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This collection of Laboratory Exercises is the introductory physics laboratory manual used by Hunter College. The original exercises were developed by the Physics Faculty over thirty years ago. A number of revisions have since been made. In particular, the revision of 1994 led by Professor Robert A. Marino, introduced several new exercises involving modern optical and electronic equipment. We are indebted to the faculty and students who participated in the creation and revision of the manual over the years.

Physics Faculty
Hunter College
July, 1999

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How to Succeed in Physics Lab

Read the lab manual before coming to class to become familiar with the experiment. Lecture and Lab are NOT in perfect synch, so you may have to give the textbook a look also.

You should take responsibility to learn safe operating procedures from the lab instructor. The lab manual is also occasionally a good source of safety tips. With electrical circuits, no power is to be supplied unless OK'd by instructor or lab tech. *Report any accidents immediately!*

You will work with a lab partner to take data, but you are individually responsible for your own data. All subsequent calculations, graphs, etc. are also your own individual responsibility.

Original data MUST be in ink. If you change your mind, cross out with a single stroke, and enter new datum nearby.

Do not leave the lab room without obtaining the instructor's signature on your original data sheet. Without it, your lab report will not be accepted. No exceptions.

The lab has been designed to be a "low pressure" experience. We hope it is an enjoyable one as you take the time to become familiar with new equipment and experiences. Still, you should aim to complete all data-taking, all necessary calculations, reach all conclusions, and at least *sketch* all graphs before you leave. It's well known (to those who know it well) that once you walk out that door, all work on lab reports will take longer. Besides, most of the grade for the course will come from the lecture part, so spend your time accordingly.

Before taking good data, run through the experiment once or twice to see how it goes. It is often good technique to sketch data as you go along, whenever appropriate.

The Report: Your Lab Report should be self-contained: It should still make sense to you when you pass it on to your grandchildren. It should include:

- a) Front page: your original data sheet with your name, partners and date. The original data **MUST** be in ink. Report not acceptable if original data is in pencil or if data sheet was not signed by your instructor. (So... don't leave lab room without it.)
- b) Additional pages with data and calculations in neat tabular form. If the original came out messy, you should rewrite your data before continuing with calculations.
- c) Any graphs. Neatness counts! It's one of the aims of this lab to produce students that know how to produce a decent graph.
- d) Answers to any Questions
- e) An Appendix made up of the pages from the lab manual that describes the experiment. Including them relieves you from having to rewrite the essential points of the procedure, description of equipment, etc.

Lab reports are due the next time the lab meets. *At the beginning of the period!* It is department policy to penalize you for lateness in handing in lab reports. This is to discourage you from working on stale data with the lab experience no longer fresh in your mind. A schedule will be announced.

Laboratory Grade: The lab instructor will make up a grade 90% based on the average of your lab reports, and 10% on his/her personal evaluation of your performance in the laboratory. This grade is then reported to your lecturer for inclusion in the final course grade (15% weight factor). The list below will give you an idea of the criteria used by your lab instructor in grading your lab report:

1. Quality of measurements. Logical presentation of report contents.
 2. Accuracy and correctness of calculations resulting from proper use of data and completion of calculations.
 3. Orderly and logical presentation of data in tabular form, where appropriate.
 4. Good-looking graphs, easiness to read, good choice of scales and labels.
 5. Comparison with theory.
 6. Answers to Questions; Conclusions.
 7. Clarity, Neatness, Promptness.
-

On Errors and Significant Figures

Errors

We could distinguish among three different kinds of "errors" in your lab measurements:

1. *Mistakes or blunders.* We all make these. But with any kind of luck, and some care, we catch them and then repeat the measurement.
2. *Systematic Errors.* These are due either to a faulty instrument (a meter stick that shrank) or by an observer with a consistent bias in reading an instrument.
3. *Random Errors.* Small accidental errors present in every measurement we make at the limit of the instrument's precision.

After blunders are eliminated, the *precision* of a measurement can be improved by reducing random errors (by statistical means or by substituting a more precise instrument, i.e., one that yields more significant figures for the same measurement.) *Accuracy* can be increased by reducing any systematic errors as well as by increasing the precision.

Significant Figures

No measurement of a physical quantity can ever be made with infinite accuracy. As an honest experimentalist, you should relay to the reader just how good *you* think your measurement is. One simple way to relay this information is by the number of *significant figures* you quote. For example, 3.4 cm says one thing, 3.40 cm tells a different story. The last digit you write down can be your best estimate made between the markings of a scale, but it still represents a willfully reported number, it still is a *significant* figure.

The placement of the decimal point does not change the number of significant figures. For example, 20.8 grams and 0.00208 grams each have three significant figures; each is assumed to be uncertain by at least ± 1 in the last figure, i.e., ± 1 part in 208, which is about $\frac{1}{2}$ %.

Normally, figuring out how many significant figures are in a stated number gives no problems, except when zeros are involved. For example, is it obvious how many significant figures are expressed in 5500 feet, 250 years, or \$1,300,000 ? A good way to tell the reader which is, in fact, the last significant figure is by using *scientific notation*. For example, 5.50×10^3 feet, 2.5×10^2 years, and 1.300 Megabucks, telegraph that the number of digits in which any confidence can be placed was three, two, and four, respectively.

Computations using raw data

How do you combine your carefully gathered data with other numbers in an expression? With a little common sense, and a hand calculator, you can verify that the following rules should be followed:

Multiplication and Division:

Report only as many significant figures in your final answer as there were in the *least precise* value. For example,

3.481 x 1.75 gets reported as 6.09, not 6.092.

Of course, you should only round off the *final* answer. If a number is used again in another computation, you should not round it off in between, or you may make a small but significant error.

Addition and Subtraction:

Again, common sense rules: $1.11 \times 10^3 + 3.33 \times 10^4$ is, unfortunately, just 3.44×10^4 .

Note: To see this you have to write it out in ordinary notation (even better: line-up one under the other):

1,110 + 33,300 = 34,410 mathematically

but the *tens* position is not significant in one of the terms, so it cannot be significant in the final sum. The answer is 34,400, or 3.44×10^4 .

A more sophisticated way to "propagate errors" is to derive the proper expression using the methods of differential calculus. For those labs where this becomes necessary, you will be given the answer.

Making a Good Graph by Hand

Start thinking about a nice title. e.g., " The Square of the Period (T^2) of a Simple Pendulum vs. its Length (L)" [A shorter title would have been even better]

Keep your axes straight: If you need to plot "A vs B", or "A as a function of B", then A is on the vertical axis and B is on the horizontal axis.

vertical axis = y-axis = the "ordinate"
horizontal axis = x-axis = the "abscissa"

The crucial part is choosing the range and scale for each axis. Two examples:

- a) 0 to 5 sec; 5 graph boxes =1 sec.
- b) -300 to +200 degrees; 2 boxes =100 degrees

The range must be: just large enough to accommodate all your data, yet allow a *readable scale*.

The scale should be: spread out enough so your data take up most of the graph area, and *labeled so plotting (and reading) is easy*.

Label the x and y axis with the appropriate magnitudes. These should be round numbers which cover the entire range of values that you will be plotting. A common mistake is to label too many boxes. If you are trying to show that one quantity is proportional to another, or if you are not told otherwise, zero is part of the range and must be located at the Origin. The numbers should be evenly spaced with the same number of boxes between the same increase in numbers including the space from zero to the first non-zero number. Choose an appropriate number of boxes between numbers. It is better to have 5 boxes between numbers than 4 since it is easier to interpolate in the first case than in the second. (Similarly 10 is better than 8, and 2 is better than 3.)

Plot the results of your measurements on this graph. Where appropriate, you should include error bars to indicate the uncertainty in your measurements. These error bars *are not* of arbitrary size but should be of the size of your uncertainty on the scale dictated by the numbers on the axis of your graph.

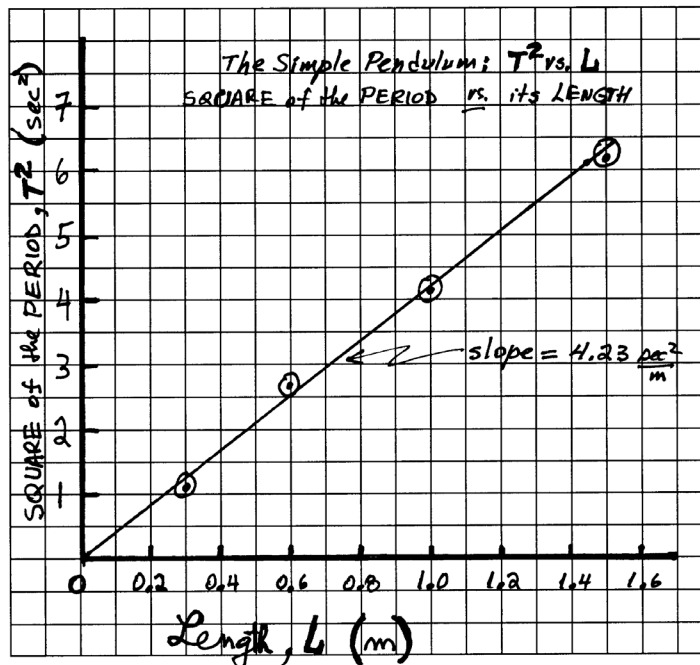
When you draw the line that best fits your data, the line should be a smooth one that need not go through any points. In general, there should be as many points on one side of the line as on the other. If you have done your work properly, the line should pass inside of the error bars for each point. (If it does not, that may be an indication that there is something wrong with the point in question. Perhaps you miss-recorded a measurement, or your estimate of the error was too small, or there was something wrong with the apparatus, or with the technique you applied, etc.) If your graph shows that one quantity is proportional to another, it should be a *straight line* that starts at the origin and passes through the plotted data with as many points on one side as the other.

If you are asked to find the *slope of the line*, choose two points *on the line* which are as *far apart as possible*. This will minimize the error that is introduced in reading the value of those points. The slope is the difference between the vertical values of those points divided by the difference in the horizontal values of those points.

A common mistake is to measure the slope of *the segment connecting two actual data points*: this does not yield the slope of the straight line you fitted to your data!

Note: Normally, the slope of your graphs has its own units. e.g., The slope of graph of velocity vs. time has units of (m/s)/(s) = m/s².

Here is a graph so messy, you can surely do better with.



Ohm's Law

Objectives

Verify Ohm's Law. Study the connection of ammeters, voltmeters and switches in electrical circuits

Equipment and supplies

7-ohm resistor; A DC ammeter, 10 V DC voltmeter, Switch; 6 Volt DC power supply, 20 Ω rheostat (variable resistor).

Discussion

Ohm found that the current that flows through an electrical conductor varies directly with the potential difference across it. The law is usually written this way:

$$V = IR \quad (1)$$

where, V is the potential difference *across* the conductor; V is measured in *volts*.

I is the current through the conductor; I is measured in *amperes* (A)

R , the constant of proportionality, is called the "resistance" of the conductor. For the units to balance in Eq. (1), R must be measured in *volt/amperes*, which was named the *ohm* (Ω).

(Note: A *resistor* is a physical object which has electrical *resistance*. A resistor is always also a conductor, unless its resistance is infinite.)

You will be provided with an *ammeter* and a *voltmeter* to measure I and V , respectively. You should know, however, that these instruments are connected very differently in a circuit:

- a) To sense the current flowing *through* a resistor, the ammeter must be connected *in series* with the resistor.
- b) To sense the voltage *across* a resistor, the voltmeter must be connected *in parallel* with the resistor. See Figure on next page.

If both instruments need to be connected at the same time, there are two possibilities, as shown below:

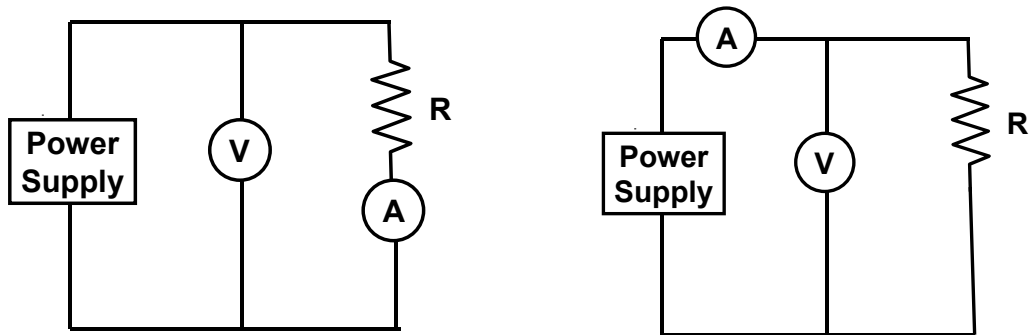


Figure 1

In both methods there will be some error if the resistance is obtained by dividing the voltmeter reading V by the ammeter reading I .

1) In the figure on the left the voltmeter reads the potential difference across both the ammeter and the resistor. Hence, the ratio (V/I) would equal R only if the ammeter resistance were exactly zero. In fact, (V/I) will more nearly equal R , the smaller the ammeter resistance in comparison with R .

2) In the figure on the right the ammeter reads the sum of the currents through the resistance and through the voltmeter. Hence, in this case, (V/I) would equal R only if the voltmeter resistance were infinite. So, (V/I) will more nearly equal R , the greater the resistance of the voltmeter in comparison with R . For the types of instruments used in your laboratory, the method of Figure 1 gives the smaller error unless R is very small.

A *rheostat* is a device you will be using a lot. It is a three-terminal element, which we could label **A**, **B** and **C**, as shown in Figure 2. The resistance between the endpoints **A** and **B** is a constant, let's call it R_0 . However, **C** is connected to a sliding contact. Therefore, the resistance between **C** and either endpoint can be varied between 0 and the maximum value R_0 . The net result is that a rheostat can be used as a variable resistance, by connecting it from **C** to either **A** or **B**. Make sure you understand this point before continuing. Ask your instructor for assistance, if necessary.

Procedure

Note: All circuits MUST be approved by your instructor before connecting to the voltage source

1. Diagram a circuit to measure the resistance of a fixed resistor R with a voltmeter and an ammeter by the method of Figure 1. Use a DC power supply for the voltage source. Include a switch and a variable resistance R' in series with the power supply. Including R' will enable you to vary the current through the fixed resistance R in a convenient way.

