General Physics Laboratory Handbook

A Description of Computer-Aided
Experiments in General Physics

Group II

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Contents

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Introduction

Laboratories offer an ideal opportunity to learn and strengthen, by means of actual observations, some of the principles and laws of physics that are taught to you in general physics lectures. You will also become familiar with modern measuring equipment and learn the fundamentals of preparing a report of the results.

GENERAL INSTRUCTIONS:

1. You must arrive on time since instructions are given and announcements are made at the start of class.
2. A work station and lab partners will be assigned to you in the first lab meeting. You will do experiments in a group but you are expected to bear your share of responsibility in doing the experiments. You must actively participate in obtaining the data and not merely watch your partners do it for you.
3. The assigned work station must be kept neat and clean at all times. Coats/jackets must be hung at the appropriate place, and all personal possessions other than those needed for the lab should be kept in the table drawers or under the table.
4. The data must be recorded neatly with a sharp pencil and presented in a logical way. You may want to record the data values, with units, in columns and identify the quantity that is being measured at the top of each column.
5. If a mistake is made in recording a datum item, cancel the wrong value by drawing a fine line through it and record the correct value legibly.
6. Get your data sheet, with your name, ID number and date printed on the right corner, signed by the instructor before you leave the laboratory. This will be the only valid proof that you actually did the experiment.
7. Each student, even though working in a group, will have his or her own data sheet and submit his or her own written report, typed, for grading to the instructor by the next scheduled lab session. No late reports will be accepted.
8. Actual data must be used in preparing the report. Use of fabricated, altered, and other students' data in your report will be considered as cheating. No credit will be given for that particular lab and the matter will be reported to the Dean of Students.
9. Be honest and report your results truthfully. If there is an unreasonable discrepancy from the expected results, give the best possible explanation.
10. If you must be absent, let your instructor know as soon as possible. A missed lab can be made up only if a written valid excuse is brought to the attention of your instructor within a week of the missed lab.
11. You should bring your calculator, a straight-edge scale and other accessories to class. It might be advantageous to do some quick calculations on your data to make sure that there are no gross errors.
12. Eating, drinking, and smoking in the laboratory are not permitted.
13. Refrain from making undue noise and disturbance.

REPORT FORMAT: The laboratory report must include the following:

1. **Title Page**: This page should show *only* the student's name, ID number, the name of the experiment, and the names of the student's partners.
2. **Objective**: This is a statement giving the purpose of the experiment.
3. **Theory**: You should summarize the equations used in the calculations to arrive at the results for each part of the experiment.
4. **Apparatus**: List the equipment used to do the experiment.
5. **Procedure**: Describe how the experiment was carried out.
6. **Calculations and Results**: Provide one sample calculation to show the use of the equations. Present your results in tabular form that is understandable and can be easily followed by the grader. Use graphs and diagrams, whenever they are required. It may also include the comparison of the computed results with the accepted values together with the pertinent percentage errors. Give a brief discussion for the origin of the errors.
7. **Conclusions**: Relate the results of your experiment to the stated objective.
8. **Data Sheet**: Attach the data sheet for the experiment that has been signed by your instructor.

Electric Field and Equipotential

OBJECT: To plot the equipotential lines in the space between a pair of charged electrodes and relate the electric field to these lines.

APPARATUS: Two different plastic templates (opaque and either cardboard, transparent, or plastic) digital voltmeter (DVM), graph sheets, BK Precision Power Supply/Battery Eliminator 3.3/4.5/6/7.5/9/12V, 1A Model#1513 potential source (with 6 Volts selected), and connecting wires.

THEORY: Electric field is an important and useful concept in the study of electricity. For an electric charge distribution, the electric field intensity or simply the electric field at a point in space is defined as the electric force per unit charge:

$$\vec{E} = \frac{\vec{F}}{q}. \tag{1}$$

From the knowledge of an electric field, we can determine the force on any arbitrary charge at different points.

Theoretically the electric field is determined using an infinitesimally small positive test charge q_0. By convention the direction of the electric field is the direction of the force that the test charge experiences. The electric field (which is a vector field), may therefore be mapped or displayed graphically by lines of force. A line of force is an imaginary line in space along which the test particle would move under the influence of the mapped electrostatic field; at any point, the tangent to the line of force gives the electric field at that point.

For a simple case of an isolated positive charge, the electric field is directed radially outward, as shown in the Fig. 3.1, since a positively charged test particle would be repelled radially.

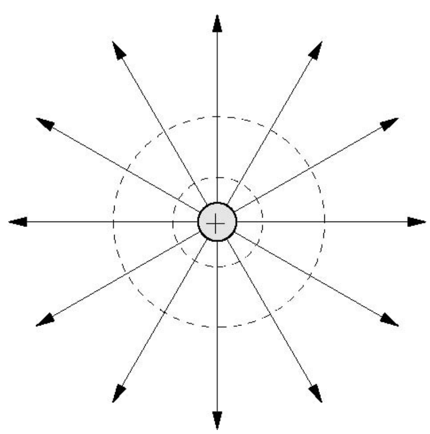


Figure 3.1: Lines of force (Solid Lines Radially Outward) and Equipotentials (Dashed Lines Concentric Circles)

For the case of an isolated negative charge, the force lines are radially directed inward, as a positively charged test particle would be attracted radially. The force lines are crowded together where the field is stronger and are further apart where the field is weaker. The field has a $(1/r^2)$ behavior; that is, it decreases inversely as the square of the distance from the isolated charge.

Experimentally we cannot truly map the field because of difficulties in placing the test charge at a point in space and determining the force acting on the test charge. However, it is possible to map the electric field indirectly from the equipotential lines. (In three dimensions, electric field is mapped from equipotential surfaces.)

The potential difference ΔV between two points is defined as the work required to move a unit positive charge from one point to the other in the electric field:

$$\Delta V = \frac{W}{q_0} \tag{2}$$

If the test charge q_0 is moved perpendicular to the electric field or the force lines, no work is done or $W = 0$. This implies that $\Delta V = 0$; that is, the potential remains constant along a path that is perpendicular to the force lines. Such a path that has the same value of potential at all points on it is called an equipotential line in two dimensions, and an equipotential surface in three dimensions.

It can be easily shown that the electric field is given by the negative gradient of the potential. The magnitude of the field is

$$\Delta E = \frac{dV}{ds} \tag{3}$$

where s is a coordinate in the direction of the electric field.

Two equipotential lines or two force lines from a given charge distribution never cross each other, since both the potential and the electric field at any point other than the point-like charges themselves always have unique values. At the location of a point-like charge, the equipotential lines collapse to that point, and the lines of force diverge from a positive point-like charge and converge into a negative point-like charge; see Fig. 3.1.

PROCEDURE:

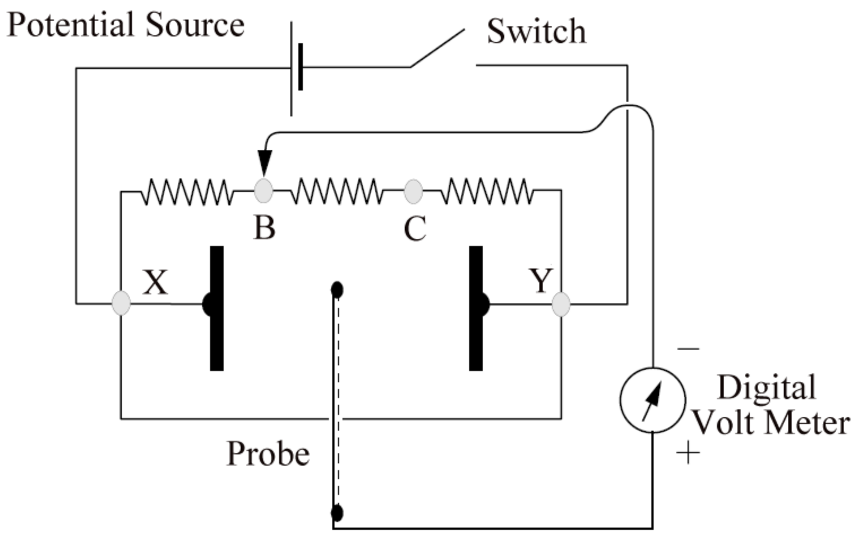


Figure 3.2: Experimental Setup.

1. Place the opaque template (for example, parallel-plate capacitor shown in the figure as dark region) at the bottom of the field mapping board.
2. Fasten a piece of graph paper on the upper side of the mapping board by pressing on the springs (located at the four corners) and push paper under the rubber stops and release the springs.
3. Place the transparent/cardboard template on the graph sheet and align according to the tiny holes located at the top of the template.
4. Turn the board upside down to ensure that the opaque template and the transparent/cardboard template on the opposite side of the board are both aligned.
5. Carefully, slide the U-shaped probe into the board, with the ball end facing the underside of the board.
6. Connect the potential source to the conducting terminals X and Y and make the connections for the digital volt meter (DVM) with the terminal B as shown in the Fig. 3.2.
7. Turn on the potential source. Move the probe over the graph sheet to find a zero reading position. This point must be at the same potential as B. Move the probe to another null point and continue this procedure to find a series of these points.
8. Connect these equipotential points with a smooth curve to display the equipotential line as B.
9. Move the digital voltmeter (DVM) connection to C now, and find the corresponding equipotential line. (The DVM should indicate zero voltage).
10. Make a mark to identify this location.
11. Repeat the above procedure for all terminals (E1, E2, E3, etc) of the series of resistors.
12. Draw in, using dashed lines, the lines of force which are everywhere perpendicular to the equipotential lines.
13. Repeat the experiment for the second template.

Networks and Wheatstone Bridge

A circuit to determine the resistance of an unknown resistor accurately has been devised by Wheatstone. It is called the Wheatstone bridge and is shown below .

