is the reference point for the "Isoelectric" line (baseline).
   - Connect the green (or negative) alligator clip to the right elbow electrode patch.
   - Connect the red (or positive) alligator clip to the left elbow electrode patch.

There are several different ways to connect the EKG sensor. This simple arrangement is appropriate for the classroom.

The Measurements

Having connected the sensors as described above, have the subject sit still and monitor the vital signs for a short period of time (10 seconds). Examine the traces for evidence of excessive noise, signal clipping (tops of peaks "squared off"), or inappropriate signals. Clipping of the heart rate signal can often be fixed by moving the sensor to a thicker part of the ear lobe or finger.

If you are satisfied that you are getting reasonable signals, measure the heartbeat, EKG and respiration for a period of 120 seconds. The subject should remain as relaxed as possible throughout the measurement to minimize the effects of muscle derived electrical activity. Normal breathing and as little other movement as possible generally yields the best results.

Save the data (use the default file location which is the E:\ drive) after the pram has stopped acquiring it. .

Remove the respiration belt and the heart rate monitor from the subject. Disconnect the EKG leads, but leave the electrodes in place. Have the subject perform some mild exercise for several minutes. Upon their return, re-attach the sensors and then repeat the above (120 second) measurement. Save this data set as well.

Data analysis is done using Excel. The data is stored in a spreadsheet compatible format, and will form 4 columns in the Excel spreadsheet. The first column is the time. The next 3 columns are the voltage readings (which are proportional to signal strength) for the heart rate, EKG and respiration sensors respectively.

Use Excel to plot (X-Y graph) the sensor signal vs time for a <u>10 second interval</u> of the data. You should configure the graph to plot all three series on the same page. The x-axis should be configured to be the time.

Create another plot that displays one full cycle of the EKG. Note that this will require you to plot about 1 to 2 seconds of data (see pg. 3).

Repeat the above two plots using the post exercise data.

Analysis:

From the two EKG plots:

1. Calculate the P-R interval, and compare it to the "accepted" value
2. Measure the peak of the S wave. Record the time of it's occurrence.
3. Calculate the Q-R-S interval, and compare it to the "accepted" value
4. Measure the peak of the T wave. Record the time of it's occurrence.
5. Calculate the overall Q-T interval, and compare it to the "accepted" value
6. Comment on any differences between the EKG taken at rest and that taken after exercise.

Determine the pulse rate as a function of time. To do this, copy the heart rate and time columns (columns 1 and 2) from your spreadsheet and paste them into a new sheet. Save the file in a **tab delimited text format.** To do this use the **Save As…** command from the File menu. In the file dialog box, use the drop down list for the **Save as type** setting and choose **Text (Tab delimited)**. In the Programs group of the Start menu, you will find another program called "Peak Detector". Open this program and press the Run button. You should be prompted for a file name. Select the tab delimited text file that you just saved. Use the peak (red) and valley (blue) threshold cursors to discriminate the upper and lower bounds for the actual peaks in the data. Check to make sure the # of peaks display indicates a 'reasonable' value for your 120 second time period. Use the Save button to export the peak detection data to a spreadsheet compatible file.

Return to Excel, and open this newly created file. The peak detector outputs two columns of data: the first is the actual time of each peak, and the second column is the amplitude. Create an equation in the third column that uses the time data from the first column to compute your heart rate (in beats per minute). Plot this (heart rate) column as a function of time (column1) using an X-Y plot. If your data provides a large number of spurious data points, it may be necessary to go back to the Peak Detector program and increase the "width" selector to a value greater than it's default value of 5.

Repeat this procedure for your post exercise data as well. Print both heart rate vs. time graphs for inclusion with your report. Comment on any interesting features of the two plots and their differences. What are your average heart rates for both cases?

Borrow a heart rate sensor from a neighbouring station. Remove the EKG sensor from your distribution box, and plug in the second heart rate sensor. Attach one of the heart rate sensors to an ear lobe and the other to your finger. Measure the heart rate for 10 seconds. Are the measurements in phase? Suggest reasons why or why not. Could the information provided allow you to measure the speed of your blood? Suggest possible ways to do this. Return the second heart rate sensor to the station you borrowed it from when you are through.

PHYSICS 132

Experiment #3

Speed of Sound

In this experiment we are trying to find the speed of sound in a medium. For starters we will just find the speed of sound in "air" and then look into other gaseous media later on.

Speed of sound v depends on various physical properties of the medium. A general equation for the speed of sound in a gas is

$$v = \sqrt{\frac{\beta}{\rho}}$$

β = Bulk modulus of the medium. This is the reciprocal of the compressibility. β has units of N/m^2.

ρ = Volume density (kg/m^3).

Sound waves are longitudinal waves and are referred to as pressure waves.

In this experiment, we calculate the velocity by measuring the time taken for a sound pulse to travel a certain measurable distance. We use a tube that can be filled with any gas we like. At one end we have a speaker that creates a sound pulse and we also have some microphones fixed at different distances along the tube length.

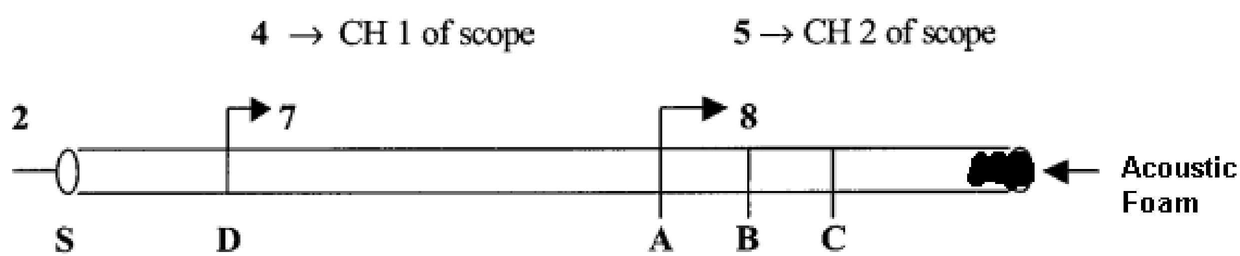


Figure 1.

