NORTHERN VIRGINIA COMMUNITY COLLEGE
ALEXANDRIA CAMPUS

LAB MANUAL
PHYSICS 231,232,243
2009

Walter L. Wimbush, Jr.
Professor of Physics

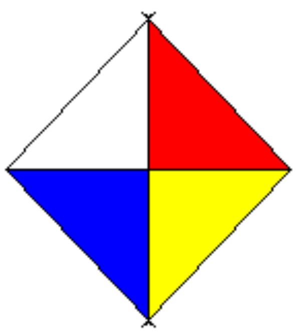
TABLE OF CONTENTS

PHYSICS 243

LABORATORY SAFETY RULES (PHYSICS)

The following regulations will be enforced. You will be asked to sign a statement indicating that you have received OSHA basic training and have received, read, and understood the laboratory safety rules.

1. No student will be permitted in the laboratory without an instructor . No visitors are permitted.
2. All experiments must be approved by the instructor.
3. Eating and drinking are not permitted in the laboratory.
4. Soft contact lenses must not be worn in the laboratory. Eye damage may occur.
5. Laboratory aprons are provided and must be worn during the laboratory. Safety goggles must be worn for specific experiments and student must purchase their own goggles!!!
6. All aisles in the laboratory must be kept open at all times. Personal belongings should be kept below the table and out of the working area.
7. Know the locations and operational details of all laboratory emergency safety equipment and evacuation routes.
8. Report all unsafe conditions, unusual odors and personal injuries to the instructor or a staff member immediately.
9. **Leave your lab bench as you found it**. With the equipment neatly placed at the end of the table nearest the center aisle. The lab bench area should be free of debris.
10. Stay out of restricted areas.
11. Observe the warning sign on the door of the prep room.



12. Carefully follow all instructions from instructors and laboratory staff.
13. Persons not following these rules will be asked to leave the laboratory.
14. Material data sheets are located in the prep room and are available to anyone who wishes to read them. A copy of the Alexandria Campus Hazard Communication Plan is on file in the science prep room and is available to any who would like to read it.

INTRODUCTION

This laboratory manual is designed for the Engineering and Physics science majors at N.V.C.C. The experiments described are specific to the equipment used on the Alexandria Campus. Although the laboratory experiments illustrate the fundamental principles discussed in the physics lectures, they are intended to introduce the student to a sense of discovery and inquiry while developing a working knowledge of the tools of modern science, particularly the computer which will be used to collect data and to analyze the data. The students can then use these tools in future courses.

There are several software packages that will make the collection of the data and its analysis very easy. The student is not required to know a computer language in order to use the computer in the lab. A large portion of the material in these experiments was derived from or inspired by the AAPT Workshop on Microcomputers and Wilson's Experiments in College Physics, Heath & Co.

Students should read the descriptions of the experimental procedures **before** coming into the lab. Data should be collected and analyzed during the lab period and the questions related to the lab should be answered **independently by each student**. Laboratory reports are due the following week at the **beginning** of the laboratory period unless otherwise specified by the instructor. There may be some computer exercises required of a particular lab, these should be completed independently by each student and the answers submitted at the end of the lab period.

VELOCITY AND ACCELERATION

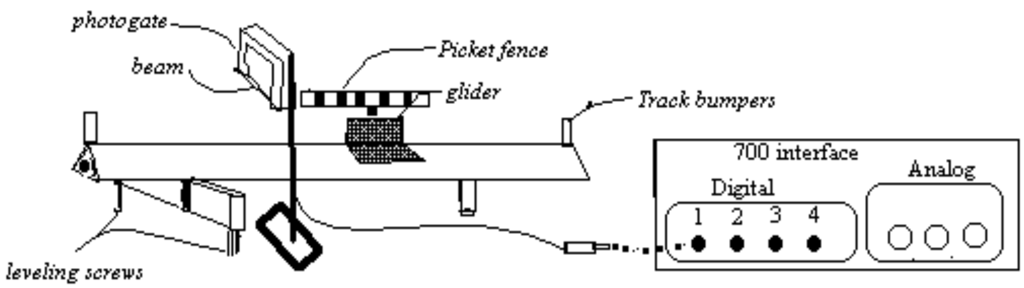
Velocity is the term which describes how fast something travels. If a Dodge Colt travels at 15 m/s while a Ford Mustang travels at 30 m/s, in 10 seconds the Mustang would have traveled twice as far (300 meters compared to the 150 meters for the Colt). The basic formula used to calculate the velocity is

$$\text{Velocity} = \frac{\text{Distance}}{\text{time}} = \frac{x_2 - x_1}{t_2 - t_1}$$

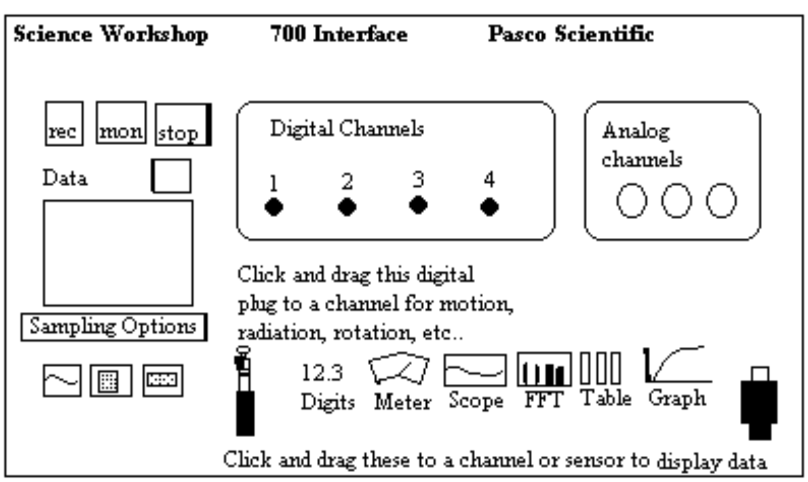
where x_2 is the position of the object at time = t_2 , and x_1 at t_1 .

<u>Part I Constant Velocity:</u>

If the velocity of an object does not change, then it should always take the same amount of time to travel the same amount of distance. Verify that this is correct by measuring the time a glider takes to travel equal distances on a <u>level</u> <u>air</u> <u>track.</u>



Procedure:
1. Place the glider on the air track, connect the air pump to the track, set the pump speed to 3. Turn on the pump.
2. **Using the leveling screws adjust the height of the left end until the glider does not accelerate down the air track**.
3. Place a photogate approximately 40 cm from the end with the air intake. Adjust the height of the photogate so that the glider with a picket fence attached will pass through the beam without hitting the gate.
4. Plug the photogate plug into the digital channel #1 of the 700 interface box.
5. Click on "Science Workshop" in the windows screen of the computer.
6. From the main Science Workshop Setup window, drag the phone plug symbol to the digital #1 input.



When the channel you are "plugging" the sensor into is highlighted with the box, release the mouse button.
A sensor selection window will appear. Click on *photogate and picket fence,* then click OK.
8. Drag the Table to channel #1. Select "delta time"," position"," velocity" and "acceleration".

9. Click **REC** in the upper left hand corner of the experiment window. Give the glider a small push and let it coast through the photogate. The table should fill up with data. Click **STOP** after the picket fence clears the photogate.
10. You can also drag the Graph icon to the sensor and graph the velocity.
11. If your click on the Σ ***(statistics)*** symbol of the graph and select linear fit, it will display the equation of the best straight line that fits your data. ***Note : for the velocity vs. time graph, the slope is the acceleration.***

PART II: ACCELERATED MOTION

When the velocity increases or decreases, there is acceleration. The rate of change of the velocity is called the acceleration. Mathematically, the acceleration is found by:

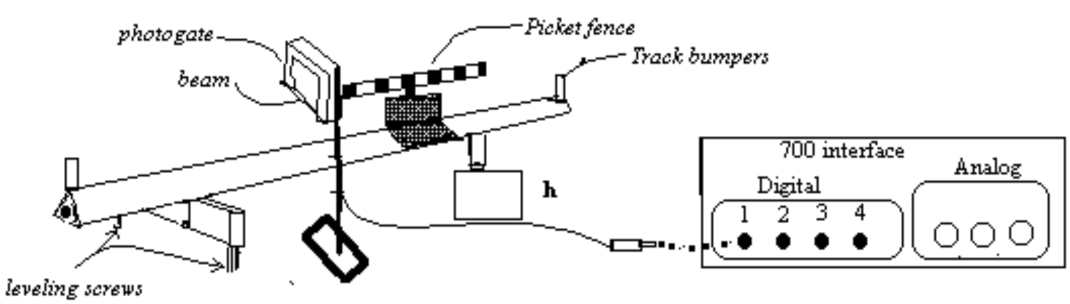
$$\mathbf{a_{12}} = \frac{\mathbf{v_2 - v_1}}{\mathbf{t_2 - t_1}}$$

When a glider slides down a straight hill, its velocity increases at a steady rate, increasing its velocity by the same amount each second. The displacement of the glider also increases at a continuously increasing rate. The relationship between the position, velocity and time of the object is summarized in the following equations:

$$x_2 = x_1 + v_1 (t_2 - t_1) + \tfrac{1}{2} a (t_2 - t_1)^2$$

$$v_2 = v_1 + a (t_2 - t_1)$$

$$v_2^2 = v_1^2 + 2 a (x_2 - x_1)$$



For the glider on the inclined plane, the acceleration along the plane depends on the component of gravity that is directed along the plane, **a = g · Sin *θ*.** (**g** is divided into two components: one perpendicular to the air track; the other parallel to the air track). **mg Sin *θ*** is the is the force of gravity directed along the plane. Sin θ can be determined using some trigonometry, studying the triangle formed by the spacer, the support screws and the inclined air track, the Sin θ is also equal to the height of the spacer divided by the length of the air track between the supporting screws.

The velocity during each distance interval can be calculated by: $v_1 = \frac{x_2 - x_1}{t_2 - t_1}$,
$v_2 = \frac{x_3 - x_2}{t_3 - t_2}$ etc... $v_i = \frac{\Delta x_1}{\Delta t_1}$.

The acceleration can be calculated by:

$$a_1 = \frac{v_2 - v_1}{\text{(time between midpoints of the velocity measurements)}} = \frac{\Delta v_1}{\frac{1}{2}(\Delta t_2 + \Delta t_1)} .$$

Procedure continues:

*Measure the thickness of your spacer, h.
*Place the spacer under the support screw.
*With the air compressor off, Place the glider inside the photogate and adjust the height of the photogate so that the picket fence is in the beam of the photogate.
*Place the glider at the top of the inclined plane.
*****Turn on the air compressor, the glider should move down the plane.
*Now hold the glider just a centimeter above the photogate.
*Press the REC button to collect data.
*Print the table of data, and the graphs of Velocity vs. Time and Displacement vs. Time <u>for one set of data</u>.
*From the graph of Velocity vs. Time determine a value for the acceleration of the glider.
*From the acceleration of the glider, find the acceleration of gravity, **g.**

$$a = g \text{ Sin } \theta$$

*You need to know the thickness of the spacer, h, you used to raise one side of the air track to make it inclined.

$$L = 100 \text{ cm.} \quad \text{then Sin } \theta = \frac{h}{L}$$

Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________

accel (th) = $(\frac{h}{L})$ g = $(\frac{h}{100\,\text{cm}})$ * 9.8 m/s^2

(1) how the angle of inclination affects the acceleration (use the 500 gram slotted weights as spacers) L = 100 cm

	A	B	C	D		E
1	Mass	h	accel (th)	$a\ from\ slope\ of\ graph$		% Error
2	(grams)	(cm)	(m/s^2)	(m/s^2)		=100*Abs(9.8 – E2)/9.8
3						
4						
5						
6						

Turn off the computer and put everything away.

Use the following questions to guide you in writing your discussion of the results.

Did the acceleration of the glider down the inclined track vary as the g sin θ? Did you have a sufficient range of angles to rule out a = g Tan θ? Would an angle of 10° be enough? (hint: calculate 9.8*Sin θ and 9.8* Tan θ then find the difference.)

Was friction a factor in the acceleration? Since friction is equal to μmg Cos θ, the friction should decrease as the angle increases. Friction would increase your % error. Does the % error decrease with increasing angle?

* **procedure to check for friction**: * If you were to give the glider a hard push up the incline and through the photogate, would you get the same acceleration as when it was accelerating down the incline? Try doing this. Why should it be different is there is friction?

(2) how the mass of the glider affects the acceleration. Use 2 spacers and change the mass of the glider

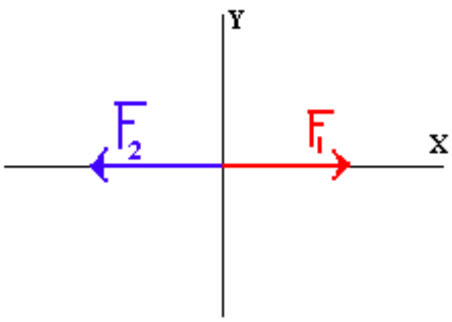
	A	B	C	D		E
1	Mass	h	accel (th)	$a\ from\ slope\ of\ graph$		% Error
2	(grams)	(cm)	(m/s^2)	(m/s^2)		=100*Abs(9.8 – E2)/9.8
3						
4						
5						
6						

The acceleration should not change when you change the mass of the glider. Did your observations support this premise?

ADDITION OF FORCES

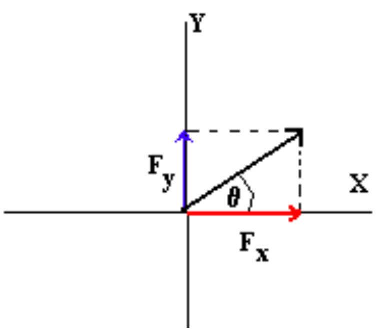
Translational Equilibrium:

Whenever two or more forces pull or push at a common point and there is no acceleration, the forces must be balancing each other. If you analyze the situation along the x-axis, all the forces (or components of the forces) pulling in the positive x-direction must be balanced by the forces (or their components) pulling in the negative x-direction. This must be the same for both y-direction and the z-direction.



Both F1 and F2 are along the x-axis. F1 is positive while F2 is negative. They balance each other. Their sum is zero.

If a force is not exactly along either the X or the Y axis, it can be decomposed into two parts, the amount of the force pulling in the X-direction and the amount of the force pulling in the Y-direction. These are called the X and Y components respectively. To find the Components of a vector you need to use some trigonometry. See the figure below.



X- component: Fx = F * Cos θ

Y- component: Fy = F * Sin θ

To find the Magnitude of the original force from its components, you can use

Pythorgean formula: Magnitude of $F_1 = \sqrt{F_{1x}^2 + F_{1y}^2}$

and to find the angle: $\tan\theta = \frac{F_{1y}}{F_{1x}}$.

Addition of Vectors: When two forces add, they combine their X-directional forces together separately from the Y-directional forces.
So to add F_1 to F_2: you need to find the X components of F_1 and F_2 and combine the X-components first, then the Y components:
example F_1 = 100 dynes at an angle of 20° F_2 = 200 dynes at an angle of 50°

X-Comp. F_{1x} = 100* Cos (20) = 94.0 F_{x2} = 200 * Cos (50) = 128.6
Total X: $F_x = 94.0 + 128.6 = 222.6$ dynes

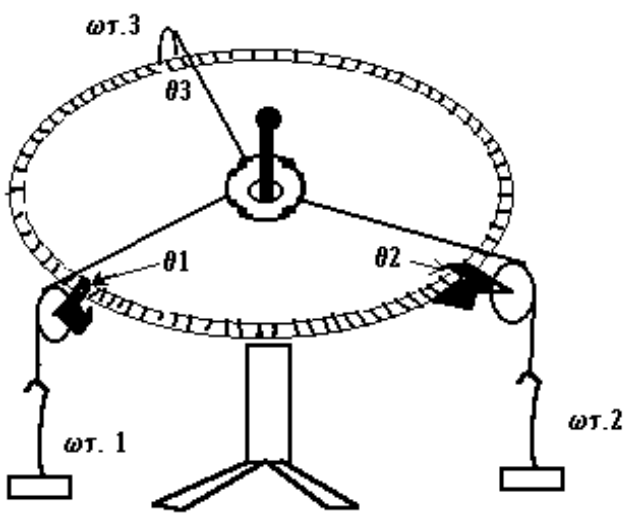
Y-Comp. F_{1y} = 100 * Sin (20) = 34.2 F_{2y} = 200 * sin (50) = 153.2
Total Y: $F_y = 34.2 + 153.2 = 187.4$ dynes

The magnitude of the final result: $F = \sqrt{F_x^2 + F_y^2} = \sqrt{(222.6)^2 + (187.4)^2} = 291.0$ dynes.

and the final angle: $\tan\theta = \frac{F_y}{F_x} = \frac{187.4}{222.6} = .842$ Therefore: $\theta = \tan^{-1}(.842) = 40.1°$

But in the case when all the forces are balanced, the final result is zero. So the sum of all the force components should be zero. The sum of F_x should equal zero, as well as the sum of F_y.

Procedure: In this lab you will verify that the sum of the forces is indeed equal to zero by having three forces pull on a ring. This is accomplished using a force table (shown in figure 1). The forces are provided by weights attached to strings which are draped over a pulley which converts the vertical force of the weight to a horizontal force pulling on the ring at the center of the force table. **You intructor will give you the values for F_1 and F_2.** First place the weight necessary for the first force F_1 on a string and place a pulley at the proper angle θ_1. Place the string over the pulley. Do the same for F_2 at θ_2 . Take the third string in your hand and pull on the string in a direction so as to balance the two forces, place a pulley at this angle. When the ring is centered around the pin on the force table, place a hook weight at the end of the string and add weight until the ring is free of the pin and once again centered around the pin. Then all three forces are balanced or in equilibrium. Record the force on each string and the angle (as read on the force table).



Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________

$The\ forces\ will\ be\ represented\ by\ the\ number\ of\ grams\ for\ easy\ graphing\ and\ calculating$ ($note$: $to\ get\ them\ into\ the\ correct\ units\ you\ would\ multiply\ by$ $980\ cm/s^2$ $to\ get\ the\ units\ into\ dynes$).

$Trial\ 1$:

$F_1 = 200\,grams \quad \theta_1 = 30^o \qquad F_2 = 150\,grams \quad \theta_2 = 135^o$

Addition of components of F_1 and F_2 :

$F_1\,Cos\,\theta_1 =$ $\qquad\qquad$ $F_1\,Sin\,\theta_1 =$

$F_2\,Cos\,\theta_2 =$ $\qquad\qquad$ $F_2\,Sin\,\theta_2 =$

$F_x =$ _______________ $\qquad$ $F_y =$ _____________

Magnitude of the sum of F_1 and F_2: $\quad F = \sqrt{F_x^2 + F_y^2} = \sqrt{(\qquad)^2 + (\qquad)^2} =$ ___________

The angle for the resultant sum is : $\quad Tan\ \theta = \frac{F_y}{F_x} = \frac{(\quad)}{(\quad)}$

$\theta = \tan^{-1}(\qquad) =$ _________

FORCE TABLE: EXPERIMENTAL VERIFICATION OF THE METHOD FOR VECTOR ADDITION

Using the force table, place as a start the mass equal the the magnitude of F1 + F2 at an angle 180° opposite the angle for the resultant. This force which balances the resultant is called the **equilibrant**, F_3; add or subtract weights to F_3 and adjust the angle so that the ring is centered on the pin. Measure F_3 and its angle.

$F_3 =$ _______grams $\quad \theta_3 =$ ____

Check: Does F_3 have the same magnitude as the sum of F_1 and F_2? _____________

Is the angle for F_3 180^oopposite to the angle for the resultant sum? ______________

If you were to add all three forces, what would the total sum be? ________________

Now draw each force vector as an arrow to scale: 25 grams = 1 cm. Use a protractor to measure the angles.

Trial 2: repeat the procedure for calculations as in trial 1:

F_1 = 100g, θ_1 = 20 F_2 = 200, θ_2 = 150

Addition of components of F_1 and F_2 :

$F_1\, Cos\, \theta_1 \; =$ $F_1\, Sin\, \theta_1 \; =$

$F_2\, Cos\, \theta_2 =$ $F_2\, Sin\, \theta_2 =$

$F_x \; =$ ______________ $F_y =$ ____________

Magnitude of the sum of F_1 and F_2: $F \; = \; \sqrt{F_x^2 \; + \; F_y^2} \; = \sqrt{(\qquad)^2 + (\qquad)^2} \; =$ __________

The angle for the resultant sum is : Tan $\theta = \frac{F_y}{F_x} \; = \frac{(\quad)}{(\quad)}$

$\theta = \tan^{-1}(\qquad) \; =$ ________

FORCE TABLE :

$F_3 =$ _______grams $\theta_3 \; =$ ____

Check: Does F_3 have the same magnitude as the sum of F_1 and F_2?____________

Is the angle for F_3 180^oopposite to the angle for the resultant sum? ____________

Now draw each force vector as an arrow to scale: 25 grams = 1 cm. Use a protractor to measure the angles.

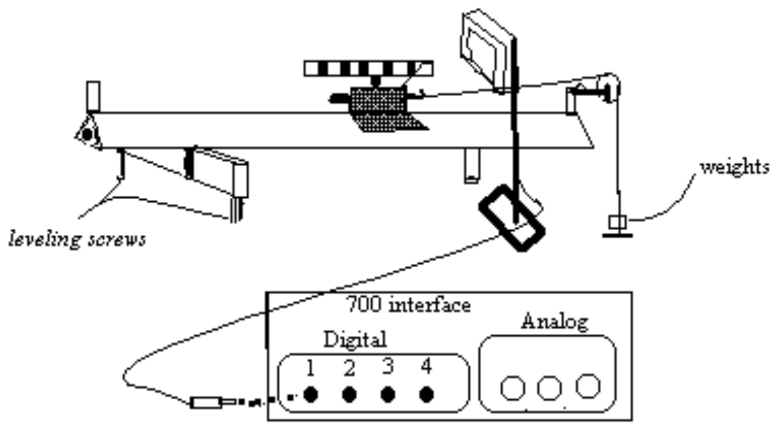
USE GRAPH PAPER

NEWTON'S SECOND LAW

Newton's Second Law is a statement of the cause and effect relationship between the force and the acceleration the force produces. Newton's Law says the the acceleration of an object is directly proportional to the force pulling the object (the mass remaining the same). It also says that if the force is kept constant, the acceleration is inversely proportional to the mass of the object. This is summed up in the mathematical statement: $\mathbf{F} = \mathbf{M\ a}$ Where F is the net force acting on the object and M is to total mass of the objects being accelerated.

Using the air track, the mass being accelerated is the mass of the glider plus that of the hook weight. The force is that of the weight of the hook weight ($M_1 g$).

$a = \frac{M_1 g}{(M_2+M_1)}$. M_2 is mass of glider, M_1 is the mass of the hook weight.



Procedure: (keeping the force constant while increasing the total mass)
*Find the mass of the glider with the picket fence.
*Position the photogate between the glider and the pulley, then adjust its height so that the picket fence passes through the beam of the photogate.
*Attach a string to the glider, pass the string over the pulley and attach the hook weight (you must weigh the small hook and each of the weights) to the end of the string.
Follow the procedure for collecting data from the picket fence as you did for the velocity and acceleration lab.
*One student holds the glider while the other student turns on the air compressor.
*Release the glider; when the glider clears the photogate, determine the acceleration and record the acceleration into your table.
*Find the acceleration from the **slope** of the velocity vs. time graph.

Part I (keeping the mass of the glider constant while increasing the force (mass of the weights)
*Increase the weight of the hook weight, and measure the acceleration.
*Repeat this procedure incrementing the weight by 2 grams each time until all the additional weights have been used.
*Compare the acceleration measured with the theoretical value: $a = \frac{mass_{wt} * g}{(mass_{wt}+mass_{glider})}$
*Determine the % difference. Did the acceleration increase with increased force?

Part II (keep the hook weight at maximum and change the mass of glider)
*Place 20 grams on the hook weight.
*Add the 50 gram weights (silvery with the hole in the center) to each side of the glider (total additional mass = 100 gm) and repeat the acceleration measurement.
*Repeat this procedure, incrementing the mass of the glider by 100 grams.
*Compare the acceleration measured with the theoretical value: $a = \frac{mass_{wt} * g}{(mass_{wt}+mass_{glider})}$
*Determine the % difference. Did the acceleration decrease with increased total mass?

Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________

Make your own table in your notebook. Below each table. summarize the main concepts supported by the data.

	A	B	C	D	E	F
1	Mass (M1)	Force	Glider (M2)	Acceleration	M1g/(M1+M2)	%Error
2	(grams)	(dynes)		from graph	(cm/s^2)	
3						
4						
5						
6						
7						
8						
9						

What is the % uncertainty for each type of Measurement: Mass, acceleration.

The acceleration from the computer graph is in m/s^2. You will need to multiply this acceleration by 100 to convert to cm/s^2.

Mass (M1)	Force	Glider (M2)	Acceleration	M1g/(M1+M2)	%Error
(grams)	(dynes)		from graph	(cm/s^2)	

Problems:

1) Two students measured the time it takes for the 200 gm. glider to travel 50 cm from rest. Their data for Δ T was as follows: 0.715 sec., 0.716 sec., 0.714 sec. What was the mass of the decending weight, M_1? (Ans. M_1 = 50 grams)
2) In verifying F_{net} = M **a** , the net force was kept constant for several readings while the total mass was increased. **Graph acceleration on the "y axis" and "1/($M_1 + M_2$)" on the "x axis".** In order to plot this graph you will need a new column in your table for $1/(M_1 + M_2)$. Is your graph a straight line? What is the slope of the graph? What should your slope be equal to?
3) Make a graph to show that the acceleration varies directly with the net force (M_1g) when the mass (M_1+ M_2) was kept approximately constant. (Note the force caused the change in the acceleration so the force goes on the "x axis".) Find the slope...Is it equal to $1/(M_1 + M_2)$?

CIRCULAR MOTION (WEAR GOGGLES)

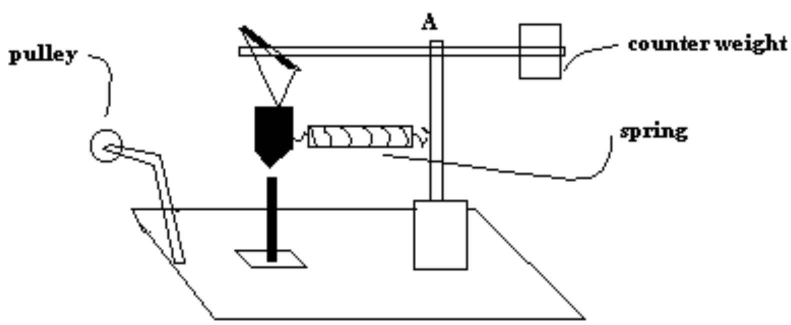
Part I: Constant Angular Velocity

Any object which is moving in a circular path requires a force to keep it in a circle. Without this force it would naturally move in a straight path. The force necessary to keep the object in a circular path is called the centripetal force. The magnitude of this force is given by $F_{cp} = \frac{mv^2}{r}$ or mrw^2 where w is ($2\pi \cdot$ frequency).

The apparatus used to verify this relationship uses a spring to provide the centripetal force, which is always directed towards the center of the circle. This force within the spring can be measured before the object is rotated, so the amount of force is known. The mass of the black bob can be measured (actually, it is written on the surface). The radius of the orbit can be set and measured before it is rotated by adjusting the "pointer" to the desired position. All that is required is for some person to actually rotate the vertical shaft so as to keep the black bob over the pointer. When it is rotating over the pointer (i.e. at the desired radius) the frequency can be measured by measuring the time it requires for 20 revolutions. (You can probably think of other ways to measure either the velocity or the frequency using the photogates and the computer.)