OBJECT: To measure the resistance of an unknown resistor using the slide-wire Wheatstone bridge and verify the resistance law for two resistors connected in series and parallel.

APPARATUS: Slide-wire Wheatstone bridge, BK Precision Power Supply/Battery Eliminator 3.3/4.5/6/7.5/9/12,1 A Model # 1513(set to 3.3 Volts), digital voltmeter (DVM), standard decade resistance box (set to 10K Ohms), unknown resistance board (use resistor numbers 2, 7, and 9), and connecting wires.

THEORY: A Wheatstone bridge is a circuit consisting of four resistors as shown in Fig. 4.1. The value of one unknown resistance can be computed from the remaining three resistances which are known.

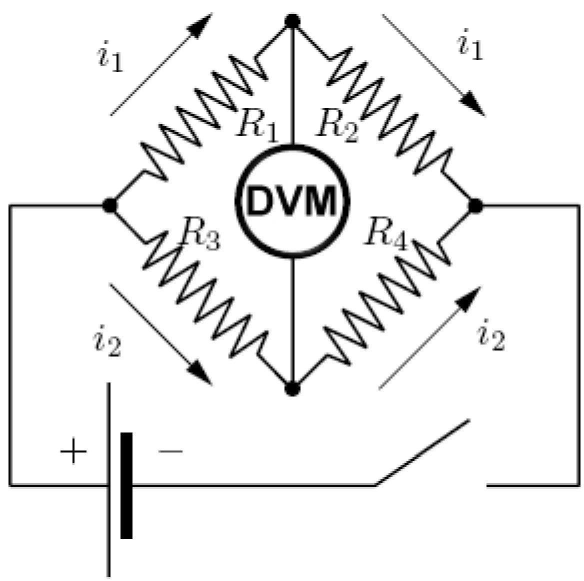


Figure 4.1: Wheatstone Bridge.

When the bridge is balanced, the digital voltmeter reads zero.

Also, the potential drop across *R*1 is equal to that across *R*3, so that

$$i_1 R_1 = i_2 R_3 \tag{1}$$

Similarly, the potential drop across R_2 is equal to that across R_4 and:

$$i_1 R_2 = i_2 R_4, \tag{2}$$

using Eq. (1).

Dividing Eq. (2) by Eq. (1) yields the final relation:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \tag{3}$$

Therefore, if any three of the resistances in Fig. 4.1 are known, the fourth one may be calculated by using Eq. (4).

In the slide-wire form of the bridge, as shown in Fig. 4.2, the resistances *R*3 and *R*4 are replaced by the lengths AB and CB, respectively, of a uniform wire AB with a sliding contact key at C. Since the wire is uniform, the resistances of the two portions are proportional to their lengths. Hence, the ratio of resistances *R*3/*R*4 is equal to the ratio of lengths AC/CB. If *R*1 is represented by the unknown resistance *X*, and *R*2, by the known resistance *R*, Eq. (3) becomes:

$$\frac{X}{R} = \frac{AC}{CB}, \quad \text{or} \quad X = \frac{AC}{CB} R, \tag{4}$$

from which the value of the unknown resistance, *X*, may be calculated.

PROCEDURE:

1. Connect the circuit as shown in Fig. 4.2, with connecting wires as short as possible. A standard resistance box is used for R. Have the circuit checked out by the instructor.

2. Contact is made to the wire at C.

3. Adjust R to 10,000 Ohms. Turn on the power supply and find the null point by shifting the contact until zero voltage is observed on the digital voltmeter (set the voltmeter on the 2000mv or 2v range).

4. Record the resistance R and lengths AC and CB.

5. Calculate the unknown resistance X (let X_1= #9 on the resistance board, X_2= #7 on the resistance board, X_3= #2 on the resistance board):

$$X = \frac{AC}{CB} R . \tag{5}$$

6. Select two more unknown resistors and determine their resistances. Connect the resistances, x_1 and x_2, x_2 and x_3, x_1 and x_3 in series and parallel and determine the total resistance of each combination. Compare the results obtained from the series and parallel combinations with the calculated values.

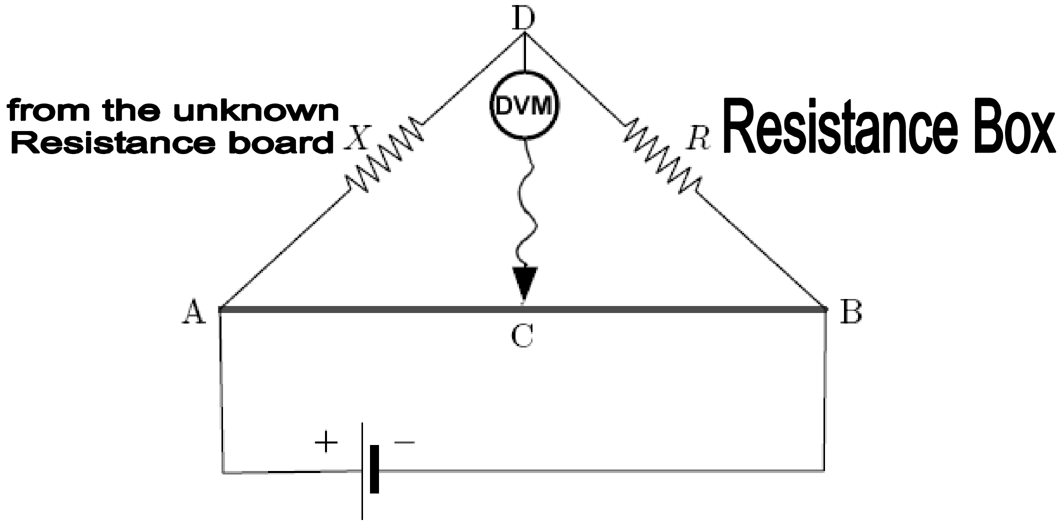


Figure 4.2: Experimental Setup.

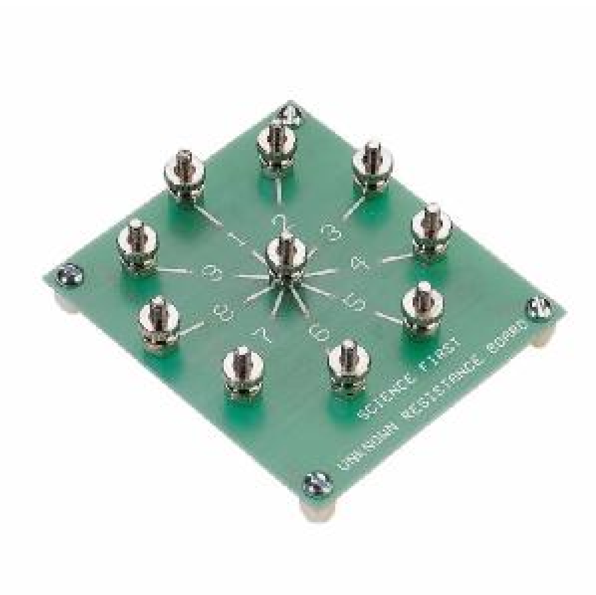


Figure 4.3 Unknown Resistance Board

Ohm’s Law

BACKGROUND: A difference of potential is required to produce a current in a circuit. The relationship between potential difference and current, discovered by George Ohm (1787-1854), is perhaps one of the most commonly applied relationships in the analysis of electrical circuits. Ohm’s law is not a fundamental law, but it is applicable to a certain class of materials called “ohmic” conductors. Materials which do not follow Ohm’s law are said to be “nonohmic”. Semiconductors exhibit nonohmic behavior.

OBJECT: To demonstrate Ohm’s law and to determine the resistance of a given resistor. THEORY: Ohm’s law applies to many conductors. For an “ohmic” conductor, it is found that the potential difference V across a conductor is directly proportional to the current, I, flowing through the conductor. Mathematically, Ohm’s law is expressed as

$$R = V / I \qquad (1)$$

the constant R is called the resistance of the conductor and is measured in units of ohms (Ω). The circuit diagram to verify Ohm’s law is shown below:

0-18 volt

D.C. Power

Supply

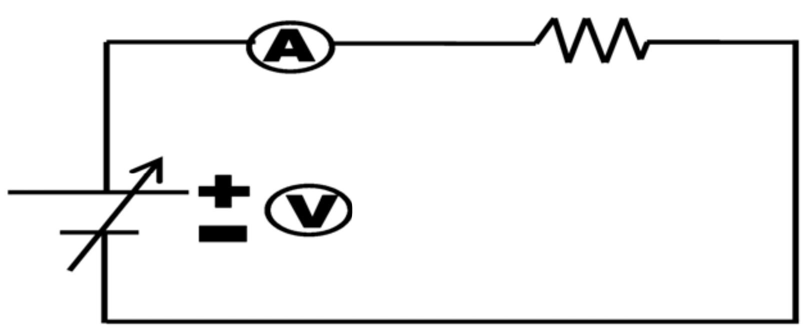


Figure 1: Ohm’s Law.

In the above figure, R is the resistor, V is the voltmeter which measures the voltage across the resistor and A is the milliammeter which measures the current through the resistor.

APPARATUS: 1 multimeters (set on the 20 mA scale), unknown resistor board, and the Extech Instruments (0 – 18 Volts) Power Supply.