A sound pulse created by speaker S will be picked up first by microphone (mic) D, and then mic A. We will use an oscilloscope to measure the time difference Δt. If we know the distance AD then we can calculate the speed of the pulse in the medium of the tube.

Set-up and Measurements

Part 1

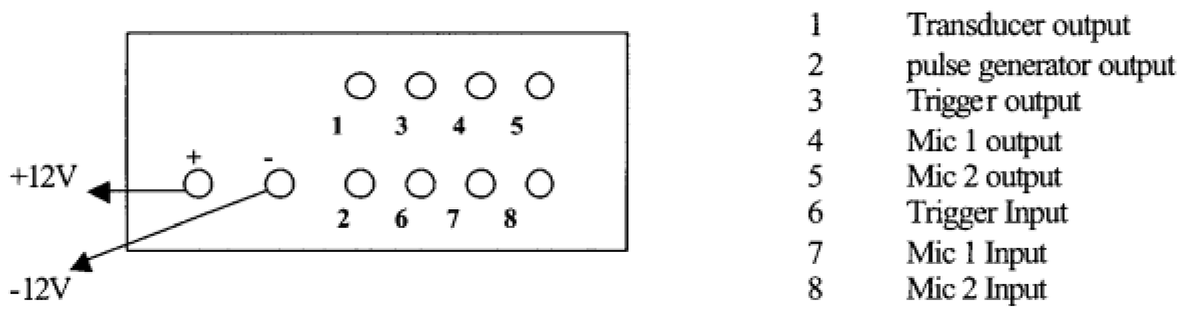


Figure 2 (Sound velocity measurement control box)

Connector 8 can be moved from A to B to C.

<u>Accurately</u> measure the distances: AD, BD and CD.

Using the BNC (bayonet style) cables, connect the speaker to terminal 2 (pulse generator output) of the sound velocity measurement control. See Figure 2 for the connection numbers. Then connect mic D to terminal 7 (mic 1 <u>input</u>) and connect terminal 4 (mic 1 <u>output</u>) to CH. 1 of the oscilloscope. Now connect microphone A to terminal 8 and terminal *5* to CH. 2 of the oscilloscope.

- Turn the HP power supply on. Depress the 18V button and check that the supply is at or very near 12V as read on the meter. Adjust as necessary using the 18V control knob.
- Turn the oscilloscope on, and press the “Autoscale” button. You should now see two traces. If the trace on the oscilloscope looks very noisy, try adjusting the CH1 and CH2 Deflection coefficients to obtain reasonable traces. A suggested value of 1 V/div for both channels should do this.
- Adjust the time co-efficient to read 1.00 ms. You should see the trace picked up by mic 1 as well as the trace picked up by mic 2.

The oscillations or the so-called "ringing" effect in the pulse display is due to the damped oscillation behaviour of the microphone.

Now, you need to find the time delay between the traces. If the display is not “frozen” on the screen it will be very difficult to proceed. To obtain a ‘stop action’ trace, proceed as follows:

1. Push the “Run/Stop” button to get the red (Stop) indicator, and then press the “Single” button.
2. It may be necessary to repeat step 1 a number of times to obtain a suitable trace.

3. If after several tries, you still don't have a suitable trace, adjust the "level" control in the trigger settings area and repeat 1 and 2. If a problem still exists, contact the instructor.

Now to obtain the time of flight of the sound pulse,

- Press quick measure button.
- Then press "cursor" button.

You should now see a series of labels corresponding to the cursor control buttons at the bottom of the oscilloscope screen.

- Select X1 by pressing the button corresponding to X1. Using the rotary knob next to the "Cursors" button (it has a circular arrow above it), you will be able to move the vertical cursor to the start of Trace 1.
- Now select cursor 2 (X2) and move it to start of Trace 2.

You will be able to read off Δx (which is in fact Δt) on the bottom left of the screen. You should (as always) also estimate what you think would be a reasonable uncertainty in this result.
Now move connection 8 to microphone B and measure Δx (time) again. Repeat these steps for mic C. Use these times and distances to obtain three values for the speed of sound. For each value you should also calculate the respective uncertainty.

Compare your results with accepted of V_{sound}, which is 343 m/s for a temperature of 20 ^{o}C, a pressure of 1.0 atm. and 40% relative humidity.

<u>Questions</u>

a) If you were to evacuate the tube (create a partial vacuum inside) what could you expect to see happen to the oscilloscope trace?

b) What would happen if the temperature of the gas in the tube were increased?

c) Evaluate $\overline{V}_{sound} \pm \Delta\overline{V}_{sound}$

Part 2

- Now connect the speaker to terminal 3 (trigger output) of the sound velocity measurement contol box.
- Connect Analog Output 1 of the grey computer interface connection box to terminal 6 (trigger input) of the sound velocity measurement control box.
- Remove the connections from CH 1 and CH 2 of the oscilloscope and connect them to Analog Inputs 1 and 2 of the grey computer interface connection box.

- Turn the computer on and click Start → All Programs → Speed of sound and pick the LabVIEW program “Speed of Sound”.

Buttons and Their Functions

Run: Starts data acquisition. The program waits idly until this button is pressed. By waiting idly the program saves CPU resources. This allows other programs (i.e. Microsoft Excel) to run at the same time.

Exit: Shuts down the program.

Save: Saves acquired data. Data from the most recent trial is saved to a Microsoft Excel file when Save is pressed. The user can choose: where to save the file, its name, and whether to create a new file or replace an existing one. The default directory is “E:\Phys 132”.

Numeric Controls and their Functions

Threshold Value:

This value is needed to determine the first wave fronts picked up by the microphones. There is a problem in that there is a certain amount of ambient noise present at all times. When the program is run it will find the first peak above the threshold value. The user should enter a value lower than the value of the 1st peaks picked up by the microphones, and higher than the ambient noise.

Distance Between Microphones:

This allows the user to input an accurate value for the distance the sound travels between microphones. The value is used by the program to calculate the speed of sound.