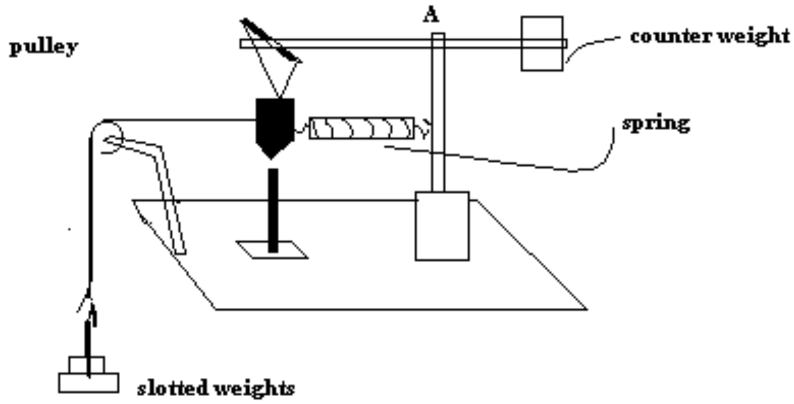
Procedure:

* Assemble the apparatus as shown in the diagram with R = 16.5 cm.



Adjusting the value of the radius:
*Place the pointer at 16.5 cm from the vertical rotating shaft.
* Release the spring from the black bob. Lossen the screw "A" and slide the horizontal bar until the black bob hangs over the pointer at the desired radius.
*Tighten screw "A" when black bob hangs 16.5 cm from vertical rod.
*Reattach the spring to the black bob.

Measuring the force in the spring:



*Attach the string to the black bob and add weights to the end of the string until the spring is stretch so that the black bob hangs over the pointer once again.
*Record the weight required to stretch the spring to this radius.
*The mass of the black bob is marked on its surface; record this value in your table.

Measuring the angular velocity:

Method I: Measure the time it takes for the object to make 50 revolutions.
$\nu = 50/ \Delta t$. $w = 2\pi \nu$ (use the computer as a simple stop watch).

Method II: Place a tongue depressor at the end of the horizontal bar attached to the counter weight. Have this tongue depressor rotate between the photogate, the computer can be used to measure the time for each rotation.

Method III: Same set up as Method II except that the velocity of the tongue depressor is measured as it passes between the photogate. Then $w = R_2$ v where R_2 is the distance of the photogate beam from the axis of rotation.

Procedure:

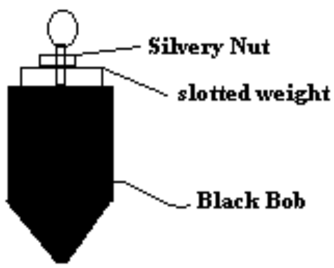
* **Wear your Goggles!**

*Remove the string from the black bob; it is now free to rotate. Place one of your hands on the wooden base to steady the apparatus while it is rotating and then place your other hand on the vertical shaft. With your fingers gently rotate the vertical shaft until the bottom of the black bob is centered over the pointer.
*Try to maintain a rotational speed such that the black bob stays over the pointer.
*You are now ready to start measuring the angular velocity, w. This can be done by measuring the frequency, ν, and then $w = 2\pi \nu$.

*If you are using method II or III to measure the frequency, you should position the photodector so that the tongue depressor will block the photogate beam without hitting it.
*Load "Precision Timer III" into the computer. Determine which mode you want and what information it can give (check out your strategy with the instructor).

*With your head at a safe distance from the apparatus, rotate the vertical shaft until the black bob rotates over the pointer. Start the timer. Keep rotating so that the bob stays over the pointer (use 20 revolutions).
*Determine w from your timing data.

Varying the mass of the rotating bob:
*Record the following: hook weight (spring force), radius, rotating mass, w.
*Increase the mass of the black bob by inserting a slotted weight (50 gm) under the "silvery" nut. Tighten the nut so that the slotted weight is secure.



*Increase the mass in increments of 100 grams. Measure w for each mass.

Varying the Radius:
*Remove the added weight from the black bob.
*Disconnect the spring from the black bob and increase the distance between the pointer and the vertical shaft by 2 cm. *Loosen Screw A on the vertical shaft and adjust the horizontal rod so that the black bob is positioned over the pointer. *Tighten Screw A and reattach the spring to the vertical shaft.
*Measure the force in the spring by attaching the string with the hooked weights to the black bob and determining the amount of weight necessary to stretch the spring until the black bob is over the pointer. Disconnect the string and the hooked weights.
*Measure w. Record the results. Increment the distance in units of 2 cm each time.

Varying the Spring Force (centripetal force):
*With the radius at its maximum distance, insert a paper clip between the spring and the vertical shaft. Remeasure the spring force with the hooked weights. Measure w.
*Add a second paper clip between the spring and the vertical shaft. Measure the force in the spring using the hooked weights. Measure w.

<u>Timing</u> <u>Modes</u>:
*Stopwatch: measure the time for 20 revolutions.
*Motion Timer: time for each rotation
*Pulse: Time that the tongue depressor blocks the photogate. $v= \frac{d}{\Delta t}$ $w = \frac{v}{R`}$
where R` is distance of gate to shaft.

Data Sheet **Name** ____________________ **Date** __________ **Group #** _________

Part I Changing the radius: Number of rotations = 20

	A	B	C	D	E	F	G	H
1	Mass Wt.	M_{wt}*g	Radius	$Mass_{rot}$	time	freq	M_{rot}*R*$(2\pi$*freq$)^2$	% diff
2	(grams)	(dynes)	(cm)	(grams)	(sec)	(Hz)	(dynes)	
3								
4								
5								

Part II Changing the mass: You would prefer to change the mass and see its effect on the centripetal force, keeping the radius and frequency constant. Since we do not have the equipment for this, keep force constant and see the effect on the frequency.

Mass Wt.	M_{wt}*g	Radius	$Mass_{rot}$	time	frequency	M_{rot}*R*$(2\pi$*freq$)^2$	% difference

Part III Changing the frequency (adding paper clips to the spring)

Mass Wt.	M_{wt}*g	Radius	$Mass_{rot}$	time	frequency	M_{rot}*R*$(2\pi$*freq$)^2$	% difference

Questions to guide your discussion of results:
Did increasing the radius cause the centripetal force as measured by M_{wt}*g to increase?

Did increasing the mass of the rotating object cause the centripetal force to increase?

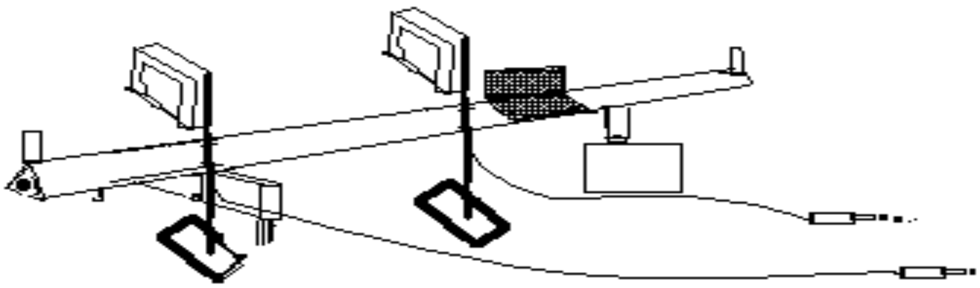
Did decreasing the frequency cause the centripetal force to decrease?

Why did the frequency change when the mass of the rotating object was increased?

POTENTIAL AND KINETIC ENERGY

When an object is lifted vertically upward with no increase in speed, the work done in lifting $\Delta W = \vec{F} \cdot \Delta\vec{h}$. The energy used in lifting is "stored" in the form of potential energy. Since gravity continues to act on the object it does the same amount of work on the way down, causing the object to increase its speed and therefore its kinetic energy, $\frac{1}{2}$ m v^2. Hence the change in potential energy, mg Δh, where Δh is measured vertically, is equal to the change in kinetic energy.

Experiment 1 Tilted Air Track



Photogate #2 photogate #1

Inclined Air Track

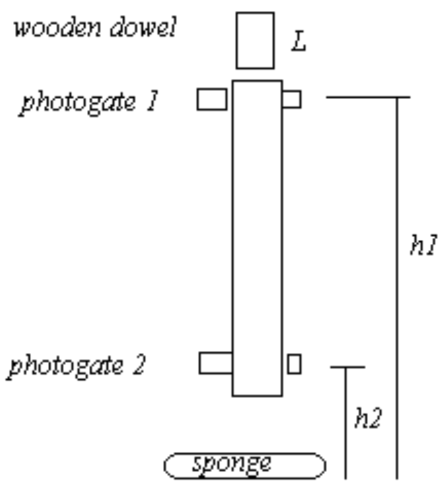
Another way of viewing this is: $PE_i - PE_f = KE_f - KE_i$

or $\mathbf{PE_i + KE_i = PE_f + KE_f}$ Conservation of Energy

* Measure the vertical height from the top surface of the air track to the table top at the position of gate #1 and gate #2 (make sure they are properly plugged in).
* Open Science Workshop. Move the icon Phoneplug to digital 1 input ...select *Photogates (2)*
* Move table icon to digital 1 input
* Choose *velocity v1* & *velocity v 2*, then enter the length of the glider 0.128 m. The time the glider takes to pass each gate is used to calculate the velocity of the glider at each gate (length of glider / time the gate is blocked).
* Measure the mass of the glider.
* Calculate the P.E. and the K.E. at gate #1 and the P.E. and K.E. at gate #2. You should repeat the measurements for several starting points. You should change the mass (add weights to the glider). You could also give the glider a small push at the bottom of the incline and have it slow down as it goes up the incline converting kinetic energy into potential energy. Record your data and calculations in Table 1.

Experiment 2 The Vertical Tube

Vary the distance, Δh, and measure the velocity.
Tabulate the mass, Δh, t, v, ΔPE , ΔKE. Compare ΔPE with ΔKE.



Knowing the length, L, of the cylinder and the time, Δt, it took to pass the photogate, you can calculate the velocity with $L / \Delta t$ and then calculate the $KE = 1/2\ m v^2$.

Another way of viewing this is: $PE_i - PE_f = KE_f - KE_i$

or $\mathbf{PE_i + KE_i = PE_f + KE_f}$ Conservation of Energy

* Measure L, h_1, h_2, v_1, v_2, and record these data in Table 2.

Data Sheet Name ______________________________ Date ____________ Group # ____

Lab Partners _______________,__________________

Table 1. (inclined air track)

h_1 t_1 h_2 v_1 v_2 $(PE_1 + KE_1)$ $(PE_2 + KE_2)$ % diff.

mass	h1		h2		v1	v2	(PE+KE)1	(PE+KE2)	% diff
(grams)	(cm)		(cm)		(cm/s)	(cm/s)	(ergs)	(ergs)	

What is the % uncertainty in each measurement: mass, height velocity and lastly in the calculated Energy?

Questions to guide your discussion of results:
Did the decrease in potential energy equal the increase in Kinetic Energy?

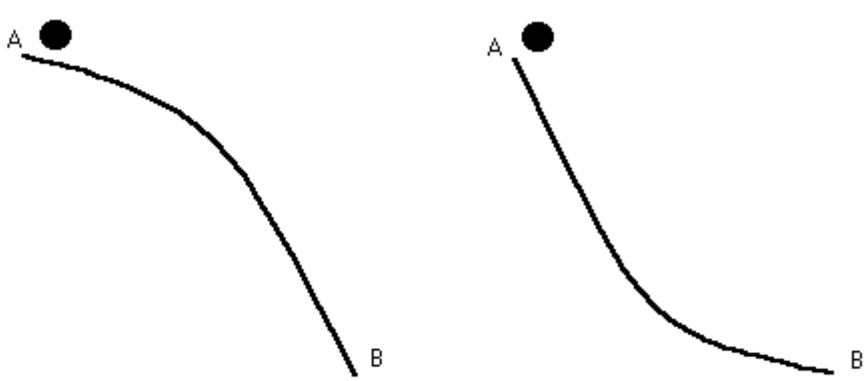
When you sent the glider up the incline was the decrease in Kinetic Energy equal to the increase in Potential Energy?

Table II (vertical tube) L = ...cm

mass	h1		h2		v1	v2	(PE+KE)1	(PE+KE2)	% diff
(grams)	(cm)		(cm)		(cm/s)	(cm/s)	(ergs)	(ergs)	

Questions

Both procedures used a straight path for the object. What if the path was curved, would the energy be conserved? Consider two paths where the starting points are at the same altitude and the ending points are at the same altitude. Will the ball have the same velocity at the bottom? Will the ball arrive at point B at the same time for each path? Which will arrive first?



22

CHALLENGE question: approximate the shape of the curve to quarter circles (1st quadrant, third quadrant) and determine the time it takes to get to point B.

LINEAR MOMENTUM

When a force, F, is applied to an object for an amount of time, $\triangle t$, the object acquires an increase to its momentum, mv*final*- mv*initial* . The term momentum is defined as $\vec{P} = m\vec{v}$, so that the change in the momentum is c P. Since F = m a and a = $\triangle$ v/$\triangle$t, F = m$\triangle$v/$\triangle$t.

Then $F \triangle t = m \triangle v$

$F \triangle t = m v_f - m v_i = \triangle P$

Where F $\triangle$t is called the impulse and $\triangle$ P is the <u>change</u> in the <u>momentum</u>.

To verify this equation, you have to measure the force, F, the time, $\triangle$t, and the initial and final velocity of the object. (Note: you may have made these measurements in the Newton's Second Law Experiment. You can repeat it again, or you can make a second set of measurements.)

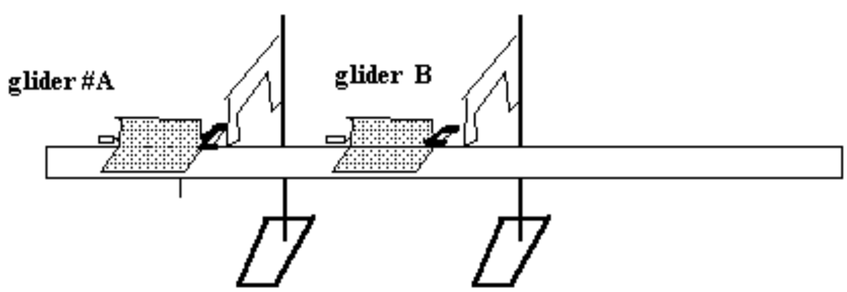
Collisions provide another example of the conservation of linear momentum. When the force exists between the two objects, the force on object #1 is equal and opposite to the force on object #2.

$$i.e.\ \vec{F}_1 = -\vec{F}_2 \quad and\, since\, \triangle t_1 = \triangle t_2\,,\ F_1 \triangle t_1 = F_2 \triangle t_2$$
$$Hence\, it\, follows\, since\, F_1 \triangle t_1 = m_1 v_{1f} - m_1 v_{1i}\ \ that$$
$$m_1 v_{1f} - m_1 v_{1i} = -\{ m_2 v_{2f} - m_2 v_{2i} \}$$

$$Which\, is\, equivalent\, to:$$
$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}.$$

Methodology :

Using the photogates to measure the amount of time that the glider takes to pass through the beam of the photogate (moves a distance equal to its length) you can calculate the velocity of the gliders (A & B) before and after the collision.



Procedure :

Setting up the apparatus:

1) Level the air track. Place a bumper on the front of each glider and a flat insert on the back of the glider. Weigh gliders A & B and record their mass in the table.

2) Place the photogates approximately 40 cm apart in the middle of the air track. This is the collision zone (the collisions will take place in this region and we'll measure the velocity of the gliders as they enter or leave the zone).

3) Plug the photogate #1 into the Digital channel #1 of the Science Workshop 700 interface box, and plug the photogate #2 into the Digital channel #2 of the Science Workshop 700 interface box.

4) Turn on the IBM PC and open Science Workshop from the Windows screen.

5) Open new experiment.
6) Use the mouse to drag the digital phoneplug to Digital channel #1.
7) Select photogates (2), enter length of glider 0.128 m , leave 0.2 m as the distance between photogates.
8) Now drag the icon for a table to Digital channel #1.
9) Select velocity vGate1 and velocity vGate2.
10) You are now ready to collect data.

Elastic collisions (kinetic energy is conserved):

I) Target glider is initially stationary.

1. Measure the mass of both gliders with a rubber band bumper on the right and a flat metal bumper on the left. The length of the glider is 12.8 cm (verify this). Record values in table 1. Place glider B between the two photogates (make sure there is enough room for glider A between photogate #1 and glider B so that glider A will clear the photogate before it hits glider B).

2. Click on record data with the mouse. Then give glider A a small push so that it passes through photogate #1 where the time is measured. It will strike glider B and come to a stop, since it would have transferred all of its momentum to glider B. Glider B will then pass through photogate #2. When it clears the photogate, you can stop it. Now click on the stop button, read the time t_1 and t_2. Record these values in your table. The two times should be the same.

3. Add 100 grams to glider B, and repeat procedure #1. Click on record data with the mouse. Then give glider A a small push so that it passes through photogate #1 where the time is measured. It will strike glider B and bounce back, since it has less mass than glider B. Glider B will then pass through photogate #2, and glider A will move in the **negative** direction through photogate #1. When it clears the photogate, you can stop it. Now click on the stop button, read the time t_1 and t_2. Record these values in your table. The second time for photogate #1 will give the negative velocity of glider A after the collision.

4. Take the 100 grams off of glider B and Add 100 grams to glider A, and repeat procedure #1. Click on record data with the mouse. Then give glider A a small push so that it passes through photogate #1 where the time is measured. It will strike glider B and continue in the same direction, since it has more mass than glider B. Glider B will then pass through photogate #2, and glider A will move in the **positive** direction through photogate #2. When it clears the photogate, you can stop it. Now click on the stop button, read the time t_1 and t_2. Record these values in your table. The second time for photogate #2 will give the positive final velocity of glider A after the collision.

Table 1: target glider initially stationary (Elastic collision)

M_{A}	M_{B}		$V_{\mathrm{A}i}$		$V_{\mathrm{A}f}$		$V_{\mathrm{B}f}$

$V = 12.8\,cm/T$

$M_{\mathrm{A}}V_{\mathrm{A}i}$	$M_{\mathrm{A}}V_{\mathrm{A}f}$	$M_{\mathrm{B}}V_{\mathrm{B}f}$	$M_{\mathrm{A}}V_{\mathrm{A}f} + M_{\mathrm{B}}V_{\mathrm{B}f}$	% difference

Remember: the kinetic energy before should equal the kinetic energy after.

½ $M_{\mathrm{A}}V_{\mathrm{A}i}^2$	½$M_{\mathrm{A}}V_{\mathrm{A}f}^2$	½$M_{\mathrm{B}}V_{\mathrm{B}f}^2$	½$M_{\mathrm{A}}V_{\mathrm{A}f}^2 +$ ½$M_{\mathrm{B}}V_{\mathrm{B}f}^2$	% difference

II) Target glider is initially moving in positive direction.

1. With no additional weight on the gliders, and both gliders to the right of photogate #1, click on the record button and give glider B a gentle push. After it has cleared photogate #1, give glider A a harder push so that it will collide with glider B between the photogates (you may wish to increase the distance between the photogates). When the gliders leave the collision zone and have cleared the photogates, you can stop them, click on STOP and record the times. Make sure that the velocity in the positive direction is marked "+" and when the glider was moving in the negative direction the velocity is marked "-".
2. Add 100 grams to glider B and repeat.
3. Move the 100 grams to glider A and repeat.

Table 2. Both gliders moving initially in the same direction (positive)

M_{A}	M_{B}		$V_{\mathrm{A}i}$		$V_{\mathrm{B}i}$		$V_{\mathrm{A}f}$		$V_{\mathrm{B}f}$

$M_{\mathrm{A}}V_{\mathrm{A}i}$	$M_{\mathrm{B}}V_{\mathrm{B}i}$	$M_{\mathrm{A}}V_{\mathrm{A}i} + M_{\mathrm{B}}V_{\mathrm{B}i}$	$M_{\mathrm{A}}V_{\mathrm{A}f}$	$M_{\mathrm{B}}V_{\mathrm{B}f}$	$M_{\mathrm{A}}V_{\mathrm{A}f} + M_{\mathrm{B}}V_{\mathrm{B}f}$	% diff

½$M_{\mathrm{A}}V_{\mathrm{A}i}^2$	½$M_{\mathrm{B}}V_{\mathrm{B}i}^2$	$KE_{\mathrm{A}i} + KE_{\mathrm{B}i}$	½$M_{\mathrm{A}}V_{\mathrm{A}f}^2$	½$M_{B}V_{Bf}^2$	$KE_{Af} + KE_{Bf}$	% diff

III) Target glider is initially moving in opposite directions.

1. With no additional weight on the gliders, and glider A to the right of photogate #1 and glider B on the left of photogate #2, click on the record button and give glider B a gentle push toward photogate #2 (negative direction), and give glider A a push so that it will collide with glider B between the photogates (you may wish to increase the distance between the photogates). When the gliders leave the collision zone and have cleared the photogates, you can stop them. Click on STOP and record the times. Make sure that the velocity in the positive direction is marked "+" and when the glider was moving in the negative direction the velocity is marked " $-$ ".

2. Add 100 grams to glider B and repeat

3. Move the 100 grams to glider A and repeat.

Table 3. Both gliders moving initially in opposite directions (v_1 is positive but v_2 is negative)

M_1	M_2		V_{1i}		V_{2i}		V_{1f}		V_{2f}

M_1V_{1i}	M_2V_{2i}	$M_1V_{1i}+M_2V_{2i}$	M_1V_{1f}	M_2V_{2f}	$M_1V_{1f}+M_2V_{2f}$	% diff

½$M_1V_{1i}^2$	½$M_2V_{2i}^2$	$KE_{1i}+KE_{2i}$	½$M_1V_{1f}^2$	½$M_2V_{2f}^2$	$KE_{1f}+KE_{2f}$	% diff

IV) Inelastic collision (target glider initially stationary, KE not conserved):

1. Measure the mass of glider A with the "nail" bumper on the left and a flat metal bumper on the right. Measure the mass of glider B with the "clay core" bumper on the right and a flat metal bumper on the left.
2. Place glider B between the photogates like you did for the elastic collision part I.
3. Give glider A a push (be careful the **nail is sharp**). Wait until both gliders exit photogate #2 before stopping them.

Table 4. Inelastic collision (target glider initially stationary)

M_{A}	M_{B}		$V_{\mathrm{A}i}$		$V_{\mathrm{A}f}$		$V_{\mathrm{B}f}$

$V = 12.8\,cm/T$

$M_{\mathrm{A}}V_{\mathrm{A}i}$	$M_{\mathrm{A}}V_{\mathrm{A}f}$	$M_{\mathrm{B}}V_{\mathrm{B}f}$	$M_{\mathrm{A}}V_{\mathrm{A}f} + M_{\mathrm{B}}V_{\mathrm{B}f}$	% difference

Remember the kinetic energy before should not be equal to the kinetic energy after.

½ $M_{\mathrm{A}}V_{\mathrm{A}i}^2$	½$M_{\mathrm{A}}V_{\mathrm{A}f}^2$	½$M_{\mathrm{B}}V_{\mathrm{B}f}^2$	½$M_{\mathrm{A}}V_{\mathrm{A}f}^2$ + ½$M_{\mathrm{B}}V_{\mathrm{B}f}^2$	% difference

CONSERVATION OF MOMENTUM (Two Dimensions)

Purpose: To verify the conservation of momentum for two dimensions in both the inelastic and the elastic type of collision.

Theory: Since the momentum is a vector quantity, it will be necessary to verify that the sum of the momentum components in the x-direction before the collision are equal to the sum of the momentum components in the x-direction after the collision. Also the sum of the momentum components in the y-direction before the collision are equal to the sum of the momentum components in the y-direction after the collision.

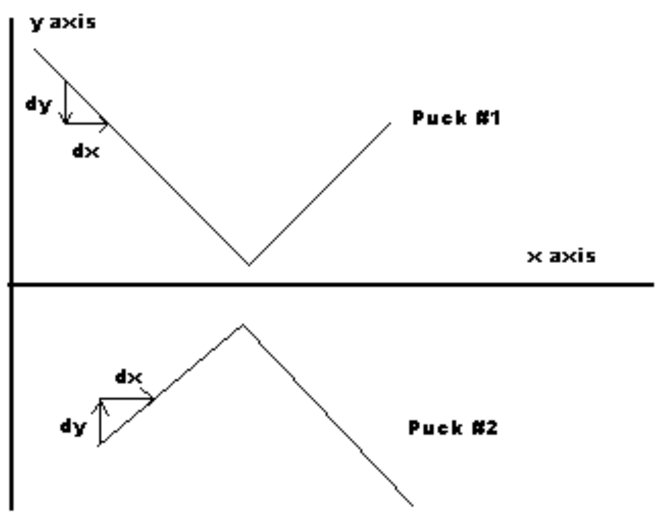
i.e., $\vec{P}_{1i} + \vec{P}_{2i} = \vec{P}_{1f} + \vec{P}_{2f}$

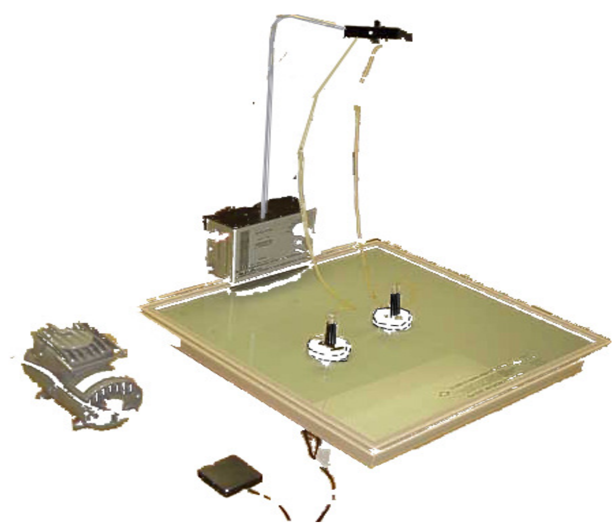
or in terms of the components:

$P_{1ix} + P_{2ix} = P_{1fx} + P_{2fx}$ and $P_{1iy} + P_{2iy} = P_{1fy} + P_{2fy}$

Also for an elastic collision, the kinetic energy of the two objects before the collision should equal the total kinetic energy of the two objects after the collision:

$\frac{1}{2}mv^2_{1ix} + \frac{1}{2}mv^2_{2ix} + \frac{1}{2}mv^2_{1iy} + \frac{1}{2}mv^2_{2iy} = \frac{1}{2}mv^2_{1fx} + \frac{1}{2}mv^2_{2fx} + \frac{1}{2}mv^2_{1fy} + \frac{1}{2}mv^2_{2fy}.$





Procedure: Elastic Collision

1. Measure the mass of each puck (unplug the unit first)
2. Record the frequency of the spark generator (10 Hz or a period of 100 mSec)
3. Practice sliding the pucks towards the center of the paper so that they collide near the center.
4. Now with your foot on the pedal (this turns on the spark timer so keep your hands on the insulated handles and do not rest your hands on the air table!) slide the pucks toward the center of the paper. Take your foot off the pedal when one of the pucks reaches the bumper of the air table.
5. Remove the paper from the table; there should be a set of dots indicating the position of each puck every 0.1 sec. Label the dots for the puck A and the puck B directions on the paper.

6. Now using a meter stick, draw a horizontal line through the center of the collision area which will become your x-axis. Using a right triangle (plastic triangle) draw a line perpendicular to the x-axis near the end of the piece of paper.

7. Using the x and y axis you have drawn, measure the distance in the x and y directions that the puck has traveled in each time interval.

8. Calculate the velocity in the x-direction (vx) and record this in the table. Do the same for the y-direction before and after the collision.

9. Calculate the momentum in each direction before and after the collision using the average velocities.

10. Compare the sum of the momenta of each puck in the x-direction before the collision with the sum of the momenta of each puck in the x-direction after the collision.

11. Repeat for the momentum in the y-direction.

12 Calculate the total kinetic energy before the collision and compare with the total kinetic energy after the collision.

Procedure for the Inelastic Collision:

Same as that for the Elastic Collision.

Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________ Physics 231

	mass	dxi	vxi	Pxi	dyi	vyi	Pyi	dxf	vxf	Pxf	dyf	vyf	Pyf
A													
B													
				KExi	KEyi	KExf	KEyf						
A													
B													

Momentum:

Initial momentum in x-direction $P_{Axi} + P_{Bxi}$ = ____________

Final momentum in x-direction $P_{Axf} + P_{Bxf}$ =____________

Initial momentum in y-direction $P_{Ayi} + P_{Byi}$ = ___________

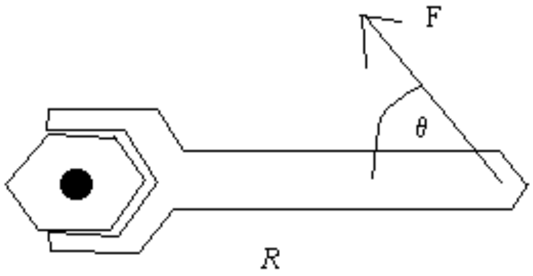
Final momentum in y-direction $P_{Ayf} + P_{Byf}$ = ___________

Kinetic Energy before = _________ Kinetic Energy After = ________

Analysis of Data: You are using a ruler to measure the distances dx, dy, and the smallest division on the ruler is 1 mm. So the estimate of error introduced into the measurement by the limitation in precision of the ruler is 1 mm/dx * 100% and the same for dy. Can you figure out how to determine the inaccuracy in the value for dt? Then use these estimates of error to find the overall estimate of error for the value of the momentum: est. of error = $\sqrt{(\text{dx \%error})^2 + (\text{dy \%error})^2 + (\text{dt \%error})^2}$.

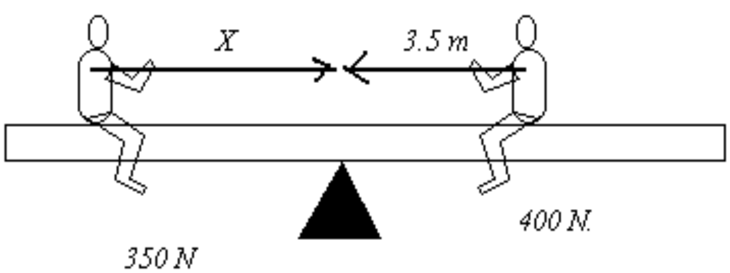
EQUILIBRIUM OF TORQUES

When you apply a force to a wrench to tighten a screw, your force is converted into a turning force which is called **Torque**. You can increase the amount of turning force by increasing the force you apply to the wrench (so the torque is proportional to the force applied). You can also increase your turning force by increasing the length of the wrench used (so the torque is proportional to the distance of the axis of rotation (screw) to the point of application of the force). The greatest amount of torque is generated when the force is applied at right angles to the wrench, so the angle of application has an effect. Only the perpendicular component of the force to the handle of the wrench causes the wrench to rotate. Putting all this together the torque is given by:



$\tau = R\,F\,\text{Sin}\,\theta$ The torque is said to be <u>positive when it rotates the object in a counterclockwise direction and negative when it rotates it in a clockwise direction.</u>

If two torques pull on an object and the object doesn't turn, then the torques are balanced and the object is in rotational equilibrium. Take for example two children playing on a sea-saw: A boy (weight = 400 N) sits 3.5 meters from the pivot or fulchrum, and a girl (weight 350 N) sits on the other side so as to balance the boy's weight (actually torque). How far from the center (fulchrum) should she sit?



The counter clockwise torque must offset the clockwise torque:

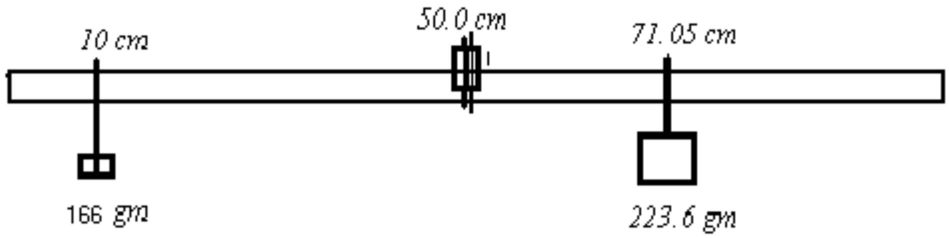
So $X * 350 * \text{Sin}\,90° = 3.5 * 400 * \text{Sin}\,90°$

$X = 4.0\text{ m}$

If the beam were not centered then it too would have an unbalanced torque. In the above example the torque produced by the weight of the beam on the right exactly balances the torque produced by the weight of the beam on the left. Your first procedure in this section is another example of this situation.

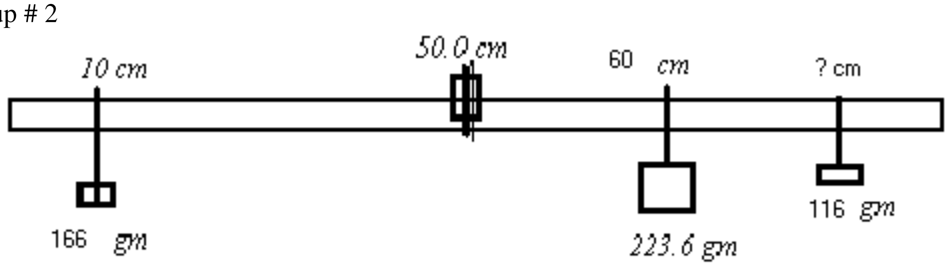
Procedure:
* Measure the mass of the meter stick.
* Measure the mass of each of the clamps.
*Place one of the clamps on the meter stick so the hook is upward and the meter stick is balanced when suspended by the hook. Record the location of the center of mass of the stick.

Setup #1



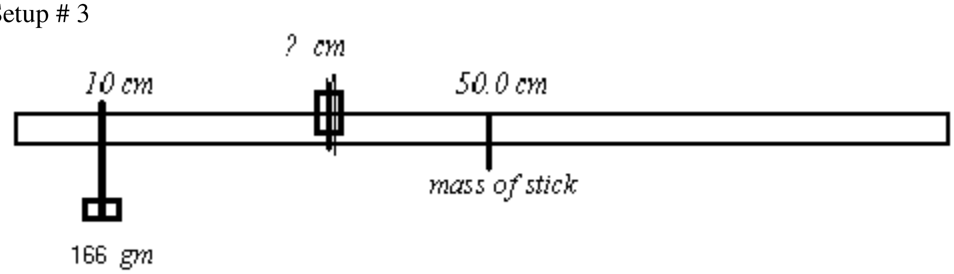
*Place another clamp with the hook downward at the 10 cm mark; place 150 grams on it. The total mass is that of the clamp plus the 150 grams.
*Place a third clamp on the meter stick with the hook downward; place 200 grams on it. Find the location on the meter stick where this will balance the first one.
*Calculate the clockwise torque produced by the (200 plus clamp) weight.
*Calculate the counter clockwise torque produced by the (150 plus clamp) weight.
*Determine the percent difference (the difference divided by the average).

Setup # 2



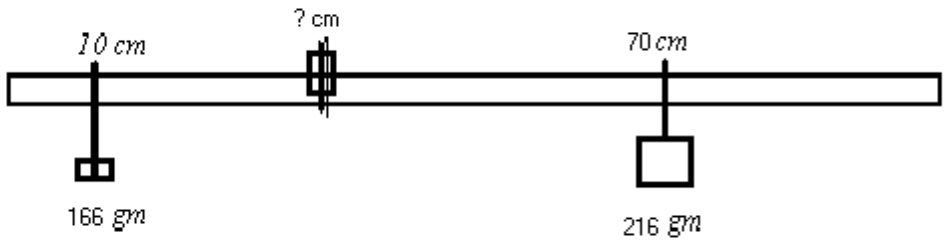
*Leave the clamp with the hook at the 10 cm. mark with the 150 grams on it.
*Move the 200 gram plus clamp to the 60 cm mark .
*Place a third clamp with 100 gram plus clamp at a point where the 200 and the 100 will balance the 150 gram on the other side of the meter stick.
*Calculate the clockwise torque produced by the (200 plus clamp) weight plus the (100 gram plus clamp) weight.
*Calculate the counter clockwise torque produced by the (150 plus clamp) weight.
*Determine the percent difference (the difference divided by the average).

Setup # 3



*Leave the clamp with the hook at the 10 cm. mark with the 150 grams on it.
*Remove the other clamps and weights.
*Slide the meter stick inside its supporting clamp to find the new location of support where it is balanced.
*Calculate the clockwise torque produced by the (mass of the meterstick * 980 cm/s^2) weight located at its center of mass.
*Calculate the counter clockwise torque produced by the (150 plus clamp) weight.
*Determine the percent difference (the difference divided by the average).

Setup # 4



Fulchrum not at the center of mass:
*Move the 200 gram weight to the 70 cm mark.
*Leave the 150 grams at the 10 cm mark on the meter stick.
*Determine the location where the clamp which is supporting the meter stick will again balance the meterstick.
*Calculate the clockwise torque produced by the meterstick and the 200 gram weight.
*Calculate the counter clockwise torque produced by the 150 gram weight.
*Determine the percent difference.

*Have the instructor check you calculations.

STATIC EQUILIBRIUM OF A RIGID BODY

OBJECT: To study the conditions of static equilibrium of a rigid body under the action of forces, all of which lie in a common plane.

METHOD: A metal disk, supported on three steel spheres, is free to move in any direction in a horizontal plane. Known horizontal forces are applied at various points on the disk and their directions and points of application are recorded on a sheet of paper lying on the disk. These data are treated graphically to verify the conditions of static equilibrium.

THEORY: A body is said to be in equilibrium when (1) its linear acceleration and (2) its angular acceleration are zero. If, in addition, both its linear velocity and its angular velocity are zero, it is said to be in static equilibrium.

1. If several forces in a plane, are applied at a single point in a body, and if the vector sum of these forces is zero, there is no linear acceleration and the body is in equilibrium. In other words, when the resultant of these forces is zero, the linear acceleration is zero and equilibrium obtains. By direct implication, if the sum of the components of the forces taken in two mutually perpendicular directions are each equal to zero, the body is in equilibrium.
2. If the coplanar forces are applied at different points on the body, the above criterion is a necessary but not a sufficient condition for equilibrium. Although linear acceleration of the body will not occur if the vector sum of the forces is zero, the body may, nevertheless, have angular acceleration in the plane of the forces.

The effectiveness in producing rotation about an axis depends upon two factors: the magnitude of the force and the perpendicular distance from the axis to the line of action of the force. This distance is called the arm of the force, or moment arm. The product of these two factors, force and arm, is called the torque or moment of the force about the axis.

When the sum of the applied moments of force about any axis or center is equal to zero, there can be no angular acceleration of the body. Consequently, there is rotational equilibrium. In this summation the direction in which each applied force tends to rotate the body about the chosen axis must be taken into account. For convenience consider those moments which tend to produce counter-clockwise rotation as positive and those which tend to produce clockwise rotation as negative. The point where the axis cuts the plane of the forces is often called the center of moments.

If the body is not accelerated about one axis perpendicular to the plane of the forces, it will not exhibit acceleration about any axis perpendicular to that plane. In the experimental procedure to follow, the tests for equilibrium will be made when linear and angular velocities of the body are initially zero. Consequently the test for equilibrium will consist of determining whether the applied forces and moments produce motion of the body. This is a test for static equilibrium.

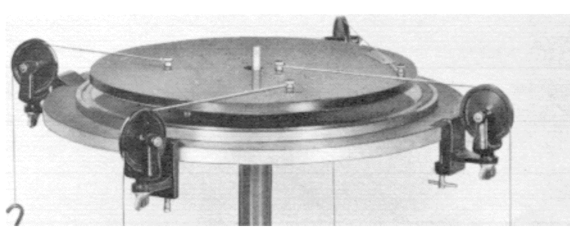


Fig. 1. The Moments Apparatus attached to the Force Table.

APPARATUS: The apparatus (Fig. 1) consists of a force table, on the top of which two circular metal disks are placed. The two disks are separated by three steel spheres. A removable peg in the center of the lower disk protrudes upward through an enlarged hole in the upper disk. Thus the latter is free to move in any horizontal direction until constrained from further motion by the peg. Cords, attached to pegs at various points on the top disk, pass over the pulleys clamped at different points about the circular force table. Known masses suspended from the ends of the cords produce the forces required. Adapters for the pulleys bring the cords which pass over the pulleys into a horizontal plane above the disk. The table is provided with leveling screws.

PROCEDURE:

Experimental: Center the plain disk on the top of the force table. Place the three steel balls on the disk at points widely separated. The balls may be kept from rolling by a drop of oil or a touch of vaseline. After carefully placing the disk containing the holes on the steel balls, level the table so that the disk will not tend to move in any one direction in preference to another. Place a piece of plain paper upon the disk and insert the center pin. Attach cords to the disk at three different points chosen at random. Place the pulleys at convenient points and add masses until two of the forces have values of several hundred grams weight. Adjust the third force, both as to magnitude and direction, until no motion results on removing the peg. Be sure that the disk is free to move on the steel balls and that the cords all lie in a plane parallel to the top of the disk. Draw lines on the paper to indicate the lines of action of the forces and indicate with arrowheads their direction. Record with each line its corresponding force, which should include the weight of the hanger. Place another sheet of paper on the disk and repeat the experiment using four forces, no two of which act along the same line.

Interpolation of Data: Smooth out the record sheet for the three-force problem and paste a piece of paper over the hole made by the centering peg. Construct a vector diagram of the forces, using as large a scale unit as possible. Is the vector diagram a closed triangle? If not, measure the distance from the end of the line representing the third force to the beginning of the line representing the first force. With the aid of the scale unit, determine the force which this represents. This is the magnitude of the experimental error. Construct a similar vector diagram for the four-force problem on the second sheet. In case the vector diagram does not form a closed figure, the length of line required to close the figure represents the magnitude of the experimental error.

Select any point not on the line of action of any of the forces and from it draw perpendiculars to the lines of action of the four forces. Measure these perpendiculars and calculate the moments of the forces about this point. Find the algebraic sum of the moments. Repeat the calculations for two other widely separated points taken in turn as centers of moments.

QUESTIONS:

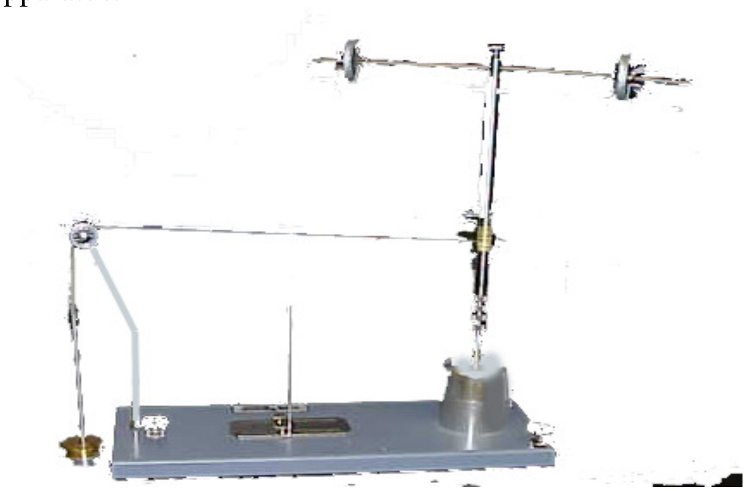
1. Show that if an extended body is in equilibrium under the action of three forces they must meet at a point.
2. If one of the four forces in the experiment were moved parallel to itself, would the vector sum still be zero? Would the sum of the moments about a given point be changed?
3. If with three forces the disk were held motionless while one of the forces is moved parallel to itself by moving peg and pulley, would this change the vector sum of the forces? What sort of motion would take place (a) when the disk is released, (b) the pin remaining in place?

No. 71990-134 (formerly M34bi)

MOMENT OF INERTIA

Purpose: to verify that the moment of inertia is given by $\Sigma M_i R_i^2$.

Apparatus:



Theory:

Consider the simplified object to the right: The falling weight provides a torque: $\tau = r*F$ which causes the disk to rotate with an angular acceleration α: $\tau = I*\alpha$. F is the force of tension within the cord. From the falling weight: $M_L g - F = M_L a$ and $a = r*\alpha$ where r is the radius of the disk that the cord is wound around.

From the time the weight takes to fall the value of the acceleration can be determined; $d = \frac{1}{2} a t^2$ so $a = 2d/t^2$, $I*\alpha = r*M_L(g - a)$ and $I = r*M_L(g - a)/(a/r)$, which leads to:

$I_{Exp} = M_L r^2 \left[\frac{gt^2}{2d} - 1 \right]$. (1)

The moment of inertia for a mass rotating at a distance R_1 is given by : $I = M * R_1^2$.
So the total moment of inertia for two objects plus the rotating apparatus itself would be:
$I_{calc} = I_o + M_1 R_1^2 + M_2 R_2^2$.

Procedure:

*Measure the radius (r) of the vertical shaft that the string is wrapped around.
*Measure 100 cm from the floor and mark the location on a strip of tape attached to the table.

*Place 100 grams on the descending weight hook and no additional weights (leave the wing nuts off) on the threaded horizontal bar.
*Release the hook weight from a height of 100 cm above the floor.
*Measure the time for the weight to fall from rest to the floor.
*Attach M_1 at a distance R_1 from the center of the rotating shaft and M_2 at a distance R_2 from the center of the rotating shaft. (Sample values for M_1 , R_1 , etc. can be found in the sample table on the next page. R_1, R_2 should be measured from the center of the weight to the center of the shaft and they do not have to be the same, although it is preferred for stability).
*Determine the value of I_{Exp} from the formula (1). I_o is found by determining I_{expt} with no additional weights on the threaded horizontal bar.
*Determine the percent difference between I_{calc} and I_{meas} for each piece of data.

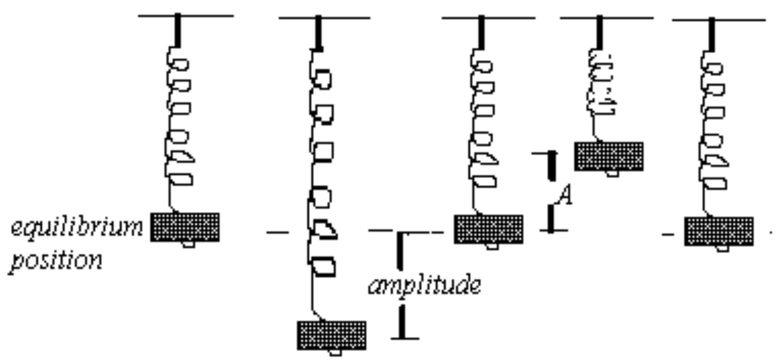
Distance of descent (cm) = ...
Mass of 2 wing nuts (gm) = ...

$M_L\,(g)$	$W(dynnes)$	M_1	M_2	R_1	R_2	$Ical(g.cm^2)$	Time(s)	$IExp(g.cm^2)$	%diff
100	98000	0	0	0	0	Io			
100	98000	50	50	5	5				
100	98000	50	50	10	10				
100	98000	50	50	15	15				
200		50	50	15	15				
250		50	50	15	15				
250		100	100	15	15				
250		150	150	15	15				
250		200	200	15	15				

SIMPLE HARMONIC MOTION

Purpose: to investigate the oscillatory properties of (1) a mass at the end of a spring and (2) a simple pendulum. Both systems are described by the frequency of the oscillation or the number of oscillation in a unit of time (ex. 20 oscillations/second), the period of the oscillation or the time it takes for the object to make one complete oscillation (the period is the inverse of the frequency T = 1/f), and the amplitude of the oscillation (the maximum distance from the equilibrium position - rest position). In an idealized system with no friction, the total energy of the system should remain constant, so that the Potential Energy + Kinetic Energy should always equal a constant.

Apparatus: Oscillation of a mass at the end of a spring



Theory: Mass - Spring System:

When a spring is stretched or compressed it responds by pushing back with a force proportional to the amount it has been stretched or compressed. Mathematically, this is written as F = $-\ k\,\Delta x$ where k is called the spring constant. The spring constant is measured by adding weights to the end of the spring and measuring Δx, or how much the weight has stretched the spring. Then k = F/Δx where F is the increase in weight, mg, and Δx is the increase in the length caused by the increased force.

Record measurements and calculations in Data Table I. Determine the average spring constant.

When the mass is attached to the end of the spring and set into oscillation, the force within the spring always brings the mass back to its equilibrium position. The number of oscillations the spring makes in a second is called the frequency of the oscillation, ν. The number of seconds it takes to make one complete oscillation is called its period, T. ν=1/T and T =$2\pi\sqrt{\mathrm{m/k}}$.

For the ideal massless spring m would be the mass of the object, but in real life the spring does have mass and it is oscillating, so m = mass$_{object}$ + $\frac{1}{3}mass_{spring.}$ Note that the amplitude is not found in the equation for the frequency or period so the frequency should not change with the amplitude of the oscillation. Record measurements and data in Data Table II.

Part II The Pendulum

The frequency of the pendulum should depend on the length of the string and not the mass of the object. For the pendulum, the equilibrium position is the vertical position where the object would remain suspended at rest. A small displacement from the vertical will cause the mg Sin θ component of gravity to pull it back towards the vertical position. The Sin θ is approximately $\frac{\Delta x}{L}$. So F = ma = mg $\frac{\Delta x}{L}$ and a = $\frac{g}{L}\,\Delta x$, which yields a frequency, ν=$\frac{1}{2\pi}\sqrt{\frac{\mathrm{g}}{\mathrm{L}}}$. Record measurements in Data Table III.

Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________

(*You can create these tables in Excel using the IBM PC and then you can graph the Δm*g vs. Δx.)

Data Table I:

Δm*g is obtained by subtracting the first value from the rest of the values. The same thing is done for calculating Δx .

	A	B	C	D	E	F
1	mass (gm)	m*g (dynes)	Δm*g	position (x)	Δx	k=Δmg/Δx
2	50		//////		///////	////////
3	100					
4	150					
5	200					
6	250					

Data Table II: Time for 20 oscillations avegare value for k found in table I =

Mass of spring = grams

	A	B	C	D	E	F	G
1				(grams)			
2	Mass(obj)	Mass(effect.)	Ampl	time.	period	Period (eq)	% error
3	100		5 cm				
4	200		5 cm				
5	300		5 cm				
6	400		5 cm				
7	400		10 cm				
8	400		15 cm				

Questions:

Plot the period on the y-axis and the $\sqrt{m}$ on the x-axis. What would the slope be equal to, if you rearranged the equation T=$2\pi\sqrt{\frac{m}{k}}$?

Data Table III: Period = time/20 osc

mass	length	Δx	time for 20 osc	Period	Period (equat.)	% error
	20 cm	5 cm				
	40 cm	5 cm				
	60 cm	5 cm				
	80 cm	5 cm				
	80 cm	10 cm				
	80 cm	20 cm				
	80 cm	40 cm				

Questions:

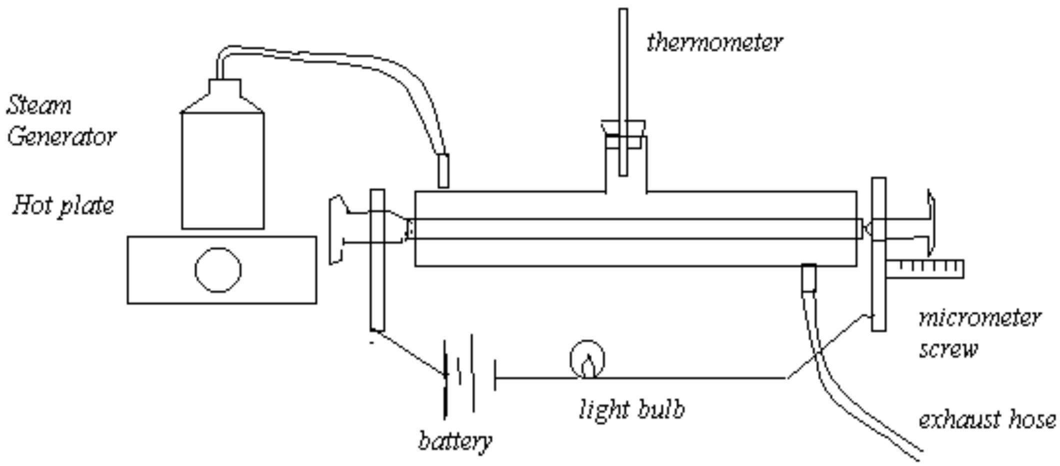
Did the amplitude of the oscillation have any effect on the frequency?

If you were to graph the period on the y-axis and the $\sqrt{L}$ on the x-axis, What would the slope be equal to? T = $2\pi\sqrt{\frac{L}{g}}$

LINEAR EXPANSION OF A METAL ROD (WEAR GOGGLES)

Purpose: To measure the coefficient of linear expansion for three different metal rods.

Apparatus:

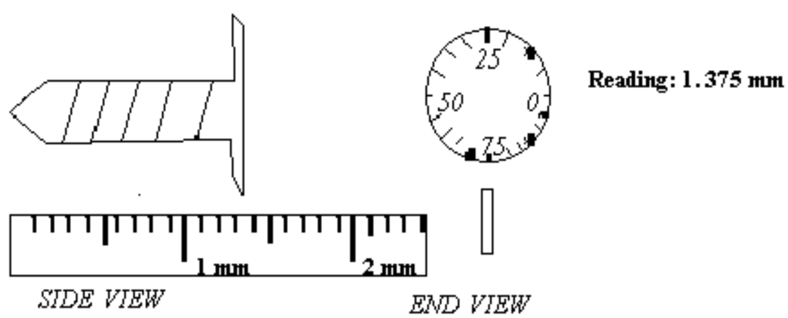


Theory: Most metals expand when heated. Each linear dimension, length, width, height, radius or circumference will increase with an increase in temperature. The increase ΔL is directly proportional to the original length, L_o, of the rod and the size of the temperature increase, ΔT.

$$\Delta L = \alpha\, L_o\, \Delta T$$

Procedure: Measure the T_o, L_o for each rod.

1. Assemble the apparatus: Carefully place one of the rods in the steam jacket for heating.
2. Measure the Initial x using the ruler and circular dial at the end of the apparatus. Screw the end screw in until the bulb lights up. Read the ruler and circular dial, repeat three times. Record the average as the initial x measurement. Back up the circular dial two rotations to give the rod room for expansion.



3. Carefully connect the steam generator to the steam jacket. Allow the steam to heat the rod for 5 to 10 minutes until the rod is at the temperature of the steam inside the jacket (you should see steam coming out of the outlet hose). Screw in the circular dial until the light bulb lights up. Measure the x final measurement three times and record the average as the final x measurement. Record the temperature of the steam inside the jacket.
4. Calculate $\Delta x = x_f - x_i$. This should be about 1 mm or a little more or less depending on the substance. Calculate $\Delta T = (T_{steam} - T_o)$. Calculate the coefficient of thermal expansion from: $\alpha = \frac{\Delta x}{L_o \Delta T}$ Find the % error between your value and the accepted value.

5. Cool down the steam jacket by running cold water through it. (Turn off the generator, remove the rubber hose connected to the steam generator, remove the stopper holding the thermometer and using a beaker, pour cold water through the steam jacket. MAKE SURE that there is a container to catch the water from the exhaust hose.
6. Repeat for the other two rods.

Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________

Table I: T_i= ___________ °C

Metal	L_o	x_i	x_f	Δx	T_f	ΔT	α_{expt}	$\alpha_{accepted}$	% error
Aluminum								24E-6	
Copper								17E-6	
Brass								19E-6	

GAS LAWS

Part A: Boyle's Law.

When the temperature of a gas is kept constant, the total pressure (gauge plus atmosphere) varies inversely with the volume. The atmosphere pressure is measured using a barometer, and the gauge pressure (pressure above or below atmospheric) is measured using a pressure sensor. In this Lab, the volume is varied inside a syringe which is attached to a pressure sensor that already takes atmosphere pressure into account. The total pressure is measured by the sensor and displayed with Science Workshop.