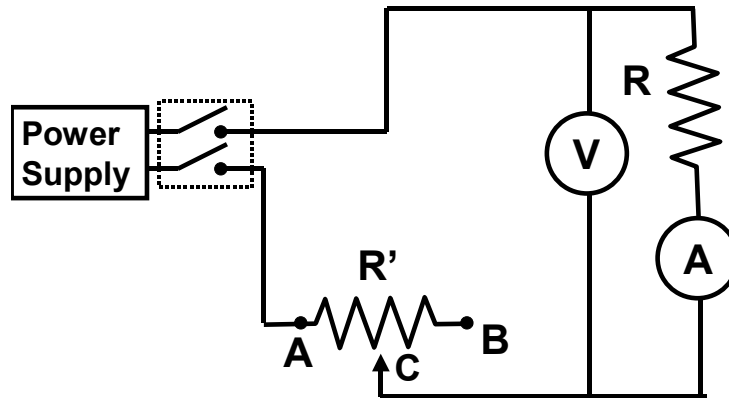


Figure 2

2. Wire up the circuit you designed in Part 1. above. *Do not turn on the power until your circuit has been approved by your instructor.*
3. Adjust R' to its maximum value. Record the ammeter and voltmeter readings. Obtain nine more pairs of readings for currents between 0 and about 1.00 ampere.

Calculations and Conclusions

- A.** For each set of readings (V , I) compute $R = V/I$. Also compute the average value of R .
- B.** Draw a graph showing the relation between potential difference (ordinate, or "y" axis) and current (abscissa, or "x" axis).
- C.** Theory, i. e., Eq. 1, predicts that the data points you plotted in Part **B** should fall on a straight line whose slope is the resistance R . After you convinced yourself of this fact, fit your data points to the best straight line, and compute its slope. Compare this value to the average R you obtained in **A**.
- D.** Explain how the graph and the computations verify Ohm's Law.

LABORATORY EXERCISE # 22

DC Circuits

Objectives

Study series and parallel circuits.

Equipment and supplies

6-Volt DC power supply, lamp sockets, rheostat, 1 A DC ammeter, 10 V DC voltmeter, wires with banana plugs.

Discussion

Resistors in series

When two or more resistors are connected end to end as shown in Figure 1, they are said to be in series. Any charge that passes through R_1 will also pass through R_2 , and then R_3 . Hence the same current I passes through each resistor. We let V represent the voltage across all three resistors, and V_1 , V_2 , and V_3 be the potential differences across each of the resistors, R_1 , R_2 , and R_3 , respectively. By Ohm's law, $V_1=IR_1$, $V_2=IR_2$, and $V_3=IR_3$. Because the resistors are connected end to end, the total voltage V is equal to the sum of the voltage across each resistor:

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \quad [\textit{series}] \quad (1)$$

The equivalent single resistance R_{eq} that would draw the same current would be related to V by

$$V = IR_{eq}$$

We equate this expression with Eq. (1) and find

$$R_{eq} = R_1 + R_2 + R_3 \quad [\textit{series}] \quad (2)$$

Thus when we put several resistances in series, the total resistance is the sum of the separate resistances.

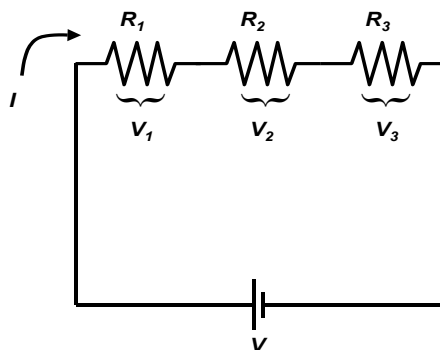


Figure 1 Resistors in series.

Another simple way to connect resistors is in parallel, so that the current from the source splits into separate branches, as shown in Figure 2. In a parallel circuit, the total current I that leaves the battery breaks into three branches. We let I_1 , I_2 , and I_3 be the currents through each of the resistors R_1 , R_2 , and R_3 , respectively. Because the electric charge is conserved, the current flowing into a junction must equal the current flowing out of the junction. Thus,

$$I = I_1 + I_2 + I_3 \quad (3)$$

When the resistors are connected in parallel, each experiences the same voltage. Hence the full voltage of the battery is applied to each resistor, so

$$V = I_1 R_1 = I_2 R_2 = I_3 R_3 \quad [\textit{parallel}] \quad (4)$$

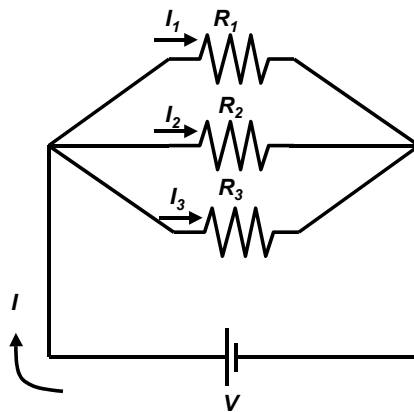


Figure 2. Resistors in parallel.

The equivalent circuit R_{eq} of the network must satisfy

$$I = \frac{V}{R_{eq}}$$

We now combine the equations above and obtain

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad (5)$$

Procedure

The lamp board contains three screw sockets for small incandescent light bulbs of various power ratings.

1. Set up a circuit to measure the resistance of a light bulb with a voltmeter and an ammeter by the method of Figure 3.

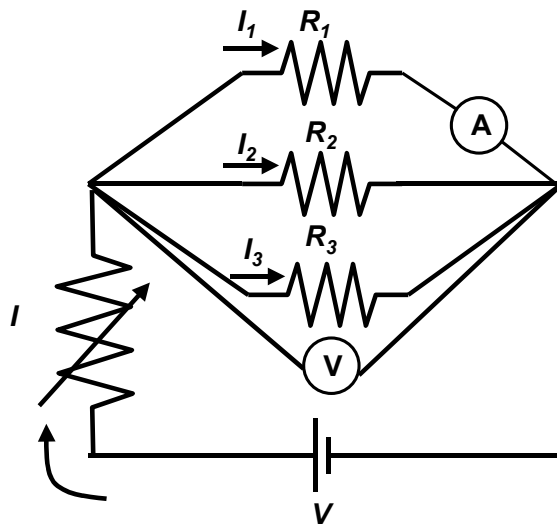


Figure 3. Circuit for measuring the resistance using a voltmeter and an ammeter.

Set the voltage drop across the light bulbs to approximately 4 V by adjusting the knob of the power supply and the rheostat. Measure the voltage drop across and the current through the light bulb. Repeat the measurement for the other two light bulbs. Make a note on the brightness of each light bulb.

Then re-arrange the ammeter to measure the total current, I , in the circuit.

2. Connect the light bulbs in series as illustrated in Figure 4. Set the current to 0.14 A. Measure the current in the circuit through and the voltage drop across the light bulb. Then repeat the measurement for the other two light bulbs.

Re-arrange the voltmeter to measure the total voltage drop across three light bulbs. Make a note on the brightness of the light bulbs.

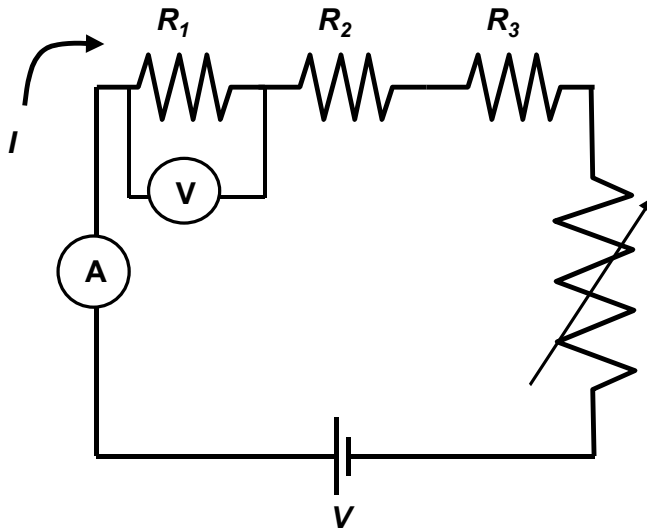


Figure 4

3. Connect two light bulbs in parallel and the third one in series as shown in Figure 5. Set up the ammeter and voltmeter to measure the total current, I , the total voltage drop, V , of the circuit, and the current through and voltage drop across each of the light bulbs.

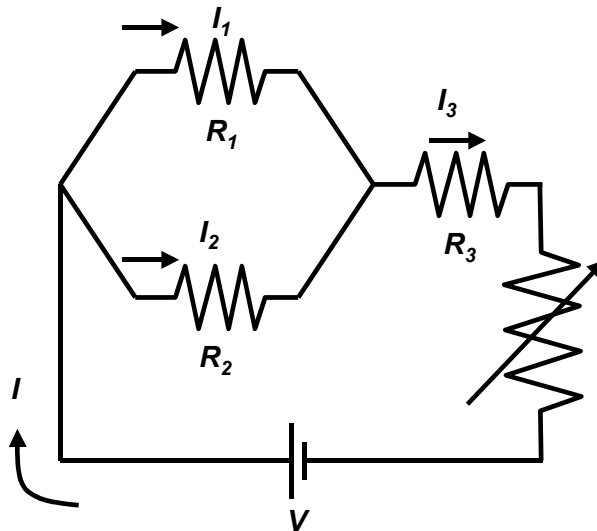


Figure 5. Combination of series and parallel circuits.

Calculations and Conclusions

1. For each set of readings (V , I) obtained from the parallel connection, compute $R = V/I$ for each light bulb. Also compute the power $P = IV$.

Draw a circuit diagram. Use the resistance value for each light bulb to calculate R_{eq} . Then compare the calculated R_{eq} and the measured value obtained from the ratio of the voltage drop and total current.

2. Draw a diagram for the series circuit. Use the measured resistance value for each light bulb to calculate R_{eq} . Then compare the calculated R_{eq} and the measured value based on the ratio of the total voltage drop and the current
3. Draw a diagram for the series-parallel circuit. Use the measured resistance value for each light bulb to calculate R_{eq} . Then compare the calculated R_{eq} and the measured value based on the ratio of the total voltage drop and the total current

Force on a Current Carrying Conductor in a Magnetic Field

PURPOSE

To show how the force on a current carrying conductor in a uniform magnetic field depends on the length of the conductor and on the current in it.

Equipment and supplies

10 A DC ammeter, 20 Ω Rheostat, vernier calipers, magnet, 4 current loops, Force on a magnet apparatus, 6-Volt DC power supply, rheostat, and current balance.

Discussion

If a current is sent through a straight conductive wire in a magnetic field, there is a force on the conductor which is perpendicular to both the conductor and the direction of the field. If the magnetic field is uniform and perpendicular to the conductor, this force is given by:

$$F = BIl \quad (1)$$

where B is the uniform field in tesla, l is the length of the conductor in meters, I is the current in amperes, and F is the force in newtons.

In this experiment, the magnetic field is supplied by a strong Alnico magnet. By Newton's third law, there is a force on the magnet equal but opposite to the force on the conductor. The magnet is placed on the pan of a balance, and the force on the magnet, rather than the equal force on the conductor, is measured.

The validity of equation (1) will be studied in three ways. Note that B , the field of the permanent magnet, cannot be varied in this experiment.

1. The force will be determined as a function of l when B and I are constant (Procedure section 2).
2. The force will be determined as a function of I when B and l are constant (Procedure section 3).

Procedure

1. Select a current loop, and plug it into the ends of the arms of the main unit with the loop extending down.

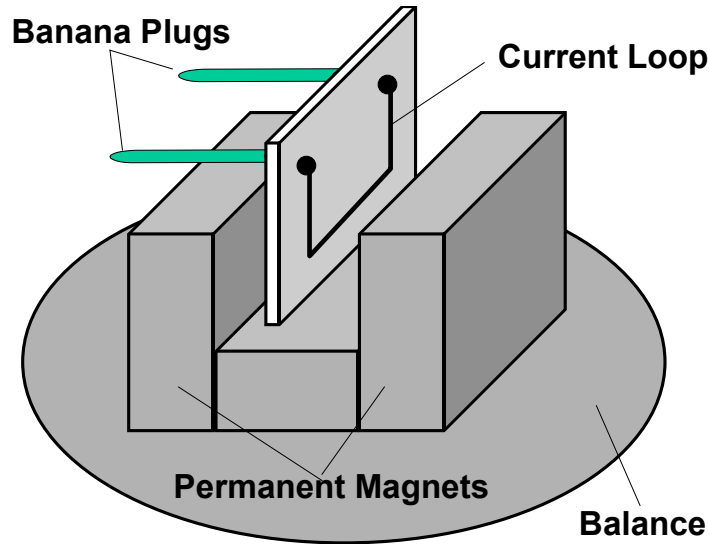


Figure 1 Current balance for measuring the magnetic force.

2. Place the magnetic assembly on the balance as shown in Figure 1. Position the lab stand so the horizontal portion of the current loop passes through the pole region of the permanent magnets. The height of the main unit on the lab stand can be adjusted by sliding unit along the pole. The current loop shouldn't touch the magnets.
3. Connect the power supply, ammeter and rheostat as show in Figure 2.
4. First, set the current to zero. Measure the weight of the magnet assembly (F_0) Then turn on the current, adjust it to the desired level, and measure the weight of the magnetic assembly with current flowing (F_1). (Use the rheostat for fine adjustment of current reading) With current flowing, the reading will be higher or lower than before. The difference in weight ($F_1 - F_0$) is proportional to the force exerted on the current-carrying loop. To investigate the relationship between the current and force, vary the current from 0 to 5 A for every 0.5 A and measure the weight at each current value.
5. To change the current loop:

Swing the arm of the main unit upward to raise the current loop out of the magnetic field gap. Pull the current loop gently from the arms of the main unit. Replace it with a new current loop and carefully lower the arm to reposition the current loop in the middle of the magnetic field.

Four current loops, SF 37, 38, 39, and 40, are supplied with the apparatus. Measure the length (l) of the horizontal segment of the current loop.

6. Repeat the measurement described in Step 4 and 5 for three other current loops.

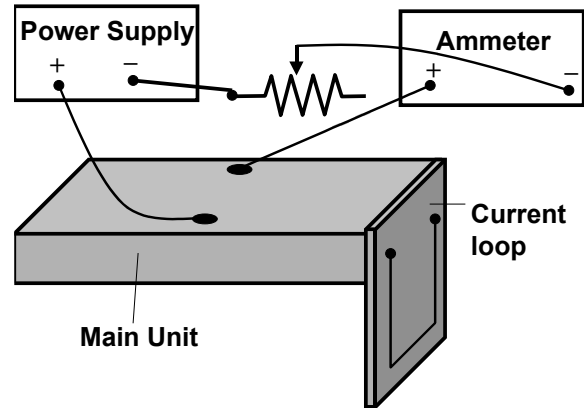


Figure 2. Circuit diagram.