Duration of Measurement:

This allows the user to specify a time period over which to acquire data. The program limits this input to values between 0.004 and 1.0 sec. Time less than 0.004 is too short, and more than 1.0 is unnecessarily long.

Displays and their Functions

Calculated Speed:

Displays a calculated value for the speed of sound in the tube. The program does this by detecting the first wave front picked up by the microphones, finding the time difference, and dividing by the distance between microphones.

Results & Analysis:

Run the program for the 3 different tube "lengths" and record the speed of sound in each case. As well, record the threshold and duration settings you used to get the results. Compare these values of the speed of sound to the average value obtained in Part 1 and to the accepted value.

Part 3

Now remove the speaker from the end of the tube. Remove the acoustic foam from the other end. Disconnect the BNC cable from A, B or C but leave the Mic connected from D to terminal 7 of the sound velocity measurement control box. Terminal 4 should once again be connected to CH. 1 of the oscilloscope. Remove the connection from CH 2 of the oscilloscope, and turn CH 2 off.

- Press the "mode/coupling" key in the trigger configuration area of the oscilloscope.
- Using the soft key menu at the bottom of the screen, select "mode" and set it to "normal".
- Set the time co-efficient of the scope to 5.00 ms/div.
- Set the Trigger Edge to be channel 1
- Press the "Single" button on the oscilloscope. It should remain illuminated white.
- Create a sound by snapping your fingers at the speaker end of the tube.
- You may have to adjust the trigger level to capture a single trace screen.
- Adjust to a suitable trigger level and push the "Single" button again. Repeat this process until you have a suitable trace on the screen of the oscilloscope.

Questions

a) How many disturbances do you see?

b) What causes these disturbances?

c) Find the speed of sound and its associated uncertainty from the display.

d) Compare your value to the accepted value of speed of sound.

Equipment

- Plexiglass speed of sound tube
- Audio Transducer end cap and acoustic foam
- 6 BNC cables
- Sound Velocity measurement control (S&D – 038)
- 2 Banana to Banana cables
- Agilent 54621A Dual Trace oscilloscope

PHYSICS 132L

Experiment #4

The Electrical Equivalent of Heat and the Resisivity of Materials.

In this experiment you will be using LabVIEW programs to measure and control temperature, and to verify the equivalence of electrical energy and heat. As well, the resistance of a metal, and that of a semiconductor material as a function of temperature will be investigated.

Part 1: The Electrical Equivalent of Heat.

The purpose of this experiment is to demonstrate the equivalence of electrical energy and thermal energy using a specially constructed copper 'calorimeter'.

The apparatus consists of a heater element which surrounds the calorimeter. The calorimeter has a thermistor probe to measure the temperature and thus the heat supplied to the copper block. LabVIEW will be used to monitor and control the temperature, as well as calculate the electrical energy supplied to the heater. The experiment aims to show the equivalence of electrical energy [W·s] supplied to the device to the corresponding increase in the thermal energy [J].

The power (P) supplied to the heater is simply the product of the applied voltage (V) and the current (I):

$$P = V \times I \qquad (1)$$

and the electrical energy W_{el} is just power × time:

$$W_{el} = V \times I \times t \qquad (2)$$

where t is the time during which power is applied to the heater.

The heat energy absorbed (ΔQ) is dependant on the specific heat capacity (c), the calorimeter mass (m) and the change in temperature (ΔT). This can be expressed:

$$\Delta Q = c \times m \times \Delta T \qquad (3)$$

The heat capacity ($C' = c \times m$) in the above expression should in fact be the sum of the heat capacities of the calorimeter, the heater, and the temperature probe. In practice, the heat capacity of the calorimeter is the dominant term, and so the analysis <u>assumes</u> the (smaller) ones can be ignored.

Part 2 Resistivity.

The purpose of this experiment is to determine the temperature co-efficient of resistivity for a copper wire, and to determine the band gap energy of a semiconductor material.

Most physical properties (including the resistivity) of a material are dependant on temperature. The resistivity ‘ρ’ of a material is given by:

$$\rho = \frac{R\,A}{L}$$

where R is the resistance of the material, A is the cross - sectional area, and L is its length. For the case of a sample with a uniform cross sectional area, and a known length, we can use the terms resistance and resistivity interchangeably

In the case of a pure metal the resistance varies almost linearly over a broad temperature region, and an empirical result for this variation is:

$$R = R_0\,\alpha(T - T_0) + R_0 \qquad (4)$$

where R is the resistance of the material at temperature T and R_0 is the resistance at some reference temperature T_0. The quantity α in the above expression is called the temperature co-efficient of resistance, and is characteristic of the material. We will use LabVIEW to determine α for a sample of copper wire.

The proper way to measure the resistance of a sample of material is to use a four point probe approach. This is necessary because as the resistance of the sample changes, so does the current flowing through it, assuming we are applying a constant voltage (Ohms Law). To accurately determine the resistance of a sample we need to apply a constant current to the sample and measure the voltage drop across a (known) length of the sample. In this experiment, we do not have a constant current supply, so we will place a resistance which is large relative to that of the sample in series with it. This effectively creates a constant current supply, as the current through both devices is governed primarily by the value of the large resistor, which does not change. The sample you are provided with is a length of copper wire with the measurement leads attached 300 cm apart. A constant current of 600 mA is supplied to the wire. The sample is mounted on a heater pad and has thermistor temperature probe embedded in it. The program will heat the sample, monitor the temperature and measure the voltage drop across it.

The second sample to be investigated is the thermistor temperature probe. It is a semiconductor material which provides a well defined resistance over a specific temperature region. It is this characteristic that allows us to accurately determine the sample temperature. In the “operating region” of any given thermistor the resistance varies as:

$$R = R_0\, e^{Eg/2KT} \qquad (5)$$

Where R_0 is some initial resistance, K is the Boltzmann constant ($K = 8.615 \times 10^{-5}$ electron volts/K) and T is the <u>absolute</u> temperature of the sample. The quantity E_g is known as the band gap energy and is characteristic of the material. To determine E_g let us take the natural log of both sides of the above equation:

$$\ell n\, R = (E_g/2K)(1/T) + \ell n\, R_0 \quad (6)$$

Thus a plot of $\ell n\, R$ vs $1/T$ will allow us to determine the band gap energy.