Apparatus:

Procedure:

1. Open Science Workshop.
2. Drag the analog plug icon to channel B, and select "Pressure Sensor (Absolute.)"
3. Set "Sampling Options" to a stop condition of 3 seconds.
4. Open a table by dragging the Table Icon to channel B. Click on the Σ button on the table to display the mean and standard deviation.
5. Set the syringe to 20 cc, and then connect it to the pressure sensor.

6. Collect data and use Excel to graph Pressure vs. Volume and a second graph of Pressure vs. 1/Volume.(Use Trendline to display the equation of the graph.)

The graph of total pressure vs. 1/volume should be straight line. The ideal gas law states that PV=nRT.

What is the slope of you graph? If you measured the temperature, you could find the value of n, the number of moles of gas trapped in the closed section of the tube.

Data Table:

Atmospheric Pressure = ___________cm Hg. Convert to Pascal

=___________Pa.

Volume (cc) Total Pressure (Pa) P*V 1/Volume

Volume(cc)	**Total Pressure(Pa)**	**P*V**	**1/Volume**
20			
18			
16			
14			
12			
10			
8			

Was P*V = Constant? Use an Excel Spreadsheet to plot P = (slope) 1/V.

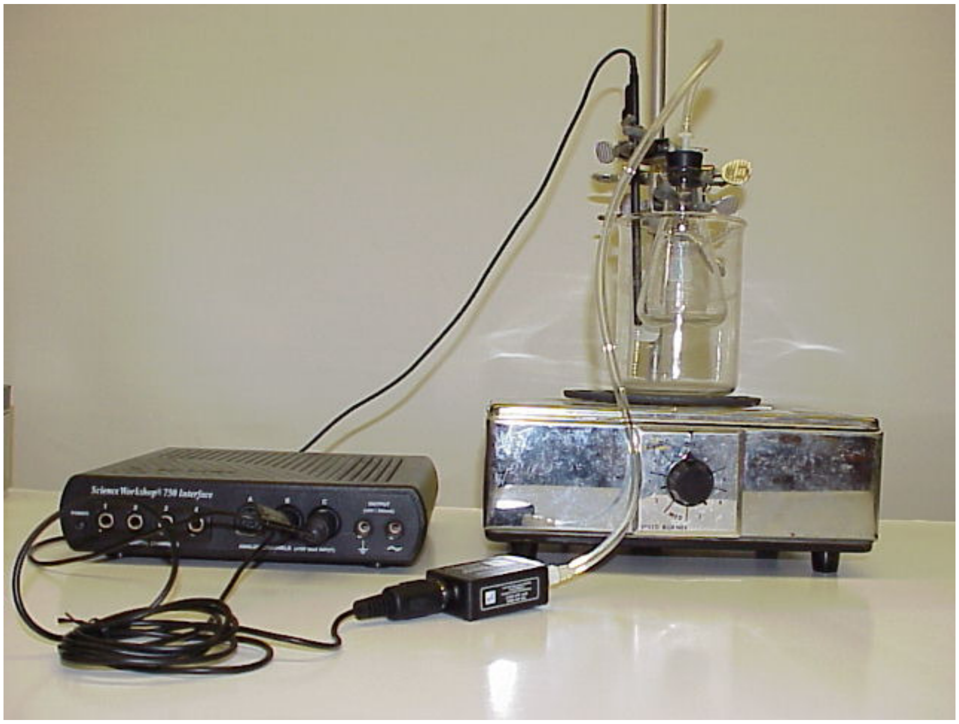
Part B: Gay Lussac's Law:

At constant volume, the pressure exerted by a given mass of gas is proportional to its absolute temperature. If you graph total pressure vs. the temperature (?C), you should get a straight line.

"P = Slope* Tc + Po" is the equation of a straight line where Po is the y-intercept at temperature 0?C. If you then extend that line into unmeasured region of lower temperature, you could find the temperature at which the absolute pressure would eventually go to zero. This temperature is referred to as

Absolute Temperature (Ta) which should be -273 ?C. So, when you make P=0 in the equation 0 = Slope* Ta + Po, where Ta is the temperature where P goes to zero. You can then calculate Absolute Zero by solving for Ta. The slope and Po are obtained by using the Trendline feature for an Excel Graph.

Apparatus:



Procedure:

1. Open Science workshop.
2. Drag the analogue plug icon to channel B and select "Pressure Sensor (Absolute)".
3. Drag the analogue plug icon to channel C and select "Temperature Sensor (Type K)".
4. Set "Sampling Options" to 60 sec. (slow), with a Start Condition of 30 sec. (Stop Condition is none.)
5. Drag a table icon to Channel B, and another column to table for channel C by clicking on the edit button and selecting add new column. Then click on the black arrow and select C.
6. Connect the pressure sensor to the 250 ml flask. Place the flask into the water bath so that the top is above water and the tube for the pressure sensor is not touching any hot metal object or the hot plate itself.
7. Use the test tube clamp to secure the temperature probe so that the bottoms two inches are in the water.
8. Turn on the hotplate and begin collecting data (about 10 reading.)
9. Use Excel to graph total pressure (y-axis) vs. temperature (x-axis.) Use Tredlines feature to find the equation of the linear graph. (Use a scatter graph. Then, click on one of the data points.) Now go to tools menu at the top of the screen and select trendline (this gives you the

best line to fit your data. Go to options and have the equations displayed, which will give you the slope and the y-intercept.)

10. Use the slope and the y-intercept given by the tredline to calculate the value of the Absolute Zero.

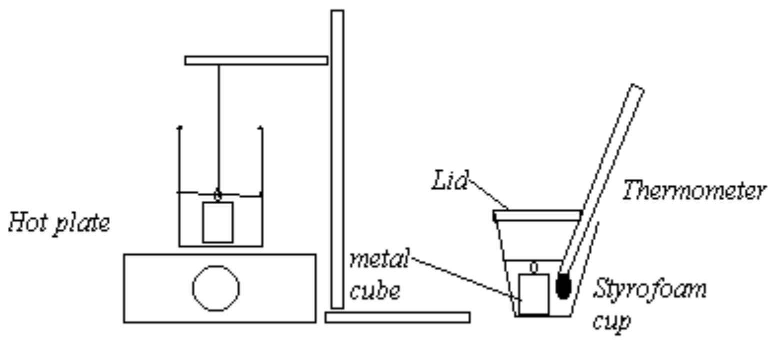
Temperature	***Total Pressure***

Since you have only 6 or 7 data points in small section of the temperature range, do not be surprised that your value for Absolute Zero is not perfect.

SPECIFIC HEAT OF A METAL (WEAR GOGGLES)

Purpose: To determine the characteristic thermal properties of different materials.

Apparatus:



Theory:

When two objects are brought into physical contact, the hotter object transfers heat to the colder object until they both have the same temperature. The sum of the heat loss (negative ΔQ) by one object and the heat gain (positive ΔQ) by the second colder object should add to zero. The heat gained or lost by an object can be calculated from $\Delta Q = c*m*\Delta T$ where c is the specific heat of the object. Hence, $\Delta Q_1 + \Delta Q_2 = 0$

$c_1 m_1 (T_f - T_i) + c_2 m_2 (T_f - T_i) = 0$, if the metal is m_1 and the water is m_2

using the specific heat, c_2, for the water = 4186 joules/kg ^{o}C, mass is in kilograms and temperature is in ^{o}C.

copper= 386 joules/kg ^{o}C

Aluminum = 900 joules/kg ^{o}C

Procedure:

1. Measure the mass of the metal samples.
2. Submerge the metal cube supported by a string into the water and raise the temperature of the water in the beaker to 100°C (measure the temperature of the hot water with your thermometer as you may choose to use 94 degrees instead of waiting for a full boil at 100).
3. Weigh the styrofoam cup. Place 200 grams (approx.) of cold water into the styrofoam cup. Weigh the stryofoam cup with the water. Calculate the mass of water.
4. Measure the temperature of the cold water in the stryofoam cup.
5. Carefully transfer the metal cube from the beaker of hot water to the cup with cold water. Do this in one smooth action trying not to waste time or spill the water. **BE CAREFUL** !!
6. Measure the final temperature of the metal and the cold water.
7. Calculate the specific heat of the metal sample. Determine the percent error.
8. Repeat the procedure for the second metal cube.

Analysis:

Estimate the experimental error in this procedure by (a) estimating the amount of hot water that may have been transferred with the metal cube from the beaker of hot water (assume to be small about 0.5 grams). Treat this as a ΔQ_3 with an initial temperature of 100 ^{o}C. What would be the new value for the specific heat of the metal cube? What percent difference is this from your previous answer? (b) estimating the percent error in measuring the temperature. The smallest division on the thermometer is 1 ^{o}C; if you can estimate to δT= 0.2 ^{o}C (this is the amount your temperature measure may be off by) and the temperature change was from 10 to 25 or ΔT = 15. So the percent error for this measurement would be $\frac{\delta T}{\Delta T} = \frac{.2}{15} = 1.6\%$ (c) estimate the percent error produced in measuring the mass of the water (the smallest division on the electronic balance is δm = 0.001 and m = 200 grams so the % error would be $\frac{\delta \text{m}}{m} = \frac{.001}{200} = .0005\%$ which is too small to be important).

Then the total estimation of the % error from the limitations of the equipment would be:

For ΔQ: $\sqrt{(1.6)^2 + (.0005)^2} = 1.6\%.$

Compare this to the procedural error in transferring some water with the metal cube calculated in part (a)

Data Sheet: Name ____________________________ Lab Partners ______________________________

Specific Heat of Metal:

Mass of styrofoam cup: ____________
Mass of styro cup + water: _________
Mass of water: ______________
Initial temp of water: __________

Mass of copper cube = ________________

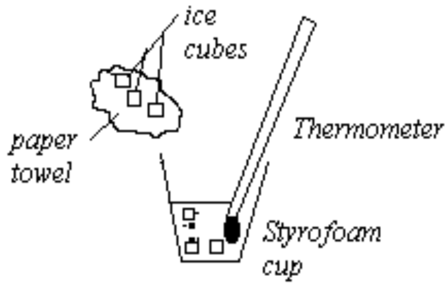
c_{water} = 1.00 cal/gm^{o}C
Final temp of water + the metal cube = __________

$c_1 m_1 (T_f - T_i) + c_2 m_2 (T_f - T_i) = 0$

LATENT HEAT OF FUSION AND VAPORIZATION (WEAR GOGGLES)

Purpose: to determine the latent heat of fusion for ice (80 cal/gm) and the latent heat of vaporization for steam (540 cal/gm).

Apparatus:



Theory:

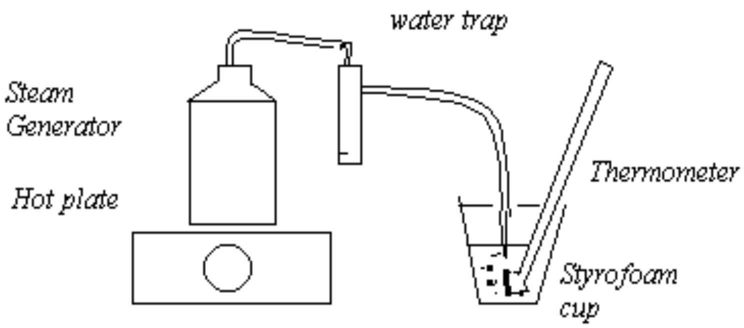
Latent Heat of Fusion:

Heat is absorbed by the ice in melting $\Delta Q = M\,L_f$ from the warm water in the styrofoam container. The ice, after it has melted, absorbs more heat from the water to reach a final equilibrium temperature with the "warm" water in the cup. The ice has a positive change in energy while the water has a negative change in energy (note: the two changes in energy should add to zero).

$$M_{ice}L_f + c_{melted\,ice}M_{ice}(T_f - 0) + c_{water}M_{water}(T_f - T_i) = 0 \qquad c_{melted\,ice} = 1\ cal/gm^\circ C$$

Procedure: Measure the mass of the styrofoam cup. Add 150 gm (approximately) of warm water (25^o approx.) to the cup. Measure the mass of the cup plus the water. Measure the temperature of the water inside the cup. Using a paper towel to transfer ice cubes into the cup (so that you do not melt the ice cubes in your hand) add about 10 grams of ice to the water in the cup. Stir with the thermometer. After the ice is melted, measure the final temperature and measure the mass of the ice + water + cup so that you can determine the mass of the ice. Calculate the Latent Heat of Fusion and compare with 80 cal/gm.

Heat of Vaporization



Theory: The heat released by the steam as it condenses at 100 ^oC is given to the cool water (10 ^oC). The steam, which is still at 100 ^oC, releases more energy to the water as it cools to the equilibrium temperature. The heat removed from the steam in condensing $\Delta Q = M\ L_v$ is a negative change of energy for the steam, as is the heat removed $\Delta Q = c\ m\ (T - 100)$ from the condensed steam as it cools to equilibrium.

$$-M_{steam}L_v + c_{condensed\,steam}M_s(T-100) + c_{water}M_{water}(T-T_{initial}) = 0$$

Procedure: Measure the mass of the empty styrofoam cup, add approximately 150 grams of cold water (approx. 10^oC). Measure the mass of the cup with the water. Measure the temperature of the water ($T_{initial}$).

Fill the steam generator with hot water to a depth of about 2 inches. Put the rubber stopper in the top of the steam generator. Connect the hose with the water trap to the steam generator. Turn on the hot plate set to "3". After about 5 minutes, you should see steam coming from the nozzel at the end of the hose. Carefully using a paper towel to hold the hot hose (as protection from burns), insert the hose through the hole in the cover of the styrofoam cup into the water. After the temperature has risen to about 25 ^oC or 35 ^oC, remove the hose. Turn off the generator.

Measure the equilibrium temperature of the water.

Measure the mass of the cup + water + steam and determine the mass of steam.

Calculate the latent heat of vaporization.

Find the percent error.

Data Sheet: Name ____________________________ Lab Partners _______________ , __________

Latent Heat of Fusion:

Mass of styrofoam cup: ____________

Mass of styro cup + water: _________

Mass of water: ______________

Initial temp of water: __________

Mass of cup + water + ice = ________________

Mass of ice = _______________

c_{water} = 1.00 cal/gm^{o}C

Final temp of water + melted ice = __________

$$M_{ice}L_f + c_{melted\,ice}M_{ice}(T_f - 0) + c_{water}M_{water}(T_f - T_i) = 0 \qquad c_{melted\,ice} = 1 \text{ cal/gm}^\circ C$$

$$L_f = -\frac{c_{melted\,ice}M_{ice}(T_f - 0) + c_{water}M_{water}(T_f - T_i)}{M_{ice}} =$$

L_f = _______________ % error = _______

Latent Heat of Vaporation:

Mass of styrofoam cup: ____________

Mass of styro cup + water: _________

Mass of water: ______________

Initial temp of water: ___________

Mass of cup + water + steam = ________________

Mass of steam = _______________

c_{water} = 1.00 cal/gm^{o}C

Final temp of water + condensed steam: ________

$$-M_{steam}L_v + c_{condensed\,steam}M_s(T - 100) + c_{water}M_{water}(T - T_{initial}) = 0$$

$$L_v = \frac{c_{condensed\,steam}M_s(T - 100) + c_{water}M_{water}(T - T_{initial})}{M_{steam}} =$$ _____________________________

L_v = __________________ %Error = ____________________

NORTHERN VIRGINIA COMMUNITY COLLEGE
ALEXANDRIA CAMPUS

LAB MANUAL
PHYSICS 232
2009

Walter L. Wimbush, Jr.
Professor of Physics

Date _______________ Course #______________ Instructor _______________

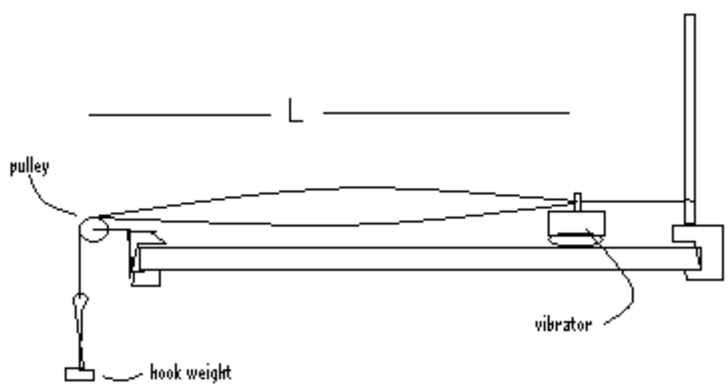
Group # _______ Names ________________, ___________________, ______________

Standing Waves in a String

Purpose:

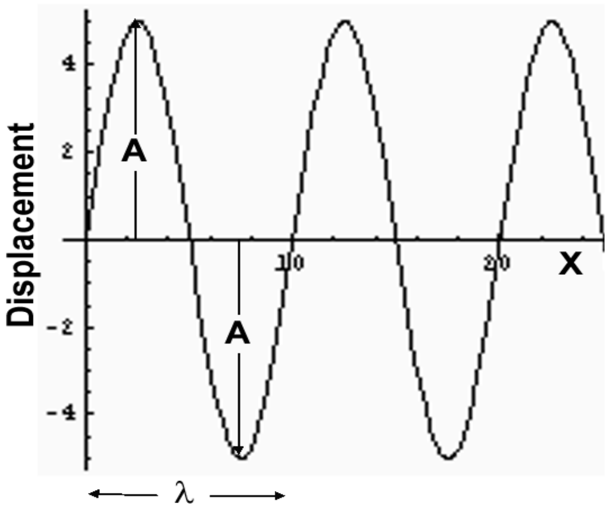
To verify the basic relationship between wavelength, frequency and velocity of waves traveling along a string.

Diagram of apparatus:



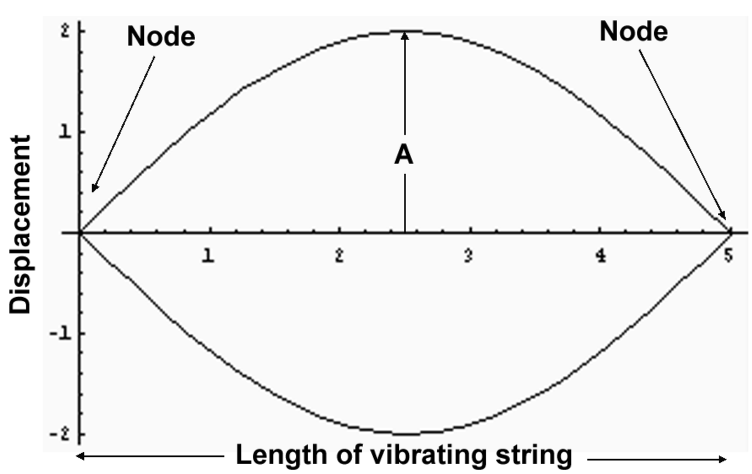
Theory:

A continuous disturbance propagated along the string is called a wave. The wave appears as a pattern of length, **λ (wavelength)**, traveling along the string with a velocity **V**. Its maximum displacement perpendicular to the direction of motion is called its **Amplitude (A)**. The particles of the wave do not move forward but move up and down with a **frequency f**.



The wave travels with a speed that depends on the tension in the string and its linear mass density, μ.

V = $\sqrt{\frac{F}{\mu}}$ The wave travels along the string and is reflected back when it reaches the end of the string. The reflected waves traveling backward interfere with the waves traveling forward to produce a **standing wave pattern**. Standing wave patterns are formed only under very stringent conditions, the length of the string must contain an integer number of half-wave patterns. In this experiment, the first pattern that can be formed is at the fundamental frequency, where the string is vibrating as shown in the diagram.



The length of the vibrating string corresponds to half a wavelength. Notice that the ends of the string do not oscillate up and down, these points are called **Nodes** and the points in the center of the string with the maximum amplitude are called **AntiNodes**.

The velocity of a wave along a string is given by:

$\mathbf{V} = \sqrt{\frac{F}{\mu}}$ *and* the $\lambda \boldsymbol{f} = \mathbf{V}$.

$$\boldsymbol{f} = \frac{1}{\lambda}\sqrt{\frac{F}{\mu}}$$

Since the length of the section of string which is vibrating, L, equals $\frac{\lambda}{2}$,

$\boldsymbol{\lambda} = \mathbf{2\,L}$, so:

$$\boldsymbol{f_1} = \frac{1}{2\,\mathrm{L}}\sqrt{\frac{F}{\mu}}\,. \qquad \textbf{Equation (I)}$$

The next frequency which produces a standing wave pattern in the string is the first overtone or the second Harmonic frequency, notice that $\boldsymbol{f}_2 = 2\,\boldsymbol{f}_1$.

Here it is seen that the length of the vibrating string corresponds to a full wavelength, (λ_2); so

$\lambda_2 = \mathbf{L}$. Therefore, $\boldsymbol{f_2} = \frac{1}{\mathrm{L}}\sqrt{\frac{F}{\mu}} = 2\boldsymbol{f_1}$.

$\boldsymbol{\lambda_n} = \frac{2L}{n}$, $\quad f_n = \frac{\mathrm{n}}{2\mathrm{L}}\sqrt{\frac{F}{\mu}}$ where n is the number of the harmonic. So, for

higher harmonics, the frequencies which will cause a standing wave pattern are given by:

$$\boldsymbol{f}_{\mathrm{n}} = \mathrm{n}\,\boldsymbol{f}_1. \qquad \textbf{Equation (II)}$$

Experimental procedure:

1. Tie a loop at each end of the string whose linear mass density, $\boldsymbol{\mu} = \frac{mass}{total\,length} \approx \mathbf{0.011}\boldsymbol{g/cm}$. Slide one loop over the clamped vertical rod. Pass the other end through the hole of the vibrator and over the pulley at the end of the table. Attach a 50 gram hook to the end of the string (This step is been set by the instructor.) Add 150 grams to the hook to make a total of 200 grams.
2. Calculate the length of vibrating string for the fundamental frequency of 25 Hz. Repeat the calculation for 50 Hz, 75 Hz, 100 Hz, 150 Hz.

   For $\boldsymbol{f}_1 = \mathbf{25\ Hz}$, $\boldsymbol{\lambda} = \mathbf{2\,L}$ *for* $\boldsymbol{f}_{\mathrm{n}} = \mathrm{n}\,\boldsymbol{f}_1$ $\quad \boldsymbol{\lambda_n} = \frac{2L}{n}$
3. Place the vibrator at a distance from the pulley equal to the length calculated for 25 Hz. . Using the Science Workshop, drag the plug on the right to socket B, select the Power Amplifier. Select Sin wave, frequency = 25 Hz, Amplitude = 4 volts.
4. Observe the pattern on the string. It should look like half of a sine wave. Adjust the length until you get the best pattern with the largest amplitude. Measure and record the length of the half sine wave. (Now double the fundamental frequency from the Power Amplifier....What is the pattern now?} Repeat for the remaining frequencies.
5. Plot the frequencies vs 1/(measured length).

Now to verify the frequency's dependence on the tension which should be proportional to the square root of the tension.

6. Using a length of 100 cm between the vibrator and the pulley, calculate what the tension should be for a frequency of 25, 30, 40, 45, 50, 55, 60 Hz, $F = \mu(4\,L^2)\,(\boldsymbol{f}^2)$ so $m = \mu(4\,L^2)\,(\boldsymbol{f}^2)/g$

7. Set the vibrator at this length for 25 Hz, place the necessary mass at the end of the string and check. adjust the mass to obtain the maximum amplitude.. **(keep the length at 100 cm)**

Repeat for the remaining frequencies.

8. Graph the frequency vs the $\sqrt{\mathbf{F}(\mathit{Tension})}$. (Remember Tension = mg.)

Now to verify the frequency's dependence on the linear mass density, μ. which should be proportional to $1/\sqrt{\mu}$.

Use a heavier strings of the same length, measure its mass and length.

9. For the same tension , 200 grams * 980 cm/s^2 and length used in procedure #5 for 25 Hz, calculate the frequency for each of these "heavier" strings. $\boldsymbol{f} = \frac{\sqrt{F}}{2L}\,[\frac{1}{\mu}]$.

10. Check the frequency, adjust it if necessary for the largest amplitude, Graph frequency vs. $[\frac{1}{\mu}]$..

Discussion of results:

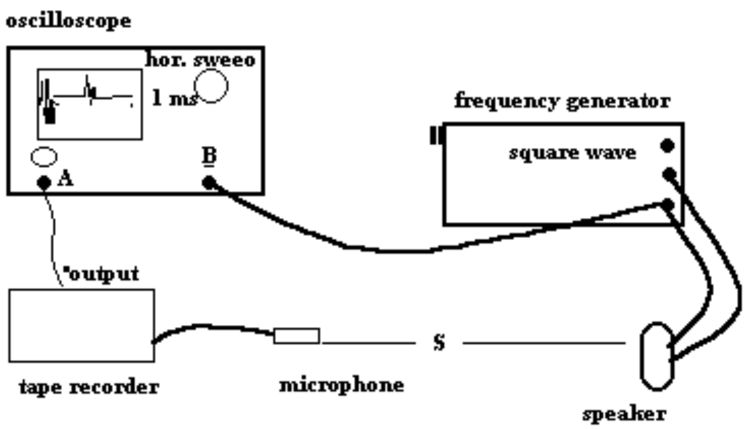
Look at your graphs, For the first graph was the graph a straight line? (i.e. was the Frequency proportional to 1/L)? For the second graph was the frequency proportional to $\sqrt{tension}$? For the third graph was the frequency proportional to $1/\sqrt{\mu}$.

How close was your data to the expected data? What do you think was the source of the difference between your data and the expected data?

Conclusion: Was the dependence of the frequency on the variables verified

SPEED OF SOUND

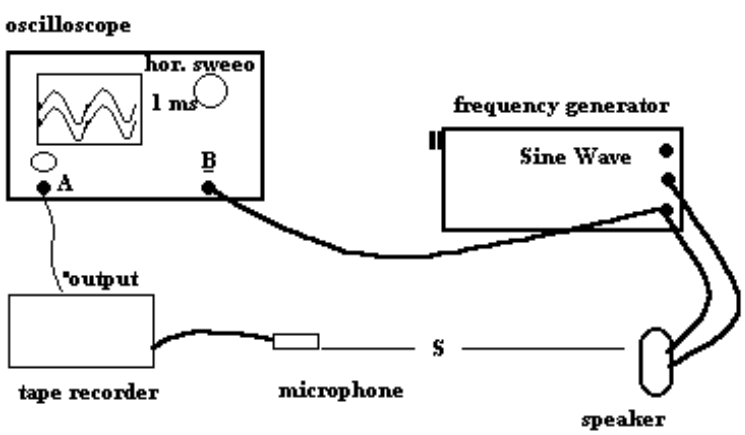
Purpose: to measure the speed of sound using an oscilloscope.
Diagram:



Procedure: Connect the frequency generator to the speaker as shown in the diagram. Also connect the frequency generator to the trigger input of the oscilloscope. Then connect the oscilloscope's vertical input to the microphone. Set the frequency generator for a square wave at a frequency of 100 Hz. Each time the square wave jerks the loud-speaker's cone forward or backward, a burst of high frequency sound is produced. The oscilloscope will detect both the outgoing sound and the received sound at the microphone. The time between the pulses can be determined by measuring the distance on the oscilloscope screen between the pulses and multiplying this by the horizontal sweep time (msec/cm).

Method II. The time delay can be observed directly in the sine wave on the oscilloscope by triggering the horizontal sweep with the audio generator. Connect the "B" input to the generator and the "A" input to the microphone. Set the trigger to "B". Move the microphone a distance "x" until the two sine waves are again in phase. The time is then the period of the oscillation (1/frequency). The velocity of the wave is the distance/time ($v = x/t = x \cdot$ frequency).