CALCULATIONS AND CONCLUSIONS

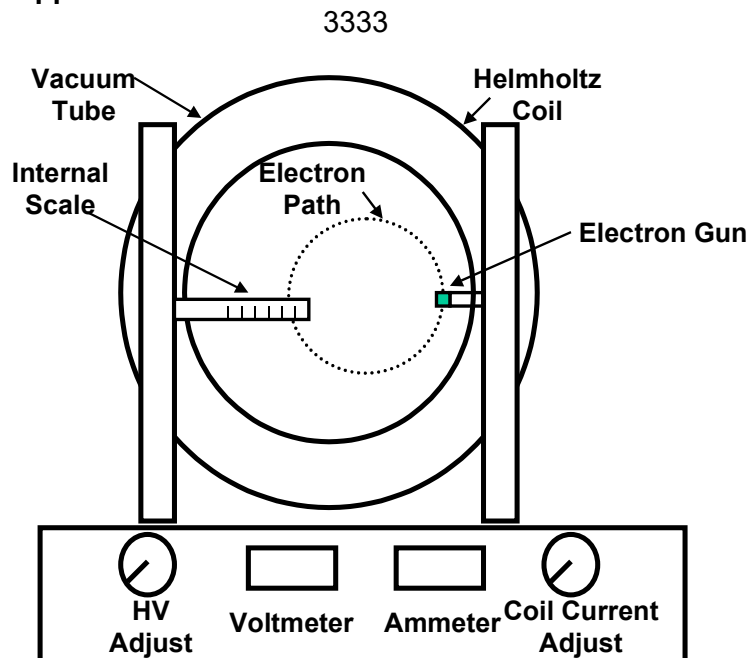
- A. From the data obtained in (4)-(6) plot graphs of force F (in newtons) against current I (in Amperes). From the slopes of the graphs and the value of l , find the magnetic field B .
- B. Explain why only the length of the horizontal segment of loop, rather than the entire length, is used in the analysis of A.
- C. From the data in (4)-(6), plot a graph of force F (in newtons) against l (in meters) for $I=2$ A. From the slope of this graph and the value of I , find the magnetic field B .
- D. Compare the results of two different methods of A and C see if the differences are within expected errors.

The Specific Charge of the Electron

Objective

To relive the classic experiment that elegantly measures the quantity e/m for the electron, thereby proving that it is a *particle* with both mass and charge.

Equipment and supplies



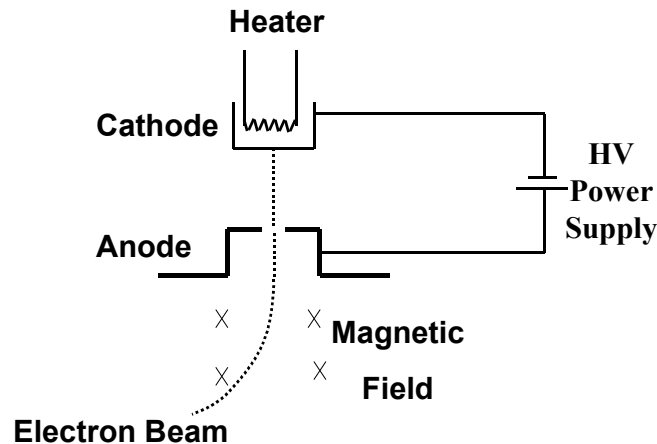
A special triode, Helmholtz coils, vernier calipers, half-meter stick.

Discussion

The equipment is all wired up for your viewing pleasure, but you should understand the basic ideas. When you look down on the tube you see a "bull's eye" circular plate. Right behind the hole, in the middle of the disk, is an *electron gun*. The electron gun consists of a filament, focusing grid and plate (three elements, hence a *triode*).

- The *filament* is heated red-hot by a 6.3 VAC power supply. Note that the filament circuit contains an AC ammeter to measure this heating current, and a 17Ω rheostat for fine control of its temperature. In the high vacuum inside the glass envelope, the hot filament "boils off" a cloud of negative electrons kicked out by the violent atomic thermal vibrations in the filament. This is the phenomenon of *thermionic emission*.

- A high positive DC voltage (with respect to the filament) is applied to a fine mesh *grid* close by. Naturally, some of the floating electrons are accelerated toward the grid.
- The grid is mostly holes, so a lot of electrons shoot right through on their way to *the plate*, which has itself been charged to an even higher positive DC voltage, up to +150 VDC. Note from the circuit diagrams provided, that the smaller grid voltage is picked off from the plate power supply by a potential divider.



The particular design of the electron gun causes a thin, highly collimated beam of electrons to emerge from the tiny hole drilled in the circular plate you see as the bull's eye center. When no magnetic field is present, the beam continues straight up. (Check it out!) By the way, the electron beam is made faintly visible because the electronic tube contains a tiny amount of a noble gas that glows purple when struck by the electron beam.

Now comes the interesting part. A set of *Helmholtz coils* produces a uniform magnetic field in the region of the beam, and perpendicular to the electron velocity. As you will see, this causes the beam to bend into a circular orbit. The centripetal force is the magnetic deflection force on a moving charge:

$$F = B e v = m v^2 / r \quad (1)$$

where, B is the magnetic field in tesla, e is the electric charge of the electron in Coulombs, v is the electron speed in m/s, m is the electron's mass in kg, r is the radius of the circular orbit. (We will use the diameter, $d = 2 r$, since that is what you actually measure when you observe the semicircular orbit taken by the electrons.)

The electron speed is related to the plate voltage, V , by the following expression of the conservation of energy, since the final kinetic energy is equal to the initial electrostatic potential energy, and remembering that the magnetic force does no work since the force is always perpendicular to the velocity:

$$V e = \frac{1}{2} m v^2 \quad (2)$$

Equations (1) and (2) can be combined into one equation by eliminating the speed, v . The resulting equation can be solved for the specific charge of the electron in terms of the accelerating voltage, V , the magnetic field strength, B , and the orbit diameter, d , to obtain:

$$\frac{e}{m} = \frac{8V}{B^2 d^2} \quad (3)$$

Since V and d are easily read off, the only other thing you'll need is the value of the magnetic field, B as a function of the relevant observable, the current in the coils, I . That relation is,

$$B = [\mu_0 (4/5)^{3/2} \frac{n}{R}] I = [C] I \quad (4)$$

where, $\mu_0 = 4 \pi \times 10^{-7}$ S.I. units

n = the number of turns in each of the Helmholtz coils, provided by the instructor

I = The current in the coils in amperes

R = The mean radius of the coils, which you should measure for yourself

C = a constant, whose value you can now compute by deft use of your scientific calculator and all the constants in the square brackets.

For a typical set of coils in this apparatus, the number of turns is 130 per coil and the radius is 0.152 m so that $B=0.77$ milliteslas/ampere. Your coil radius will be a little different from this value, so measure the dimensions carefully.

Finally, you can use equation (3) to calculate the value of e/m .

Procedure

1 . Set the apparatus on a level table. The room light should not be too bright, because the electron beam will be hard to see.

2. In order to minimize the influence of geomagnetism. use a compass to locate magnetic North and align the Helmholtz coils so they are parallel to the needle. If this is not convenient, it can be disregarded with little effect on the results (certainly less than other errors in the measurement).

This will have the effect of reducing the influence of geomagnetism on the magnetic field parallel to the coil axis. The influence of geomagnetism or other sources of magnetic fields can be observed by the deflection of the circular motion of the electron beam while

the apparatus is rotated. The magnitude of this deflection is greater when a small current is flowing through the coils.

3. With the power switch off, connect the line cord to the correct line voltage power.
4. Turn on the power switch. The unit will perform a 30-second self-test, indicated by the digital display changing values rapidly. During the self-test, the controls are locked out, allowing the cathode to heat to the proper operating temperature. When the self-test is complete, the display will stabilize and show "000". Although the unit is now ready for operation, a 5- 10 minute warm-up time is recommended before taking measurements.
5. Turn the *Voltage* Adjust control up to 200V and observe the bottom of the electron gun. The bluish beam will be travelling straight down to the envelope of the tube.

Note: Both the Voltage and Current outputs are controlled by an on-board microprocessor. Because the microprocessor automatically locks out the controls at both the minimum and maximum settings, there is no need to provide a manual "stop" on the knobs. When the knob reaches the maximum setting, it will still turn, although the value shown on the appropriate display will not change. These features prevent excessive loads being placed on the tube and provide a smooth, jitter-free display.

6. Turn the Current Adjust control up and observe the circular deflection of the beam. When the current is high enough, the beam will form a complete circle within the envelope. The diameter of the beam can be measured using the internal centimeter scale inside of the tube. The scale numbers fluoresce when struck by the electron beam.
7. For an accelerating voltage of 200V, measure the beam diameter for 8 coil current settings.
8. Set the accelerating voltage to 300V, and repeat the measurements in Step 6.
9. Repeat Step 7 for two additional accelerating voltages.
10. If a small ceramic magnet is available, move it close to the tube and observe the deflection of the beam. It is easy to see how properly designed magnets can be used to focus and steer an electron beam.

II. Reset both controls to zero and switch off the apparatus.

12. Measure the internal and external diameter of the Helmholtz coils on several axes. They may not be quite round and the two coils may not be quite the same. Average your measurements and determine the standard error, so that you will be able to decide whether it has a significant effect on the accuracy of your results.

If the electron gun is not pointed downward, the electron beam will travel on a spiral path. To correct this, loosen the mounting screws of the vacuum tube and rotate the tube a little until the electron gun is in the proper orientation and the beam is circular.

This adjustment should be done by a laboratory technician before the laboratory session and not left to the student.

Calculation and Conclusions

A. Compute the value of the constant C in Eq. (4).

B. From Equation (3) it can be seen that the product of the electron path diameter, d , times the value of the magnetic field, B , should be a constant for a single setting of the acceleration voltage V . From this average value, the value of e/m can be calculated.

C. Compare your value of the specific charge of the electron with the accepted value, 1.76×10^{11} Coulomb/kg. Does your experiment agree with the accepted value within your stated precision? If not, you have some explaining to do!

Question: Is there evidence of systematic errors? If so, what is the effect on e/m expressed as a percent?

Question: After you subtract out any systematic error, what is the average random error in V that is needed to enable your data to be consistent with the theory? Express as a percent.

The two above percent values give you a very precise idea of how "good" your experiment was.

The Oscilloscope

Objectives

To become familiar with a general-purpose oscilloscope, an instrument that can display and measure time-varying voltage

Equipment and supplies

A dual-trace digital oscilloscope, a 5-foot oscilloscope probe with option of "10x" attenuation, i.e., by a factor of ten, an R-C circuit box with variable capacitor and variable resistor, a 1.5 Volt dry cell, and a function generator.

Introduction

The Oscilloscope is an instrument for measuring and displaying the instantaneous voltage of an electrical signal. Modern digital oscilloscopes contain fast electronics which digitize and store the time series of incoming signals and display the waveforms according to the mode of operation set by users. Key options of the mode of operation are summarized below:

DC coupling and AC coupling:

When the voltage signal contains a time-varying signal superimposed on a DC background, the signal can be displayed through DC coupling which retains the DC component or through AC coupling which removes the DC component, as shown in Figure 1. When the time-varying signal is small compared to the DC background, removing the DC background can help highlight the time-varying part for better viewing.

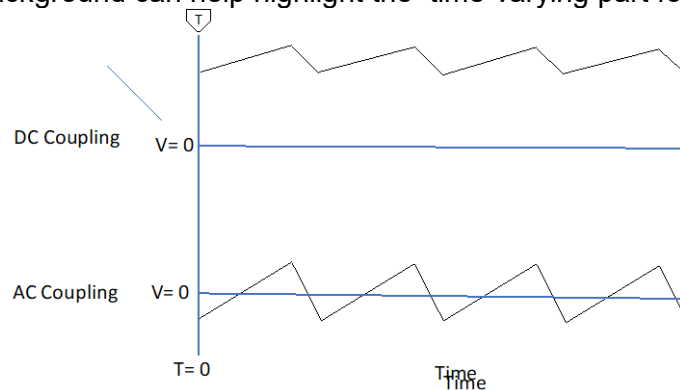
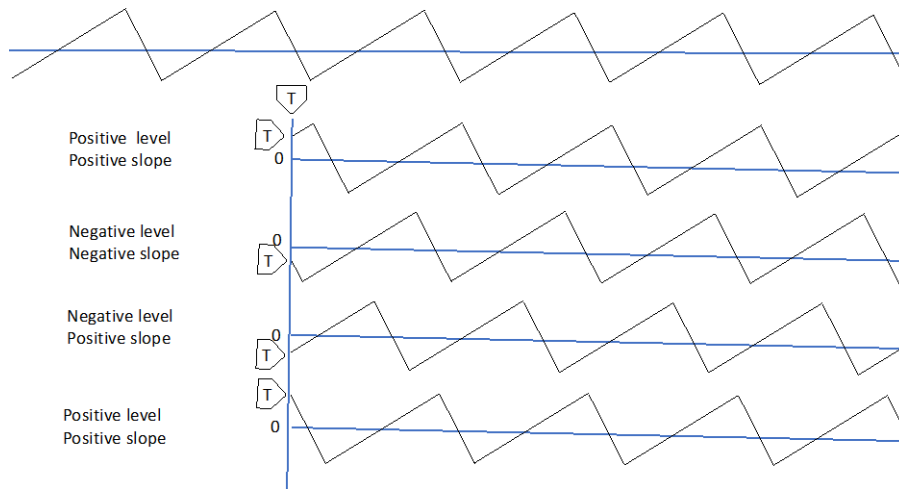


Figure 1. A sawtooth waveform with a DC background through DC coupling and AC coupling.

Trigger Mode:

The time to begin a sweep is determined by the Trigger. The waveform of a free-running signal can start at different levels and slopes as shown in Figure 2.



$$V_v = V_0 \sin(2\pi t / T_v)$$

Figure 2. The waveforms under different trigger levels and slopes. The trigger level for each waveform is marked by a trigger level cursor.

If the trigger level is not properly set, the displayed waveform will be unstable.

Procedure

A. Disconnect all cables from the front of the scope. Connect the oscilloscope to the bench AC power source, turn on the power, and carefully adjust the controls following the steps below:

You will see a horizontal yellow line which is the signal from Channel 1 (CH1). Since there is no signal yet, you will see a featureless horizontal line.

Press 2 to activate CH2. A purple trace will show up.

An example of a screenshot with an sinusoidal signal in CH1 and various cursors and readings is shown in Figure 3.