<u>Procedure:</u>

<u>Electrical Equivalent of Heat:</u>

Ensure the + and - terminals of the HP 3617A power supply are connected to the red and black terminals of the calorimeter device. The input terminals of the First Thermistor on the 50µA current source should be connected to the yellow terminals of the calorimeter device. The output of the current source should be connected to Analog *Input* 1 of the grey distribution box. Analog *output* 1 should already be wired to the rear terminals of the HP3617A. Contact your instructor if it is not. Switch on the DMM, the HP 3617A. Make sure that the DMM, the 3617A and the grey distribution box share a common ground connection.

On the computer select Start → Programs → Calorimetry and Resistance → Electrical Equivalent of Heat. **Before proceeding, check the temperature display. It should have a “reasonable” value. If it does not, contact an instructor before proceeding.**

- Set the heater current control to 0.800 A
- Set the setpoint temperature to 70° C

Once these have been set, press the Start button. The chart is configured to simultaneously plot the electrical energy and the temperature of the sample. Observe the behaviour of these two plots as the sample heats up.

When the sample temperature is very close to 70°C press the Stop button. You will be prompted to enter a filename to save the data to an Excel file. The data is saved in a three column format, the first column being the power [J/s] supplied to the heater, the second column is the calorimeter temperature, and the third column is the elapsed time.

<u>Analysis:</u>

From the data, determine the total electrical energy supplied and the corresponding change in temperature of the sample. Using equation (3) determine the specific heat of copper in cal/g°C. The mass of the copper calorimeter is 357 g and 1cal = 4.1863 J. Compare your result to the accepted value for copper which is 0.094 cal/g°C . Suggest reasons for any discrepancy between your value and the accepted one.

Plot graphs of electrical energy vs time and sample temperature vs time. Comment on the results. Suggest some ways to improve the experimental technique.

Resistance of Copper:

Connect the leads from the First Thermistor input to the yellow terminals on the base of the sample heater stage. Connect the leads from the HP 3617A power supply to the red and black terminals

Set the (small) HP 6532A power supply +6 V control to zero (fully counter-clockwise). Set the meter selection buttons to '+6' and 'A'. Connect the double banana jack plug that is pre-wired to the circuit to the +6V and COM terminals of the power supply. Connect the leads from the Agilent DMM to the red and black terminals on the BNC to banana adapter that is fitted to the center terminal of the sample holder. Adjust the +6 V control of the HP supply to obtain a sample current of 0.60 A as read off the small meter on the front.

On the computer, Exit the previous application (if you haven't already done so) and select Start → Programs → Calorimetry and Resistance → Resistivity Measurements.

Enter the sample current (0.60 A) and then set the Heater current control to 0.600 A. Switch the Heater ON. **Make sure the sample temperature display gives a "reasonable" value before proceeding.**

Press the Start button and acquire the data. The program is internally set to limit the upper temperature to 70°C. The chart will plot the sample resistance as a function of temperature. When the sample has obtained a temperature of at least 60° C, stop the acquisition. You will be prompted for a filename to which the program will write the temperature and resistance values as an Excel file. When thorough, Exit the program.

Analysis:

- Use Excel to plot the sample resistance vs change in temperature. Print a copy for your report. Comment on the results.
- From the graph, determine the temperature co-efficient of resistance: α
- Compare this to the accepted value for copper which is 4.3×10^{-3} °C^{-1}
- Suggest some possible reasons for any discrepancy between your result and the accepted value.
- The wire has a diameter of 0.570 mm, and a length of 300 cm. Calculate the resistivity of copper at a temperature of 25 °C

Resistance of a semiconductor:

Connect the leads from the First Thermistor input to the yellow terminals of the copper calorimeter device. Connect the Leads from the HP 3617A power supply to the red and black terminals of the calorimeter. The wires of the semiconductor device should be clipped to the alligator clips on the end of the double banana to alligator test leads. Connect these leads to the V/Ω and Com terminals of the Agilent DMM. Insert the device all the way down into one of the holes on the top of the copper calorimeter. Allow a couple of minutes for the device to reach thermal equilibrium with its environment.

On the computer, Exit the previous application (if you haven't already done so) and select

Start → Programs → Calorimetry and Resistance → Thermistor Resistance. **Check the temperature before proceeding.**

Set the heater current control to 0.800 A and switch the heater on. Start the acquisition. The resistance of the thermistor is displayed as a function of the calorimeters temperature. Stop the acquisition when the temperature reaches 70° C. Again, you will be prompted for a filename, to which the data file (resistance and temperature values) will be saved. Exit the program.

Analysis:

- Use Excel to plot resistance vs temperature for the thermistor device. Print a copy to include with your report. Comment on the results. Is the plot in keeping with the expectations of equation (5)?
- Use Excel to calculate the natural log of resistance and the inverse of the absolute temperature. Plot ℓn R vs 1/T and from this graph determine a value for the band gap energy (in electron-volts) of the semiconductor material. Print a copy for your report.

Equipment:

- Copper calorimeter
- Heating stage with sample of copper wire.
- Agilent 3441A Digital multi-meter
- HP 3617A analog programmable power supply
- HP 6532A triple output power supply.
- 10Ω 10W power resistor.
- Connecting leads.

Revised 2003-02-28 J.G.