PROCEDURE:

1. Construct the circuit, as shown in figure1 and figure 4. Use resistor #2.
2. Choose the 20 milliampere range on the other meter.
3. Get the connections checked by the instructor.
4. Plug the power cord into an electrical outlet and turn on the unit.
5. Start with 15 volts.
6. Record both the voltage (V) and the current (*I*) values in the spreadsheet.
7. Repeat this procedure to obtain records of V and I for successive voltages in 1 volt increments down to 5 volts.
8. Plot a graph of I as a function of V using computer. Fit the straight line that best fits the data. Determine the slope of this line, which equals the resistance of the resistor. (On the computer, open DataStudio and choose cancel on the "OPEN" window. Choose the "experiment" tab-scroll down and click on "New empty data table". Enter data, then drag data icon to the graph icon on left of screen to plot. Then fit your data to the best straight line and print.
9. Repeat for resistors #7 and #9.

Data: Ohm's Law

Resistor #2

Reading	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

Resistor #7		
Reading	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

Resistor #9		
Reading	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

Resistors #2 & 7 in series		
Reading	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

Resistors #7 & 9 in Parallel		
Reading	Voltage (V)	Current (mA)
1		
2		
3		
4		
5		
6		

Additional Laboratory Exercise:

RESISTORS IN SERIES: The equivalent resistance R_s of two resistors, with resistance R_1 and R_2, in series is given by

$$R_s = R_1 + R_2 \,. \tag{2}$$

0-18 V D.C.
Power Supply

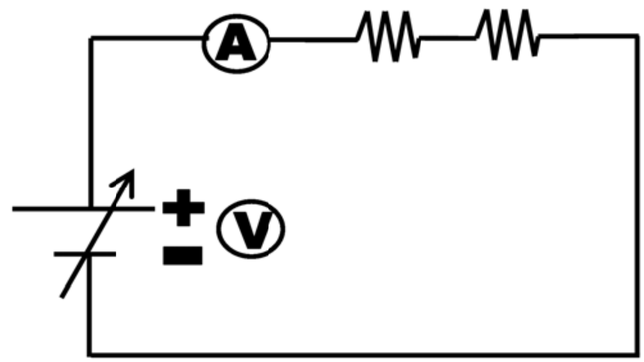


Figure 2. Resistors in series.

RESISTORS IN PARALLEL: The equivalent resistance R_p of two resistors, with resistance R_1 and R_2, in parallel is given by

$$1/R_p = 1/R_1 + 1/R_2 \tag{3}$$

$$R_p = R_1R_2 \,/\, (R_1+R_2) \tag{4}$$

0-18 V D.C.

Power Supply

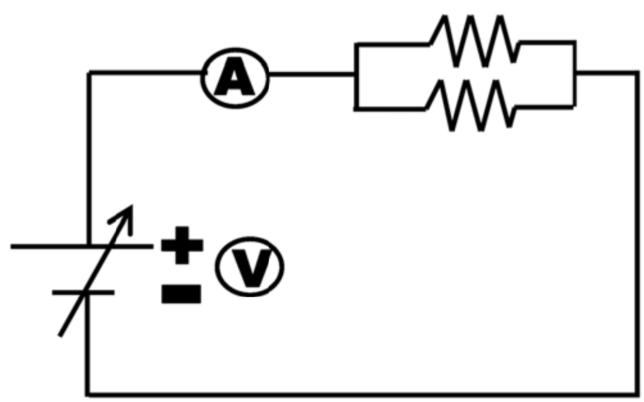


Figure 3. Resistors in parallel.

Determine the resistances R_1 and R_2 of two given resistors used previously when connected in series (Fig. 2) and in parallel (Fig. 3) by the method described earlier. Use the multimeter to measure resistors 2, 7, and 9. Compare the average value of the resistance obtained experimentally for the series and parallel circuits with those determined from Eqs. (2) and (4), respectively using the multimeter measured resistances (#2, #7, and #9) for R_1, R_2, and R_3.

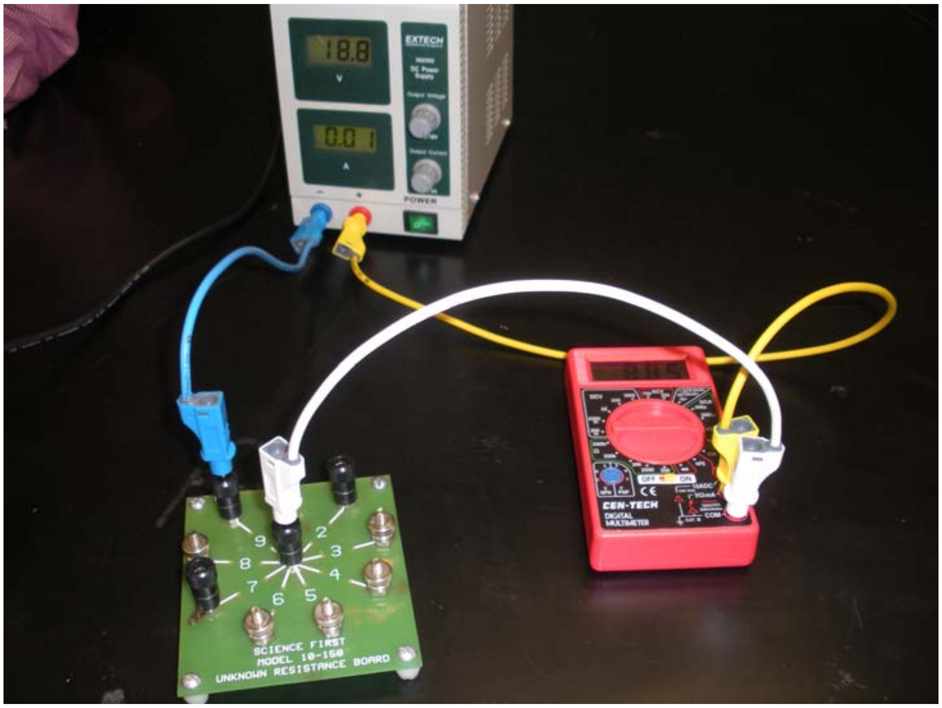


Figure 4. Experimental setup.

External Field of a Bar Magnet and Inverse Square Law

BACKGROUND: Since early times the existence of magnetic force has been known; certain kinds of rocks called 'lodestone' would attract pieces of iron. Also, forces of attraction and repulsion between two pieces of lodestone were observed to depend on their relative orientation. A freely suspended lodestone would always point in the same direction; the end which pointed toward the geographic North was labeled the North (or N) pole and that pointing toward the geographic South was labeled the South (or S) pole. It therefore would appear that the earth acts like a giant bar magnet with its South magnetic pole in the Northern hemisphere and its North magnetic pole in the Southern hemisphere since opposite magnetic poles attract each other.

A single modern concept of a magnetic field always accompanies an electric current or a moving charge. A circulating electric current in an atom and its electronic spin will produce a magnetic field. Permanent magnets, such as a bar magnet made from iron alloys (ferromagnetic materials), have small clusters of adjacent atoms, called magnetic domains. The unpaired spins in the atoms of a magnetic domain are aligned to produce a sizeable magnetic field. In an unmagnetized piece of a magnetic material, these domains are randomly oriented and their magnetic fields well-nigh cancel each other out. However, under the influence of a sufficiently strong external magnetic field, the domains become generally aligned in the direction opposite of that of the external field. Now the magnetic fields of the individual domains add up to produce a magnetic field, as in a bar magnet.

OBJECT: To investigate the magnetic field about a bar magnet and to show that it varies inversely as the square of the distance from an isolated magnetic pole.

APPARATUS: Long bar magnet, drawing board, compass (one small and one large, if possible), aluminum plate guide for bar magnets, iron filings, and paper.

THEORY: The magnetic field is a vector field since its strength or intensity may be defined as the force on a unit North pole. Somewhat analogous to electric fields, magnetic fields can be represented by lines so that the strength of the field is represented by the density of lines and its direction represented by a tangent to these lines. We illustrate below the magnetic field of a bar magnet in Fig. 5.1 and an expanded view near the North pole of a long bar magnet in Fig. 5.2.

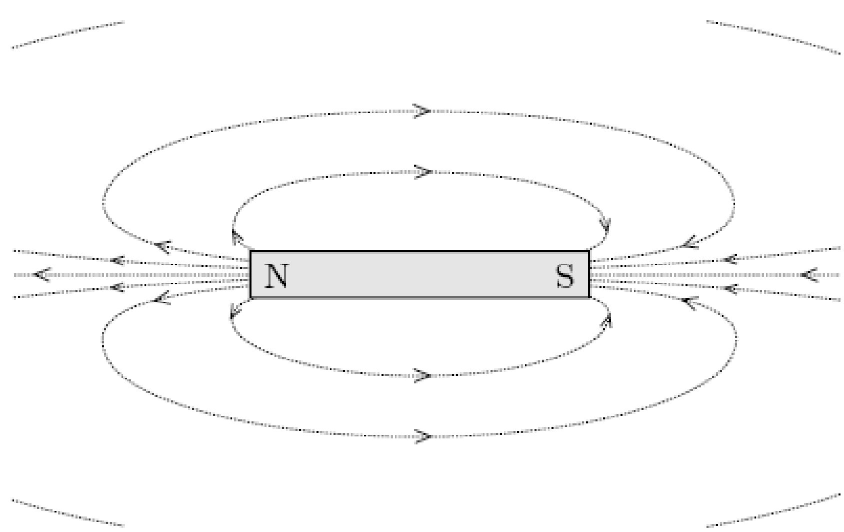


Figure 5.1: Magnetic Field of a Permanent Bar Magnet.