Diagram:

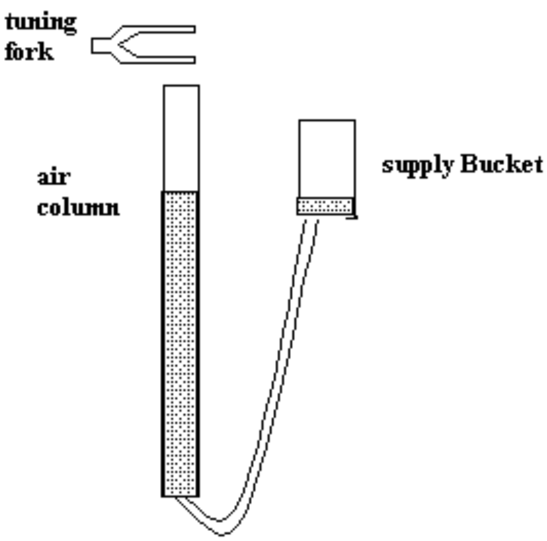


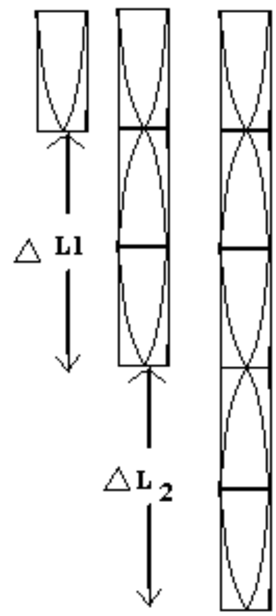
Make your own data tables.

AIR COLUMN RESONANCE

Purpose: to determine the speed of sound within the air column by measuring the length of the air column necessary for resonance at a fixed frequency.

Apparatus:





Theory: Resonance should occur at lengths: $\lambda/4$, $3\lambda/4$, $5\lambda/4$ etc...
So that the distance between these lengths should equal $\lambda/2$.

Procedure:

a. Carefully fill the tube with water from the supply bucket.
b. Place the tuning fork above the air tube with the lower tine 2 cm above the top.
c. Raise or lower the water level in the air tube until you hear the amplitude of the sound increase to a maximum. Mark the water level in the tube with a grease pencil. Continue lowering the water until you hear the next maximum. Repeat. You may get the third resonance but <u>you probably will not get the fourth in which case you will have to leave ΔL_3blank</u>.
d. The distance between maxima is equal to $\lambda/2$. Calculate the average λ.
e. Calculate the speed = $f \cdot \lambda$
f. Since the speed of sound in air depends on the temperature of the air, you can obtain a second value for the speed of sound from the formula $v = 331 + .6\,T_C$ Find the % difference between the two values for the velocity of sound.

Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________

Temperature = C Velocity of sound from formula = m/s.

Freq. (Hz)	$\Delta L_{1\ (m)}$	$\Delta L_{2\ (m)}$	ΔL_3(m)	$\Delta L_{avg.\ (m)}$	$\lambda=2*\Delta L_{avg.}$(m)	$\lambda*\nu$ =v	% Δ

ELECTRIC FIELD MAPPING

Purpose: To measure the potentials established by two charged objects on the resistance paper; to map the equipotential and the electric field lines produced; and to verify the potential distribution for the two charged "blobs" is that of two long rods.

Theory: The concept of an electric field was introduced to simplify the calculation for the effect one charge or a collection of charges would have on another charge in its (their) vicinity. The presence of an already existing charge changes the electrical nature of the space surrounding it. The force another charge would experience when it is near the already existing charge could be calculated from Coulomb's Law or from the electric field. The electric field produced by the already existing charge should be such that the force on another charge at a given point is proportional to the electric field there. The electric field is a vector quantity - it has both magnitude and direction.

The most direct method of measuring the electric field at some point would be to measure the force on a test charge placed at this point in space. However, this is very difficult to do. It is easier to measure the voltage (potential) at different points and to calculate the electric field from them ($E = -\frac{\Delta V}{\Delta x}$).

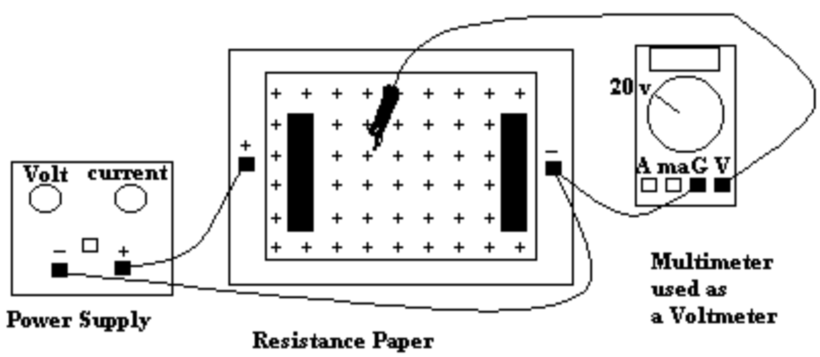


Figure 1.

Materials and Methods:

In this experiment, you will use a digital multimeter to measure the potentials on a sheet of resistance paper. The resistance paper consists of a thin conductive coating of carbon bonded to an insulating backing, having uniform resistance per unit area. Metallic conductors, charged objects, can be simulated by painting the object onto the resistance paper using silver paint. If two or more such objects are painted on the resistance paper, current will flow between them through the resistance paper. The potentials between the two objects will be intermediate between the potential of each object. We can measure the potential of each point on the resistance paper by touching the probe of the multimeter (set for volts) to the surface of the paper.

By connecting points of equal potential, we form equipotential lines from which we can determine the electric field. The direction of the electric field is in the direction of the most rapid decrease of the potential - the electric field is always perpendicular to the equipotential lines. The magnitude or strength of the electric field is a measure of how fast the potential is changing ($E = \Delta V/\Delta x$).
Hence the field is strongest where the equipotential lines are closest together and weakest where they are farthest apart. In Figure 2.a, the equipotential lines (dotted lines) and the electric field lines (solid lines) are drawn for two equal but opposite circular charges. In Figure 2.b, the lines are drawn for two parallel sheets of opposite charge.

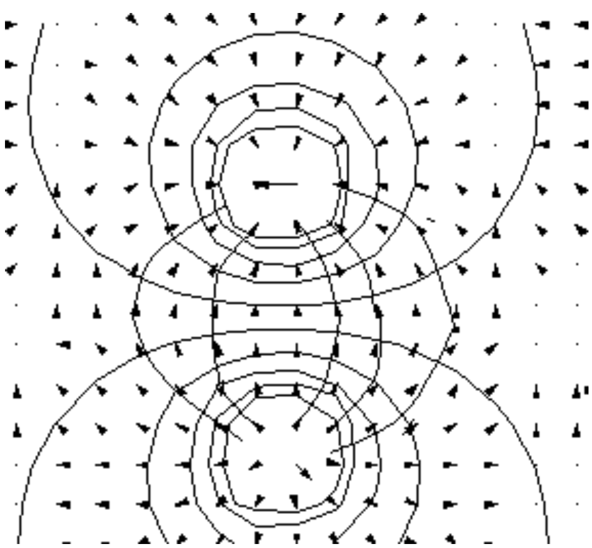


Figure 2.a

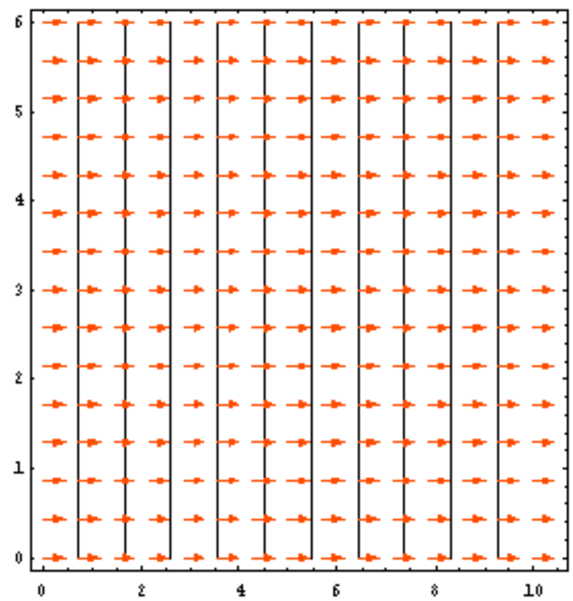


Figure 2.b

The silver circles on the resistance paper represent a cross section of two long parallel rods or cylinders and the potential field produced by the charged circles on the resistance paper will resemble that produced by the charged rods. For the charged rods, the potential at a point in the space surrounding them is given by the equation:

$$V_p = C_1 \text{ Ln } (R_2/R_1) + C_2$$

where C_1 and C_2 are constants (C_1 is the slope and C_2 is the y intercept of the V vs. $\text{Ln}(R_2/R_1)$), R_2 is the distance from the positively charged circle to the point with voltage, V_p, and R_1 is the distance from the center of the negative circle to the point with the voltage, V_p.

Procedure:
* Set up the apparatus as shown in Figure 2.
* Set the multimeter for 10 volts.
* Adjust the power supply for 10 volts.
* Connect the ground lead of the multimeter to the negative of the power supply. The probe is used to measure the potential of the points on the paper. The resistance paper is provided with a grid of dots one centimeter apart. The data paper provided also has a grid of circles into which you can write the voltage of the corresponding point of the resistance paper. You can plot the potential field and estimate the location of the equipotential lines on the data sheet. **Do not mark on the resistance paper, and be especially careful not to scratch the resistance paper with the probe.**
* Each group should do a charged circle sheet and a parallel plate sheet. You will have to exchange boards with other groups.
** On each data sheet, sketch the **electric field lines** and the **equipotential lines** similar to that shown in Figures 1.a and 1.b.

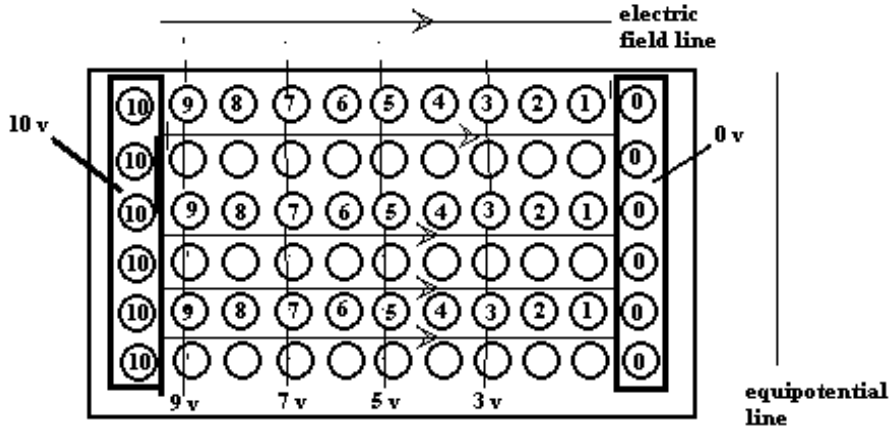


Figure 3. (insert data into circles in data sheet)

Analysis of data:

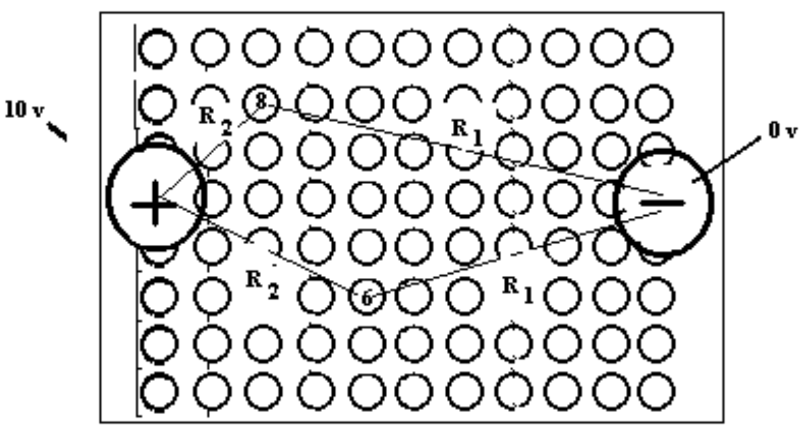


Figure 4.

* On the data sheet for the circles **ONLY**, make a table of voltages found on the data sheet in the range of 1 to 9 volts (for example: select a circle with a voltage about 8 v and measure the distance from the center of each circle to the center of the positive and negative source circles). See Figure 4.

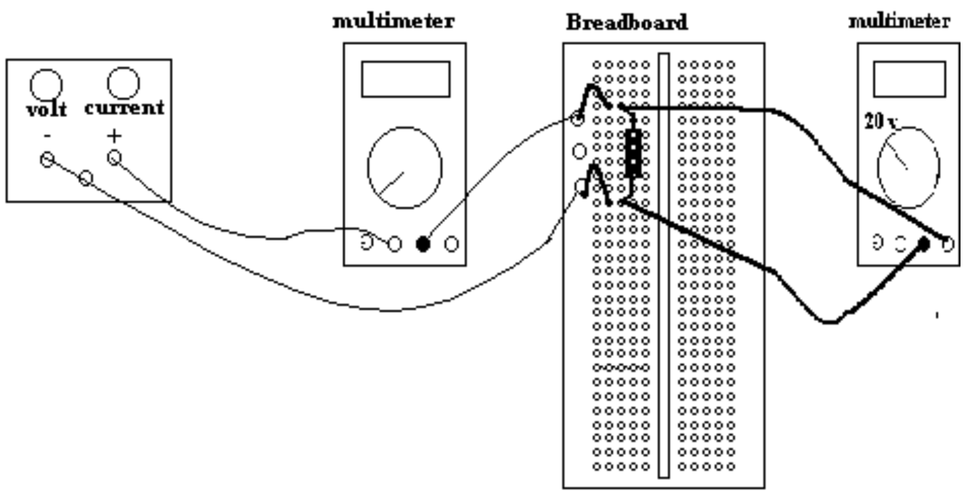
Then graph Voltage vs. Ln(R_2/R_1). Determine the slope and intercept.
Use Excel to graph your data, and find the slope and intercept and the coefficient of regression (% goodness to a straight line).
* Identify the major sources of error in this experiment.

DIRECT CURRENT CIRCUITS

Purpose: Verify **Ohm's Law** as applied to a single resistor or combinations of resistors.

Theory for a single resistor: If a potential difference is maintained between the two ends of a conductor, a current, I, flows from the higher potential to the lower potential. For most conductors (linear), V and I are proportional to each other. $\Delta V = RI$ where V is in volts, I is in amps and the resistance, R, is in Ohms. This is Ohm's Law.

Apparatus:



Procedure:

Do not plug in the power supply until you are told to do so!

1. Identify the 1000 Ω resistor by the colored rings on the resistor: Brown Black Red. (Brown = 1.....Black = 0...... so that gives your 10 as the first two digits and Red = 2 (which is the exponent for the power of ten) now you have 10 x 10^2, which is 1000.) There should be a sheet with a complete color code giving the number equivalent for each color.

2. Study the multimeter; there are three selections: Ohms, Volts, Amps. Depress the Ohms button to use the multimeter as an Ohmmeter to measure resistance. Insert a wire with a "banana plug" at one end and an "alligator clip" at the other end into the socket marked Ω and a second wire into the socket marked "Com". Since you will measure the resistance of a 1 kΩ, depress the range button for 2 KΩ. Connect the alligator clips on opposite ends of the resistor and measure its resistance. Record its value in Table I.

3. Set the multimeter to **Volts**, and the 20 volt range.

4. Set the second multimeter to **Amps,** and the 200 ma range.

5. Connect the circuit as shown in Figure 1.

6. Have the instructor check the circuit - you should have the voltage dial on the power supply set at zero and the current dial set on maximum (fully clockwise).

7. After having it checked, turn on the power supply. Watch the ammeter. Increase the current to 1 ma. and measure the voltage with the voltmeter. Record the current and the voltage in Table I. Increase the current to 2 ma. and measure the voltage. Continue to increment the current in 1 ma steps up to 8 ma. Then turn down the power supply to zero volts and turn it off.

8. Locate the 2000 Ω, 3000 Ω, 3900 Ω, 5100 Ω resistors.

9. Replace the 1000 Ω resistor with the 2000 Ω resistor and measure the current for a voltage of 10 v. Repeat for the other resistors and record the results in Table 2. Do not forget to include the previous measurement for the 1000 Ω at 10 v.

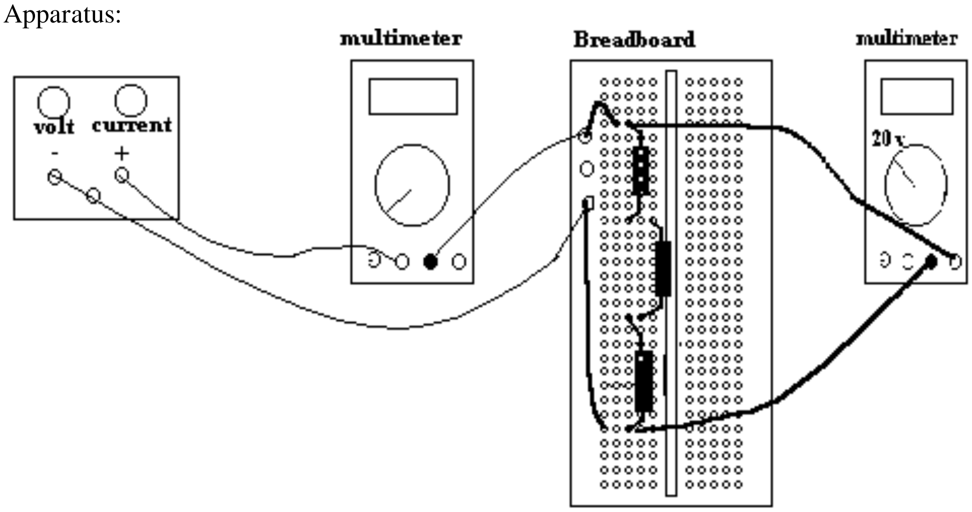
Analysis:
1. Plot the voltage (y-axis) and the current (x-axis) from the data in Table I.
2. Determine the slope of the graph (it should equal the value of the resistor - Why?).

3. Plot the Current (y-axis) and $\frac{1}{\text{Resistance}}$ (x-axis) from the data in Table 2.
4. Determine the slope of the graph (it should equal the value of the voltage - Why?).

Purpose for series resistors: Verify that the voltage across all the them is the sum of the voltages across each of them and that the total Voltage is equal to the total resistance x current.

Theory for resistors connected in series: When resistors are connected in series they are placed end to end as in a chain or like box cars on a train. The current that leaves one resistor enters the next resistor in the chain, hence all resistors will have the same current passing through them. The total voltage across all the resistors is the sum of the voltage across each of them. Their total resistance is $R_s = R_1 + R_2 + R_3 + ... + R_n$.
The total resistance is often called the equivalent resistance.

Apparatus:



Procedure:
1. Set up the circuit as illustrated in the figure above. **Have it check by the instructor!**
2. Increase the voltage across the three resistors to 10 v.
3. Measure the current going to the series combination of resistors.
4. Measure the voltage across each of the resistors.
5. Record all measurements in a Data Table III.

Purpose for Parallel Resistors: Verify the voltage is the same for all the resistors connected in parallel, that the sum of the currents in each of the resistors is equal to the total current entering the combination.

Theory:

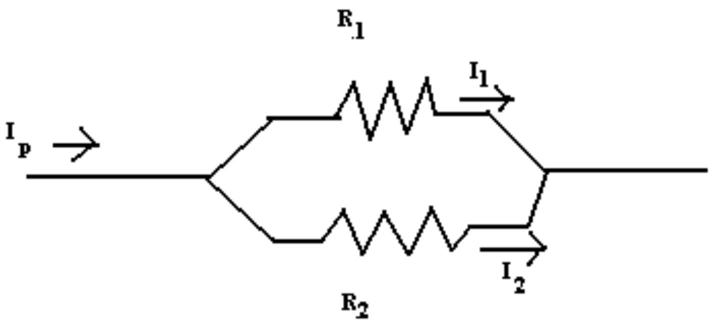
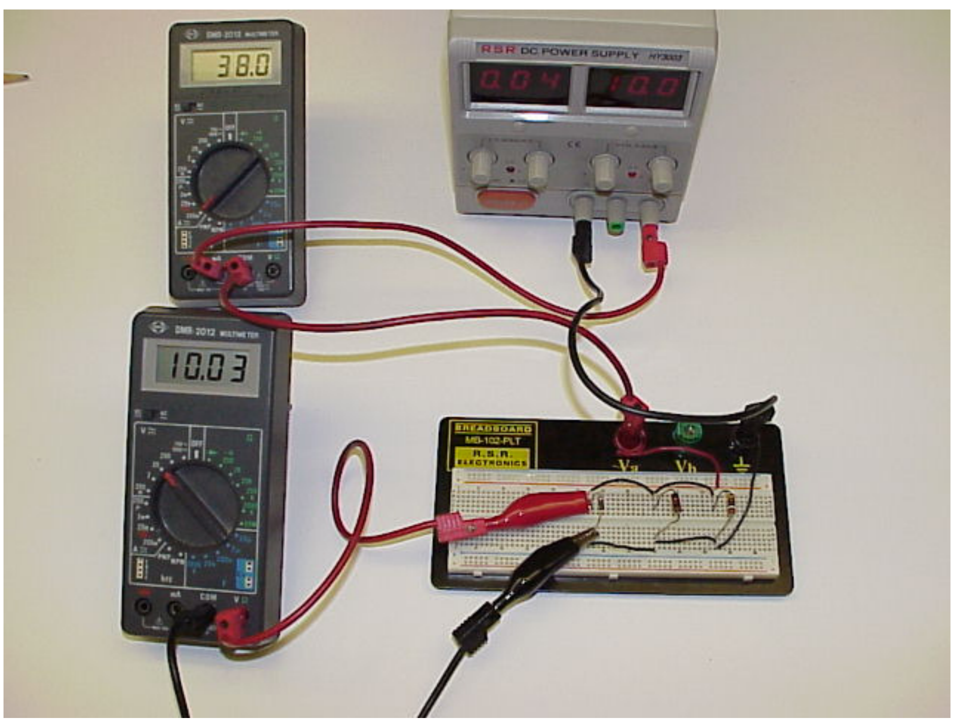


Figure 3

In Figure 3, the resistors are connected in parallel. Note the current splits at point "a" and some of it goes through $R_1$and the remainder goes through R_2. The total current is the sum of the current flowing through each of them: $I_p = I_1 + I_2$. Since the top end of R_1 and R_2 are connected to the same potential, V_a, and the bottom of each is connected to the same potential, V_b, then the potential difference across each resistor is the same, $V_a - V_b = V$. Then,

$$I = I_1 + I_2 = \frac{V}{R_1} + \frac{V}{R_2} = V\left(\frac{1}{R_1} + \frac{1}{R_2}\right). \quad \text{Hence } \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}.$$

Apparatus :



Procedure:

1. Connect the circuit as shown in the diagram above. Note how the current splits at the " + " input plug of the multimeter used as an ammeter: some of the current going to the resistor in the board while the rest goes through the ammeter (measuring the current) before it goes to the second resistor in the board.
2. Measure the voltage across each resistor using the voltmeter.
3. Record the current and the voltage in each resistor in a TABLE.
4. Interchange the resistors and remeasure the current and the voltage.

Analysis:

Sum the currents in each resistor and compare the sum with the total current that enters the set of parallel resistors.

Data Sheet Name ________________________________ Date ____________ Group # ____

Lab Partners _______________,___________________

Data Table I:

	A	B	C
1		Voltage (v)	Voltage (v)
2	Current (a)	for 1000 Ω resistor	for 2000 Ω resistor
3	0.001		
4	0.002		
5	0.003		
6	0.004		
7	0.005		
8	0.006		
9	0.007		
10	0.008		

Data Table 2
Voltage = 10 v.

Resistance (ohms)	Current (a)	1/Resistance
1000		
2000		
3000		
3900		
5100		

For the Series Circuit:
Analysis: Add the voltages for the three resistors and compare the sum with the voltage across the combination.

V_s = __________________ I_s= _______________ R_1= _________ R_2= ________ R_3= __________

V_1= _________ V_2= ________ V_3= __________

$I_1 = V_1/R_1$= ______ $I_2 = V_2/R_2$= _____ $I_3 = V_3/R_3$= ______ $V_1 + V_2 + V_3$ = _____

For the Parallel Circuit:
Analysis: Calculate the current in each resistor from (I = V/R).
Add the currents for the three resistors and compare the sum with the total current entering the combination.

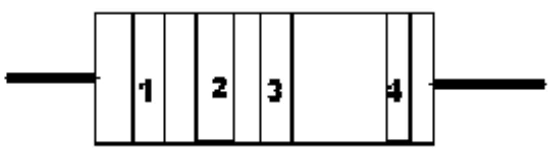
V_s = __________________ I_s= _______________ R_1= _________ R_2= ________ R_3= __________

V_1= _________ V_2= ________ V_3= __________

$I_1 = V_1/R_1$= ______ $I_2 = V_2/R_2$= _____ $I_3 = V_3/R_3$= ______ $I_1 + I_2 + I_3$ = _____

Resistor Color Codes:

Bands 1 & 2		Band 3		Band 4	
Color	Number	Color	Multiplier	Color	Tolerance
Black	0	Black	1	Silver	+/- 10%
Brown	1	Brown	10	Gold	+/- 5%
Red	2	Red	100		
Orange	3	Orange	1000		
Yellow	4	Yellow	10000		
Green	5	Green	100000		
Blue	6	Blue	1000000		
Purple	7				
Gray	8				
White	9				

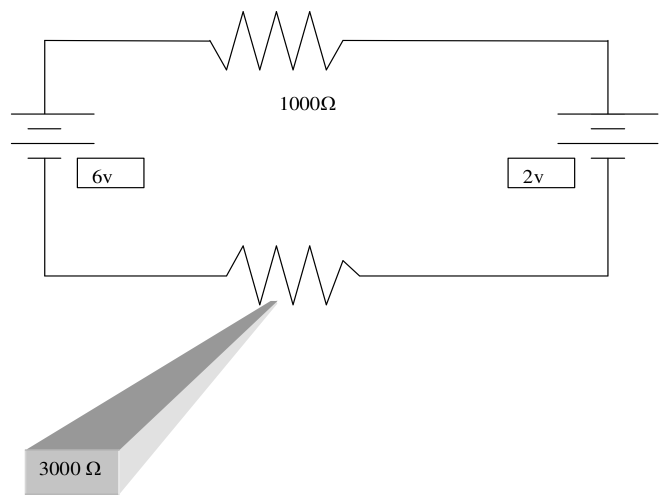


KIRCHHOFF'S LAW

Purpose: To analyze a multiloop circuit using Kirchhoff's Law and to then verify the rules by measuring the current and voltage within the circuit.

Theory: Kirchhoff's Law is:

1) When three or more wires are joined at a junction, the total current flowing towards the junction must equal the total current flowing from the junction.
2) The sum of all potential gains plus the sum of all potential losses around the loop must equal zero (i.e. start at one point in the circuit and return to the same point in the circuit).