PHYSICS 132

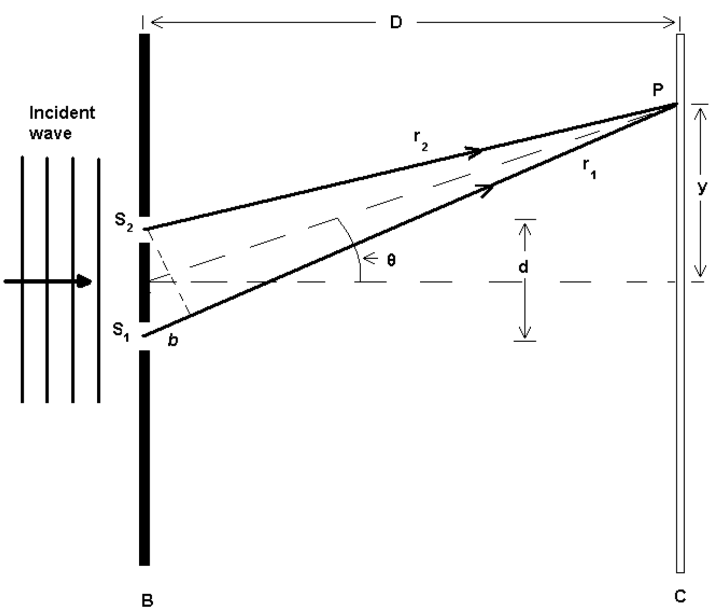
Experiment #5

Optical Interference

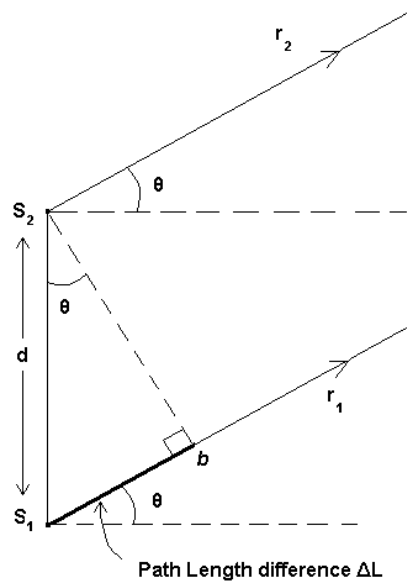
In this experiment, we will observe and study the diffraction and interference of light from a coherent source as it passes through narrow slit(s).

1. Young's double slit experiment

Light is incident on the two slits S_1 and S_2 (as in figure 1) on the slide B. This light diffracts through the slits and produces an interference pattern on screen C. At an arbitrary point P (distance y, or at an angle θ from the central axis) is a point where the two rays: (r_1 from the bottom slit and r_2 from the top slit) converge to form an interference maximum.



(a)



(b)

Figure 1.(a) Waves from slit S_1 and S_2 cause constructive interference at P.
(b) Parallel approximation if D >> d

Since D is much larger than d, we can consider r_1 and r_2 as being parallel, thus the path length difference between r_1 and r_2 is the distance from S_1 to b. Using the right triangle formed by S_1, S_2 and b, we have:

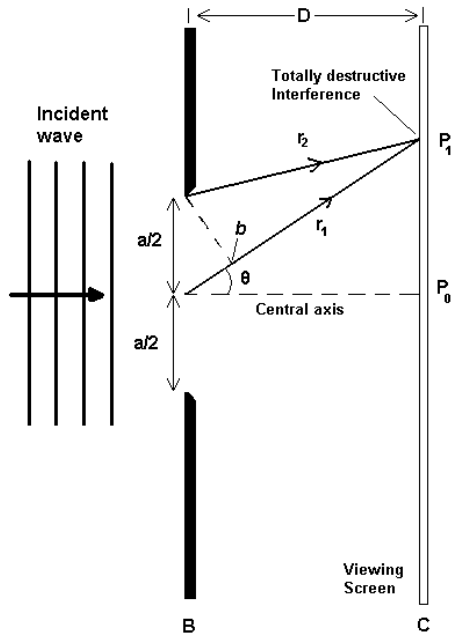
$$\Delta L = d \sin\theta \qquad \text{(path length difference)}$$

For a bright fringe at P, ΔL must be zero or an integer multiple of λ. Thus we can rewrite the above equation as:

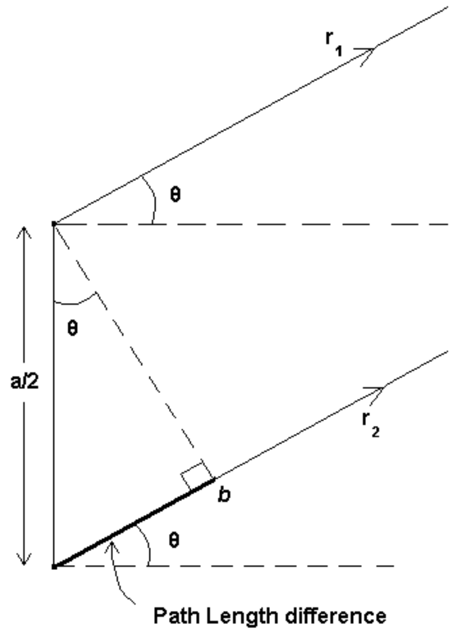
$$d \sin\theta = m\lambda \quad \text{where} \quad m = 0,1,2,3,... \quad \text{(maxima or bright fringes)}$$

2. Single Slit Diffraction

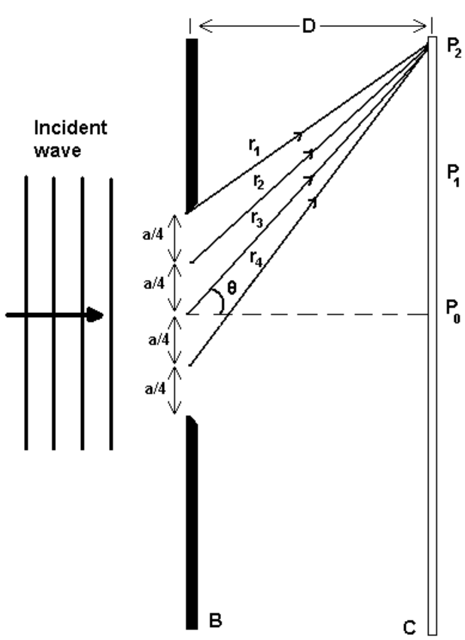
We examine here the case of plane waves of light of wavelength λ that are diffracted by a single long slit of width a (as in figure 2).