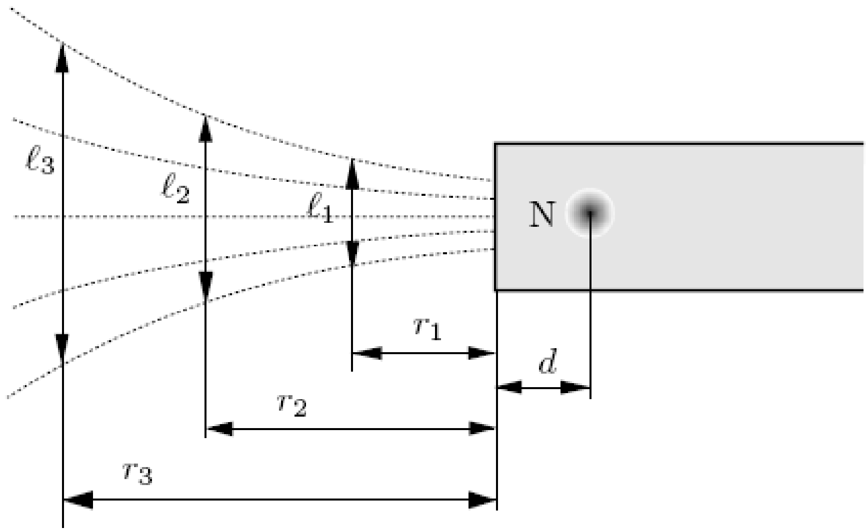


Figure 5.2: The Magnetic Field Near the North Pole of a Bar Magnet.

It is seen from Fig. 5.1 that the magnetic lines of force always from closed loops. The location of the poles is generally uncertain and we will suppose that the pole is situated inside the magnet at a distance d from the end of the magnet.

In Fig. 5.2, the same number of lines thread through the lengths ℓ_1, ℓ_2 and ℓ_3 which are located at r_1, r_2, and r_3 from the end of the magnet. The strength of the magnetic field at a point is described by the number of lines per unit area crossing a small area perpendicular to the field at that point. The magnetic field is inversely proportional to the square of the distance from the pole. Together these statements for the average value of B will give:

$$B \propto \frac{1}{\mathbf{l}^2}, \; and \;\; B \propto \frac{1}{(r+d)^2}, \qquad (1)$$

or

$$\ell = c(r + d), \qquad (2)$$

where c is the propotionality constant and d is the distance between the pole and edge of the bar magnet. However, bear in mind that the influence of the South pole (visible in the bending of the magnetic lines of force as in Fig. 5.1) renders this relation approximate.

PROCEDURE:

1. Place the bar magnet in the center of the paper with its South pole facing North. A compass needle, in the absence of any external magnetic fields other than that of the Earth, will align itself in the N–S direction Make sure that it is a strongly magnetized magnet. Draw the magnet outline.
2. Place the small compass near the North pole of the magnet and make a dot on the paper at each end of the compass arrow. Move the compass forward till its South pole is over the dot of the previous North pole location.

3. Plot at least 10 to 12 lines of force by moving the compass, marking arrow positions and repositioning the compass. Take care that these lines originating from the North pole are nearly equally spaced at the starting point.
4. Draw a smooth curve through the series of dots and place arrows indicating that these lines emanate from the North pole.
5. Locate the points where the compass needle has no tendency to turn in any direction. These points are called neutral points and should indicate where the magnetic field of the Earth and that of the magnet are equal and opposite to each other.
6. To further visualize the magnetic field of a bar magnet, position the bar magnet beneath a sheet of paper. Sprinkle iron filings above the paper and magnet and tap the box slightly so that the filings will align along the magnetic field lines.

CALCULATIONS:

1. Measure several ℓ's (ℓ_1, ℓ_2,...), keeping them much smaller than the length of the bar magnet, and the corresponding r's (r_1,r_2,...). The closer (as compared to the length of the bar magnet) you are to the pole for these measurements, the better your results will be since the magnetic field will more closely resemble that of an isolated magnetic pole, for with Eq. (1) applies.
2. Plot ℓ versus r using the computer. The linearity of this plot, implied by Eq. (1), is only approximate because Eq. (1) itself holds only approximately as explained above. (This is the reason for keeping the ℓ's as small as possible compared to the length of the bar magnet.) Determine the value of d from the intercept with the axis displaying r in the ℓ– r plot.

Oscillators and Oscilloscope

OBJECT: To study the features and operation of the oscilloscope; to use the oscilloscope to measure the frequency and amplitude for various sources; to display and study Lissajous figures.

THEORY: The oscilloscope is one of the most widely used and versatile instruments. It is a standard piece of instrumentation in scientific laboratories of all kinds. By moving an image across a LCD (liquid crystal display) screen, it can be used to draw graphs of *y* (vertical) versus *x* (horizontal). The values of *y* and *x* which are provided to the oscilloscope are voltages. The *y* voltage is usually the dependent variable. The independent variable is time, *t*. The equations for the waves follow the form:

$$y = A \sin(\omega t) \quad \text{or} \quad y = A \cos(\omega t) \tag{6.1}$$

where A is the amplitude, ω is the frequency, and t is the time. The oscilloscope has an internal device, called a sweep oscillator, which moves the beam across the screen at a constant rate. Hence, we can think of the oscilloscope as plotting *y* versus *t*.

Lissajous figures are graphs of complex harmonic motion between parametric equations. The motion is described by equations of the form:

$$x = A \sin(a t + \delta) \quad \text{and} \quad y = B \sin(b t) \tag{6.2}$$

with A and B being the amplitudes, a and b are the frequencies, t is the time, and δ is the phase shift.

APPARATUS: Oscilloscope (OWON PD55022S Dual Channel Digital Color), two audio oscillators (Global Specialties 200 kHz Function Generator 2001A), connectors, computer interface, USB A-Male to A-Male cable.

PROCEDURE:
1. First, study the controls and setup of the oscilloscope as shown in Fig 6.1.
POWER: The power button is located on the top left side of the unit.
USB PORT: Located on the back of the unit, this port allows the oscilloscope to be connected to the computer interface.

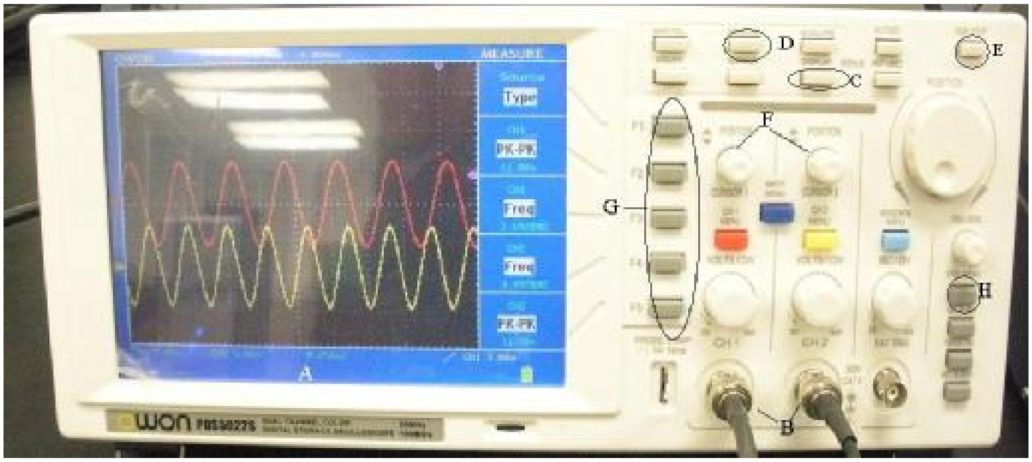


Figure 6.1

<u>A</u>: SCREEN: The area shows the wave patterns produced by the audio oscillators and is located on the left front of the unit.
<u>B</u>: SIGNAL INPUT: The connection ports on the bottom right front of the unit that allow the audio oscillators to connect to the oscilloscope.
<u>C</u>: DISPLAY: Changes to the display menu where the axis can be changed from XY to YT.
<u>D</u>: MEASURE: Measures the peak-to-peak and frequency values of the waves.
<u>E:</u> RUN/STOP: Toggles between freezing the on screen image in place and allowing the waves to oscillate.
<u>F</u>: HORIZONTAL and VERTICAL POSITION: Controls the horizontal and vertical positions respectively.
<u>G</u>: MENU OPTIONS: Located next to the screen, the menu options range from F1-F5, giving specific settings for each selected menu.
<u>H</u>: TRIGGER/ TRIGGER MENU: This selects internal, external, or line modes for triggering the sweep. Once in one of these modes, you can select automatic or some level to trigger on, and you can select either positive or negative slope.

2. Connect the two audio oscillators 600 Ω ports (6 in Figure 6.2) into the oscilloscope's channel 1 and channel 2 ports (B from Figure 6.1) using the connectors. Make sure that the voltage on the oscillators is set on the 1V-10V range (5 in Figure 6.2), the DC offset is set to off (4 in Figure 6.2) since the oscilloscope is set to AC coupling, the frequency (1 in Figure 6.2) is set to ~2kHz (set the frequency at ~2 and the frequency mult. (2 in Figure 6.2) at 1K), and the function (3 in Figure 6.2) is set to sine wave. Plug in the oscillators and oscilloscope and turn the units on.

Figure 6.2

3. Adjust the various triggering controls until stable wave patterns are obtained. The trigger level control selects the value of the voltage signal or threshold at which the sweep will be initiated. The level control is continuously variable from negative values at one extreme, through zero somewhat in the middle to positive values at the other extreme. The automatic AUTO setting triggers the sweep when the level crosses zero voltage. The slope control allows you to select whether triggering will take place while the voltage is increasing or decreasing. A positive slope means that triggering can take place only on an increasing voltage, even if the level or value is negative. A negative slope allows triggering to take place only when the voltage is decreasing. By selecting appropriate slope and level you can trigger the sweep at any point like on the input signal. Trigger on channel 1 by selecting the trigger menu and ensuring the selected source is channel 1 (if not, use the F3 button to select CH1).

4. Select the Measure menu to obtain the peak-to-peak amplitude of the voltage from the audio oscillator. The amplitude of the voltage is half the peak-to-peak amplitude. Also, obtain the voltage.