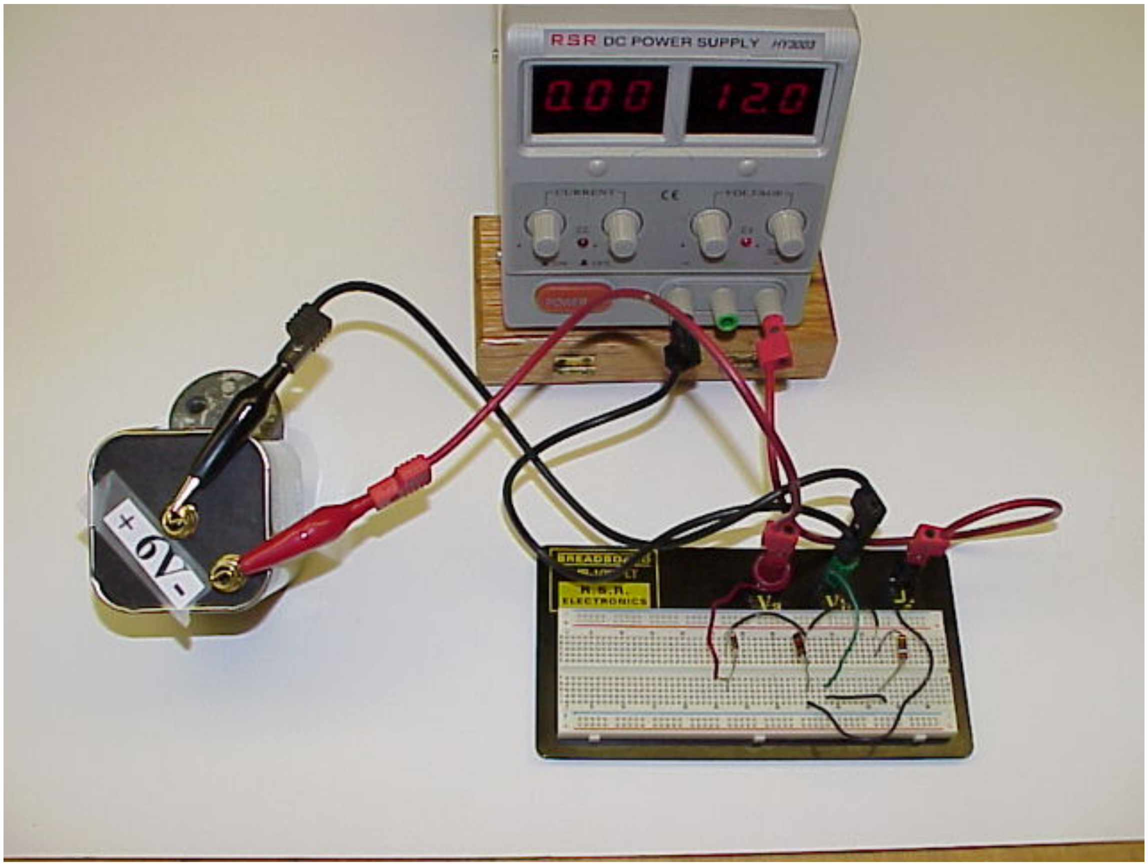


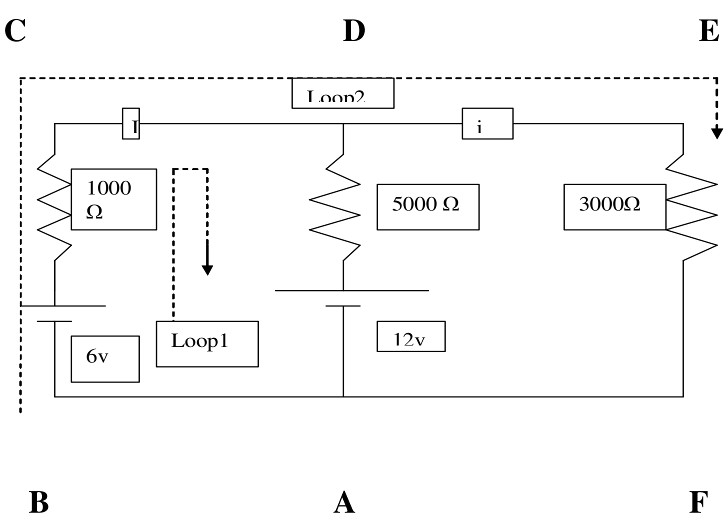
(Fig. 1)

Starting at point A on the negative side of the battery in Figure 1, trace the loop in the direction of the current. Battery is pushing against the "current," hence it is negative:

$$6 - 1000I - 2 - 3000I = 0$$
$$4 - 4000I = 0$$
$$-4000I = -4$$
$$I = \frac{4}{4000}\, amps$$
$$I = \frac{1}{1000}\, amps$$
$$I = 1 * 10^{-3}\, amps$$
$$I = 1\, milliamp$$

Procedure: A two loop circuit is assembled as shown in Figure 2.





Loop #1: A B C D A

$6 - 1000I - 5000(I - I_1) - 12 = 0$

$-6 - 6000I + 5000\,I_1 = 0$

Loop #2: A B C D E F A

$6 - 1000I - 3000I_1 = 0$

Solve these simultaneous equations for *I* and I_1 :

#1) $I =$ __________ $amps$ $I_1 =$ __________ $a.$ $I - I_1 =$ __________ $a.$

#2) $I =$ __________ $amps$ $I_1 =$ __________ $a.$ $I - I_1 =$ __________ $a.$

Have your assembled circuit checked by the instructor. Measure the three currents and the voltage from point A to point D.

$R_1 =$	$R_2 =$	$R_3 =$
$I_1 =$	$I_2 =$	$I_3 =$
$V_1 =$	$V_2 =$	$V_3 =$

Measure the voltage between point A and the point between the 6 v. battery and the 5000Ω resistor. Likewise, measure the voltage between point A and the point between the 12 v. battery and the 1000Ω resistor. How will this enable you to determine V_1, V_2, and V_3 ?

CAPACITORS - RC CIRCUITS

Purpose: To determine the relaxation time constant for a RC circuit.

Theory: A capacitor is constructed by placing a sheet of insulating material between two sheets of conducting material. The capacitor has the ability to store charge; the amount of stored charge is directly proportional to the voltage on the two conducting sheets, where the proportionality constant, C, is called the capacitance.

$$Q = C \cdot V \quad (A)$$

The basic unit of capacitance, C, is called the farad which is defined as the capacitance necessary to store one coulomb of charge at a potential difference of one volt. For practical purposes, the microfarad is used; this can be written as either μF or as MFD and is one millionth of a farad.

The way in which charge is stored on a capacitor or removed from a capacitor is very interesting. To see this, study the circuit shown in Fig. 1, as the switch is closed then opened.

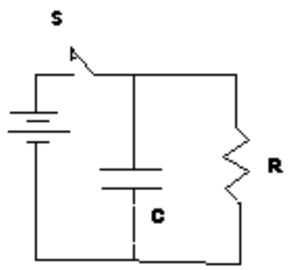


Fig. 1

When the switch, S, is closed, positive charge flows onto the upper surface of the capacitor and negative charge to the lower surface. As more and more charge is placed on the upper surface, the charge already there opposes additional positive charges, thus slowing down the rate of accumulating charge (i.e. current in the branch containing the capacitor). The current in the branch stops when the capacitor is fully charged (i.e. when the voltage across the capacitor is equal to that of the battery).

When the switch, S, is opened, the positive charge is forced off the upper surface through the resistor, R, and to the negative lower surface. As more and more positive charge leave the upper plate, there is less force of repulsion by the remaining charge and thus the rate of charge leaving the upper plate slows down (i.e. the current through the resistor decreases with time). The current through the resistor will depend on the voltage across the capacitor.

$$I = \frac{V}{R} \quad (B)$$

Since the current is the rate of flow of charge which will equal the rate of loss of charge from the capacitor,

$$\frac{dQ}{dt} = -I \quad (C)$$

Combining the above equations (A), (B) and (C) we get:

$$\frac{dq}{dt} = -\frac{Q}{RC}$$

The solution to this differential equation is:

$$Q = Q_o e^{-t/RC}$$

where Q_o is the original charge on the capacitor at $t = 0$ sec.

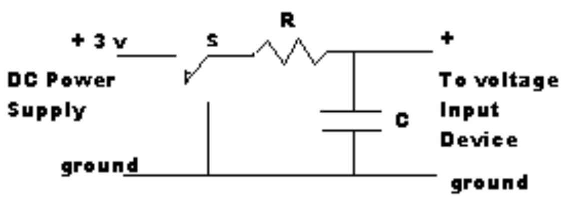
The charge on the capacitor decreases expotentially with time and with the product RC. RC, often called the relaxation time, determines the rate of discharge for the capacitor. When $t = RC$, the capacitor is reduced to approximately 37% of its initial charge. In measuring the relaxation time, it is more convenient to measure the time it takes for the capacitor to decrease its charge to half its initial value, the half life, $T_{1/2}$.

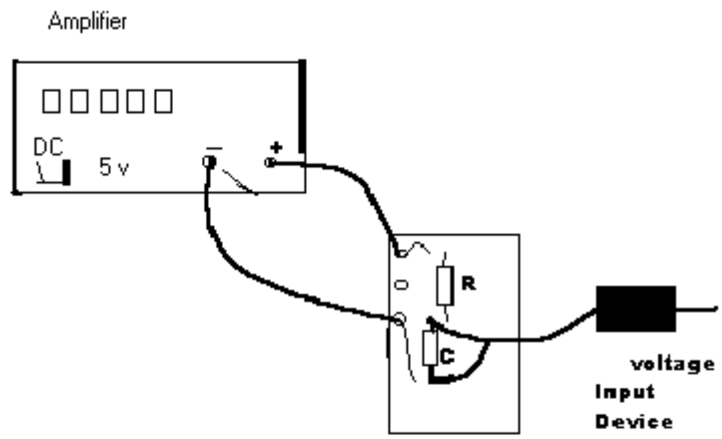
$$e^{-T_{1/2}/RC} = 1/2$$

$$RC = T_{1/2} / \text{Ln } 2 = 1.4425\, T_{1/2}$$

Procedure A:

1. Set up the circuit shown in Fig. 2 with the power supply set for 3.0 volts (measure this before connecting the power supply to the rest of the circuit).





Before charging of the capacitor, connect both wires from the breadboard to the negative of the Amplifier. The time constant, $\tau = RC$, determines the time needed to charge or discharge to 63% of maximum. A good selection of values would be:
R = 1 Mega 0hm, C = 4.7 μF; this will give you a time constant of 4.7 seconds.
*Open Science Workshop.
1. Drag the plug icon on the right to analog A. A menu window will open. Select Power Amplifier.
2. A generator panel window will open, click on "DC" and adjust the voltage to 5 volts. Click the power "ON" button.
3. Connect the voltage probe to the Analog "B" socket in the 750 interface.
4. Connect the aligator clips to the capacitor (make sure the black is connected to the negative side of the capacitor).
5. Use the "mouse" to move the icon for the analog plug to the "B" input...then move the table and graph icons to the B input.

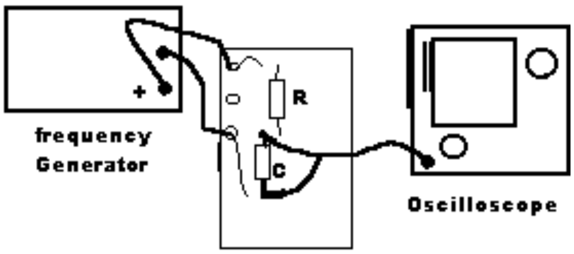
Begin charging the capacitor.
1. Click the record button on the Sci. Workshop panel
2. Plug the positive wire into the positive terminal of the power supply.
3. **After 20 sec.** move the positive wire to the negative terminal of the power supply.
4. After another 20 sec. click the "OFF" button on the Sci. Workshop panel.

Analysis of Data:
1. Click on the graph and select **Print Graph.** Then, after your graph is printed, click on the data table.
   You should be able to see the capacitor charge and discharge on the graph.

From the table you should be able to divide the data into two sets (set I is the charging process); calculate the natural log of the (maximum voltage − voltage); and then plot a second graph for the charging process with ln ($V_o - V$) vs. time (set II is the discharge). Calculate the ln V and plot a graph of ln V vs. time.

Procedure B: Use the oscilloscope to monitor the fast changing voltage.

1. Set up the circuit shown in Fig. 3 with R = 10 KΩ and C = 0.1 μF. Measure the half life directly from the oscilloscope.



2. Repeat for another combination of R and C.

Analysis of Data:
1. Determine the percent difference between your value of the time constant determined from the experiment and the value of R*C from the values stated on the Resistor and Capacitor (do not forget to include the resistance of the signal generator along with the value of the resistor to determine the total resistance of the circuit).

Additional Exercise:
Use the value of the time constant τ = RC and the value of R to determine the value of C. Do this for the (R = 1000 Ω C =0.01 μF).

Magnetic Dipole Moment

Purpose: To measure the dipole moment of a Bar Magnet and the horizontal component of the Earth's Magnetic Field.

Theory: A bar magnet is an example of a Magnetic Dipole; it has a North pole and a South pole. Magnetic field lines leave from the north pole spreading outward curving so as to converge on the South pole. Although magnetic monopoles do not exist, they afford a convenient way of introducing magnetic dipole moments. In Electricity, isolated charges, +q and -q, when separated by a small distance, s, formed an electric dipole with a dipole moment, p = qs. If we assume that a North pole of a bar magnet to have a magnetic charge, +m, and the South pole to have a magnetic charge, -m; then it would have a dipole moment given by μ=mL where L is the length of the magnet.

When a current carrying coil is placed in an external Magnetic Field, a torque due to the interaction of the magnetic field on the moving charges in the coil, acts on the coil tending to align the coil with the external field (fig. 1). In a bar magnet, a large number of atoms have their magnetic moments oriented inthe same direction. The magnetic moment of the atoms is due to the orbital and spin motion of the electrons.

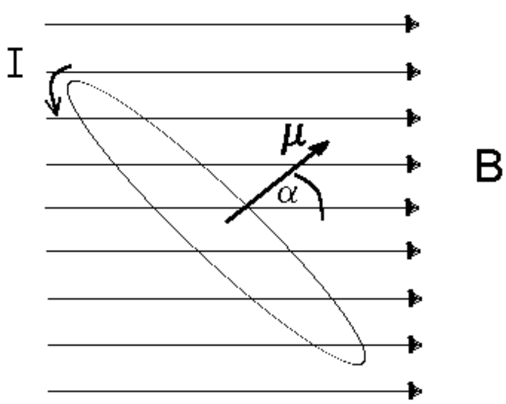


Fig. 1

In the case of an electric dipole in an external electric field, the dipole experienced a torque tending to align it with the external field (fig. 2). In figure 3, the concept of magnetic poles is used to calculate the torque on the dipole. Note the similarity.

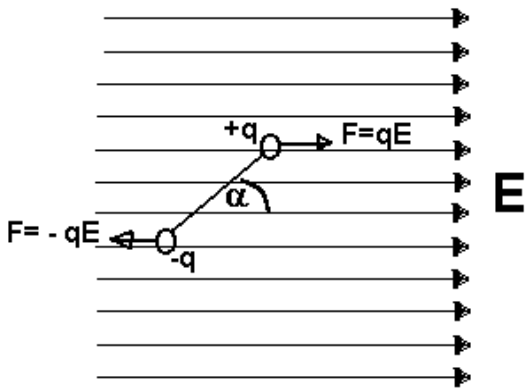


Fig. 2

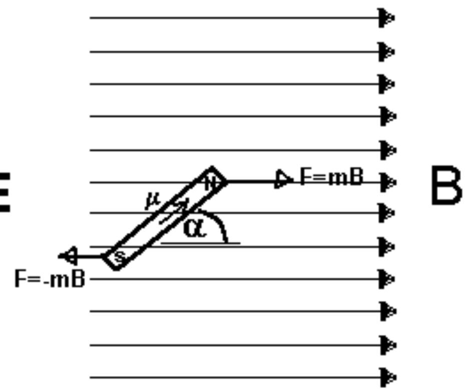


Fig. 3

$\Gamma_{electric}$ = qs E Sin α
= **p E** Sin α

$\Gamma_{magnetic}$ = ms B Sin α
= **m B** Sin α

If the magnet is suspended from its center of mass in the magnetic field, it will oscillate about its equilibrium position. (Halliday and Resnick, Chapter 37 - Example #1). For small oscillations, the sin α term in the restoring torque may be replaced with α reducing the expression to: $\Gamma_{magnetic}= \mathbf{m\ B}\ \alpha = -\ \kappa\ \alpha$ where κ is the torsional constant for the string. Since $\Gamma_{magnetic}$ is proportional to α, the condition for simple harmonic motion is fulfilled, and the frequency of the oscillation is given by:

(A) $$\nu = \frac{1}{2\pi}\sqrt{\frac{\kappa}{\mathrm{I}}} = \sqrt{\frac{\mu \mathrm{B}}{\mathrm{I}}}$$ where I for the bar magnet is: $\mathrm{I} = \frac{1}{12}\,\mathrm{ML}^2$.

From this equation μ can be determined provided we can measure ν, B_{earth} and I.

We need to know the value of the external magnetic field, B_{earth}. Instead of measuring the field directly with a gaussmeter, we will find a second equation involving the field, B_{earth}, and solve the two equations simultaneously.

Just as with electric fields whenever two magnetic fields from different sources overlap at a point in space, the point in space experiences only the resultant effect produced by the Vector Addition of the two fields. Hence, in figure 3, the bar magnet produces a magnetic field at the point, p, given by:

(B) $$B_{magnet} = \frac{\mu_o\,\mathrm{m}}{2\pi\,\mathrm{R}^3}$$

and the earth's magnetic field alone has a horizontal component which would be perpendicular to the field produced by the bar magnet. The two magnetic fields add together to produce the resultant magnetic field which makes an angle θ with the axial direction of the magnet.

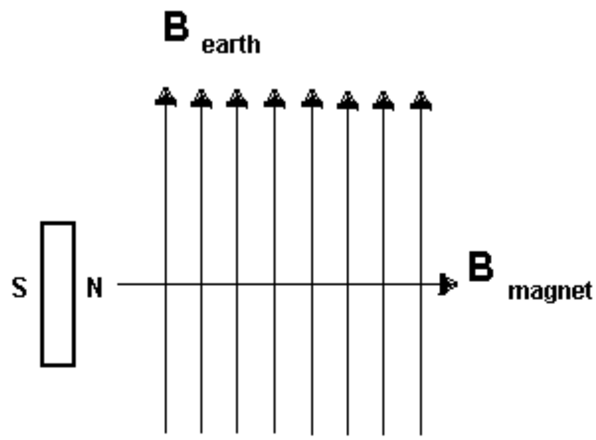


Fig. 4

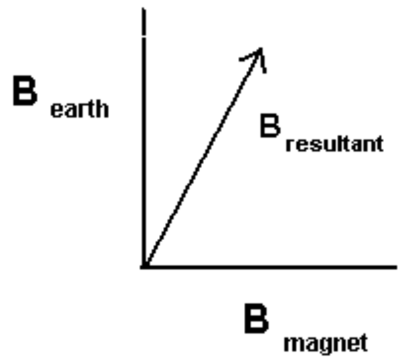


Fig. 5

Hence, the horizontal component of the earth's magnetic field is related to the magnetic field of the bar magnet by:

(C) $$B_{earth} = B_{magnet} \operatorname{Tan} \theta$$

Substituting equations (B) and (C) into equation (A), the magnetic dipole moment of the bar magnet can be found from:

(D) $$m = \sqrt{\frac{8\pi^3 R^3 \nu^2 I}{\mu_o \tan\theta}}$$ note: $\theta = (90° - \alpha_{deflection})$

and the horizontal component of the earth's magnetic field can be determined by :

(E) $$B_{earth} = \frac{\mu_o m}{2\pi R^3} \operatorname{Tan} \theta$$ where $\theta = (90° - \alpha_{deflection})$

Procedure:

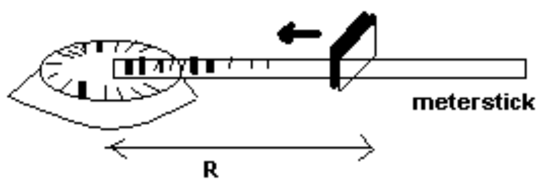
1. Determine the direction of the horizontal component of the earth's magnetic field using the large compass. (you will have to wait your turn as we only have one large compass).
2. Place a meter stick perpendicular to the direction of the earth's magnetic field with the compass still in place.
3. Place your bar magnet on the meter stick with its North pole pointing towards the compass. Slide the bar magnet towards the compass until the compass needle deflects about 10 degrees. (Make sure that there are no other bar magnets in the vicinity of the compass). Measure the angle of deflection and the distance from the center of the bar magnet to the center of the compass. Record these in your data sheet.
4. Measure the long dimension of the bar magnet (use a vernier caliper) and its mass (use a triple beam balance).
5. Suspend the bar magnet from a string about its center of mass (there is a hole in the center). Displace it from its equilibrium position (about 5°) and measure the frequency of oscillations by measuring the time it takes for 10 oscillations. Record this data on the data sheet.

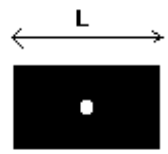
Analysis of data:

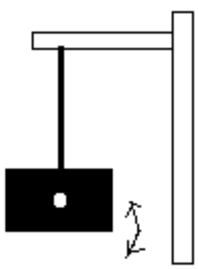
1. Calculate the moment of inertia of the magnet, I.

2. Use equation (D) to determine the magnetic dipole moment of the magnet. (should be between (0.1 and 0.5 amps m^2). (make sure you are using meters for L and R)

3. Find the horizontal component of the earth's magnetic field using equation (E). (should be about (10^{-5} Teslas). Remember if $\alpha = 10°$ then $\theta = 80°$







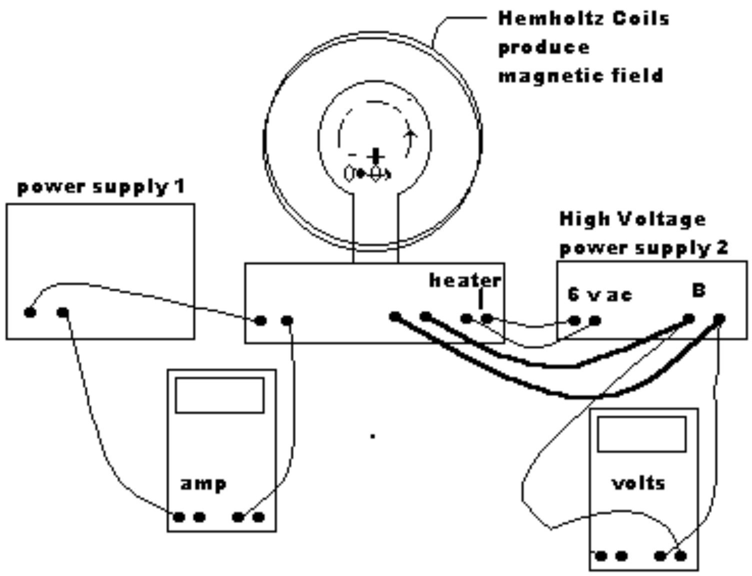
Conclusion: State the value for the magnetic dipole moment of the magnet and the horizontal component of the earth's magnetic field.

Estimation of Error: analyse each part of the procedure and estimate how accurate was each measurement (percent of total measurement).

E/M EXPERIMENT

Purpose: To determine the ratio of the Charge to Mass for an electron using a magnetic field to bend the electron into a circular orbit.

Apparatus:



Theory: The electron is accelerated across the potential difference provided by the high voltage power supply #2. $q\,\Delta V = \frac{1}{2}mv^2$ eq. A

Then the electron's trajectory is bent into a circle by the magnetic field. $qvB = \frac{mv^2}{R}$ eq. B

Solve for v in eq. A: $v = \sqrt{\frac{2q\,\Delta V}{m}}$ and substitute into eq. B

$$qBR = m\sqrt{\frac{2q\,\Delta V}{m}}$$

$\frac{q}{m} = \frac{2\,\Delta V}{(BR)2}$ The magnetic field is determined by measuring the current into the coils:

$$B = 7.8 \times 10^{-4} * I \text{ Teslas}$$

The charge on the electron is $q = 1.6 \times 10^{-19}$ coul, and the mass is 9.1×10^{-31}kg, so the value of $q/m = 1.76 \times 10^{11}$ coul/kg.

Procedure: The equipment will be wired and ready to go. Turn on both power supplies.

The power supply #1 controls the magnetic field, given by the equation B = 7.8 x $10^{-4} * I \ Teslas$ where I is the current in amps. Then turn on the standby switch and increase the accelerating voltage to 90 volts. Increase the current in the magnetic field until the electron's orbit is about 5 cm in radius, read the mirror ruler in the back of the tube. You want to view the ruler perpendiculary (close one eye, look at the beam and the reflection of the beam in the ruler...move your head from side to side until the beam is directly in front of the refection). **Measure the current**, determine the magnetic field, **measure the voltage**, **measure the radius**, now calculate the ratio of q/m from the equation.

Increase the voltage to 120 volts and repeat.
Increase the voltage to 140 volts and repeat.
Increase the voltage to 160 volts and repeat.

Make a table of your results. Determine the percent error.

AC CIRCUITS

Purpose: To measure the voltage across different circuit devices in response to an alternating voltage source.

Theory: Study the circuit diagram in Figure 1. Realizing that the voltage on the capacitor depends on the amount of charge on the plates, if the amount of charge varies because of the variation of the current from the generator (shown as a sine wave in the figure) then the voltage on the capacitor will vary as a sine wave does also. At time t = a on the graph, the top plate of the capacitor is charged negatively and the bottom plate is charge positively; the current flows from the positive lower plate to the negative upper plate. By the time t = b, all of the positive charge on the lower plate has been removed and the capacitor is uncharged (has zero voltage). Then from time t = b to time t = c, the current continues to flow clockwise in the circuit, charging the upper plate positively and the lower plate negatively. Hence at time t = c, the capacitor is again fully charged having its maximum voltage, whereas the current reached its maximum at time t = b, one quarter of a cycle before the capacitor had its maximum voltage. Therefore the voltage on the resistor (which is in phase with the current) has its maximum 90° before the capacitor reaches maximum (i.e. they are not in phase with each other).

The combined voltage, (resultant), is found from:

$$V_{RC} = \sqrt{V_R^2 + V_C^2}$$

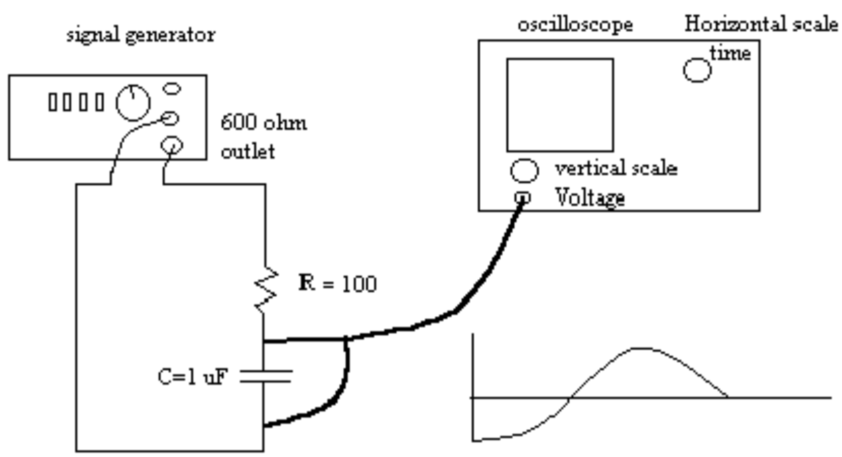


Figure 1.

(The oscilloscope is shown for measuring the voltage across the capacitor; to measure the voltage across the resistor, interchange the resistor with the capacitor.)

The capacitor has an effective resistance to an alternating current called the capacitive reactance, X_C.

$$X_C = \frac{1}{2\pi f C} \qquad X_C = \frac{V_C}{I} \quad \text{or} \quad X_C = \left(\frac{V_C}{V_R}\right) \cdot R$$

Note: Since the ground (negative) of the oscilloscope must be connected to the ground (negative) of the signal generator, you must rearrange the connections of the circuit so that the ground are connected together.

Procedure:

* With the generator set for sine wave and a frequency of 100 Hz and the amplitude (white dot on knob set for "12 oclock") and the DC Offset (white dot on knob set for "12 oclock"), connect the circuit. (Note: the ground is the middle outlet socket and the positive outlet is the lower socket.)