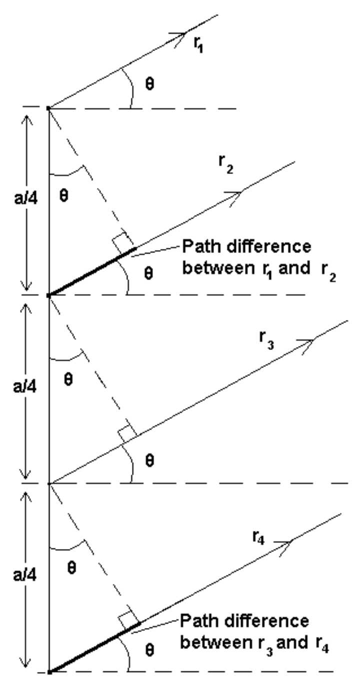
(a)



(b)



(c)



(d)

Figure 2: (a) waves sent through the slit are looked at as two zones of width a/2 which undergo destructive interference at P_1. (b) Parallel approximation if D >> a. (c) waves sent through the slit can also be looked at as 4 zones of width a/4 undergo destructive interference at P_2. (d) Parallel approximation if D >> a.

For the destructive (or dark) fringes, we use simplified strategies of pairing up all the rays coming through the slit that are exactly out of phase (or have a $\lambda/2$ path difference). For the rays that came through the slit at a spacing of a/2 (as in figure 2a and 2b), and applying the same criteria on the path difference as in the double slit example, we then have

$$(a/2)\sin\theta = \lambda/2 \quad \text{(path difference for minimum or dark fringe)}$$

Which gives

$$a\sin\theta = \lambda \qquad \text{(first minimum)}$$

Similarly, for rays that came through the slit at a/4 spacing (as in figure 2c and 2d) and using similar argument we have

$$(a/4)\sin\theta = \lambda/2 \qquad \text{or} \qquad a\sin\theta = 2\lambda \,\text{(second minimum)}$$

In general, we have

$$a\sin\theta = m\lambda \quad \text{where } m = 1, 2, 3, \ldots \text{ (minima – dark fringes)}$$

Where a is the slit width, θ is the angle of diffraction from the central axis and λ is the wavelength of light and m is the order number of the minima

3. <u>Diffraction Grating</u>

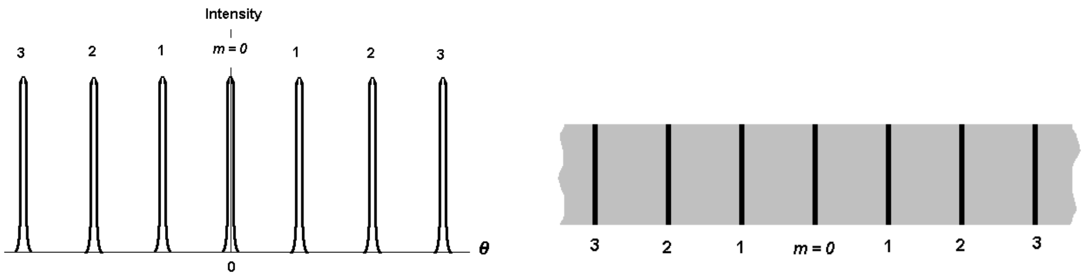
For a diffraction grating, the device is similar to that of a double-slit arrangement but it has a much greater number of slits (sometimes called rulings or lines). Using the same arguments as were used for the double-slit it can easily be shown that

$$d\sin\theta = m\lambda, \qquad \text{for} \quad m = 0,1,2,3,\ldots \qquad \text{(maxima lines)}$$

where d is the separation between rulings, which is referred to as the grating spacing. If N rulings occupy a total width w, then d = w/N. As in the previous case, θ is the angle of the diffraction maxima, and m is the order number.

Intensity of the fringes

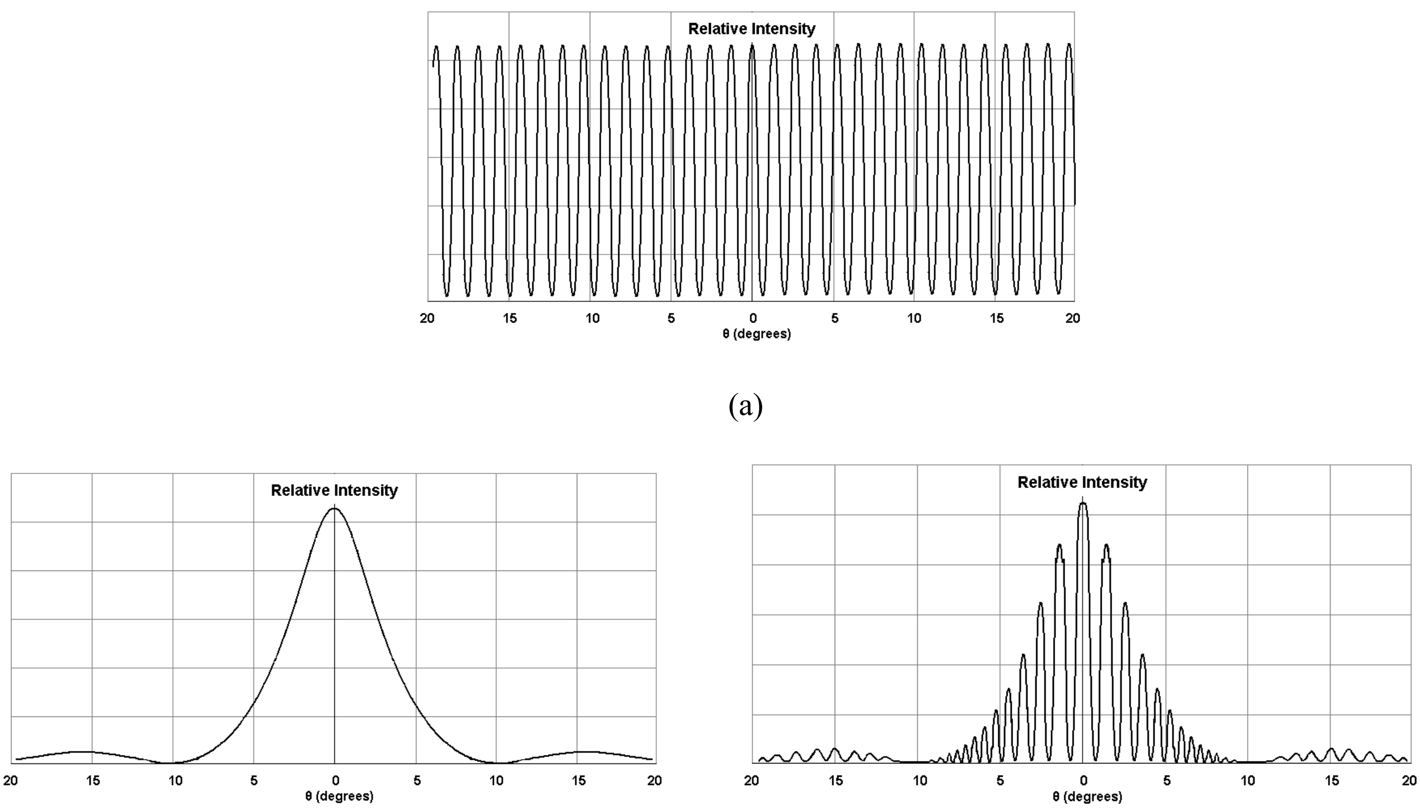
Figure 3 illustrates the relative intensity plot produced by a grating which shows many narrow peaks (bright lines) with corresponding order number m, for zeroth (or central fringe), first, and then the second and third orders shown (where corresponding θ is less than π/2).