5. Use the Measure menu to obtain the frequency of each wave pattern. Compare the oscilloscope's measured value, to the value set on the oscillator. Use Run/Stop to freeze the image on screen. Open Data wave on the computer interface. Go to the communication menu and select get data. Print a copy of the waves. Repeat the experiment at ~5 kHz, ~8 kHz, and ~10 kHz. Each member of the group should lead a trial and print his/her own results.

6. Set the first oscillator to approximately 100 Hz. Vary the input frequency of the second oscillator (by one half the frequency of the first oscillator and twice the frequency of the first oscillator) until you obtain stable wave patterns. Using the Display menu change the display to XY. Using Run/Stop and the computer interface, capture the display screen image. Print a copy of the images for each group member. Indicate

the oscillator frequencies to which each pattern corresponds. Do you see any systematic relationship between the oscillator frequencies? The patterns displayed on the scope in this exercise are called Lissajous figures. Repeat setting the oscillator at 150 Hz.

Figure 6.3

In the lab report include: the Lissajous figures and a write up for what each means, a copy of the wave patterns and a comparison of the set and measured frequencies, and the amplitudes of the voltages.

RC Circuits

When a capacitor is placed in series with a battery and a resistor, the capacitor charges up to the voltage of the battery. This kind of circuit is called a RC Circuit because the only two components besides a power supply are a resistor and a capacitor. The resistor limits the electrical current so that the charging takes place over an extended time. This allows students time to think about what must be happening as the circuit charges up to the applied voltage of the battery. After the simple voltage—time data for the charging is collected, fundamental electrical quantities of charge, current, and capacitance can be calculated via a spreadsheet. At the end of the experiment, you will be able to understand how the charge, voltage, and current change as the capacitor charges.

OBJECTIVES

Collect voltage-time data for a capacitor in a RC circuit and curve fit the data.
Calculate the capacitance of the capacitor in a RC circuit.
Develop a mental image of what is happening to electrons during an RC circuit charging cycle.

THEORY

In the circuit shown below, when S_1 is closed the voltage across the capacitor charges:

$$V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$$

When S_1 is opened and S_2 is closed the voltage across the capacitor discharges $V = V_0 e^{-\frac{t}{RC}}$.

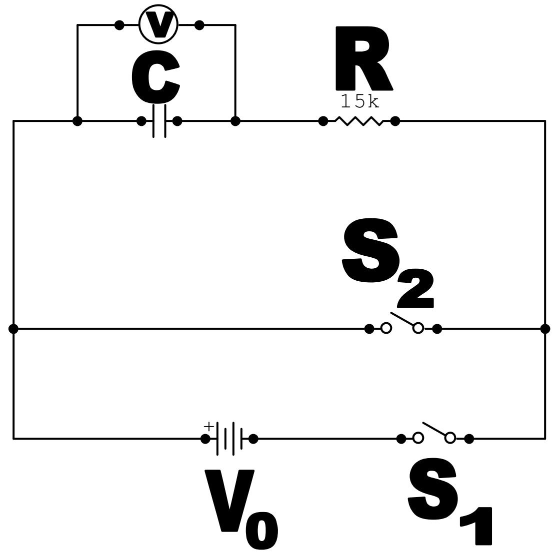


Figure 1

MATERIALS

PASCO *ScienceWorkshop* 500 or *750* computer interface, with *ScienceWorkshop* or DataStudio software, RC Circuit Board, Pasco Voltage Sensor with alligator clip leads, voltmeter (optional), and the Central Scientific Company Model #33031 (0 – 6 Volts) Low Voltage Power Supply.

PROCEDURE for Measuring Capacitor 1

1. Set the Battery/External power switch on the RC Circuit Board to "External"
2. Set the Charge/Discharge switch on the RC Circuit Board to "Discharge."
3. Connect a wire between points A and B on the RC Circuit Board.
4. Connect the red lead of a computer interface voltage probe to the positive (+) side of the capacitor at board position #6. Connect the black lead of the computer interface voltage probe to the negative (-) side of the capacitor at board position #5.
5. Connect the DIN end of the voltage probe to port A of the computer interface.
6. Start the collection file and immediately move the Charge/Discharge switch on the RC Circuit Board to "Charge." After the capacitor is charged move the charge/discharge switch to discharge.

PROCEDURE for Measuring Capacitor 2

Repeat above except for
Step 4: remove jumper/wire from points A and B, connect capacitor 2 between point C and B. Be careful to make sure capacitor is pointing the correct way. See figure below labeled "Measurement for Capacitor 2". Also leave the voltage probe red lead at board position #6 while connecting the voltage probe black lead at board position #4.

PROCEDURE for Measuring Capacitors in series

Repeat above except for
Step 4: remove jumper/wire from points A to B, connect capacitor 2 between point A and B. Be careful to make sure capacitor is pointing the correct way. See figure below labeled "Measurement for Capacitors in series". Also leave the voltage probe red lead at board position #6 while connecting the voltage probe black lead at board position #4.

PROCEDURE for Measuring Capacitors in parallel

Repeat above except for
Step 4: place jumper/wire from points A to B, connect capacitor 2 between point C to A. Be careful to make sure capacitor is pointing the correct way. See figure below labeled "Measurement for Capacitors in parallel". Also leave the voltage probe red lead at board position #6 while reconnecting the voltage probe black lead back to board position #5.

ANALYSIS

Part A: Best Fit the Data

1. Best fit the discharging data with a curve fit available in the collection program.

Part B: Calculate the Capacitance

1 Calculate the actual capacitance of the capacitor in the RC Circuit.
2 Using your collected voltage-time data, calculate the percent error in the capacitance printed on the capacitor compared to the actual capacitance determined by the spreadsheet. Tolerances for capacitors are often ± 20%.

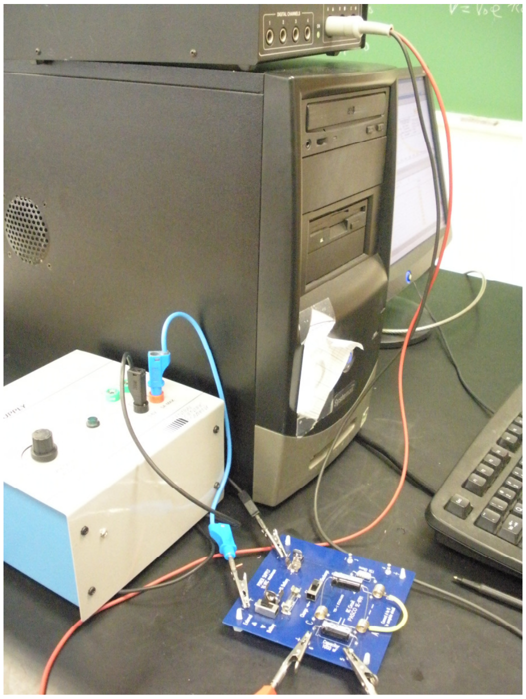
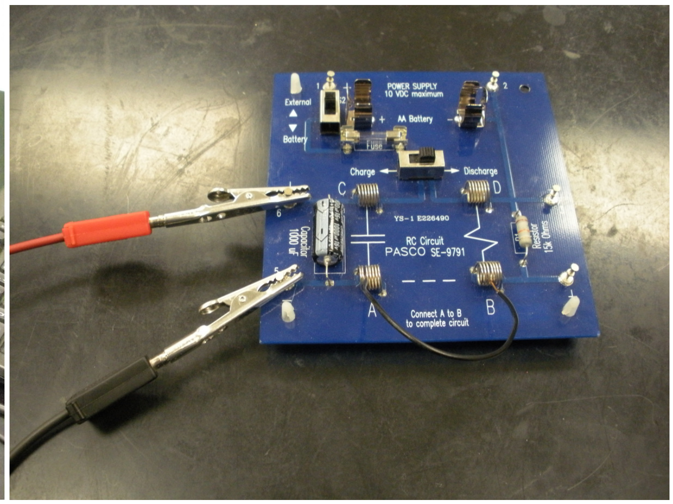
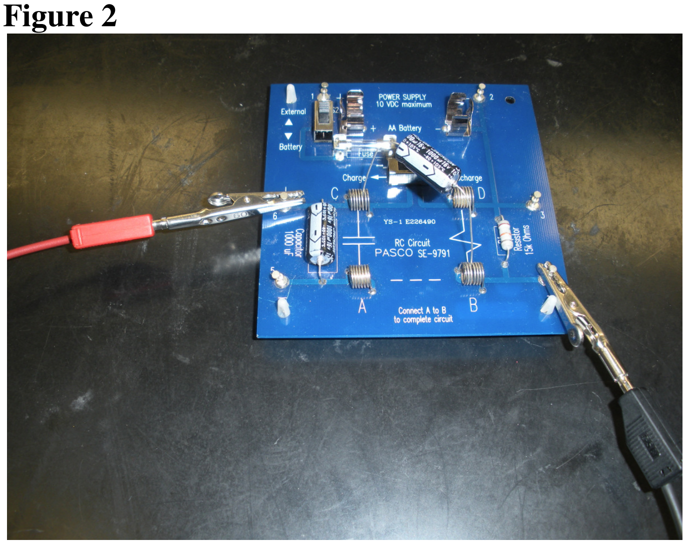