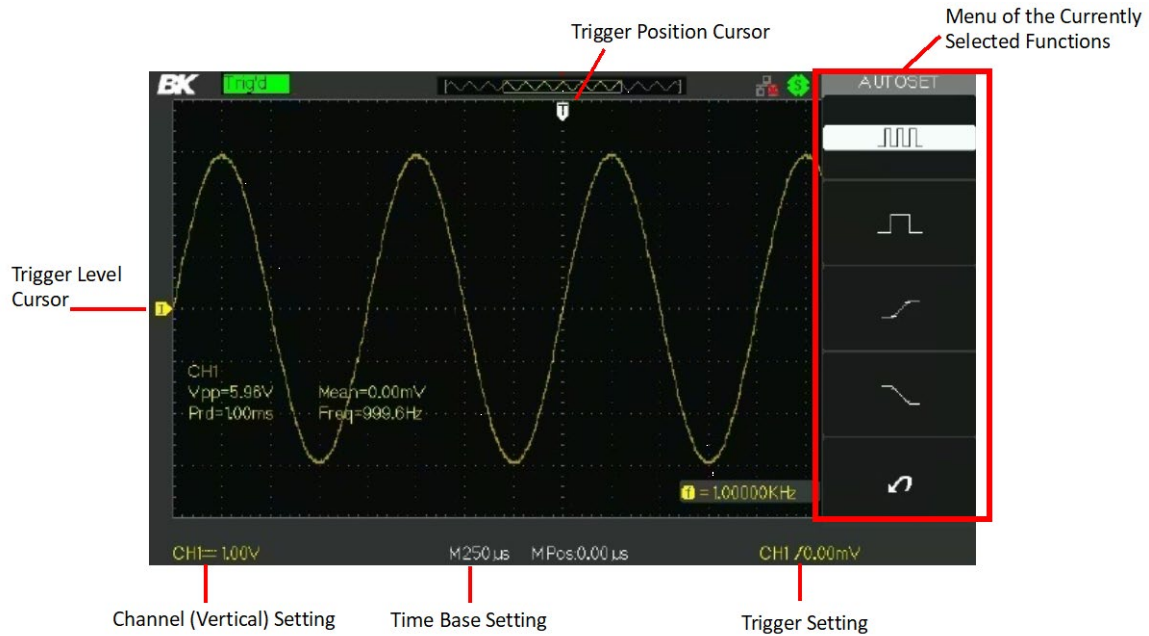


Figure 3 A typical screen shot

To display the waveform, you need to set Horizontal time scale, the Vertical voltage scale and Trigger level and slope.

Horizontal group (time scale):

Select:

TIME ----- Set the horizontal sweep rate to $500\mu\text{s}$ per division (M500 μs at the bottom center of the screen)

POSITION----- Observe how Trigger Position Cursor T (the white cursor on the very top of the screen) moves as the knob is rotated. Cursor T points to the beginning of the sweep or time=0. Note that Time Zero, as marked by Trigger Position Cursor is necessarily on the left edge of the screen. Digital oscilloscopes can display "prehistoric" events.

Trigger group

Press Trig Menu on the right side of the panel. The trigger menu will show up on the right side of the screen.

Select :

- Trigger Type : Edge
- Source: CH1
- Slope: Rising slope
- Trigger Mode: Auto

TRIGGER LEVEL-- Rotate the knob to see how the Trigger Level T and trigger line move.

These settings tell the machine to start a sweep when the signal in CH1 has a positive slope and when the voltage reaches the Trigger Level set by the knob.

Vertical group (signal channels):

CH 1

Press Button 1 for CH 1 to enable it if the button is not lit.

POSITION-----Play with it, to see how the trace moves. Position it to the middle.

Voltage. -----500mV (reading shown on bottom left of the screen)

Coupling-----Press the button to select DC .

CH2

Press Button 2

POSITION-----Play with it, to see how the trace moves.

Coupling-----Press the button to select DC .

A1. Play with the vertical position knobs of CH1 and CH2 to see how the knobs control the vertical positions of the yellow and purple traces. Return the traces to convenient positions with the yellow trace above the purple trace by at least one vertical division

A2. Play with the horizontal position knob, and then return trace to a convenient position (centered).

A3. Set the horizontal **time scale** to 500 ms. Note that the traces sweep to the right at a rate of 1 cm every 1/2 second, then quickly return to the left to start all over again.

Now slowly rotate the **time scale** knob to increase the sweep speed. Note that after about 5 milliseconds per division, the moving dots will appear to be continuous lines.

B. Channels 1 input

B1. Find and examine the special five-foot oscilloscope "probe". One end has a male BNC connector, which you should now connect to the input of CH1. The other end has a spring-loaded hook to allow good contact with small circuit parts, and an "alligator clip", to make "ground" connections. You see that this probe can connect the CH1 input to any voltage source.

Note: The body of the probe has a tiny red switch. You will use the "1x" setting. The 10x (ten times) setting attenuates all input voltages by a factor of ten; It is useful for looking at voltages which go off scale.

B2. The first circuit you will study is built into the chassis of the oscilloscope. The jack on the lower right corner of the front panel supplies a square-wave calibration signal between it and chassis ground. You can display it by connecting the probe to CH1 and attaching the hook probe to the output terminal and the alligator clip to the grounding jack labelled with $\frac{1}{2}$. Now take the data requested in your data sheet. (The last column should always come out to be the same value, if all is well.)

B3. Connect the calibration signal to CH2 and assure yourself that this channel also is well calibrated. If the signal is not steady or is travelling, press Trig Menu and select trigger **SOURCE** to CH2 and play with the trigger knob. Measure the amplitude of the calibration signal. Complete the data sheet.

B4. Rotate Horizontal time base setting to observe the square-wave for all possible settings. Answer the question in the data sheet.

B5. Using whatever **Horizontal** sweep time setting you find most convenient, measure the period of the square-wave signal. Then repeat for two more sweep-time settings. Here the horizontal and vertical **POSITION** settings will come in handy in positioning the square wave on the scope grid.

C. Signal coupling to the oscilloscope.

CI. So far you have been using the DC setting on the inputs to the scope for both CH1 and CH2. Now press CH1 button and then the coupling button to rotate the choices from DC to AC to GND observe the following:

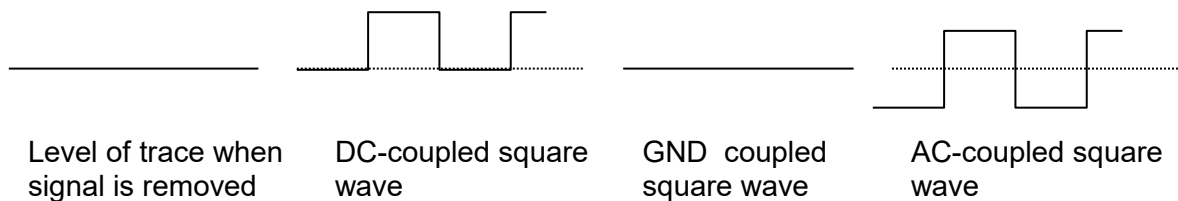


Figure 4

Summary of results:

- DC coupling---- allows correct display of all signals, AC and DC.
- GND----- "grounds" the input, thereby displaying zero signal no matter what the input
- AC coupling---- Displays only the AC part of the signal by suppressing the average value of the input signal.

Note, AC coupling is useful when you want to look at a small AC signal riding on top of a large DC signal. e.g.,

$$V(t) = 100Volts + (5millivolts) \sin \omega t$$

Next, turn on the Function Generator, choose sinusoidal wave shape, and select a frequency between 200 Hz and 1000 Hz, Set the knob for amplitude to the middle. Connect the probe to the output of the function generator. Note that the black alligator clip on the probe must be connected to the black output of the function generator.

Press the **Trig Menu** button on the right side of the panel under Trigger. This will bring up the menu on the screen.

Select

Trigger Mode : AUTO

(In the AUTO mode, the oscilloscope displays a waveform when the trigger conditions set by user are met. If the conditions are not met, the oscilloscope will force the sweep to begin anyway.)

Turn the knob that controls the trigger level until the trigger level is above the highest signal level. Describe and explain what you see.

Move the Trigger cursor and observe how the displayed waveform shifts as the knob is turned.

Press the rising and descending slope buttons and observe how the trigger slope affect the waveform. Take a screenshot and explain how the trigger conditions are reflected in the waveform.

C2. Measure the voltage of the dry cell on your benchtop using the alligator clip and hook probe. Which coupling is appropriate, AC or DC? (Hint: if you AC couple a DC voltage, you'll **see** nothing!)

D. Series RC circuit.

D1. Connect the following circuit using the output of the function generator with the RC Series selection. Connect the positive lead of the function generator to the top of the variable capacitor. Connect the probe hook to the top of the variable resistor, and both the ground of the function generator and the alligator clip to the bottom of the variable resistor. Start with 1M ohm as the resistor selection and 100 pF as the variable capacitor selection. Select Square Wave using the wave shape switch on the front panel of the function generator.

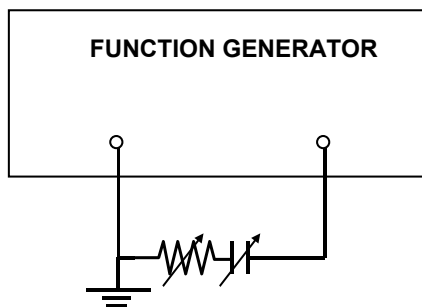


Figure 5

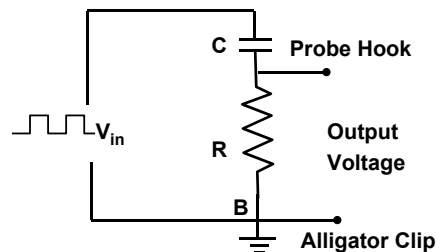


Figure 6 Equivalent circuit of Figure 5

Now, use the 1 x probe to display the voltage across the resistance R on the scope. Make sure the probe ground clip is on the ground side of the resistance. Set the

frequency of the function generator to be 500 Hz and voltage output to be 2 V . Vary R and C using the labeled knobs, and observe the following:

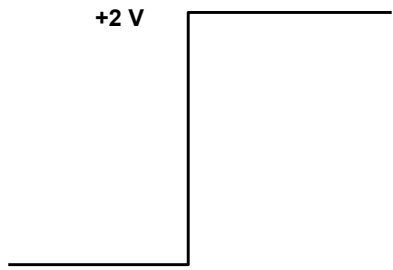


Figure 7a Input voltage

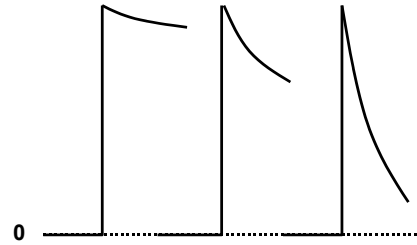


Figure 7b Output voltage for high medium and low RC product

Check that the product of the values of R and C used in the circuit is indeed the time constant of the exponential decay you see on the scope. Measure the decay constant by using the fact that an exponential decreases by a factor of $1/e \approx 0.37$ when the time advances by one time constant. Display and measure at least two values of RC that are at least one order of magnitude apart.

To accurately measure the time constant, you may need to turn the Time position knob to move the Trigger Position Cursor to the left end of the screen and vary the Trigger Level and Trigger Slope until a clear rising edge of the waveform appears on the left edge and a single decaying pattern fill most of the screen.

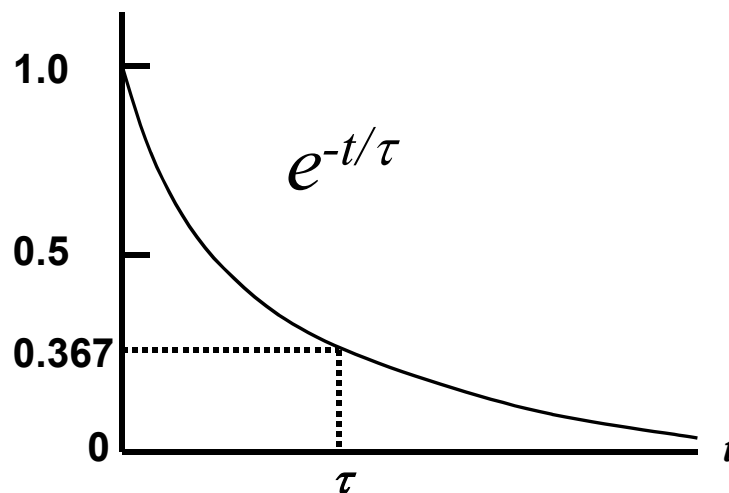


Figure 8

Data Sheet: Oscilloscope

Date: _____

Name: _____ Partners: _____

Instructor's Signature: _____

Note: Data should only be taken on well triggered, i.e., not jittery displays. If playing with trigger settings does not work, call your instructor. (You may not look so good, if it's a simple matter of making sure the trigger source is chosen wisely, here INT, the slope is the one you want, +, and the trigger level has been carefully turned in the pushed-in position.)

B2. Vertical Sensitivity	CAL Signal Amplitude	CAL Signal Amplitude
(Volts/Division)	(# of Divisions)	(Volts)
5		
2		
1		
0.5		

Why was it unnecessary to connect the ground clip?

Ans:

B3. Measure the amplitude of the calibration signal using CH2 at four different settings 5, 2, 1, 0.5 Volt/ Div. Record the results.

Are the measurements of CH1 and CH2 reasonably well in agreement? i.e., are the readings obtained on the 5, 2, 1, 0.5 Volt/ Div settings the same?. Circle one:

Yes/ No

B4. For what range, approximately, of the SWEEP TIME settings does the square wave still look to your eyes as a recognizable square wave?

Time range:

B5.

SWEEP TIME/DIV	# of Divisions	Measured period, T	Frequency=1/T (Hz)

C1. The effect of Trigger

When the trigger level is above (below) the highest (lowest) signal, describe and explain what you see.

Provide screenshots of oscilloscope traces for two trigger conditions: 1. Positive level and negative slope, and 2. Negative level and positive slope. Explain how the settings are reflected in the waveforms in the screenshots.

C2. emf of dry cell: -----(Theoretical value is 1.5 Volts.)

What will be displayed if the dry-cell voltage is AC-coupled to the scope input?

a) zero b) 1.5 Volts c) something else.

D. Post screenshots for the decaying waveforms for at two values of RC that are at least one order of magnitude apart. Record the R and C values for each. Compare the theoretical time constant with the time constant measured from the waveform.

In what sense are you observing the current flowing in the circuit when you display the voltage across the variable resistance R ?

D1.

R (ohm)	C (farads)	RC (sec)	The time it took for the decay to fall to $1/e$ ($=0.37$) of the initial value?