(a) (b)

Figure 3. (a) The intensity plot produced by a diffraction grating with their order number m and (b) is seen as fringes with corresponding order number m.

Figure 4(a) illustrates an expected relative intensity versus θ for a double-slit interference pattern, while figure 4(b) illustrates the single slit diffraction pattern. Since light still diffracts within each slit of the double-slit case, the intensity result for a double-slit interference is a combination of the two (4a and 4b) where the relative intensity for the double slit is inside a limiting envelope, and therefore produces an intensity pattern similar to figure 4(c). Note that the first order minima of the (single slit) diffraction pattern of figure 4b effectively eliminates the double slit interference fringe that would occur near 10^{o}.



(b) (c)

Figure 4. (a) The expected relative intensity plot for the double-slit interference experiment. (b) The intensity plot for the diffraction by a typical narrow slit. (c) The intensity plot of the resulting double-slits (a combination of (a) and (b), where the envelope of (b) is limiting the intensity of (a))

Experimental Procedure

Set-up

Place the stepper motor stage and the laser pointer on the bread board as shown in figure 5 and maximize the distance between them**.** The location of the laser beam should roughly be in the middle of the stage.

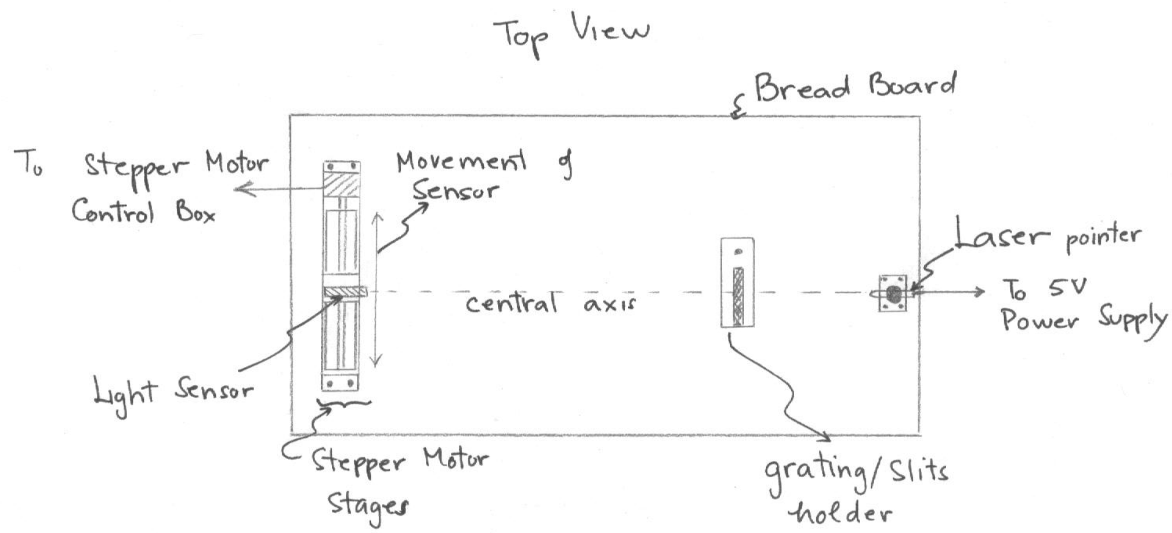


Figure 5. Experimental set-up

Connect the stepper motor cable and the power supply to the back of the stepper control box. Connect the banana jacks on the front of the stepper control box to the computer interface connection box as follows:

Direction (blue)	:	Digital I/O #1
Clock (white)	:	Digital I/O #0
Ground (2 x black)	:	Digital I/O DGND

CAUTION: The following procedure will turn the laser pointer on. Avoid direct eye exposure to the primary laser beam. Connect the laser to the +5 (red) and COM/GND (black) terminals on the interface connection box.

The height of the laser can be adjusted to ensure the laser beam is at the same height as the aperture of the light sensor. This is done by first unlocking the lock nut (the enlarged knurled disc on the shaft) and then turning the laser holder (clockwise for downward movement, counter clockwise for up.). Note that when the height of the laser pointer is being adjusted, the laser should first be disconnected from its power supply.

Using the 5 pin DIN connector cable, connect the light sensor to the Pasco Sensor Input #1 of the interface connection box. Set the gain of the light sensor to 100 using the switch on top of the sensor.