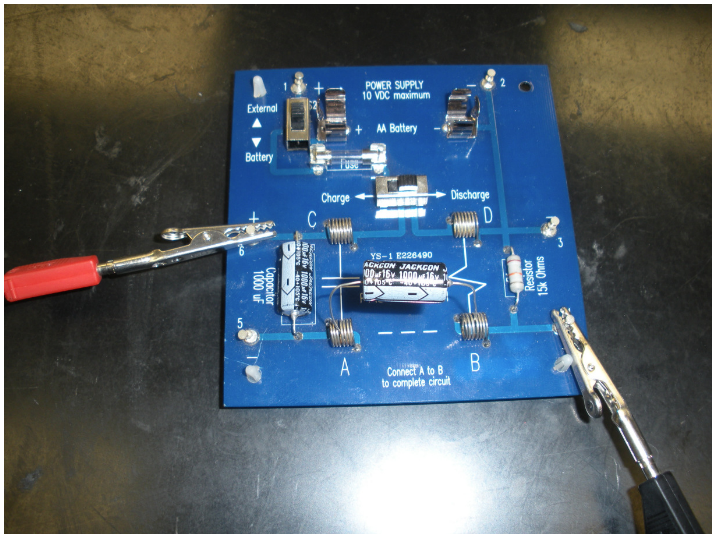
Figure 2



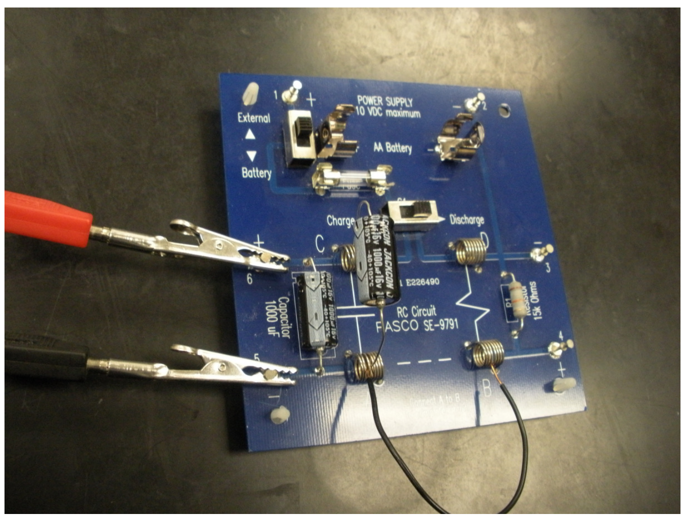
Measurement for Capacitor 1



Measurement for Capacitor 2



Measurement for Capacitors in Series



Measurement for Capacitors in Parallel

RAY TRACING

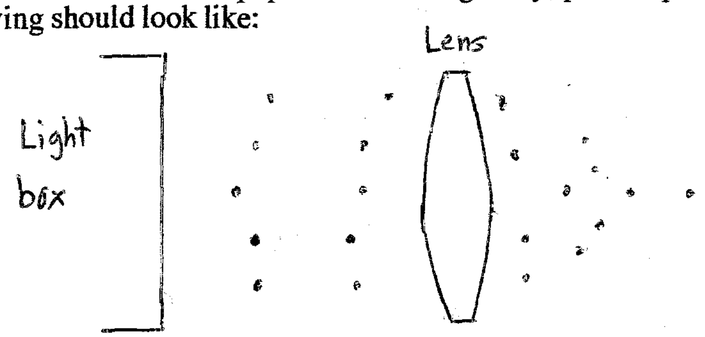
Bring small ruler (with cm scale), protractor and soft pencils to class.

APPARATUS: Light box, lens, mirrors, prisms

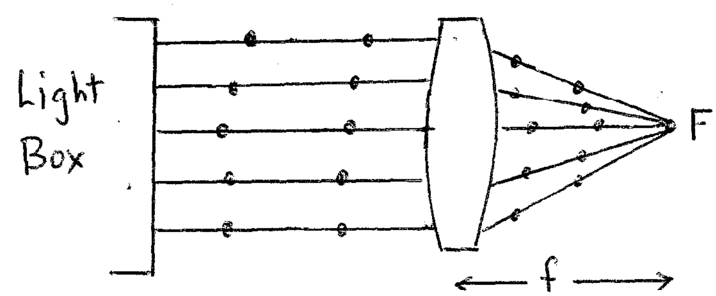
OBJECTIVE: To use ray tracing to determine the focal lengths of lens and mirrors visually; to sutdy "total internal reflection"; to determine critical angle for glass.

CONVEX LENS:

Place the light box and convex lens on a sheet of paper on the table. Turn down the lights in the room. You should see the "light rays" (bright lines) clearly shining on the paper. Use 5 light rays. Make sure that the center ray pass through the center of the lens. Draw the outlines of the light box and the convex lens on paper. For each light ray, place a pair of dots at some distance apart. Your drawing should look like:



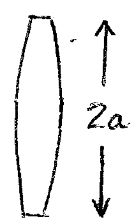
Remove the light box and the lens. Use your ruler to connect each pair of dots into a straight line. This is your "RAY TRACING" and should be submitted as one of your "data sheets":



On the right side, all rays converge (intersect) at the common point F known as the "focal point" or "focus". The distance between the point F and the lens is defined as the "focal length" f. Measure and record this distance f and compare wth the theoretical value:

↔ thickness

$$f = \frac{a^2}{2b(n-1)} \text{ for lens}$$



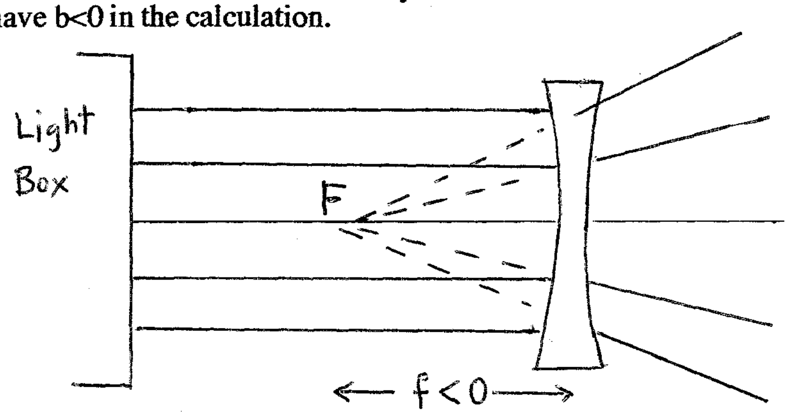
a=radius of lens (in cm)

b=bulge (in cm)=(center thickness)−(edge thickness)

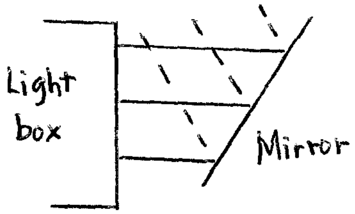
(b is positive for convex lens as shown)

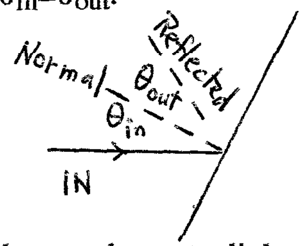
n=refractive index of plastic (typically, n=1.5)

CONCAVE LENS: The "ray tracing" is obtained the same way. On the right side, the ray diverges and is extended toward the left by dashed lines to meet at the focal point F. We have $f<0$. We also have $b<0$ in the calculation.

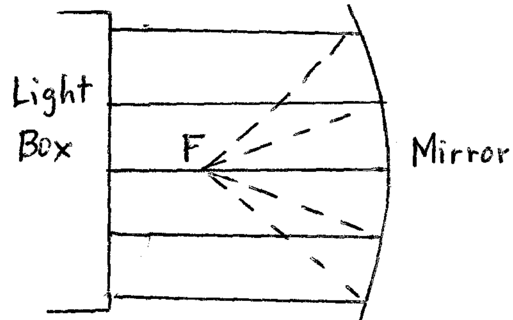


MIRRORS: Draw reflected rays as dashed lines to avoid confusion.
PLANE MIRROR: Draw the normal (perpendicular line) to the mirror. Use protractor to measure the angles θ_{in} and θ_{out}. Verify the relation $\theta_{in}=\theta_{out}$.



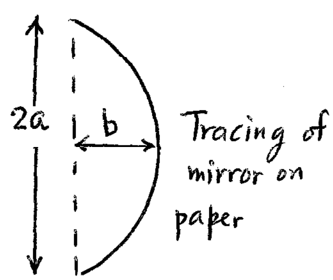


CONCAVE MIRROR: Use 5 light rays. Make sure the center lighr ray hits the center of the mirror. The reflected rays converge at the common point F known as the "focus" or "focal point". Measure the distance f from F to the mirror. This distance f is known as the fccal length.

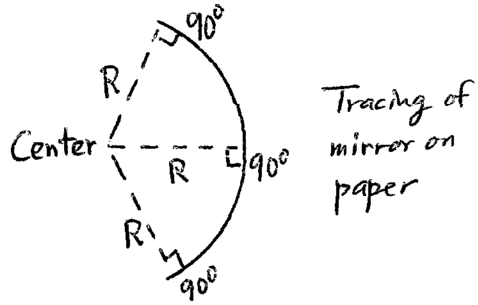


Compare your experimental value of f with theoretical value f=R/2, where R is the radius of curvature of the mirror. Trace the mirror on paper. This trace has the shape of an arc. R can be detrmined by either method:

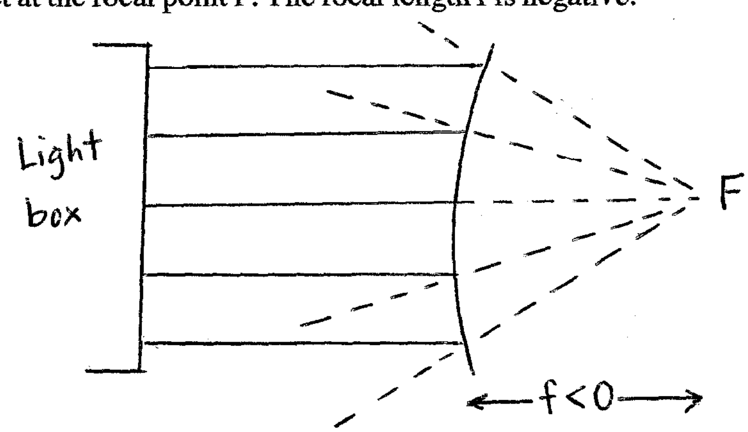
$R=a^2/(2b)$



Dashed lines are normals (perndicular at 90° to) to mirror. All dashed lines intersect at the center. R is the distance from the center to any point on the mirror.