Do the last two columns match within your reading precision (which, no doubt, you indicated in the data table above)?

- a) **yes** (the answer we are hoping you got)
- b) **no** (you must have done something wrong, Go back and try again.)

LABORATORY EXERCISE #26

PN Junction Diode

Objectives

To study the current-voltage characteristics of a junction diode and its application for rectification.

Equipment and supplies

6-Volt power supply, 1-k Ω rheostat, 10-k Ω resistor, 10- Ω resistor, mounted diode, two multi-meters, variable capacitor box, dual-trace oscilloscope, one scope probe, function generator, banana-plug connectors.

Warning: When you use a *multimeter*, you should make sure that it is switched to the function you want before you make any connections. If you are not comfortable with this, you should not proceed.

- A *voltmeter* has a HIGH input resistance, so it will draw very little current from the circuit to make its measurement.
- An *ammeter* has a LOW input resistance, so if you were to connect it across the power terminals a dangerously large current would flow, sparks would fly, and fuses would blow. It should never be used to "short" two points of different voltage.
- An *ohmmeter* should never be connected to a powered circuit. Its only purpose is to measure the resistance of an *isolated* resistor.

Discussion

The diode is like a one-way street for electric current. It is a *non-linear* device: it does not obey Ohm's law. One section of this silicon device is n-type silicon; electrons are the majority carriers. The other section is p-type silicon, so named to remind us that the charge carriers are positively charged "holes". The region in between, the PN junction, creates a barrier to the flow of one type of carriers, but not the other. As a result the effective conductivity of the device depends heavily on the *direction* of the applied voltage.

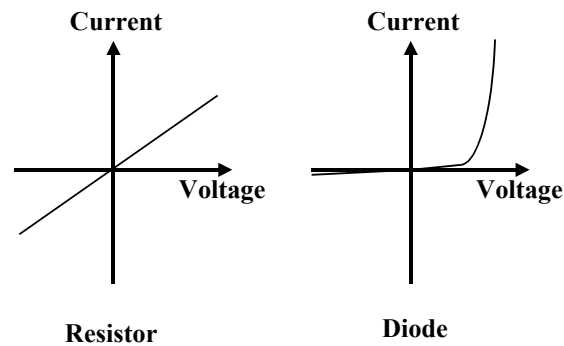


Figure 1 Comparison of the current vs. voltage characteristics of a resistor and a diode.



Figure 2 Forward bias and reverse bias.

The arrow in Figure 2 is the symbol of the diode. The arrow indicates the permitted direction of current. If the voltage is applied in the direction that enables the current to flow, the diode is under "forward bias". If the voltage is applied in the opposite direction, the diode is under "reverse bias" and the current is nearly very small.

Procedure:

A. Current-voltage characteristics for a diode.

1. Measure the open-circuit output voltage of the power supply at its various settings.

To do this, switch a multimeter so it measures DC voltage and connect it directly to the open terminals of the DC power supply. The idea is to convince yourself that the equipment is working properly and that you know how to measure a voltage with a multimeter. (By the way: with the voltmeter leads connected to each other, record the nominal zero. You will need to subtract this value from your readings to get the true voltage. You should find this important only for the lowest voltage measurements.)

2. Set up and use a "voltage divider" that allows you to vary the voltage.

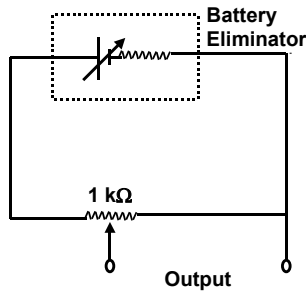


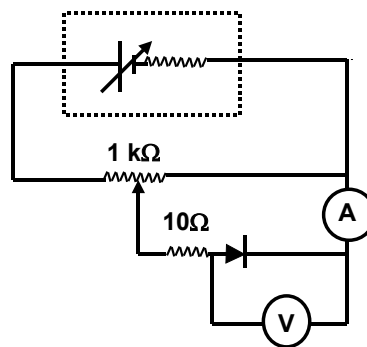
Figure 3. A Voltage divider.

Wire-up the circuit using a $1\text{ k}\Omega$ rheostat and the DC power supply as shown in Figure 3. Connect a voltmeter to measure the output voltage. Move the rheostat slider and note that you can now apply any desired voltage between 0 and some maximum value.

3. Measure the Current-Voltage characteristics of a forward-biased diode. (This is the main event of Part A).

Study the circuit in Figure 4. The initial setting of the battery-eliminator is around 1.5 Volts. The voltage divider allows you to smoothly change the applied voltage. The actual voltage across the diode can be measured by placing a voltmeter directly across it. Do so. Meanwhile, the ammeter reads the same current as flows through the diode since it is in series with it (the voltmeter draws negligible current). As a safety precaution, a $10\text{-}\Omega$ resistor is also placed in series with the diode to limit the current through it to a safe value no matter where you push the rheostat slider. Finally, note that the polarities of the power supply and diode as shown in the circuit will "forward bias" the diode.

Figure 4. Circuit for the I - V measurement.



After you understand the circuit, wire it up, have it checked by the instructor, especially the multimeter settings, and take I vs. V data. Pay attention to the current readings; take data from 0 to 10 milliamperes. *Warning: The I vs. V curve is highly non-linear. so it is necessary to take more data points in the region where the current increase sharply as the voltage increases. Sketching your data as you go is practically a must here.* By judicious setting of the rheostat slider, do not allow currents greater than 100 mA to flow.

4. Get the Current-Voltage characteristics for a reverse biased diode.

Switch the polarity of the diode and take the I - V data for voltages from zero to about 1 Volt.

Since reverse biased diodes don't conduct much, your current readings will be small.

5. Present your results in graphical form.

On a full-page, graph all the data you took in parts 3 and 4, above. V should be between -1 and about +3/4 Volts. Your grade in this lab depends most heavily on this one graph. It is expected that by now you know how to make a good looking graph.

B: Demonstrating half-wave rectification

6. Study, then wire up the circuit shown in Figure 5.

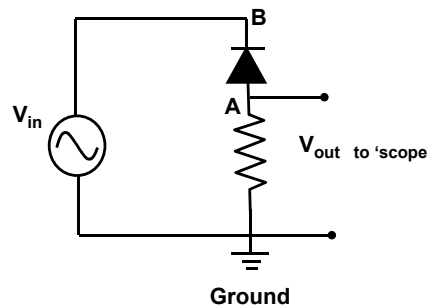


Figure 5 Circuit for measuring the effect of rectification. .

A sinusoidal voltage (V_{in}) is applied to a diode circuit. The resulting current through the diode is measured by monitoring the *voltage*, V_{out} , across a series resistance. For the AC power source use a sine-wave set at 1 kHz. Use a value of $R = 10 \text{ kW}$)

7. Display input voltage V_{GB} on the oscilloscope. "DC" couple the input signal so you can display DC as well as AC signals. Use the GND (ground) switch to locate the 0 Volt. Make sure you know how to display a steady signal for amplitudes from about 3 volts down to about 0.2 volts. (The trick is in the triggering controls.) Also, make sure all instruments used are wired so that grounds are common: It's a no-no to connect the oscilloscope ground to point A, for example. After you are convinced that you have an AC voltage source whose amplitude and frequency you know how to vary, return to the initial settings of about 3 volts peak and 1 kHz. Sketch this sinusoidal in your data sheet.

B. Display the current through the circuit and sketch its shape in your data sheet. This is done by connecting the oscilloscope from G (ground) to point A. Since the voltage

across a resistance is proportional to the current through it (Ohm's law), V_{GA} has the same shape as the current in the circuit. The signal you see on the scope is called "half-wave rectified AC." Make sure your 0 volt level is where you want it (check using the GND ground switch on the scope) then sketch two or three cycles of the displayed signal. Note that it does matter if you AC or DC couple the input. (Now you know why this switch is important.)

9. Connect a variable capacitor in parallel with R. Note what happens to the shape of V_{GA} as you increase the value of C. Make a series of sketches, corresponding to increasing values of C, which show the transition from half-wave rectified voltage to DC voltage. Start with the smallest value of C and watch the oscilloscope as you increase C. Before your very eyes you have made a circuit which changes AC to DC!

10. The relevant parameter is the ratio of the "RC" time constant (remember that 1 ohm x 1 farad = 1 second) to the period of the AC voltage. Investigate this by changing the *frequency* of the input voltage. For 100 Hz, and also for 10 kHz, what values of C give an output voltage with the same degree of smoothing as you sketched in a middle sketch in part 9,above?

Calculations and Conclusions

1 What is the effective resistance of the diode when it was forward biased by 0.7 volts?

($R_{eff} = V/I$)

2. What is the effective resistance of the diode when it was reversed biased by 0.7 Volts?

Tell how the fancy graph you drew from Procedure 3-5 can be used to explain how half-wave rectification occurs.

Explain the action of the capacitor in smoothing out the pulsating input voltage into progressively smoother DC.

The Speed of Light

Objectives

In this experiment you will measure the speed of red light in an optical cable made of transparent polymer material. I expect many of you will find this experiment elegant in its simplicity.

Equipment and supplies

Speed of light apparatus on a Printed Circuit board ("Griffin speed of light unit"), 15 cm optical fiber, 20 m optical fiber, dual trace oscilloscope, battery eliminator, 2 dual banana plugs, 3 red banana to micro leads, 2 black banana to micro leads.

Discussion

Brief pulses of light are generated by an integrated circuit provided for you, in such a way that you can display their outline on one of your two oscilloscope channels. The light pulses then travel down an optical fiber you yourself connect. At the other end, an optical receiver turns the light pulses into electrical pulses you can display on the second oscilloscope channel. When the scope is properly triggered, the time delay, t , between the "transmit" pulse and "receive" pulse can be measured and divided into the known optical path length ($D=20$ meters, for the cables provided) to yield the speed of light in the polymer medium:

$$v = D / t.$$

Procedure

INSTRUCTOR MUST CHECK CIRCUIT BEFORE ELECTRICAL POWER MAY BE APPLIED.

1. Power up the speed-of-light unit. Using "banana" plug connectors provided, apply 9 Volts DC to the appropriate terminals of the printed circuit (PC) board. Note that the terminals are labelled "0 V" and "+9 V", respectively. The former is color-coded **black** and will eventually also be connected to the oscilloscope ground. Note that red light is visible from the "TRANSMITTER" terminal in the lower right of the PC board.

2. Connect the 15 cm optical fiber to the PC board. Note that the optical fibers have "sweet spot" connectors on each end to enable you to easily insert and easily take out the optical fibers. A little careful practice is needed here.

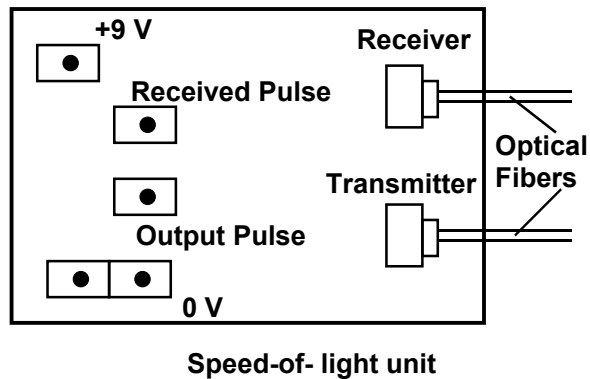


Figure 1: Speed-of-light unit.

Connect the DC power supply ground and the oscilloscope ground at lower left connections.

Connect the DC power supply positive terminal to the +9V pin.

Connect the oscilloscope Channel 1 to the "OUTPUT PULSE" pin.

Connect the oscilloscope Channel 2 to the "RECEIVED PULSE" pin.

3. Display the "OUTPUT PULSE" on the first oscilloscope channel.

This is actually a continuous series of short pulses, spaced about a microsecond apart. These are the pulses to be sent down the optical fiber. They are automatically generated by the PC board once the DC power is turned on. They are available for oscilloscope display at the white terminal labeled, "OUTPUT PULSE". You should connect the oscilloscope channel 1 to this white terminal, and the oscilloscope ground to the black "0 V" (zero volt) terminal. Next, you need to "trigger" the oscilloscope to obtain a steady display of two or three pulses. "Trigger source" should be Channel 1, which will have the steadier of the two signals you will eventually display.

4. Display the "RECEIVED PULSE" on the second oscilloscope channel.

First, connect the 15 cm optical fiber to both the TRANSMITTER and the RECEIVER connector jacks. Next, connect oscilloscope Channel 2 to the white terminal labeled, "RECEIVED PULSE". No new ground connection is necessary: One is enough, two would be too many. You are now ready to take data.

5. Measure the time it takes light to travel down 20 meters of fiber, using the oscilloscope.

When you completed procedure (4) above, you should have noticed that the "received pulse" was considerably more distorted than the relatively clean "output pulse". Also, that instrumental and other electronic phase shifts already caused a time delay between the two pulses. To subtract out these effects, we measure the time delay as the *difference* between the long and short optical fibers. The length difference is 20.0 meters. The time difference is your data for today. So, before you go on, pick a sharp feature of the "received pulse", and using the oscilloscope controls, center it on a grid-crossing of the oscilloscope display. Then, substitute the longer optical fiber, and measure the increase in delay time. Your result should be roughly 0.1 microsecond.

You should measure it as precisely as you can (two significant figures?) and check yourself by repeating the measurement several times, switching short and long fibers each time, and adjusting the horizontal position knob as necessary.

Hint: For your final run, use the oscilloscope 10x knob, located in upper right corner, which magnifies the time axis by a factor of five, giving you a higher reading precision on your time measurement.

Calculations and Conclusions

1. Compute the speed of light in the polymer, v .
2. Compute the "index of refraction" of the polymer material, n , defined as the ratio of the speed of light in vacuum to the speed of light in the medium, where c is the speed of light in vacuum, 3.00×10^8 m/s.

$$n = c / v.$$

3. Because of poor calibration, it is possible that some of the oscilloscopes' time bases are as much as 15% off. Assuming for the moment that this was the case for you, what statements do you need to make about the *accuracy* and the *precision* of your result for the speed of light in the polymer medium, v , which you computed above.

Part I: Refraction

Objectives

To determine the index of refraction from the measurements of (a) angle of incidence and refraction, (b) the critical angle.

Equipment and supplies

Light box, slits, plexiglass semicircular lens, semicircular water cell, ruler, protractor, white papers.

Refraction

When light strikes the boundary between two media it may be reflected, transmitted, or absorbed. Often all these three processes occur simultaneously. If the velocities of light in two transparent media are different and if an incident ray is not normal to the boundary separating the two media, the direction of the ray will be changed as it passes from one medium to the other. This bending of light is called refraction.