* Connect the alligator clip from the oscilloscope probe to the side of the capacitor which is connected to the ground of the signal generator and the tip of the probe (+) to the other end of the capacitor. Set the horizontal sweep knob of the osc. for 1 msec/cm (

1 x 10^{-3} sec) and the vertical input for 1 volt/cm (this establishes the vertical and horizontal scales for the graph which appears on the screen to the right of the vertical input); now set the input for AC.
* Have the instructor check your circuit.
* Turn on the power for the osc. and the signal generator; a sine wave should appear on the screen. Use the vertical position adjustment knob (next to the vertical input) to orient the horizontal axis of the graph in the center of the screen.
* Measure the amplitude, V_C, (the maximum height from the x-axis of the sine wave); check the vertical scale knob since this is a graph. Then record this voltage in the table. Change the frequency of the frequency generator and measure the voltage across the capacitor for all the required frequencies.
* Connect the resistor where the capacitor is and move the capacitor to where the resistor was (they should change places). The osc. should be connected across the resistor now. Measure the voltage across the resistor, V_R, for all the frequencies.
* Connect the (+) probe of the oscilloscope to the other side of the capacitor so that both the resistor and the capacitor are between the (+) and the alligator clip (-) of the oscilloscope (the osc. will now measure the combined voltage of the resistor and capacitor, V_{RC}). Change the frequency of the sig. gen. to 100 Hz. and measure the combined voltages for all frequencies.

* Calculate the $\sqrt{V_R^2 + V_C^2} = V_{RC}$ calculated and enter this value in the table.
* Calculate the % difference between the measured and calculated V_{RC}.
* Calculate $X_C = (V_C/V_R) \cdot R$
* Calculate $C = 1/(2\pi f X_C)$. Is this value constant for all frequencies?

Resistor and Inductor

Theory: The inductor's voltage depends on the rate of change in the current. This occurs at points a and c. So once again the voltage on the device is 90° different from that of the current (voltage in the resistor).

Hence the combined voltage, $V_{RL} = \sqrt{V_R^2 + V_L^2}$.

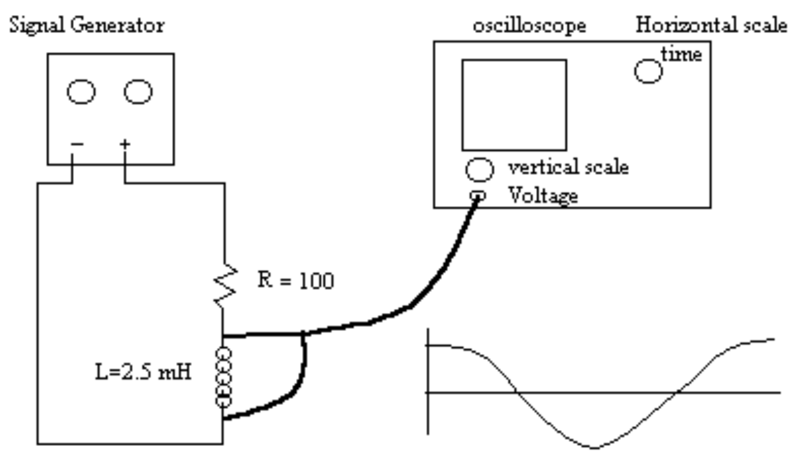


Figure 2.

(The oscilloscope is shown for measuring the voltage across the inductor; to measure the voltage across the resistor, interchange the resistor with the inductor.)

The effective resistance of an inductor is called the inductive reactance, X_L. $X_L = 2\pi fL$ $\quad x_L=(\frac{V_L}{V_R}) \cdot R$

Procedure:
* Set the generator for sine wave and a frequency of 1000 Hz.
* Connect the alligator clip from the oscilloscope probe to the side of the inductor which is connected to the ground of the signal generator and the tip of the probe (+) to the other end of the inductor. Set the horizontal sweep knob of the osc. for
1 msec/cm (1 x 10^{-3} sec) and the Vertical input for 1 volt/cm

* Have the instructor check your circuit.
* Turn on the power for the osc. and the sig. gen. A sine wave should appear on the screen.
* Measure the amplitude, V_L. Then record this voltage in the table. Change the frequency of the frequency generator and measure the voltage across the inductor for all the required frequencies.
* Interchange the connections to the resistor and inductor from the generator. The osc. should be connected across the resistor now. Measure the voltage across the resistor, V_R, for all the frequencies.
* Connect the (+) probe of the oscilloscope to the other side of the inductor so that both the resistor and the inductor are between the (+) and the alligator clip (-) of the oscilloscope (the osc. will now measure the combined voltage of the resistor and inductor, V_{RL}). Change the frequency of the sig. gen. to 2000 Hz. and measure the combined voltages for all frequencies.

* Calculate the $\sqrt{V_R^2 + V_L^2} = V_{RL}$ calculated and enter this value in the table.
* Calculate the % difference between the measured and calculated V_{RL}.
* Calculate $X_L = (V_L/V_R) \cdot R$
* Calculate $L = X_L/2\pi f$. Is this value constant for all frequencies?

RLC Circuit

Theory: Wire the circuit as shown in Figure 3. Measure the voltage across the resistor and vary the frequency of the generator. When the voltage of the inductor is equal and opposite to the voltage of the capacitor, they offset each other and the voltage of the signal generator goes to the resistor, giving the resistor its maximum voltage. The frequency at which the resistor has its maximum voltage is called resonant frequency. Resonant frequency = $\frac{1}{2\pi}\sqrt{\frac{1}{LC}}$. Monitor the voltage across the resistor while you change the frequency; determine the frequency where the resistor has its maximum voltage. Determine the period of the sine wave using the oscilloscope, then calculate the frequency = $\frac{1}{T}$. Compare this measured frequency with the calculated frequency. Then determine the frequency where the V_R is $\frac{1}{2}$ of its maximum voltage. Then determine the frequency where the V_R is $\frac{1}{4}$ of maximum.

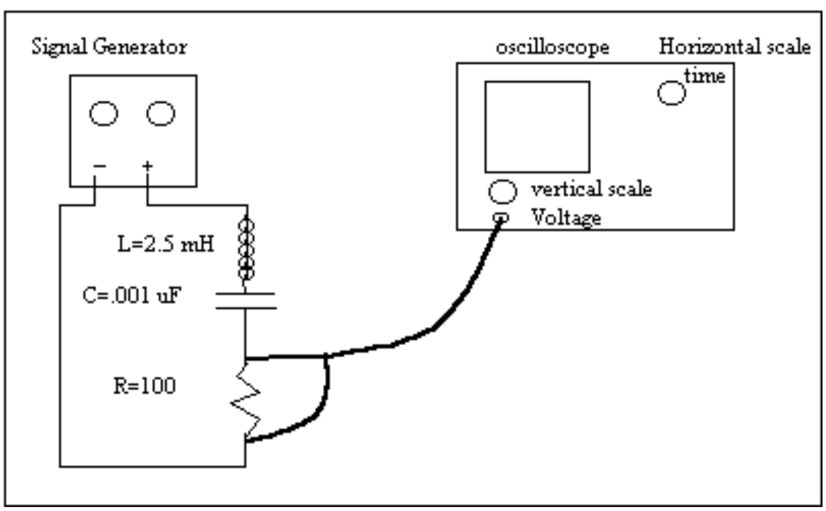


Figure 3.

Data Table I

Frequency	V_c	V_R	V_{RC}	V_{RC}calc.	% diff	$X_c = (V_c/V_R)$*R	C
(Hz)	volts	volts	volts	volts		ohms	Farads
100							
200							
300							
400							
500							
1000							
2000							
3000							
4000							
5000							

Data Table II

Frequency	V_L	V_R	V_{RL}	V_{RL}calc.	% diff	$X_L = (V_L/V_R)$*R	L
(Hz)	volts	volts	volts	volts		ohms	Henries
1000							
2000							
3000							
4000							
5000							
10000							
20000							
30000							
40000							
50000							

Data Table III

Resonant Frequency = ...Hz Voltage across Resistor = ...v.

Freq. at 1/2 Max. = ...Hz Freq. at 1/2 Max. = ...Hz

Freq. at 1/4 Max. = ...Hz Freq. at 1/4 Max. = ...Hz

Calculated Resonant Frequency = __________Hz % diff. = _________

RL CIRCUITS

Section_______ Date Performed ___/___/___ Name ___________________________

OBJECT: To measure the relaxation time for an LR Circuit and to determine the inductance of the inductor.

THEORY: An inductor may consist of one loop or many loops of wire forming a coil. If the cell (inductor) is placed in an increasing or decreasing magnetic field, an emf is induced in the inductor so as to oppose the increase in magnetic field inside the coil or the decrease of the magnetic field inside the coil. Faraday's Law states this as:

$$\mathcal{E} = -N\frac{d\phi}{dt} \qquad \text{(A)}$$

where ϕ is the magnetic flux through the coil, given by:

$$\phi = \int B \cdot dA \qquad \text{(B)}$$

where A is the area of the coil in cross section.

An induced emf can be produced in a coil by changing current in the coil since the current in the coil will produce a magnetic field in the coil, and any change in the current will produce a change in the magnetic field inside the coil. According to Amphere's Law, the magnetic flux produced inside the coil is proportional to the current, i.e.,

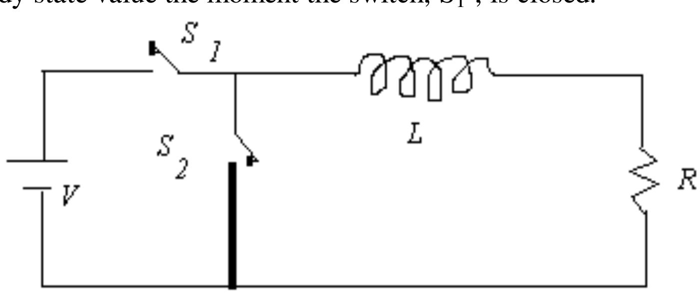
$$\phi = L\, i \qquad \text{(C)}$$

where L is the self inductance of the coil.

For a time varying current, using equations (A) and (C), the emf produced in the coil will be:

$$\mathcal{E} = -N\frac{d\phi}{dt} = -L\frac{di}{dt} \qquad \text{(D)}$$

In the circuit in Figure 1, the presence of the inductor in the circuit prevents the current from instantly attaining its steady state value the moment the switch, S_1 , is closed.



With the switch S_1 closed, a steady current i_o will eventually be achieved. If the switch S_2 is opened and switch S_2 is closed, the current will decay in the circuit. Using Kirchhoff's Voltage Law,

$$- i R - L\frac{di}{dt} = 0$$

Rearranging this equation, $\frac{di}{dt} = -\frac{R}{L}\, i$
Separating the variables and integrating:

$$\int \frac{di}{i} = -\int \frac{R}{L}\, dt$$

$$\mathrm{Ln}\left(\frac{i}{i_o}\right) = -\frac{R}{L}\, t$$

$$\frac{i}{i_o} = e^{-\frac{R}{L}t}$$

$$i = i_o\, e^{-\frac{R}{L}t}$$

The current decreases exponentially with the time in a manner similar to the RC circuit with a characteristic relaxation time, L/R. Using the half life, $t_{1/2}$.

PROCEDURE:

1. Set up the circuit as shown in Figure 2.

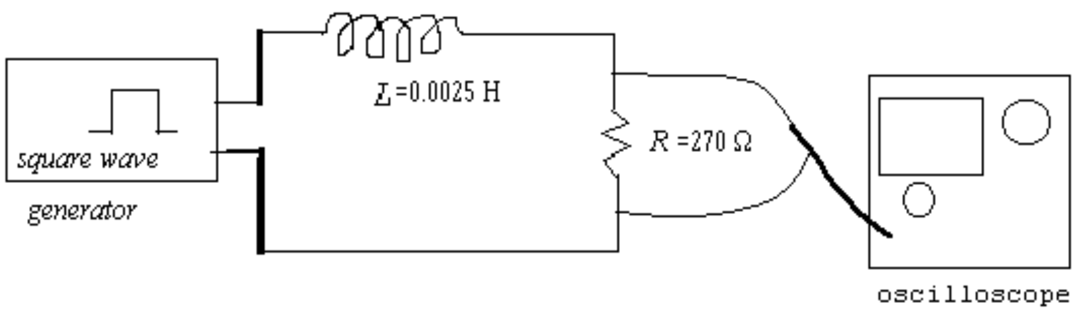


Figure 2.

2. Sketch the waveform on the oscilloscope and measure the half life.

ANALYSIS OF DATA :

1. Calculate L/R from the half life found in Procedure 2.

2. Calculate L from the relaxation time. Don't forget that R includes the internal resistance of the square-wave generator (the resistance of the inductor and the resistance of the resistor R).

CONCLUSION:

1. State the self inductance of the coil.

RLC-TRANSIENT RESPONSE

Purpose: To measure the frequency of the underdamped oscillations for a RLC Circuit and to measure the resistance necessary for critical damping.

Theory: In the circuit shown in Figure 1, the capacitor and the inductor are connected in series when the switch S1 is open and the switch S2 is closed. Assume the inductor does not have any resistance.
Using Kirchhoff's voltage law for this circuit gives us a second order differential equation:

$$\mathrm{L}\frac{di}{dt} + \frac{Q}{C} = 0 \qquad \text{(A)}$$

where i = dg/dt, we get

$$\mathrm{L}\frac{d^2Q}{dt^2} + \frac{Q}{C} = 0 \qquad \text{(B)}$$

This equation is very similar to that for the mass on a spring (i.e. Simple Harmonic Motion). The solution for this equation would be expected to be similar to that for the simple harmonic oscillator:

$$Q = A \cos(wt) \qquad \text{(C)}$$

Substituting this into equation (B) we find that in order to satisfy equation (B) there is a condition on the value of 'w' and 'A'.

$$\mathrm{A} = Q_o \qquad \mathrm{w} = \frac{1}{\sqrt{LC}}$$

And from the initial (boundary) conditions at t = O, Q = Qo so A = Qo.

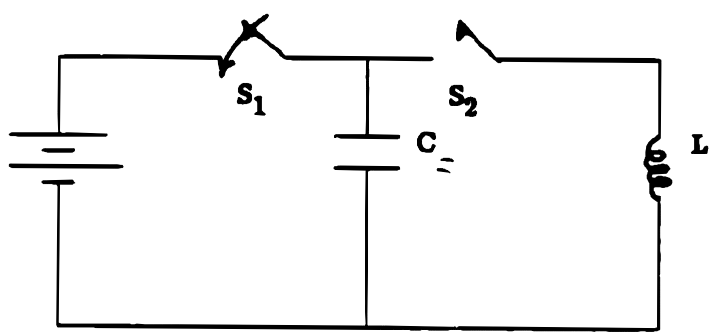


Figure 1.

With SI closed and S2 open, the capacitor, C, charges to Qo. Then when SI is open and S2 closed, the capacitor discharges through the inductor, the current in the inductor surges to a maximum and then gradually decreases with time. This time varying current in the inductor induced an emf which acts to charge the capacitor in the opposite direction (i.e. produces a voltage in the direction of the decreasing current). Hence, the charge oscillates from one side of the capacitor to the other with a frequency given by equation (D).

When we include the resistance, the resistance removes energy from the circuit in the form of heat every time current passes through it. This results in a decrease in the amplitude of the oscillation for each successive oscillation. (Remember: the energy of the oscillation is proportional to the square of the amplitude.) The full circuit including the resistor is shown in Figure 2.

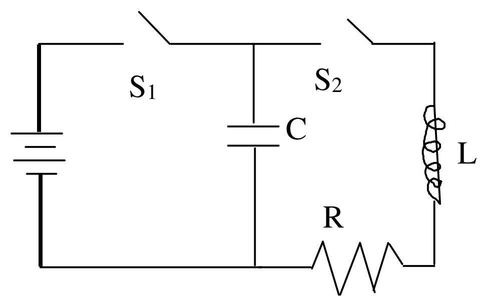


Figure 2.

From Kirchhoff's Law:

$$L\frac{dQ^2}{dt^2}+R\frac{dQ}{dt}+\frac{Q}{C}=0 \qquad \text{(E)}$$

One solution to this equation is:

$$Q = Ae^{-bt}Cos(wt) \qquad \text{(F)}$$

From the initial conditions: $Q = Qo$ at $t = 0$: $A = Qo$.

To determine the other constants, b and w, it is necessary to substitute the trial solution (F) into the equation (E) and perform the required differentiations and find out what b and w must be in order to satisfy the equation (E).

$$\frac{dQ}{dt} = Ae^{-bt}(-b\cdot Cos(wt) - w\cdot Sin(wt)$$

$$\frac{dQ^2}{dt^2} = Ae^{-bt}[(b^2 - w^2)\cdot Cos(wt) + 2b\cdot Sin(wt)$$

Substituting these into Equation (E) and dividing by Ae^{-bt} yields

$$(b^2 - w^2)\ \text{Cos (wt)} + 2\ \text{bw Sin (wt)} - (R/L)\ (\text{b Cos (wt)} + \text{w Sin (wt)}) + (1/LC)\ \text{Cos (wt)} = 0$$

Since the solution must hold for any time, t, the sum of the coefficients for the Cosine terms must add to zero as well as the sum for the sin terms.

For t = 0: $b^2 - w^2 - (Rb/L) + (1/LC) = 0$ (G)

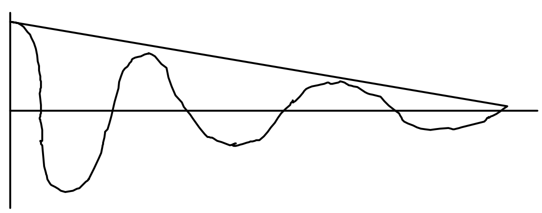
Likewise when $t = \pi/2$, for the sine terms:

$$2\,bw - (Rw/L) = 0 \qquad \text{(H)}$$

which means that $b = R/2L$.

Substituting this into equation (G) yields: $w = \sqrt{\dfrac{1}{LC} - \dfrac{R^2}{4L^2}}$

This describes an oscillation with exponentially decreasing amplitude as shown in the figure below:



This situation called underdamped oscillations occurs when $R < 2\sqrt{\dfrac{L}{C}}$

If $R = 2\sqrt{(L/C)}$ then w = 0 and the solution becomes $Q = Q_o e^{-bt}$, which is an exponentially decreasing function in time. This is called critically damped condition.

The third possibility is when $R > 2\sqrt{(L/C)}$; this produces an overdamped condition where b is smaller and it takes longer for the amplitude to decrease to zero.

Procedure:

1. Assemble the circuit shown in Figure 4. R = 47 + 600 Ω C = 9.5 nF L = 0.033 H
   Set frequency generator for square wave and 1000 hz
   Set Oscilloscope for horizontal sweep 1 ms/div and vertical to 2 volts/div , AC.

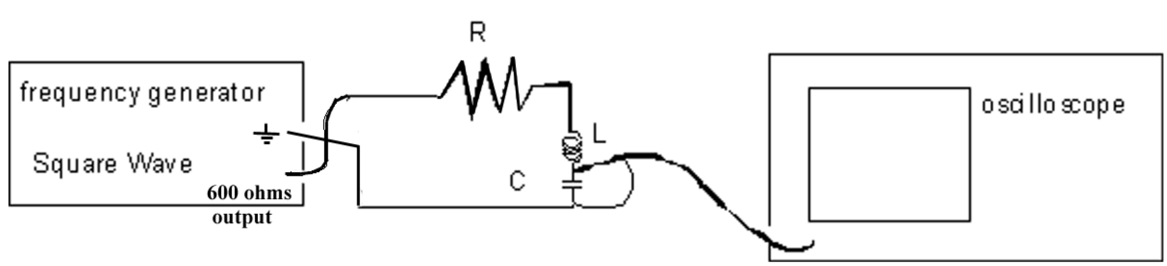


Figure 4.

2. Set the square wave generator at 1 k Hz.
3. With the oscilloscope connected across the capacitor, the Vc will be displayed.
a. Sketch the waveform that appears on the screen.
b. Measure the frequency of the oscillations (not the square wave).
c. Measure the half-life of the exponential decay (estimate). How could you get a better value using the coordinates (time, amplitude) for each oscillation?
4. Add the variable resistor in series into the circuit; vary the resistance until the oscillation does not drop below the horizontal.
a. Turn off the generator and disconnect it from the circuit, measure the resistance of the variable resistor that caused the critical damping.
b. Compare your value with Equation (J).

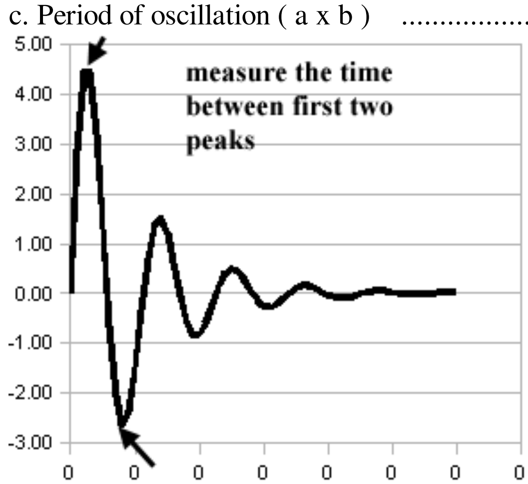
DATA SHEET: RLC

1. RI= .... ohms (approx. 50 Ω) L = ... Henries (0.033 H)

C = ... Farads (9.5 nF) Frequency of generator .... Hz (1 K Hz)

Rgen = 600 Ω So actual resistance is 650 Ω

2. Measurement of frequency of oscillations
a. Sweep time ....
b. Distance on scope .... cm
c. Period of oscillation (a x b) .... sec. w = 2 π f = ... rad/sec



3. Measurement of half life:	
a. Sweep time	
b. Distance to half-amplitude	
c. Half-life	

4. Measurement of the resistance required for critical damping.
Rvariable = ... ohms

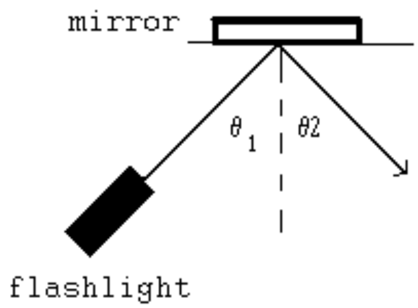
Rcritical = Rvar + Rgen + Rind + RI

Calculations:

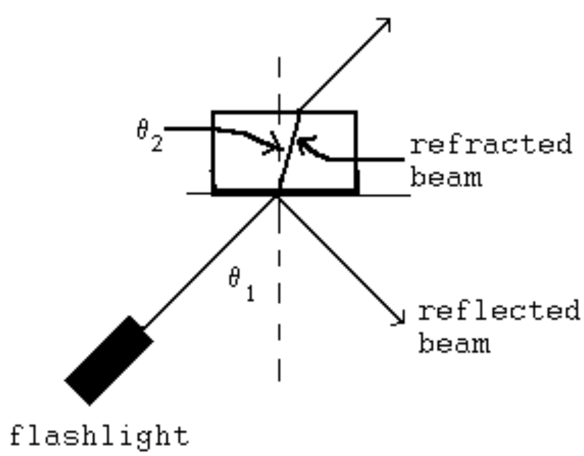
RAY OPTICS AND LENSES

Purpose: The general concept that light travels in straight lines except when it is reflected from a surface or refracted as it passes from one material into a second different material is to be examined. Then the laws of image formation from mirrors and lenses is checked for convex and concave mirrors and lenses.

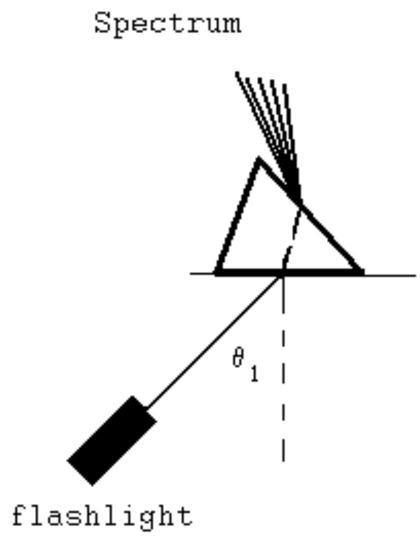
Theory:
a) For reflection from a surface, the angle of incidence is equal to the angle of reflection (both angles are measured with respect to the perpendicular to the surface).



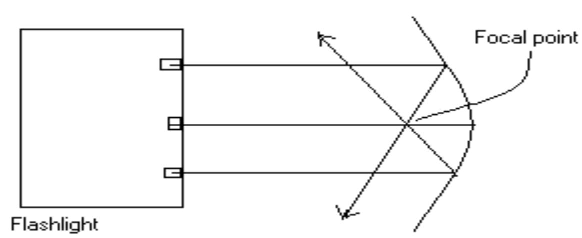
b) For refraction: the phenomena of refraction (when a beam of light passes from one substance into a second substance of different optical density) is described by Snell's Law: $n_1 Sin\,\theta_1 = n_2 Sin\;\theta_2$ where n_1 is the index of refraction (a measure of the optical density of the material).



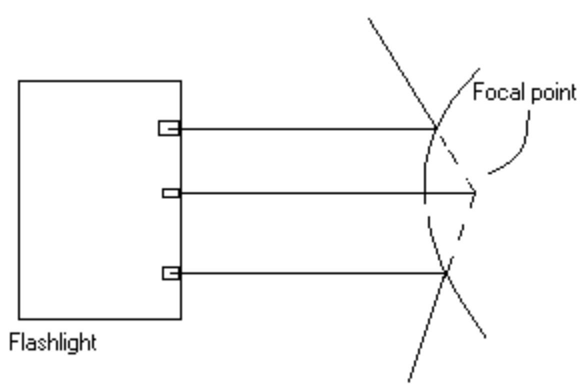
c) A prism: Different colors of light have different wavelengths and the index of refraction is slightly different for each color. So when the light enters the glass at an angle each color is refracted at a slightly different angle, and if the glass were wide enough you could see them separate before the beam reached the other side of the glass where the second refraction would refract them parallel to each other. The different colors would be refracted parallel because the right side of the glass is parallel to the left side. But if the right side was not parallel to the left, the second refraction would not cause the different colors to merge back together but to continue to separate until the separation would be visible and each of the colors would be distinguishable; this is called a spectrum.



d) Concave Mirror: Insert the slide with the three slits in front of the light souce, then adjust the light to make the three beams parallel. Since the beams will be reflected so that the angle of incidence = the angle of reflection, the beams will be refected through a common point called the focal point. The distance from the focal point to the mirror is called the focal length which is half of the radius.

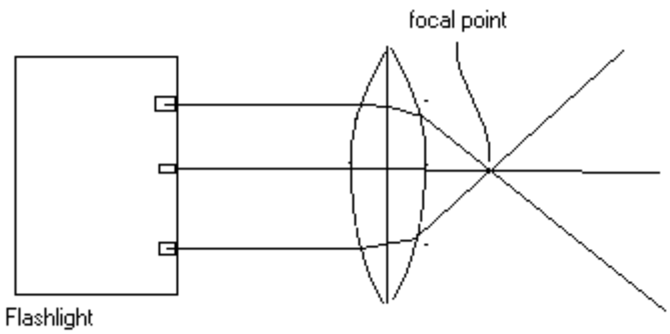


e) Convex Mirror: The three parallel beams of light are reflected from the surface of the convex mirror such that the angle of incidence = the angle of reflection. Here the reflected beams are seen to deviate from the principle axis (they are spreading apart not being focused to a point). However, the reflected beams seem to be dispersed from a common point behind the mirror. This is its focal point; and the distance from the mirror to the point is the focal length (considered negative) and is half the radius.