CONVEX MIRROR: The reflected rays diverge from mirror.The reflected beams should be extended to meet at the focal point F. The focal length f is negative.



FOCAL LENGTH OF LENSES

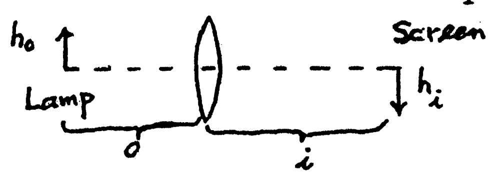
OBJECTIVE: To measure the focal length of convex (positive or convergent) lenses and concave (negative or divergent) lenses.

APPARATUS: Optical bench, lens holders, screen, illuminated object (lamp) convex lenses, concave lenses

THEORY: The lens equation $(1/o)+(1/i)=(1/f)$ holds both for convex and concave lenses, and for real and virtual objects and images. o is object-to-lens distance, i is image-to-lens distance, f is focal length of lens. Magnification M is $h_i/h_o = i/o$, where h_i is image size, h_o is object size.

PROCEDURE FOR CONVEX LENS:

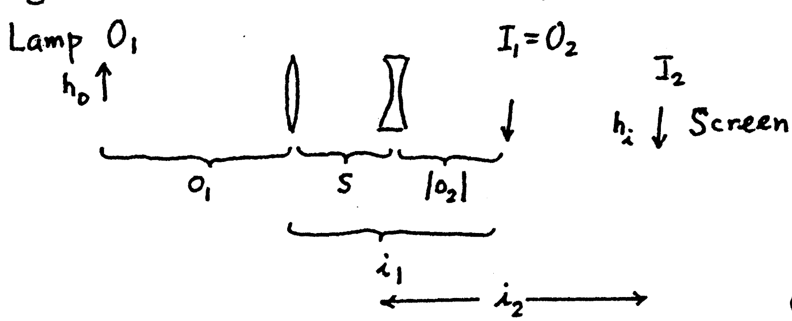
1. Place the lamp and screen on the optical bench about 40 cm apart. Place the convex lens in between the lamp and the screen. Adjust the lens position until a sharp image is formed on the screen. Record object distance o, image distance i, object size h_o (size of arrow on lamp) and image size h_i (size of inverted arrow on screen). You will find two positions of the lens for which sharp images are produced. Use the lens equation to calculate focal length f. Calculate M from h_i/h_o and from i/o. You should obtain comparable values.



2. Repeat the above procedure for other distances between the lamp and the screen.

PROCEDURE FOR CONCAVE LENS:

Since a concave lens does not form a real image, it is necessary to use an additional convex lens with known focal length f_1. The focal length of concave lens will be denoted as f_2. (f_1 is positive; f_2 is negative). When a sharp image is observed on the screen, record the distances o_1, s, i_2 Also, record the object size h_o (size of arrow on lamp) and image size h_i (image size of arrow on screen). Calculate $M=h_i/h_o$.



First image (I_1) is same as second object (O_2).

$(1/o_1)+(1/i_1)=1/f_1$

$(1/o_2)+(1/i_2)=1/f_2$

$o_2=s-i_1$ $\quad o_2$ is negative!

Compare M with $(i_1/o_1)(i_2/o_2)$.

2. Repeat the above procedure for other distances.

Refraction

BACKGROUND: The bending of light rays in passing from one medium to another is called refraction. In Fig. 10.1. light is traveling in media 1 with index of refraction n_1, and is incident on medium 2 which has an index of refraction of n_2. The light ray in medium 1 is referred to as the incident ray, and that in medium 2 is referred to as the refracted ray. The angle of incidence is defined as the angle that the incident ray makes with the normal to the surface. Similarly the angle of refraction is the angle that the refracted ray makes with the normal to the surface.

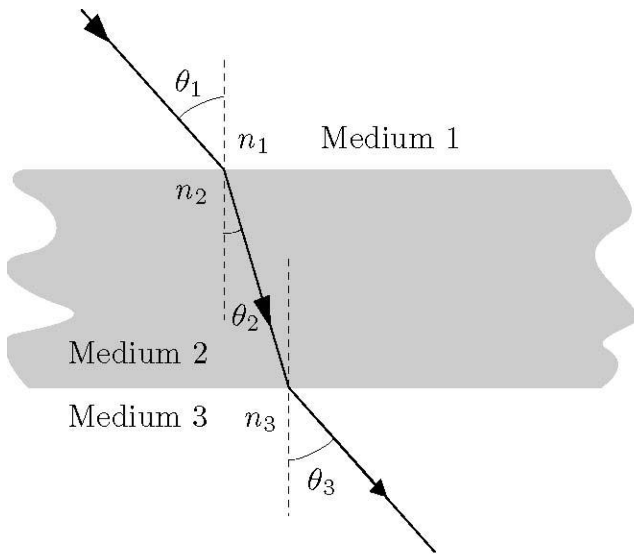


Figure 10.1: Double Refraction.

The angles of incidence and refraction are related to the indices of refraction of the two media through Snell's Law:

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \, , \tag{1}$$

or, more conveniently for us:

$$n_2 = n_1 \sin(\theta_1) \sin(\theta_2) \, . \tag{2}$$

From Eq. (2), it can be seen that the index of refraction of the second medium, with index of refraction n_2, can easily be determined from measurements of the angles θ_1 and θ_2 if the index of refraction in thefirst medium, n_1, is known. For this laboratory exercise the first medium will be air, so that $n_1 \approx 1$.

OBJECT: To investigate Snell's Law and determine the index of refraction of liquid media.

APPARATUS: HeNe Laser, Refraction Tank-Protractor Unit.

WARNING: Never look directly into a laser beam.

PROCEDURE:

1. Locate the glass side of the tank that has a clearly etched vertical line. Arrange the tank on the base so that the etched lined is over the axis of rotation of the protractor arm. It may be necessary to disassemble the tank from the base to obtain the proper orientation.
2. Partially fill the tank with water. Be certain to clear any residue material from the tank before filling it. With the laser turned off, arrange the tank and laser so that the laser is away from the side of the tank that contains the etched line.
3. Turn the laser on and direct the beam through the tank of water so that the refracted beam strikes the etched line on the opposite side of the tank.
4. Rotate the protractor arm until the emergent beam strikes the center of the protractor arm. The angle specified by the arm is θ_1.
5. Place the movable slits on the sides of the tank so that the beam passes through them. Sight over the surface of the water to align the protractor arm with the slit. The angle specified by the arm in this configuration is θ_2.
6. Reposition the laser so the angle of incident is changed. Note that best results occur when the angle of incidence is large, at least 45^0. Repeat the procedure for five different angles.
7. Add the prepared salt solution to the water tank, and again obtain measurements for five different angles.
8. Enter all data in the data tables and determine the average value for the index of refraction of water and for the index of refraction of the water-salt mixture.
9. Determine the percentage of error in the measured index of refraction for water using 1.33 as the accepted value.

QUESTIONS:

1. Why does light bend when it travels from one medium to another?
2. For what incidence angle would light not bend when passing from water to glass?
3. Explain the differences in the values that you obtained for the index of refraction for water and for the water-salt mixture. Where there significant differences in the two answers? What would you guess the difference in these two values to be? Explain.

Data to determine the index of refraction of water.					
Trial	θ_1	$\sin(\theta_1)$	θ_2	$\sin(\theta_2)$	n_2
1					
2					
3					
4					
5					
Average					
% of error					
Data to determine the index of refraction of water-salt mixture.					
Trial	θ_1	$\sin(\theta_1)$	θ_2	$\sin(\theta_2)$	n_2
1					
2					
3					
4					
5					
Average					

Refraction: page 3

Diffraction Grating

BACKGROUND: When coherent monochromatic light, such as that from a laser, passes through narrow slits an interference pattern is formed. A diffraction grating is composed of a large number of narrow evenly spaced slits. When laser light passes through the grating, a regular pattern of sharp bright maxima in the intensity of the light can be formed on a screen. The location of the mth maximum in the pattern is given by the relationship

$$m\lambda = d\sin(\theta_m), \qquad m = 1, 2, 3, ... \tag{1}$$

where m is the order of the diffraction maximum, d is the separation between slits, λ is the wavelength of the light, and θ_m is the angular displacement from the center of the zeroth order maximum (center of the pattern) to the center of the m^{th} order maximum.

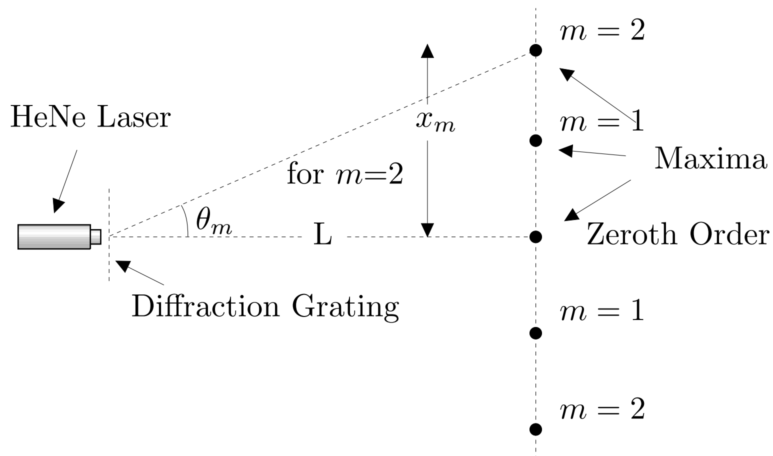


Figure 9.1: Schematic arrangement of diffraction experiment.