The law of refraction of light applied to the surface separating vacuum and a medium, discovered by Snell, is

$$\frac{\sin \theta_i}{\sin \theta_r} = n \quad (1)$$

where θ_i = the angle between the incident ray in vacuum and the normal to the surface, θ_r = the angle between the refracted ray in the medium and the normal to the surface, n = a constant depending on the two media called the index of refraction of the second medium (where the angle with the normal is θ_r) relative to the first (where the angle with the normal is θ_i). The index of refraction, n , is equal to the ratio of the speed of light in the first medium (vacuum) to the speed of light in the second medium and varies with the wave length of the light.

$$n = \frac{v_1}{v_2} \quad (2)$$

The index of refraction of a medium relative to a vacuum is called its absolute index of refraction and equals the velocity of light in vacuum divided by the velocity of light in the medium. Its index of refraction relative to air is practically the same as its absolute index since the speed of light in air is only very slightly less than its speed in vacuum. In this exercise, we assume the index of refraction of air equals that of vacuum.

The critical angle

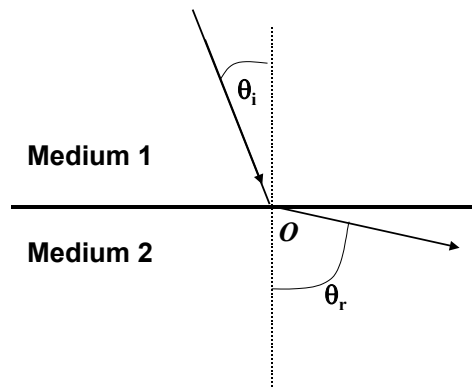
When light passes obliquely from medium 1 where its velocity is v_1 into medium 2 where its velocity is v_2 , it will bend away from the normal if v_2 is larger than v_1 (See Figure 1). As angle θ_i is increased, angle θ_r will increase to its maximum value of 90 degrees. The value of θ_i for which θ_r is 90 is called the critical angle . If θ_i exceeds θ_c , total internal reflection will occur. The index of refraction of medium 2 relative to medium 1 is equal to $\sin \theta_c$ since $\sin \theta_c = 1$, or the index of refraction of medium 1 relative to medium 2 is

$$n = \frac{1}{\sin \theta_c} \quad (3)$$

If medium 2 is air, the absolute index of refraction of medium 1 may be found by a determination of θ_c and the use of equation (3).

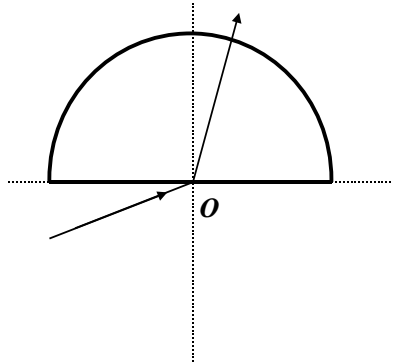
Figure 1. The light bends away from the normal when it enters Medium 2 in which the speed of light is larger.

Procedure



1. Insert the slit plate into the slot in the front of the light box to create a narrow beam of light. Adjust the light box (by sliding the top relative to the bottom) to make the beam collimated, without spreading, as much as possible.

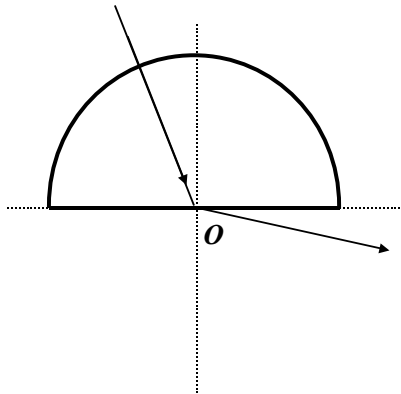
Place a sheet of unruled white paper on the wooden platform. Draw coordinate axes (x,y) with dashed lines on the white paper. Position the plexiglass lens so that the origin of the x-axis coincides with the flat edge of the lens and the origin, O, of the axes coincides with the center of the flat edge as shown in the following photograph. Arrange the sheet so that the beam is incident on the flat edge at point O.



(The beam is incident on the flat surface at point O.)

2. Adjust the angle of incidence, θ_i , to be between 45 and 60 degrees. Using two dots made with a sharp pencil to determine the direction of a straight line, trace the ray of the light and the outline of the lens. Repeat with an angle of incidence at an angle greater than 60 degrees.

3. Arrange the lens so that the beam is incident at the flat surface from the plexiglass. Make sure the laser beam passes through the origin of the coordinate axes as shown in the following photograph. Increase the angle of incidence so that the angle of refraction is 90. Trace the outline of the lens and the ray of light.



The beam is incident at the flat surface from the plexiglass.

4 Fill the semicircular cell with water. Wipe off any air bubbles and wipe the exterior dry. The water-filled container becomes a semicircular lens. Repeat 2) and 3).

CALCULATION AND CONCLUSIONS

- A. Measure the angles of incidence and refraction in the tracings of Procedures (2) and (4). Determine the indices of refraction of plexiglass and water from these measurements.
- B. Determine the critical angles from the tracing of Procedures (3) and (4). Determine the index of refraction for plexiglass and water from these critical angles.
- C. Calculate the velocities of light in plexiglass and water using results of A and B.

Part II. Focal length

Objectives

To study the principle of lenses by ray tracing, to verify the lens maker's formula, and to observe spherical aberration.

Equipment and supplies

Light box, four plexiglass lenses(plano-convex, plano-concave, biconvex, semicircular), pencil, half-meter stick, ruler, white papers, flash light.

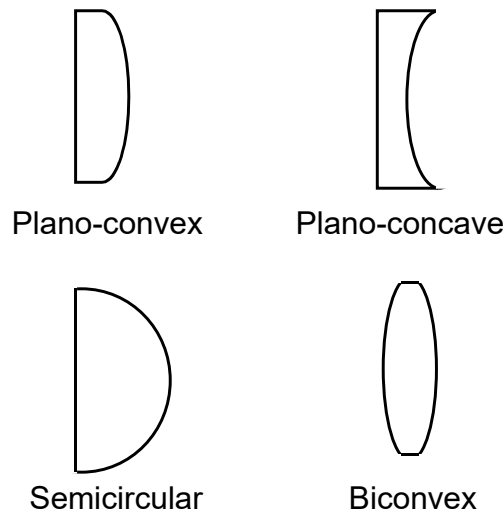


Figure 1 Plexiglass lenses used in this experiment.

Discussion

The lens bends the rays when the lens material and the surrounding medium have different indices of refraction and when the two surfaces are not plane parallel. Typically, the two surfaces can be convex, planar, or concave. If the lens material at the center of the lens is thicker than at the edge, the lens is a converging lens. Parallel rays can be brought to a focus by a converging lens.

Consider the rays parallel to the axis of a converging lens, which is shown in Figure 2. We assume that the lens is made of a transparent material, so its index of refraction is greater than that of the air. The axis of a lens is a straight line passing through the very center of lens and perpendicular to both lens surfaces. By applying Snell's law to both lens surfaces, we can see that each ray is bent toward the axis after passing through the lens and focused to a point, F , called focal point. This will not be precisely true for a lens with spherical surfaces. But it will be nearly true for "thin lenses"- that is, parallel

rays will be focused to a tiny region that is nearly a point.- if the diameter of the lens is small compared to the radii of curvature of the two spherical surfaces.

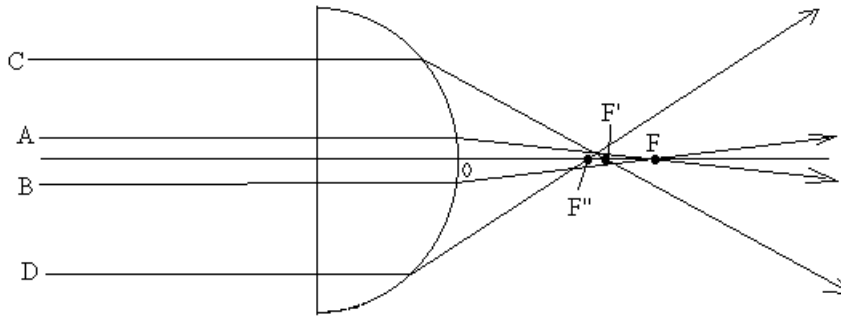


Figure 2

In general, when the diameter of the beam is not small compared to the radii of curvature of the spherical surfaces, the focal point is not a point. In Figure 2, rays A and B, closer to the axis of the lens, are focused to a focal point F while rays C and D, farther away from the axis, are focused to a slightly different focal points F' and F''. Thus the focused spot as view on the screen placed at the focal point F is not sharp. This phenomenon is known as the spherical aberration.

The focal length of a thin lens is given by

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

where f is the focal length, n is the index of refraction of the lens material, and R_1 and R_2 are the radii of curvature of the two surfaces. R_1 and R_2 are positive for convex surfaces, negative for concave surfaces, and infinity for planar surfaces.

Procedure

1. Insert the slit plate into the slot in the front of the light box to create three narrow beams of light. Adjust the light box (by sliding the top relative to the bottom) to make the beams parallel as much as possible.
2. Place the plano-convex plexiglass lens on a white paper. Arrange the light box so the rays are parallel to the axis and pass through the central portion of the lens. Use a pencil to trace the rays.
3. Measure the focal length, defined as the distance from the focal point to the center of the lens.
4. Repeat the measurement for the plano-concave and biconvex lenses. For the plano-concave lens, the focal point is obtained by extending the rays to the back of the lens.

5. Repeat steps 2 and 3 with the semicircular lens. Measure the focal points for rays close to the axis, corresponding to A and B in Figure 2, and away from the axis, corresponding to C and D.

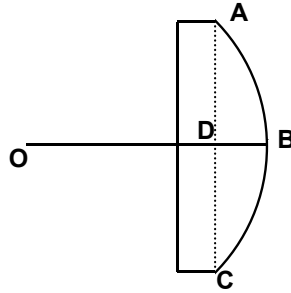


Figure 3

6. Determine the radii of curvature of the spherical surfaces of the lenses using the following method. First, use a pencil to trace the shape of the lens as illustrated in Figure 3. Measure the width AC and the thickness BD of the spherical surface. The radius of curvature OB can be calculated using the following relation:

$$\overline{OB} = \frac{\overline{DB}^2 + \overline{AC}/2^2}{2\overline{DB}} \quad (2)$$

Calculation and Conclusions

- A. Calculate the theoretical focal lengths for the plexiglass lenses using the radii of curvature determined in Step 6 and the index of refraction measured in Part I. Compare the calculated results with the measured results.
- B. Discuss the effect of spherical aberration observed in the semicircular lens.

Mirrors and Lenses

Objectives

To study how mirrors and lenses form images and to measure their *focal length*. To use the *lens* and *mirror equation*.

Equipment and supplies

Optical bench with 4 carriages and 4 holders, illuminated object, half screen, full screen, plane mirror, concave mirror, convex mirror, converging lens, diverging lense, white screen, meter stick, and flash light.

Discussion

Concave Spherical Mirror

The *principal focus* of a concave mirror is half way between the mirror and its center of curvature. Light rays parallel to the *principal axis* of the mirror converge after reflection from the mirror* to this *focal point*. Light from a far-away object will form a *real, inverted image* in the *focal plane*. The "mirror equation" tells where the image will be formed:

$$1/p + 1/q = 1/f \quad (1)$$

where, f is the focal length, i.e., the distance from the focus to the mirror,
 p is the object distance, i.e., the distance from the luminous object to the mirror,
 and q is the image distance, i.e., the distance from the image to the mirror.

This same mirror equation can describe more complicated situations if we adopt the following "sign convention":

- f is always positive for a concave mirror,
- p is positive for a real object, negative for virtual object,
- q is positive for a real image, negative for a virtual image.

A *real* image is formed by light rays actually converging to form an image. For example, if you place the luminous object at any distance p greater than f , you will get a *real* image. (It will be *inverted* and *in front of* the mirror.) Light rays do not converge to a physical place in the case of a *virtual* image, as you discovered when you tried to touch your (*virtual !!*) image in your bathroom mirror. A virtual image that you can obtain right now is formed by placing the luminous object closer to the mirror than the principal focus. This image will be *erect* and *behind* the mirror.

The following equation tells you how the relative size of the image depends on its relative position:

$$\{\text{image size}\} / \{\text{object size}\} = \{\text{image distance}\} / \{\text{object distance}\} = q / p \quad (2)$$

Converging Lens:

Note: Converging lenses are thicker in the middle than at the edges.

Lenses have two focal points, symmetrically placed, one on each side. Their distance to the lens is the focal distance, f . Light from a very distant object will *converge* to a real image in the focal plane. Try this right now using the skyline as the distant object. Note: the image will be *real* and *inverted*.

The position of the image is given by the *lens equation*. Amazingly, this looks just like Equation (1). Also, equation (2) applies here just as well. To make your life even simpler, the sign conventions for a concave lens are the same as for a concave mirror. Examples:

- a) A real object placed at a distance greater than f , will result in a real, inverted image on the other side of the lens.
- b) A real object placed between the focal point and the lens, will result in a virtual, erect image on the same side of the lens.

Note: if an object were to be placed at a distance just equal to f , rays of light from any point on the object would emerge from the lens as parallel rays (this is really the definition of f). Now, if a plane mirror were placed behind the lens, the bundle of parallel rays would be reflected back toward the lens also as a parallel bundle. (The mirror distance should not be too important, here.) Then, the lens will converge the rays to a focus in the focal plane, forming a real image superimposed on (or right next to) the original object. You will use this method to determine f , in Procedure 6.

Diverging Lens

Note: Diverging lenses are thicker at the edges than in the middle.

After a parallel bundle of rays goes through a diverging lens, the rays *diverge*, but appear to come from a point on the same side as the luminous object. This defines the focal point, and focal distance, $-f$, as usual. Equations (1) and (2) apply if we use the revised sign conventions, which are summarized below, and now apply to all cases:

Sign conventions:

- f is positive for a concave mirror or lens, but negative for a convex mirror or lens,
- p is positive for a real object, negative for virtual object,
- q is positive for a real image, negative for a virtual image.

All images of real objects formed by diverging lenses are virtual, erect and on the same side of the lens as the luminous object.

Procedure

In recording data, for each part draw a horizontal line to represent the optical bench, and a vertical segment to represent each piece of apparatus (object, screen, mirror, lens, etc.) in the appropriate location on the bench. Record below each vertical segment the exact position as read from the calibration on the optical bench.