Proceed as follows:

Step 1: Place the diffraction grating in the grating/slits holder and fasten the holder using the nylon thumbscrews in the 5^{th} row of threaded bolt holes from the light sensor.

Step 2: Slide the holder laterally, until the laser beam is intercepting the grating (or slits). Place a sheet of paper in front of the light sensor to see the interference pattern. You may need to rotate the grating (or slits) in the mount, so that the interference pattern formed on the screen is parallel to the plane of the desk.

Step 3: Measure D (minimum distance from the grating or slits to the light sensor) and record this value.

Step 4: Unlock the lock nut on the translation stage (lever toward laser) and slide the sensor away from the motor end, sufficiently far enough past the first order maxima (or the 2^{nd} order diffraction minima in the case of the slits) and then lock the lock nut (lever away from laser). This is your starting position (Note: When locked properly, the sensor should only be able to be wiggled a little bit along the axis of the translation stage.)

Step 5: Set the "translation distance" control in the software to a value appropriate to ensure both first order fringes (or the 2^{nd} order diffraction minima for slits) are within the range of travel. Use a ruler to assist you in accurately estimating this distance.

Step 6: Click the "Run" button in the software to start data acquisition. The sensor will first move toward the motor, then backtrack to the original position while it records the intensity data. When data acquisition is completed, click the "Save" button to save your data to an Excel compatible file.

Step 7: Replace the diffraction grating with the combination single/double-slit projector type slide and move the holder as close to the laser as possible. Adjust the lateral position of the slide holder until the laser beam falls directly onto the single slit. Repeat Steps 2 to 6, making sure that your sensor travel includes all second order minima.

Step 8: Repeat step 7 using the double slit.

Results & Analysis

For the diffraction grating:

For the bright fringes of the diffraction interference pattern, we have

$$d \sin \theta = m \lambda \qquad \text{where } m = 0,1,2,\ldots \qquad (1)$$

Where θ is the angle of diffraction and is measured from the central axis. We can convert the linear displacement to angular displacement using

$\theta = \arctan(\Delta x/D)$ Where $\Delta x = x - x_o$ is the x is the position of the sensor, and x_o is the position of the central axis.

Plot the Intensity versus θ, and determine the angle where the first order bright fringes occur. There are 2 values (left and right) of these.

Record your "N" value, which is the number of lines/inch and is printed on the diffraction grating. Use this to compute the value for the grating spacing "d" (Note 1 inch = 2.54 cm)

Using equation (1) and the average value of θ (for first order: m=1 maxima) and the grating spacing "d", determine λ, which is of course the wavelength of the laser.

For the single slit:

For single slit diffraction minima (dark fringes), we have

$$a \sin\theta = m\lambda \quad \text{where } m = 1,2,3,\ldots \qquad (2)$$

Repeat the analysis procedure of the previous part in order to find θ for cases where m=1 and m=2 (4 values for DARK fringes). Use equation (2) and the previously determined λ, the appropriate θ and m to determine the width of the single slit: "a" (4 values). Then determine an average value for the width of the single slit

For the double-slit:

For the double-slits, diffraction maxima (bright fringes), we have

$$d \sin\theta = m\lambda \quad \text{where } m = 0,1,2,3,\ldots \qquad (3)$$

Repeat the analysis procedures of the previous part to once again find θ for cases where m = 1,2 and 3 (6 values for BRIGHT fringes). Use equation (3) and the previously determined λ, the appropriate θ, and m to determine the separation of the double slits "d" (6 values). Determine an average value for the slit separation as well.

Question:

Assuming a constant value for λ, use the average "a" and "d" values to determine the number of bright fringes you would expect to see in:

a. The central diffraction envelope.
b. The first order diffraction envelope.

Compare the observed numbers and your determined values, and attempt to explain any discrepancies.

Required Hardware:

1 Light Sensor
1 Translation Stage (10.61cm in length)
1 Stepper Motor
1 Stepper Motor Control Box
1 Laser Diode (laser pointer) and Stand
1 Diffraction Grating
1 Single/Double-slits slide
1 Slide holder

Revised 2003-03-14
J.G.

<u>About the Software</u>

<u>*Buttons and Their Functions:*</u>

"Run" : Starts data acquisition. The program waits idly until this button is pressed. By waiting idly the program saves CPU resources. This allows other programs (i.e. Microsoft Excel) to run at the same time.

"Stop" : Stops data acquisition. The program runs and acquires data until this button is pressed (or the sensor has returned to the starting position). After Stop has been pressed, the program waits idly until Run is pressed. Data that has been acquired is not deleted until Run is pressed again. Pressing Stop does not delete acquired data.

"Exit" : Shuts down the program. Exit will not stop data acquisition. Data acquisition must be stopped in order for this button to work. Either the Stop button must be pressed or the sensor must have returned to the starting position for the Exit button to work. This is so to prevent accidental termination of data acquisition.

"Save" : Saves acquired data. Data from the most recent trial is saved to a Microsoft Excel file when Save is pressed. The user can choose: where to save the file, its name, and weather to create a new file or replace an existing one. The default directory is "C:\Data From Trials".

<u>*Numeric Controls and Their Functions:*</u>

"Translation Distance" : This tells the program how far to move the sensor. When this distance has been reached, the program moves the sensor back to it's original position. The default time distance is 5cm. This can be changed to suit the needs of the user. The program will change time values of less than 0 to the lower limit 0, and values higher than 10.61 to 10.61 automatically (to avoid trying to move the sensor beyond the length of the stage).

Displays and Their Functions:

"Sensor Position" : Displays the position of the sensor relative to how far it has to go.

"Status" : Lets the user know what the program is doing. When display reads "Acquiring Data", the program is locating the central maximum and defining the zero mark. When display reads "Graphing", the program is acquiring intensity data and graphing intensity vs. distance.

"Waveform Graph" : This is a graphical representation of the diffraction pattern created by the diffraction grating. It is a measure if the intensity of the pattern versus distance. The zero mark is set where the central maximum is found. X-axis displays distance, Y-axis displays intensity.