If the linear distance between the center of the zeroth order maximum and the mth bright maximum is given by x_m, then the $sin(\theta_m)$ is approximately given by

$$\sin(\theta_{\mathrm{m}}) = \frac{x_m}{L} \tag{2}$$

where L is the distance from the grating to the screen where the pattern is displayed and $L \gg x_m$. Combining Eqs. (1) and (2) yields

$$x_m = \frac{m\lambda L}{d}, \quad \text{or} \quad \lambda = \frac{d x_m}{mL}\ , \qquad \text{for} \quad m = 1, 2, 3 \ldots \tag{3}$$

If the diffraction angle, θ_m, is not small, then the wavelength must be calculated from the formula:

$$\lambda = \frac{r}{m}\sin\left[\tan^{-1}\left(\frac{x_m}{L}\right)\right]\ . \tag{4}$$

OBJECT: To study the characteristics of a diffraction grating and to measure the wavelength of the light from the HeNe laser.

APPARATUS: Diffraction Mosaic, meter stick, He Ne Laser (λ=632.8 nm).

WARNING: Never look directly into a laser beam.

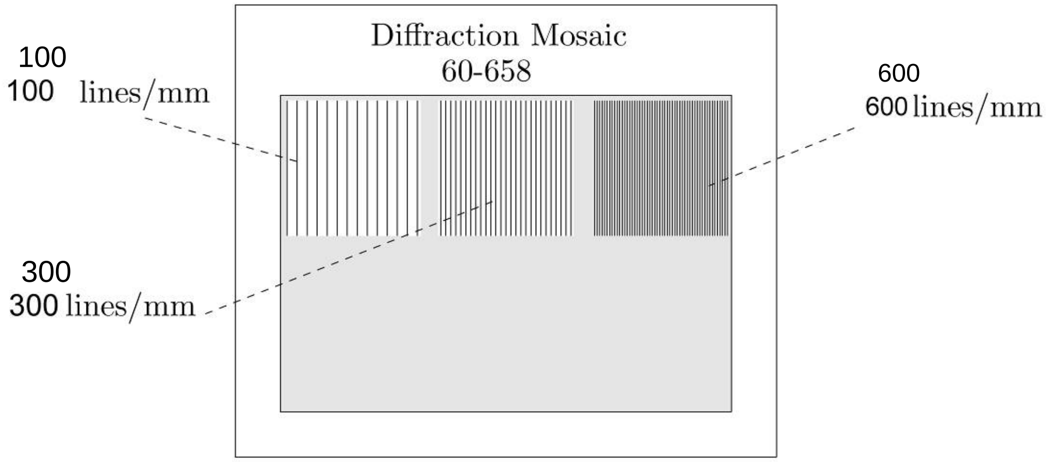


Figure 9.2: The Diffraction Mosaic.

PROCEDURE:

1. Arrange the laser and diffraction grating mosaic so that the mosaic is about 5m from a white wall in the laboratory. This wall will serve as the screen.
2. Place the laser behind the Mosaic so that the beam is incident normal to the 100 lines/mm grating (grating in upper left corner of the Mosaic).
3. Measure the separations between the zeroth order maximum and the 1st, 2nd and 3rd order maxima.
4. Record these data in the data table and determine the value for the wavelength, λ.
5. Compare your average calculated value of the wavelength to the given value for the HeNe laser.
6. Repeat steps 3 and 4 for the 300 lines/mm grating (top center of Mosaic).
7. Compare your average calculated value of the wavelength to the given value for the HeNe laser.
8. Repeat steps 3 and 4 for the 600 lines/mm grating (top right of Mosaic).
9. Compare your average calculated value of the wavelength to the given value for the HeNe laser.

Grating	d	L	X_m	$\tan(\theta_m)=X_m/L$	$\theta_m = \tan^{-1}(X_m/L)$	$\lambda=d\sin\theta_m/m$
100 lines/mm	1mm/100		x_1		$\theta_1 =$	
			x_2		$\theta_2 =$	
			x_3		$\theta_3 =$	
300 lines/mm	1mm/300		x_1		$\theta_1 =$	
			x_2		$\theta_2 =$	
			x_3		$\theta_3 =$	
600 lines/mm	1mm/600		x_1		$\theta_1 =$	
			x_2		$\theta_2 =$	
			x_3		$\theta_3 =$	

Questions:

1. Describe the differences observed in the diffraction patterns for the three gratings.
2. Show that Eq. (2) is (or is not) a valid approximation when $L \gg x_m$.

Atomic Spectra

BACKGROUND: Atoms are quantized. That is the atom can only exist in specific energy states. When the atom radiatively changes from a state of high energy to a state of lower energy a photon is emitted. The energy of the emitted photon, E_p, is given by the difference in the initial state energy and the final state energy of the atom. Thus the emitted photons only have certain allowed energies that depend on the atomic structure of the substance producing these photons. The wavelength of a photon can be expressed in terms of the photon's energy through the relationship

$$\lambda = \frac{hc}{E_p} \ , \tag{1}$$

where c is the speed of light and h is Planck's constant. Since E_p can only have distinct (or quantized) values, Eq. (1) indicates that the wavelength of the emitted photons must also be quantized. That is, only *discrete bands* of light will be observed. Such bands will be observed when the light emitted from low pressure gas discharge tubes is observed using a grating spectrometer. When light from the source is incident on the grating, photons of wavelength λ will be diffracted through an angle θ whereby

$$n\lambda = d\sin(\theta) \ . \tag{2}$$

In this equation n is the order of the diffraction pattern ($n = 1, 2, 3\ldots$) and d is the spacing between the lines of the grating. We will normally use $n = 1$ for this particular experiment.

OBJECT: To use a grating spectrometer and measure the discrete wavelengths emitted from a gas discharge tube.

APPARATUS: Grating spectrometer, diffraction grating, gas discharge tube, tube holder, and power supply.

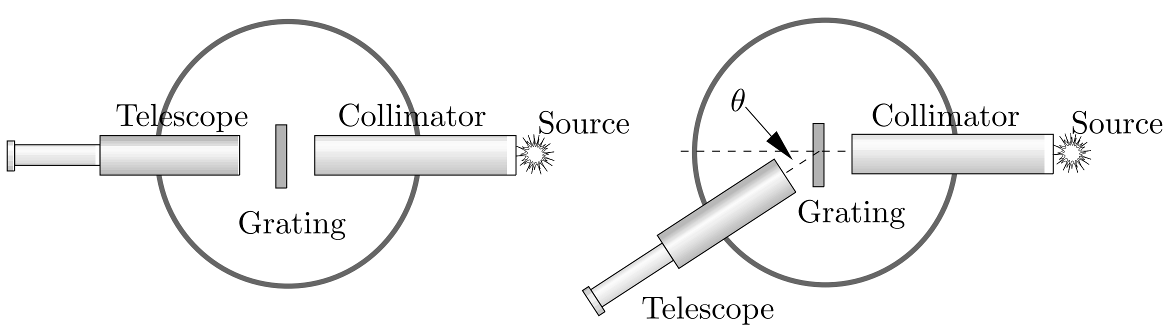


Figure 11.1: Layout of Spectrometer and Light Source.

PROCEDURE:

1. The gas discharge tubes are connected to a high voltage power source. Additionally the tube becomes very hot when in use. Exercise **CAUTION** when using this apparatus. Connect the spectra tube to the power source as instructed by the laboratory instructor.
2. Arrange the spectrometer so that its collimator arm is adjacent to the gas discharge tube. Looking through the collimator you should see a small rectangle of light coming from the discharge tube. The rectangle is formed by the small slit on the end of the collimator.
3. Arrange the telescope arm of the spectrometer so that it is aligned with the collimator. Place the grating on the spectrometer and carefully arrange it so that it is perpendicular to the collimator. With this alignment, the light will be incident normal to the grating.
4. Looking through the telescope arm you should again see the slit. Focus the eye piece until a sharp image is obtained. If necessary, rotate the eyepiece slightly so that the slit is in the center of the field of view.
5. Adjust the scale on the spectrometer, without moving the telescope and collimator, so that the scale reads $0°$. If it is not possible for you to make this adjustment, then you will need to record this reading and make all subsequent measurements relative to this value.
6. Swing the telescope slowly away (clockwise) from $0°$ until a series of bright lines is observed. Record the angle θ that corresponds to the angular location of the observed lines for the colors indicated in the data table. If more than one line is observed for a given color, use the angular location for the first observed lined, i.e. the line that corresponds to the smallest angular displacement. Record the angular locations in the tables. (Be certain to correct the measurements for any zero off-set that you noted in step 5 above.)
7. Repeat the same series of measurements by swinging the telescope counter-clockwise from the zero position.
8. Complete the data table and compare the calculated value of λ with the known values provided by the laboratory instructor.

QUESTIONS:

1. Why is it correct to use $n = 1$ when calculating λ from Eq. (1) in this experiment?
2. If one wanted to determine the relative amount of the substance in the discharge tube, what other information (other than λ) could you observe in this experiment to assist in making this determination?

Measurements and Calculated Values for First Material

Material =			Grating Spacing (d)=			
	Angle (degrees)			**Calculated** λ	**Correct** λ	% **error**
Color	**Clockwise Rotation**	**Counter-Clockwise Rotation**	**Average Value**			
Violet						
Blue						
Green						
Yellow						
Orange						
Red						