Concave Mirror

1. Obtain a *real* image of the luminous object on a screen using a single converging mirror. Final data should be for the case $p = q$, i.e., so that the object distance is the same as the image distance. Record the relative sizes of image and object, and whether the image is erect or inverted.

2. Repeat, but with the image distance only half the object distance. Measure and record the heights of the object and image, and whether the image is erect or inverted.

Converging Lens

3. Obtain a *real* image of the luminous object on a screen using a single converging lens. Final data should be for the case $p = q$, i.e., so that the object distance is the same as the image distance. Record the relative sizes of image and object, and whether the image is erect or inverted.

4. Repeat, but with the image distance only half the object distance. Measure and record the heights of the object and image, and whether the image is erect or inverted.

5. Keeping the object and screen positions in (4) unchanged, move the lens toward the object until a sharp image is again obtained on the screen. Is the image larger or smaller than the object? Is it erect or inverted?

6. Place a plane mirror between the lens and screen. Now move the lens only until a real image is formed in the plane of the object. This is a little tricky, make sure the mirror is lined up straight, and look for the image right on the face of the object mask.

7. Obtain an image of a distant object (the sky line or a nearby building) on the screen with the converging lens. You will have to remove them from the optical bench, and ask your partner to measure q .

Diverging lens

8. Arrange the luminous object, *converging lens*, *diverging lens*, and the screen on the bench. Position the converging lens at 50 cm from the luminous object. Next, place the *diverging lens* at 20 cm from the converging lens. Then, move the screen until a real image is formed on the screen. Record all the positions.

Calculations and Conclusions

A. Compute the focal length of the concave mirror from the data in (1) and (2).

B. Compute the focal length of the converging lens from the data in (3), (4), (5), (6) and (7).

C. Compute the focal length of the diverging lens from the data in (8).

C. For all the cases where image and object dimensions were measured, check the validity of Equation (2).

Interference and Diffraction

Objectives

To study the wave nature of light by observing the interference fringes of double slits (Young's experiment) and the diffraction patterns of single slits.

Equipment and supplies

Helium-neon laser, single slits, double slits, slit holder, optical rail, 2 rail carriers, translation stage with micrometer, filter, microscope, white viewing screen, detector, digital multimeter, and graph paper.

Discussion

Interference- Young's double-slit experiment

Thomas Young's double-slit experiment is the first evidence for the wave nature of light. Consider plane waves of light of a single wavelength falling on a double slits, s_1 and s_2 , as shown, in Figure 1. Because of diffraction, the waves leaving the two small slits spread out as shown in Figure 1. This is equivalent to the interference pattern produced when two rocks are thrown into a lake. If light consisted of particles, we would expect to see two bright lines on the screen behind the slits. Instead, Young observed many bright and dark lines. If the distance d between the slits is very small compared to the distance to the screen, constructive interference occurs on the screen at an angle, when the path difference $d \sin \theta$ equals a whole number of wavelength,

$$d \sin \theta_m = m\lambda \quad m=0, 1, 2, 3, \dots \quad [\text{constructive interference}] \quad (1)$$

The value of m is called the order of the interference fringe. For example, the first order ($m=1$) bright fringe forms at angle θ_1 on each side of the center at $\theta=0$. Dark fringes of destructive interference occur when

$$d \sin \theta_m = (m+1/2)\lambda \quad m=0, 1, 2, 3, \dots \quad [\text{destructive interference}] \quad (2)$$

The intensity of the bright fringes is greatest at the center and decreases for higher orders. The interference fringes produced by the double-slit experiment can be detected by moving a detector across the fringes. In Figure 1, the angle is equal to x/L .

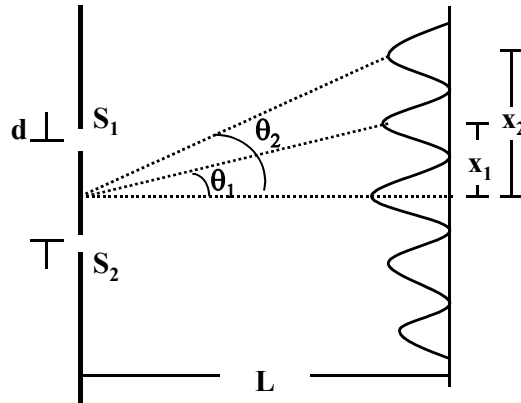
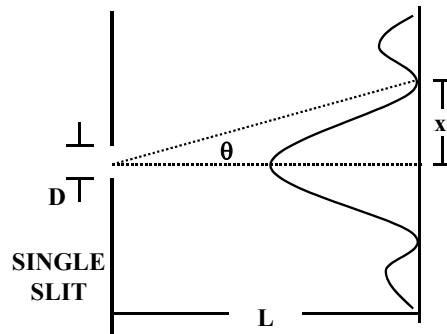


Figure 1 Young's double-slit experiment.

Diffraction-

When plane waves of light of single wavelength illuminates a narrow slit, light can diffract around the edges, giving rise to bright and dark fringes. To see how a diffraction pattern arises, parallel rays fall on the slit of width D as shown in Figure 2.

Figure 2 Single slit experiment.



If the viewing screen is far away, the rays heading for any point on the screen are essentially parallel. Consider the waves emanating from the upper half and lower half of the slit. Destructive interference, a dark fringe, occurs if the path difference from any point in the upper half of slit and the corresponding points in the lower half of the slit is an integer multiple of $\lambda/2$ so that the total electric field is zero. The angle at which this occurs can be seen from the diagram to be

$$D \sin \theta = \lambda \quad \text{[first minimum]} \quad (3)$$

The intensity is a maximum at $\theta = 0$ and decrease to zero at the angle given by (3).

At a larger angle , there will be a bright line, but not nearly as bright as the central spot at $\theta=0$. As the path difference becomes an integer multiple of $\lambda/2$, there will again be a minimum of zero intensity when

$$D \sin \theta_m = m\lambda \quad (4)$$

Procedure

Warning: A helium-neon laser is used in this experiment. Your eyes could be harmed if directly exposed to the intense laser beam.

DIFFRACTION

(1) Place the slit holder at 10 cm in front of the laser. Place the screen on the rail at about 60 cm in front of the laser. Turn on the helium-neon laser. Remove the filter cap if it is on. Place slit plate #9165 A, containing a set of four single slits of various widths, on the holder. Adjust the position of the slit holder so that the laser beam illuminates one of the slits and a clear diffraction pattern appears on the screen. Observe the diffraction patterns for various slit widths.

The motion of the translation stage is controlled by a delicate high-precision micrometer with a travel range of 2.5 cm. Do not force the micrometer to travel beyond the range of reading.

(2) Remove the screen and place the detector at the same position. Adjust the height of the detector so that the diffraction pattern is at the same height as the marks on the detector.

The photo detector is a solar cell which, when illuminated by light, generates electric current proportional to the intensity of light. In order to increase the spatial resolution the front center of the detector is covered by a 100-micron-wide slit.

Measure and record the distance between the slit and the detector.

Screw the filter cap on the laser head. Set the reading of the micrometer on the translation stage to 1.5 cm. Slide the slit holder laterally until the laser beam illuminates slit "D". Loosen the screw and slide the mounting plate of the detector laterally and find the position where the meter reading reaches maximum. (If the maximum reading is larger than 0.7 mA, move the slit laterally until the maximum reading is within the scale.) Clamp the detector mounting plate on the translation stage by fastening the screw.

Record the background current reading when the laser beam is blocked. This reading can be positive or negative.

Record the current reading as a function of position for every half turn (one turn = 0.5 mm) of displacement. Plot the recorded photo-current as a function of position. The plot should include the central maximum and at least one secondary maxima on each side. Make sure to subtract the background current reading.

(3) Place the viewing screen back on the rail at the end of the rail. Remove the filter cap from the laser head. Position plate #9165 B, containing four pairs of double slits, so that the laser beam illuminates both slits. With proper illumination, the interference pattern appears clearly on the screen. The typical pattern is a superposition of the single-slit diffraction patterns which you have seen in PROCEDURES (1)-(2) and fine structures of the interference fringes of double slits. For this part of the experiment, we will concentrate on the fine structures within the central maximum of the diffraction pattern.

Observe the interference fringes for slit pairs of various slit separation.

Record the distance between the detector and the slits.

(4) Remove the white screen. Place the filter cap on the laser head. Position the detector at the end of the rail and adjust the height so that the interference pattern is at the same height as the detector.

Slide the slit holder so that the laser beam illuminates slit pair A.

Clamp the slit holder. Record the photo-current as a function of position for every 1/4 turn of the micrometer. Take readings for at least four intensity maxima.

Measure the distance between adjacent **dark** fringes by reading the distance of the positions of minimum photo-current. The accuracy can be improved by measuring the total distance of more than one fringe and take the average.

(5) Measure the separation between the double slits using a microscope. The separation should be measured from center to center or from edge to edge.

Calculations and Conclusions

- A. Plot the angular distribution of the data recorded in PROCEDURE (2) for the single slit on a graph paper.
- B. Calculate, from the given slit width and the laser wavelength = 632.8 nm, the angular separation from the central maximum to the first and second minimum of the diffraction pattern. Compare this calculated values with the measured values of PROCEDURE (A).
- C. Plot the angular distribution of the data recorded in PROCEDURE (4) for the double slit.
- D. From the measured fringe spacing in PROCEDURES (4) and the measured slit separation in PROCEDURE (5), calculate the wavelength of the He-Ne laser. Compare the measured values with the known value.

Grating Spectrometer

Objectives

To measure with the grating spectrometer (a) the wavelength of light from a sodium lamp, and (b) the wavelength of the lines in the visible portion of the mercury lamp.

Equipment and supplies

Spectrometer, diffraction grating with 300 lines/mm, sodium arc lamp, mercury arc lamp, magnifying glass, flash light.

Discussion

When a beam of light is incident perpendicularly on a system of evenly spaced slits (a diffraction grating), interference between the light from the different slits results in transmitted beams travelling in only certain directions which make angles θ_1 and θ_2 with the direct beam (Figure 1). The value of θ depends on the wavelength of the light, the distance between the slits d and the order of the spectrum n .

$$n\lambda = d \sin \theta_n \quad (1)$$

If d is known and θ_n is measured, λ can be found. For a grating with 300 lines/mm, $d = 1\text{mm}/300 = 3.3$ microns.

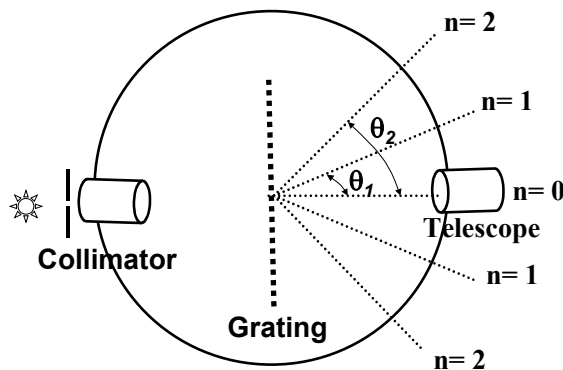


Figure 1

In this experiment, the diffraction angles will be measured with the spectrometer. The spectrometer consists of an entrance slit, a collimator, a grating, and a telescope. The light entering the entrance slit is collimated and illuminates the grating at normal incidence. The various orders of diffracted light can be observed by the telescope.

The grating is clamped on the spectrometer table so that it is roughly perpendicular to the incident beam from the collimator. The telescope is then set to position $n=1$ on one side of the directed beam so that the collimator slit image for the wavelength to be measured is bisected by the cross hairs. The angular position of the telescope is then read from the circular scale. The telescope is then turned to the position $n=1$ on the other side of the direct beam where the image of the slit is again bisected by the cross hairs and the new angular position recorded. The difference of the two readings is twice the diffraction angle. This method eliminates the error resulting if the grating is not exactly perpendicular to the incident beam. The same method is used to determine the second order diffraction angles. With some gratings, third and fourth order spectra may be observed.

Procedure

FOR THIS EXPERIMENT, THE SPECTROMETER ADJUSTMENTS HAVE BEEN MADE. IF THESE ADJUSTMENTS ARE DISTURBED THEY MUST BE REMADE AND A SERIOUS DELAY WILL RESULT. Check the collimator and telescope adjustments by illuminating the collimator slit with white light and observing its image in the telescope. If the image of the slit is not sharp or if parallax with the cross hairs is observed, the adjustments have been disturbed. In this case, notify your instructor. Throughout the experiment, a narrow slit is to be used.

1. Turn on the sodium lamp and allow it to warm up for 15 minutes. In the warm-up period, check the spectrometer adjustment. With the sodium lamp illuminating the entrance slit, and the telescope in the $n=0$ position, observe the image of the collimator slit. If the image of the slit and the cross hairs are not sharp or if there is parallax between the cross hairs and the image of the slit, the instrument adjustments have been disturbed. Focus the telescope for parallel light by bringing the cross hairs and the image of a distant object, such as a distant building, into coincidence. Then focus the collimator for parallel light by moving its slit until a sharp image of it is seen in the telescope.
2. When the color of the sodium light turns bright yellow, the lamp is ready for use. Clamp the grating on the grating table of the spectrometer so that it is perpendicular to the incident beam of light from the collimator. With the grating in this position, clamp the spectrometer table and DO NOT CHANGE ITS POSITION DURING THE EXPERIMENT. Record the number of lines per centimeter for your grating.

The front surface of the grating must be aligned with the center of the grating table.

3. Using a sodium lamp, measure the first order diffraction angles for the yellow lines. (wavelength = 589.3 nm) If the collimator and telescope is properly focused, two closely spaced lines can be resolved. The separation between the two yellow lines increases with diffraction orders. Record the positions of the doublets for all orders.
4. Using a mercury arc source, measure first order diffraction angles for the bright lines in the visible spectrum of mercury. Also measure the second order diffraction angles for two of the brightest lines.

The wavelengths of the strong lines in the mercury spectrum are:

Violet-----	404.6 nm	moderate intensity
-----	407.8 nm	weak
Blue-violet-----	435.8 nm	strong
Blue-green-----	491.6 nm	very weak
Green-----	546.1 nm	strong
Yellow-----	577.0 nm	strong (unresolved)
-----	579.0 nm	strong (unresolved)

Calculations and Conclusions

- A. Calculate from your data the wavelengths of sodium light and the separation between the doublets, and compare the calculated value and the accepted value.
- B. Calculate from your data the wavelength of each of the mercury lines and compare each calculated value and the accepted wavelength.
- D. Determine, using Equation (1), which of the lines are to be expected in the second, third, fourth, and fifth order of the mercury spectrum for the grating used. Compare with observation.

Absorption of Radiation

Objectives

The purpose of this experiment is to observe the penetrating power of radiation. At the same time you will learn a little about radiation detection and about the statistical nature of radioactive events.

The radioactive samples you will be given are harmless under the conditions of the experiment. However, you should handle them with caution.

Equipment and Supplies

Geiger Counter, Geiger tube, plastic stand, Solid alpha, beta and gamma sources, 5 aluminum sheets each containing 1, 2, 5, and 20 (two) sheets of aluminum foils mounted on a slide, 5 lead sheets, Vernier calipers, electric timer,

Discussion

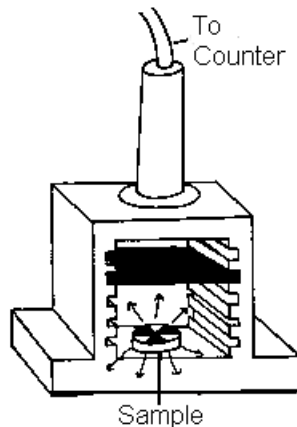
"Radioactive" nuclei spontaneously break up into high-energy fragments. The ensuing radiation can normally be classified as alpha, beta or gamma rays, with each event potentially delivering energy in the MeV range. (MeV = 10^6 electron Volts = 1.6×10^{-13} Joules.)

Alpha rays are positively charged objects consisting of four tightly bound nucleons (two neutrons and two protons).

Beta rays are high energy electrons or positrons.

Gamma rays are high-frequency quanta of electromagnetic energy (MeV photons).

While there are many ways to detect radiation, you will use one of the most common, the Geiger Counter. It can measure the *activity* of the source, i.e., the number of nuclear disintegrations per second. In addition to the radiation from the particular source you are measuring, your Geiger counter will also respond to *Background radiation*, i.e., radiation from all other distributed sources, like your classmates' sources, cosmic rays and other naturally occurring radioactivity.



Background radiation counts must be subtracted from all your readings before your data can be interpreted.

Procedure

1. Learn how to use the Geiger counter by practicing with the gamma source.

The Geiger tube you have needs 450 Volts DC from the back of the Geiger Counter. Make sure you locate the "900/450 VDC" switch and keep it at the 450 setting for the rest of your lives. Right next to this switch there is another that enables/disables an audio circuit to let you hear each recorded event: Use whichever setting pleases you more.

With the gamma source (printed side up) in the depression in the bottom of the white plastic stand, practice getting counts per minute using the RATE setting, and absolute counts using the CONTINUOUS setting. In each case, the red LED (light emitting diode) flashes to show that a count is recorded. In the CONTINUOUS mode each count is recorded immediately on the 2 cm red digital display. In the RATE mode, the display changes only once every 60 seconds showing the value of "counts for the last minute" immediately preceding the change. Practice reading with the gamma source "near" and "far"* (let's say up to about 20 cm) and with the unit switched alternatively to RATE and CONTINUOUS modes.

Important note about the RESET button: In CONTINUOUS mode, this button has an immediate effect on the digital display, just as expected. In RATE mode, however, the display will only change 60 seconds later, to the then current value of "counts for the last minute". Absorb this distinction, or you'll be confused and upset.

2. Measure the background radiation count rate.

With all sources at least one meter away, measure the background count by taking 60-second counts (take five in a row), using the RATE mode. *You will use the average of these five measurements to correct all subsequent data.*

Note: The statistical nature of radioactivity implies that the "error" on a measurement of n counts is

$$\pm \sqrt{n}$$

This result means that the *percent* uncertainty on a count of n is $\pm(100/n^{1/2})\%$. For example, a count of 548 should be entered in your data sheet as 548 ± 23 , since the square root of 548 is 23.4. Convince yourself that this count is good to about 4%. On the other hand a low count, let's say of only 47 would be uncertain to $\pm 15\%$. (take out your calculator and check it out!) So, for situations with low count rates, you may want to count for a longer period of time to bring the count up and the uncertainty down. (Good "counting statistics").

Catching on to this reality about random events may be the most important lesson you take with you from this laboratory exercise.

Another example, to test your understanding: You obtain the following counts in three separate RATE measurements of the background : 51, 62, 40. In all, you got 153 (± 12) counts in 3.00 minutes. Therefore, your measured background rate is 51 ± 4 counts/min (an 8% uncertainty).

3. Study the shielding power of Aluminum and Lead against gamma rays.

a) Measure the count rate when the Co^{60} **gamma** source is in place, and one lead (Pb) sheet is placed immediately below the Geiger tube. Repeat for 2, 3, 4 and 5 lead sheets between source and Geiger tube. Plot the log of (background-corrected) counts/min vs. the number of shielding sheets. It's expected that you get a straight line fit to these five points.

b) Repeat using the aluminum (Al) sheets instead of the lead. Plot both the aluminum and the lead data on the same graph. Do not take data for 0 (zero) shielding sheets in place, but leave room on the graph paper as if you did. Your finished graph should show "error bars" on all data points, showing the uncertainty of each count. Only then can you decide how good is your straight-line fit, and whether you should now go back and repeat your measurements with greater precision (better counting statistics).

c) Measure the thickness of the aluminum and lead sheets. Use the bulk density of aluminum ($2,700 \text{ kg/m}^3$) and lead ($11,350 \text{ kg/m}^3$) to compute the surface mass density for each type of sheet. Now, replot the data from parts a) and b) above, but label your horizontal axis in units of surface mass density, g/cm^2 .

4. Measure the shielding power of Aluminum against beta rays.

Unlike γ -rays, β -particles are electrically charged, so they interact much more strongly with ordinary matter. For this experiment, you will need thin aluminum foils. They have been mounted in cardboard slide-mounts for ease of handling, and are labeled in a corner with the number of single sheets pressed together. With the six slides you should be able to take data for 0, 1, 2, 5, 10, 20, 30, and 50 sheets. For each case,

measure the counting rate to better than 10% and plot the log of the corrected count vs. number of thin Al foils. Show error bars on each data point and fit a straight line to the data points.

5. *Check out the alpha radiation source.*

Check to see under what conditions, if any, you are able to get a reading above background for the α -source. This is a 2-minute exercise.

Calculations and Conclusions

Make sure that every count number you wrote in your data sheet has an explicit uncertainty associated with it.

Answer these questions on a separate sheet:

Gamma:

- (1) How many lead (Pb) sheets would it take to stop half the γ radiation from the Co^{60} source ?
- (2) How many to permit only 1/8 of the radiation to get through?
- (3) How many to be completely assured that 100% would be stopped?
- (4a) If we had to use aluminum instead of lead, how many more sheets would it take to stop half the γ -radiation from the Co^{60} source? Express as a factor.
- (4b) Within experimental error, is this factor the same as the ratio of the surface mass densities (Pb/Al)?
- (4c) What evidence do you have that in determining the shielding power of a material to γ -rays the most important parameter is its density ?

Beta:

- (6) If your instructor provides the *thickness* of the thin aluminum foil used in your experiment, calculate the thickness of aluminum needed to cut down the β -radiation by half. Compare with the corresponding value for γ -rays you found above.

Alpha:

- (7) The manufacturer suspects that the thin material covering the Geiger tube window is unfortunately thick enough to stop almost all the α -particles emitted by the source provided. On the basis of your experiments in part (6), do you agree? Can you give a quantitative justification for your answer ?

Data Sheet: Ohm's Law

Date: _____

NAME: _____ Partners: _____

Instructor's Signature _____

V, Potential Drop across <i>R</i> Volts	<i>I</i> , Current through <i>R</i> Amperes	Computed resistance $R = V/I$ ohms

Average value of *R* from above computation: _____ ohms.

Data Sheet: DC Circuits

Date: _____

NAME: _____ Partners: _____

Instructor's Signature _____

A. Parallel circuit

	V, Potential Drop across (Volts)	I, Current through R (Amperes)	Computed resistance $R = V/I$ (ohms)	Computed Power $P=VI$ (Watts)
R_1				
R_2				
R_3				
R_{eq}				

Draw a circuit diagram and calculate R_{eq} and I .

Compare the sum of the power of each light bulb in the parallel circuit with the total power based on VI .

B. Series circuit

	V, Potential Drop across (Volts)	I, Current through R (Amperes)	Computed resistance $R = V/I$ (ohms)	Computed Power $P=VI$ (Watts)
R_1				
R_2				
R_3				
R_{eq}				

Draw a circuit diagram and calculate R_{eq} and I .

Compare the sum of the power of each light bulb in the parallel circuit with the total power based on VI .

C. Parallel-Series circuit

	V , Potential Drop across (Volts)	I , Current through R (Amperes)	<i>Computed resistance</i> $R = V/I$ (ohms)	Computed Power $P=VI$ (Watts)
R_1				
R_2				
R_3				
R_{eq}				

Draw a circuit diagram and calculate R_{eq} and I .

Compare the sum of the power of each light bulb in the parallel circuit with the total power based on VI .

Data Sheet: Force on a Current....

Date: _____

Name: _____

Partners: _____

Instructor's Signature: _____

Procedure (4)-(6)

Wire Length = _____ m

Current (A)	Balance Reading (Kg)	Net Force (newtons)
<i>I</i> =0 (Reference Balance)		
0.50		
1.00		
1.50		
2.00		
2.50		
3.00		
3.50		
4.00		

Wire Length = _____ m

Current (A)	Balance Reading (Kg)	Net Force (newtons)
<i>I</i> =0 (Reference Balance)		
0.50		
1.00		
1.50		
2.00		
2.50		
3.00		
3.50		

4.00		
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Wire Length = m

Current (A)	Balance Reading (Kg)	Net Force (newtons)
<i>I</i> =0 (Reference Balance)		
0.50		
1.00		
1.50		
2.00		
2.50		
3.00		
3.50		
4.00		

Wire Length = m

Current (A)	Balance Reading (Kg)	Net Force (newtons)
<i>I</i> =0 (Reference Balance)		
0.50		
1.00		
1.50		
2.00		
2.50		
3.00		
3.50		
4.00		

$I = 2 \text{ A}$

Length, l , in meters	Balance Reading (Kg)	Net Force (Newtons)
Reference Balance		-----

Explain why only length of the horizontal segment of the current loop is used in the analysis in this experiment.

Data Sheet : Specific Charge of Electron Date _____

Name: _____ Partners: _____

Instructor's Signature: _____

Helmoltz Coils: Number of turns = 130 Mean Radius = _____

Accelerating Voltage=300 V

Coil Current	Magnetic field	Electron Path Diameter	Product Bxd

Mean value of Bxd = _____

e/m = _____

Accelerating Voltage=200 V

Coil Current	Magnetic field	Electron Path Diameter	Product Bxd

Mean value of Bxd = _____

e/m = _____

Accelerating Voltage= V

Coil Current	Magnetic field	Electron Path Diameter	Product Bxd

Mean value of Bxd = _____

e/m = _____

Accelerating Voltage= V

Coil Current	Magnetic field	Electron Path Diameter	Product Bxd

Mean value of Bxd = _____

e/m = _____

Data Sheet: Oscilloscope

Date: _____

Name: _____ Partners: _____

Instructor's Signature: _____

Note: Data should only be taken on well triggered, i.e., not jittery displays. If playing with trigger settings does not work, call your instructor. (You may not look so good, if it's a simple matter of making sure the trigger source is chosen wisely, here INT, the slope is the one you want, +, and the trigger level has been carefully turned in the pushed-in position.)

B2. Vertical Sensitivity	CAL Signal Amplitude	CAL Signal Amplitude
(Volts/Division)	(# of Divisions)	(Volts)
5		
2		
1		
0.5		

Why was it unnecessary to connect the ground clip?

Ans:

B3. Are the amplifiers of channels 1 and 2 reasonably well calibrated? i.e., can you read the correct value of a known 2-Volt signal on the 5, 2, 1, 0.5 Volt/ Div settings. Circle one:

Yes/ No

B4. For what range, approximately, of the SWEEP TIME settings does the square wave still look to your eyes as a recognizable square wave?

Time range:

B5.

SWEEP TIME/DIV	# of Divisions	Measured period, T	Frequency=1/T (Hz)

C2. emf of dry cell: -----(Theoretical value is 1.5 Volts.)

What will be displayed if the dry-cell voltage is AC-coupled to the scope input?

- a) zero b) 1.5 Volts c) something else.

D. In what sense are you observing the current flowing in the circuit when you display the voltage across the variable resistance R ?

D1.

R (ohm)	C (farads)	RC (sec)	The time it took for the decay to fall by 1/e .0.37

Do the last two columns match within your reading precision (which, no doubt, you indicated in the data table above)?

- a) yes** (the answer we are hoping you got)
b) no (you must have done something wrong, Go back and try again.)

Data Sheet: The Diode

Date _____

Name: _____ Partners: _____

Instructor's Signature: _____

Data Sheet: Speed of Light

Date _____

Name: _____ Partners: _____

Instructor's Signature: _____

	D (m)	t (sec)	v = D/t (m/s)	n = c/v
Trial 1	20.0			
Trial 2				
Trial 3				
Trial 4				
Trial 5				

Data Sheet: Refraction

Date _____

Name: _____ Partners: _____

Instructor's Signature: _____

Air → Plexiglass

θ_i	θ_r	n	v

Speed of light=

Plexiglass → Air

θ_i	θ_r	n	v

Speed of light=

Air → Water

θ_i	θ_r	n	v

Speed of light=

water → Air

θ_i	θ_r	n	v

Speed of light=

Data Sheet: Focal Length

Date _____

Name: _____ Partners: _____

Instructor's Signature: _____

Data Sheet: Mirrors and Lenses Date _____

Name: _____ Partners: _____

Instructor's Signature: _____

Data Sheet: Interference and Diffraction Date: _____

Name: _____ Partners: _____

Instructor's Signature: _____

Data Sheet: Spectrometer

Date _____

Name: _____ Partners: _____

Data Sheet: Absorption of Radiation

Date: _____

Name: _____ Partners: _____

Instructor's Signature: _____

Background Counts:

--	--	--	--	--

Average Background (Counts/min): _____

Gamma Source:

Absorber	Rate	Rate	Rate	Rate	Rate	Average: Counts/min
1 Pb sheet						
2 Pb sheets						
3 Pb sheets						
4 Pb sheets						
5 Pb sheets						
1 Al sheet						
2 Al sheet						
3 Al sheet						
4 Al sheet						
5 Al sheet						

	Thickness	Bulk density of metal: gm/cm ³	Surface density: gm/cm ²
Al sheet		2.70	
Pb sheet		11.3	

Beta source:

# of Al foils	Rate	Rate	Rate	Rate	Rate	Average Counts/min
0						
1						
2						
5						
10						
20						
30						
50						

Alpha source