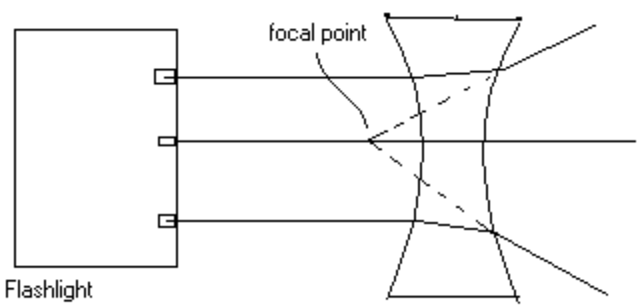
f) Convex Lens: The three beams are refracted by the optically denser glass of the lens and are seen to be focused to a point called the focal point. the distance from the center of the lens to the focal point is focal length given by the lens makers equation ($R_1$and R_2 are positive):

$$\frac{1}{f} = (n - 1)(\frac{1}{R_1} + \frac{1}{R_2}).$$



g) Concave Lens : The three beams are refracted by the optically denser glass of the lens and are seen to be diverged from a point called the focal point. The distance from the center of the lens to the focal point is focal length, (considered negative) given by the lens makers equation ($R_1$and R_2 are negative):

$$\frac{1}{f} = (n - 1)(\frac{1}{R_1} + \frac{1}{R_2}).$$



Procedure:

1. To make a beam of light visible, a special type of "flashlight" is used; it produces a sharp beam of light which is focused onto the surface of the table.

a) Reflection: Place a piece of paper on the surface of the table and tape the corners of the paper to the table. Place the mirror near the top half of the paper facing down the paper. Draw a line along the edge of the mirror, so you know the orientation of the mirror (in case you should accidental bump it during the experiment). Now position the "flashlight" so that the beam makes an angle with the mirror. The beam will be visible on the sheet of paper. Trace the beam from the flashlight to the mirror and the reflected beam from the mirror onto the sheet of paper with a pencil. Measure the angles θ_1 and θ_2 from the normal. The two angles should be the same.

b) Refraction: Place the rectangular piece of transparent material on the sheet of paper in the lower half of the paper. Position the flashlight so that the beam is approximately 45° to the left surface of the glass and the beam exits the glass on the right side. Trace the rectangle of the glass and the beam from the flashlight to the glass and the beam exiting from the glass. Remove the glass and draw the beam that was inside the glass from the point where it entered to the point where it exited the glass. Measure the angles the beam makes with the perpendicular at the point of entry.

c) Prism: Set up the flashlight and the prism so as to produce a spectrum. Rotate the prism to produce different angles of incidence. As you increase the angle of incidence, what happens to the angles of the spectrum exiting from the second surface?

d) Concave Mirror: Insert the slide with the three slits in front of the light souce, then adjust the light to make the three beams parallel. Trace the three beams from the flashlight to the mirror and then the reflected beams. Do not forget to trace the outline of the mirror. Now measure the radius of the mirror and the focal length. The focal length should be equal to half the radius.

e) Convex Mirror: Trace the three beams from the flashlight to the mirror and then the reflected beams. Do not forget to trace the outline of the mirror. Now measure the radius of the mirror and the focal length.

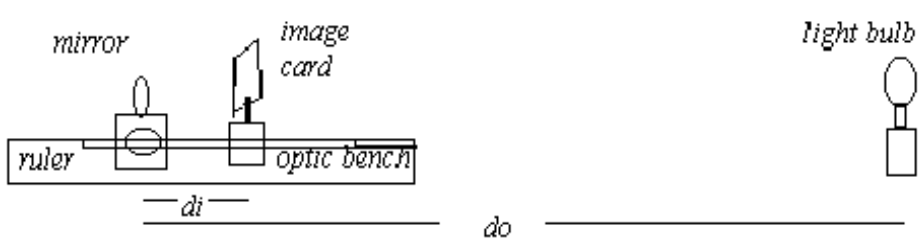
f) Convex lens: Trace the three beams from the flashlight to the lens and then the refracted beams. Do not forget to trace the outline of the lens. Now measure the radii of the lens and the focal length. Does this agree with the lensmakers equation?

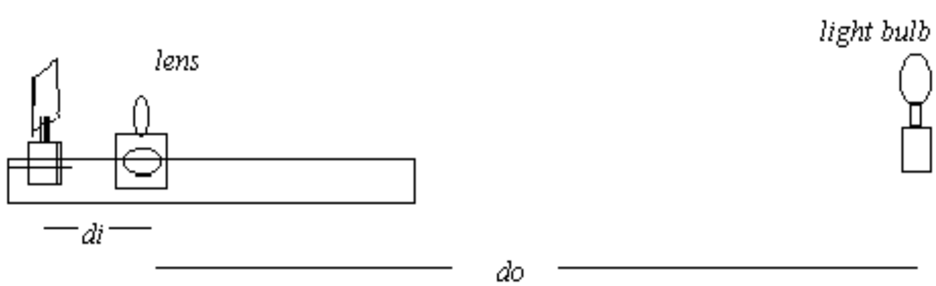
g) Concave lens: Trace the three beams from the flashlight to the lens and then the refracted beams. Do not forget to trace the outline of the lens. Now measure the radii of the lens and the focal length. Does this agree with the lensmakers equation?

LENSES

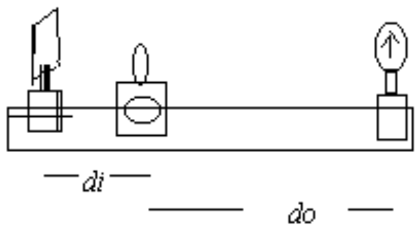
An image is produced by a mirror or lens according to the following equation: $\frac{1}{\mathrm{f}} = \frac{1}{\mathrm{d}_o} + \frac{1}{\mathrm{d}_i}$ $with$ a magnification given by M = $\frac{h_i}{\mathrm{h}_o} = \frac{\mathrm{d}_i}{\mathrm{d}_o}$

1. Determine the focal length of a convex lens and a concave mirror by focusing a distant object onto the image card (use the optical bench). d_o is approximately 10 meters. so that $1/\mathrm{d}_o \approx 0$ $so\,that$ f $\approx \mathrm{d}_i$





2. Measure the focal length of the lenses by measuring the object and image distances; calculate *f* using the lens equation. On the optical bench place the light source with the arrow on it at one end of the bench and a screen at a distance equal to approximately 5X its focal length. Place the lenses one at a time between the object and screen and move until a clear image is obtained. Measure the object to lens distance, the lens to image distance, the size of the object arrow and the size of the image.



Repeat using the red convex lens and then a combination of red and blue with the red and blue in contact with each other.

Calculate the focal length of the concave lens from : $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f_{red+blue}}$

and $\frac{1}{f_{red}} + \frac{1}{f_{blue}} = \frac{1}{f_{comb}}$.

Data Tables

1. Measure f directly, by measuring the image distance for a very distant object. (Optic bench)

a. Mirror f= ________-

% diff. _________

Lenses: Measure f directly

F = ___________ red

F = ___________ green

F = ___________ red-Blue $\frac{1}{F_{red}} + \frac{1}{F_{blue}} = \frac{1}{F_{red\text{-}blue}}$

2. Lens equation $1/d_o + 1/d_i = 1/f$

Use the light souce on the optic bench, measure d_i , d_o, and use the lens equation to solve for f_{calc} and then compare with the value obtained from the measurement of d_i for a distant object h_o is the length of the arrow on the light source. h_i is on the image card.

Magnification

lens	d_o(cm)	d_i (cm)	f_{calc} (cm)	% diff	h_i (cm)	h_o (cm)	h_i/h_o	d_i/d_o	%Δ	
red										
green										
red+blue										
blue	///	///			///	///	///	////	////	

INTERFERENCE AND DIFFRACTION

Purpose: To measure the interference pattern, ie. the distance between successive minima in the double slit interference pattern and single slit diffraction pattern and thereby verify the formulae governing the two phenomena.

Apparatus: DRAW A SKETCH OF THE APPARATUS (USE A RULER)

LASER SLITS SCREEN

Part I

Using the laser, direct the laser beam through the two slits and focus the pattern on the screen with a small piece of paper on it. Mark the dark lines on the sheet of paper. Turn off the laser and measure the distance, Δy, between the dark lines. Measure the distance, x, from the slits to the screen. The wavelength of the HeNe laser is 632.8 nm. the equation is $m\lambda = d \sin\theta$ or $\lambda = d\left(\frac{\Delta y}{x}\right)$. $d \approx 0.5$mm

You should actually measure the distance between 4 or 5 dark lines and average the Δy.

| | | | | | | | |

double slit interference pattern

WAVELENGTH = __________ nm Distance for ___ spaces = _______mm Δy=______ mm

distance of slits to screen = ___________ m

determine the value of distance between slits, d = _______ mm % error = ___________

Part II

Direct the beam of the laser through the single slit of the glass slide. The slit width is approximately 0.25 mm. The diffraction pattern is given by: $m\lambda = a \sin\theta$ where "a" is the slit width and the $\sin\theta$ can be determined from $\sin\theta = \Delta y/x$. Δy is the distance between dark lines (note the first Δy is from the central maximum to the first dark line)

| | | | · | | | |

single slit diffraction pattern

Width of central maximum = ________ mm

size of apperature = _________mm % error = ____________

Part III Air wedge

Carefully clean two glass plates, first with water, then with a paper towel dipped in alcohol, and finally with the lens paper.

Place a strip 1 cm wide across the end of one glass plate and then place the other glass plate on top of the first. Position the sodium lamp over the glass plates and carefully count the number of dark lines in 2 cm length of the pattern. Measure the distance from the point of contact between the glass plates and the front edge of the aluminum foil strip. The thickness of the strip should be equal to:

$t = (N - 1)\frac{\lambda}{2}$ where $N = \frac{L}{2\text{cm}} \cdot n$ where n is the number of dark lines in 2 cm length of the pattern.

NORTHERN VIRGINIA COMMUNITY COLLEGE
ALEXANDRIA CAMPUS

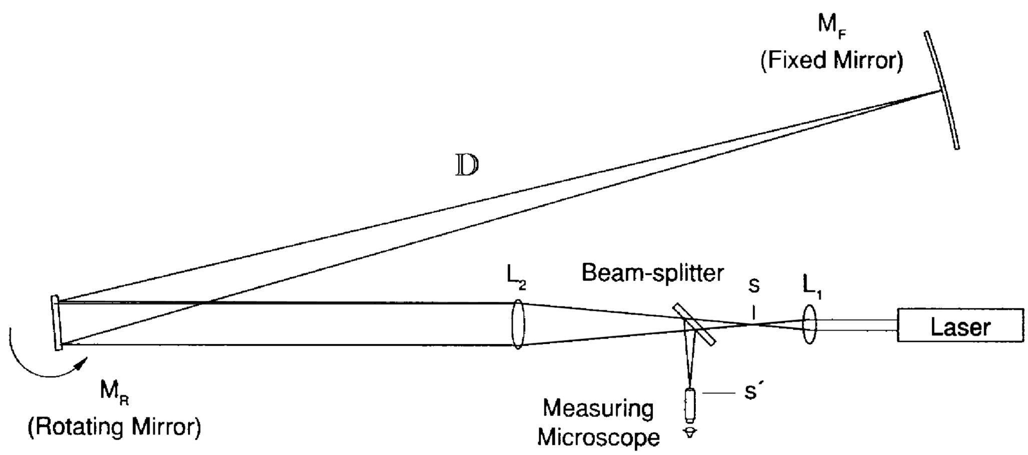
LAB MANUAL
PHYSICS 243
2009

Walter L. Wimbush, Jr.
Professor of Physics

Speed of Light

Purpose: The speed of light is to be determined using the Foucault method i.e; creating a light pulse using a rotating mirror.

Apparatus:



Theory: A simple description of the theory would be that the rotating mirror will reflect light to the fixed mirror when it's normal makes an angle "A" with the x-axis. When the light returns from the fixed mirror, the rotating mirror, R_m , has rotated an angle $\Delta\theta$= w Δt. The second reflection from R_m will therefore make an angle with the original incident ray along the x-axis and be focused to a point s' by the lens. The "ray diagram" below indicates the path of the ray of light from the laser to the focused point.

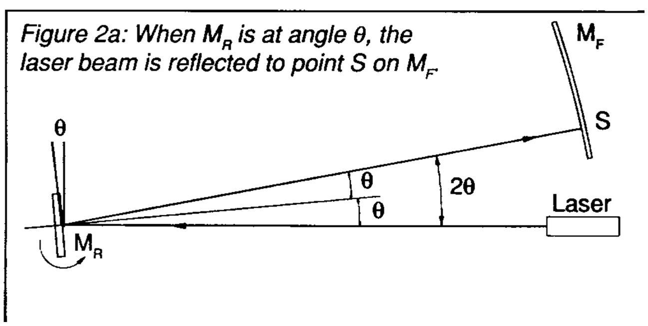


Figure 2a: When M_R is at angle θ, the laser beam is reflected to point S on M_F.

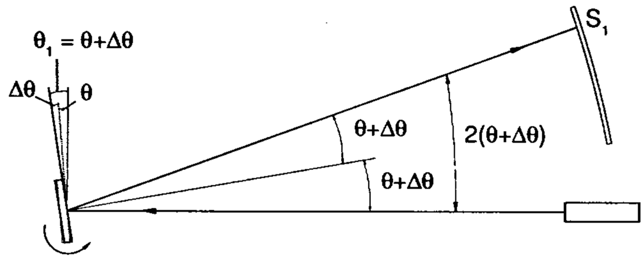
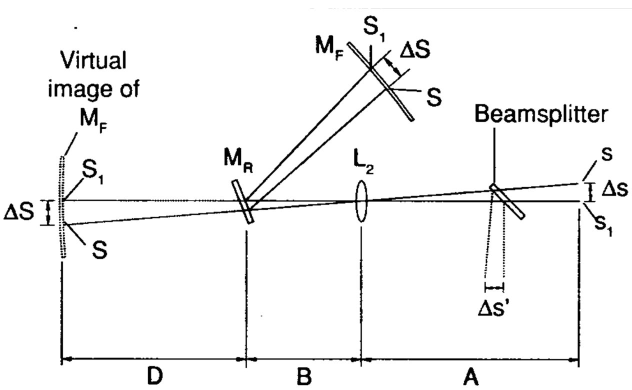


Figure 2b: When M_R is at angle θ_1, the laser beam is reflected to point S_1 on M_F.



After striking the rotating mirror, R_m, when it is at a position M_o, the ray is reflected to the fixed mirror, F_m, a distance "D" away (along a path such that the angle, θ, the incident ray makes with the normal to the surface of the mirror, N_o, is equal to the angle the reflected ray makes with the same normal). It is reflected back towards the rotating mirror which has rotated through an angle, $\Delta\theta$, by the time the ray reaches it. The ray makes an angle, α, with the new normal, N', and is reflected at the same angle with the new normal. The reflected ray from R_m strikes the lens at point "P" and is then focused to the point s'_i. The apparent object of this focused point is at S'_{obj}, (all rays of light leaving from the source point S'_{obj}. would be focused to the point s'_i). From the geometry of the diagram, one can see that:

$$\theta=\alpha + \Delta\theta$$
$$2\,\theta= 2\alpha + 2\Delta\theta$$
$$2\Delta\theta=2\,\theta - 2\alpha$$

From the triangle on the left, $2\Delta\theta = \frac{S'_{obj} - S^{o}_{obj}}{D}$.

From the two triangles formed from the lens to the objects and from the lens to the images:

$$\frac{s'_i - s^o}{A} = \frac{S'_{obj} - S^o_{obj}}{D + B} .$$

$$\Delta\theta = \frac{s'_i - s^o}{A} . \bullet \frac{(D + B)}{2\,D} .$$

The angle the mirror rotates: $\Delta\theta$ = w t, where Δt is the time for the ray of light to go from the R_m to the fixed mirror, F_m, and return to R_m. Therefore, $\Delta t = \frac{2\,D}{c}$ where c is the speed of light.

$c = \frac{2\,D\,w}{\Delta\theta}$. Substituting for $\Delta\theta$ from the geometric derivation, one gets:

$c = \frac{4\,D^2\,A\,w}{(s'_i - s^o_i)(D + B)}$ where $w = 2\pi f$.

Procedure: The apparatus was set up as described in the "Pasco instruction Manual". The location of s'_i was measured with the mirror rotating clockwise at the frequency, f_{cw}. Then, $s'_{i\,ccw}$ was measured with the mirror rotating counterclockwise at a frequency, f_{ccw}. Then, the speed of light can be calculated using:

$$c = \frac{8\,\pi\,A\,D^2\,(f_{cw} + f_{ccw})}{(D + B)\,(s'_{cw} - s'_{ccw})} .$$

The measurement was repeated at a different frequency and the measurements recorded in table I.

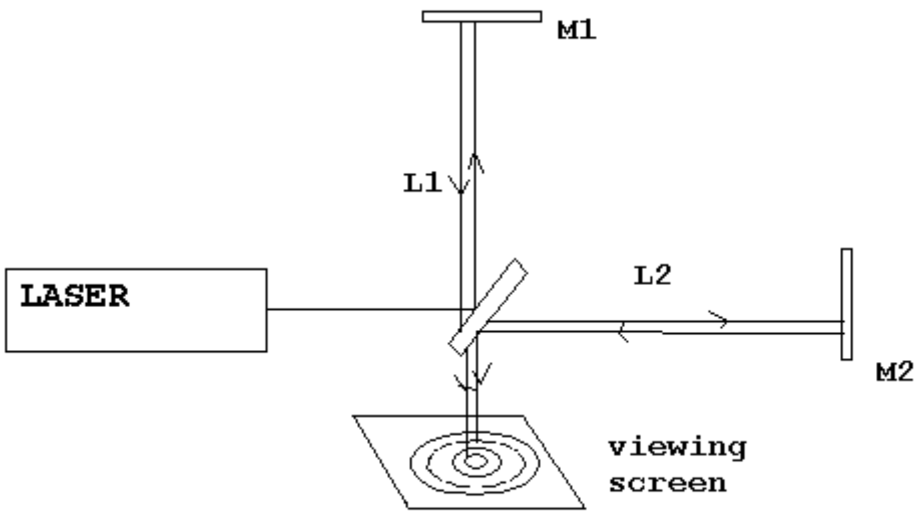
Estimation of experimental Error:

Find the per cent error in each measurement. Determine the total percent error expected for the experiment.

Michaelson's interferometer

Michelson devised an instrument which will take a beam of the light, split it in half send the two Beams different paths, and then bring them back together to have them add either constructively or destructively. This instru is capable of measuring minute variations in the differences between the lengths of the two paths or the time it take beams to travel their respective paths. The wavelength of monochromatic light will be measured using this instrume well as the index of refraction of air.

Apparatus:



Theory: when two beams Of light or originate from two different sources, top fluctuations in the two beams are general, correlated in any way. If the two beams are super produced on each other, the intensity distribution of the res beam displays a series of maxima, and minima. This phenomena is called interference. When the two beams are in they produce a maxima, which is called constructive interference. When the two beams are out of phase they prod minimum, which is called destructive interference. If the light is monochromatic consisting of only one color(wavele the fluctuations are more correlated and hence the interference fringes sharper.

The.interferometer divides an incident beam into two beams via a partially reflecting mirror called a beam sp The two resulting beams are coherent and travel two separate paths. Both are reflected by mirrors, and consequ recombined at the viewing screen. If both paths are not quite the same length, then circular fringes appear. The differe optical path lengths determines whether it will be a bright center(constructive) or dark center(destructive). If L1 distance between the beam splitter and a mirror, M2 , Then the path difference is: optical path difference = 2L2 – 2L1 =

For a bright center(constructive interference). If mirror, M2 , Is moved back distance Δx, The bright center w from bright to dark, and then back to bright. Every time the mirror is moved a distance equal to $1/2\lambda$

, this would be one fringe shift. If the mirror is moved back producing and fringe shifts, then the optical path diffe will be:

$$2(L2 - \Delta x) - 2L1 = (m + n)\lambda$$

Subtracting the equation:

$$2L2 - 2L1 = m\,\lambda$$

Yields: $$2\Delta x = n\,\lambda$$

.

By measuring Δx The distance the mirror is moved, and N. the number of Fringe shifts, the wavelength of the ligh be measured.

If the two mirrors are perpendicular to each other, then the pattern consists of circular fringes. If the two mirro not perpendicular to each other, then the pattern consists of almost parallel straight lines.

Note: The Mirror moves 25 μm for 1 rev of the micrometer.

Procedure:

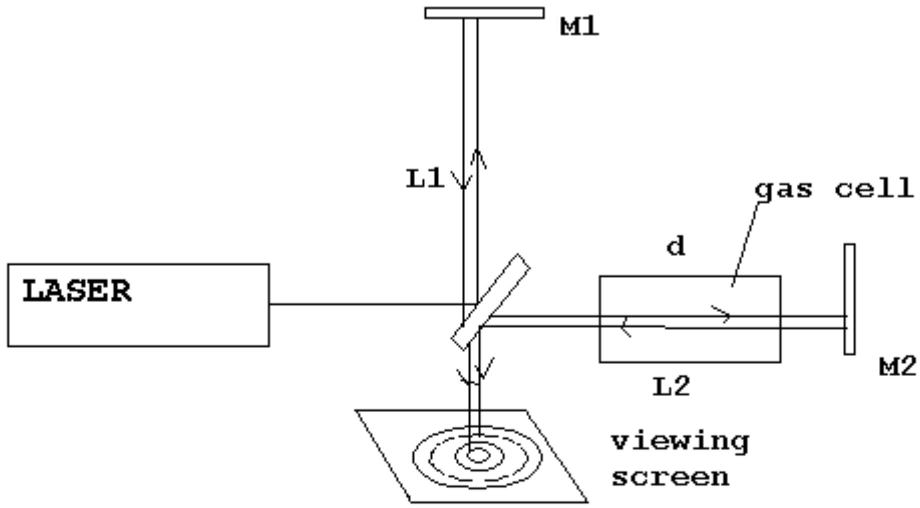
Position the interferometer base on the lab table with a micrometer handle pointing towards you. The interfero has been aligned prior to the lab, so do not disturb it. Turn on the laser and view the fringe pattern on the viewing sc Turn the micrometer dial and observe the fringes move. You should observe the first or second dark fringe from the c mentally mark this point on the scale of the viewing screen and watched the fringes move past the point on the scale.

Turning the micrometer dial in a clockwise direction moves the mirror to the right. Before counting the fringe the micrometer, one revolution clockwise to eliminate any backlash in the micrometer.

Record the reading on the micrometer, now, while looking at the pattern. Turn the micrometer while countin fringes. Count at least 20 fringes, then read the final position of the micrometer. Remember one revolution o micrometer is 25?m. Calculate the wavelength of light, ? for the helium neon laser is 632.8 nm.

Part II: Measure the index of refraction of air

Position that gas cell between the beam splitter and a movable mirror. The light beam should pass through the Make any minor adjustments to obtain a clear set of fringes. Now slowly pump air, out of the cell. Watch the fringes p by. Record the vacuum guage reading, and then pump out the cell to a convenient pressure while counting the fr Record the final guage reading. Now the refracted index of the gas varies directly with its density. The index o fraction for a vacuum is 1.



L2 is the distance between the beam splitter and mirror, M2, excluding the length of the gas cell, d. At norm pressure, the index of free fraction of air is na, so the path difference will be:

$$2(L2 - na\, d) - 2L1 = m\, \lambda$$

When the pressure is reduced. The index of refraction is reduced so the path difference becomes $(m - n)\, \lambda$. H the optical path difference becomes

$$2(L2 - n'\, d) - 2L1 = (m - N)\, \lambda.$$

Subtracting yields: $2\, na\, d - 2\, n'\, d) = N\, \lambda$

Therefore, $na - n' = N\, \lambda / 2d$.

Plot the Δn Versus pressure. At initial pressure, $\Delta n = 0$, And at total absolute pressure = 0, $n' = 1$.
Hence, $\Delta n = na - 1$ = y intercept.

ANALYSIS OF LIGHT USING A DIFFRACTION GRATING

Purpose: To determine the wavelengths of the different colors of light emitted by an element and to compare those calculated with the standard values.

Apparatus: (sketch the apparatus)

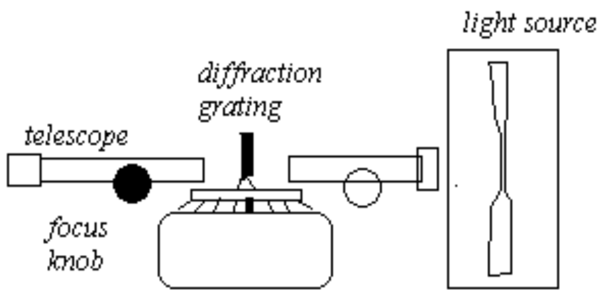


Figure 1. The Spectroscope

Theory:

When a tube filled with Hydrogen gas is connected across a high voltage, the gas is seen to glow with a purple light. When the light is sent through a diffraction grating to separate out the different colors, the purple light is found to be composed of several different colors (the color can be identified by the wavelength of the light). The separate colors appear as distinct lines which is called the spectrum. Each element has its own set of wavelengths or spectrum. So each element can be identified by its spectrum; much like fingerprints.

To explain the distinct set of lines each with a precise wavelength, Neils Bohr hypothesised the existence of electron orbits in the atom. In each orbit the electron would possess a different amount of energy; small amount in an orbit with a small radius and an increasing amount of energy with increase in radius.

Draw a sketch of the hydrogen atom with six orbits.

Figure 2.

Possible orbits for an electron in an atom: (a) lowest energy (ground state) (b) excited state

When an electron makes a transistion from an orbit with more energy to an orbit of lesser energy the excess energy is released as a pulse of light called a photon. The frequency of the light is directly related to the amount of energy released.

$\Delta E = h\,\nu$ where $\Delta E = E_{initial} - E_{final}$ and $h = 6.63 \times 10^{-34}$ j · sec and ν is frequency.

Since $\nu\,\lambda = c$ $c = 3 \times 10^{8}$ m/s (speed of light) $\Delta E = hc/\lambda$

So the wavelength of the light is inversely related to the energy released.

For the hydrogen atom, each orbit has an energy given by $E_n = -\frac{13.6\text{ eV}}{n^2}$ where n is the number of the orbit.
In joules, $E_n = -(13.6) \cdot (1.6\text{x}10^{-19})/n^2$.
If the atom absorbs an amount of energy sufficient to raise the electron from the n=1 orbit to the n=4 orbit, then the electron can make the following transistions back to the n=1 orbit (ground state) : a) #4→ #3 then #3 → #2 then #2 → #1
b) #4 → #2 then #2 → #1 c) #4 → #3 then #3 → #1 d) #4 → #1
Each transition producing a precise wavelength of light. Six different transitions were mentioned so six different wavelengths would be produced. Note however, only those making transitions to #2 produce visible light (λ between 400 nm and 700 nm) the others are either ultraviolet (λ < 400 nm) or infrared (λ > 700 nm) which would be invisible to the naked eye.
Calculate the energy for the first six energy states of Hydrogen.
***Determine the wavelengths for transitions from #6 → #2, #5 → #2, #4 → #2, #3 → #2.**
***You should compare your experimental values with these theoretical values for λ.**

A spectrometer is used to determine the value of each wavelength emitted by the gas within the tube. The spectrometer can use either a prism or a diffraction grating to separate a beam of light into is component colors. You will use a diffraction grating – it is simpler to use! 600 lines/mm so $d = 1\text{x } 10^{-3}$ m/600

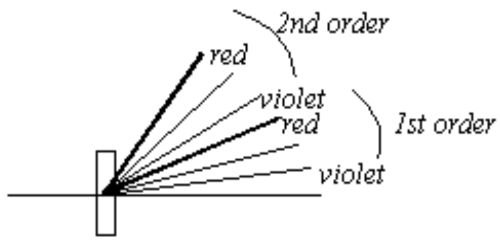
Mercury

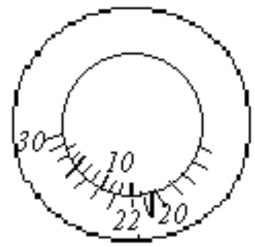
color	angle	d*sin θ	λ	% error

Hydrogen

color	angle	d*sin θ	λ	% error

A diffraction grating is a series of double slits. The condition for constructive interference of two beams leaving the double slit is $m\lambda = d \text{ Sin } \theta$. The equation governing the contructive interference from a diffraction grating is the same where d is the distance between any pair of slits. For example, if there are 600 slits per mm, then the distance, $d = 1 \text{ x } 10^{-3}$ m/ 600. For the first order, m = 1, each color of wavelength, λ, has a value of θ where it is maximum. So each color leaves the grating at its own specific angle (see fig. 2). If you measure the angle, you can determine the wavelength.





to read the angle on the spectrometer use the vernier scale
angle = 22.0 + 13/60=22.22

Figure. 3
A beam of light passes through a diffraction grating and separates into its component colors.
The first order spectrum m = 1, second order m = 2 and the third order m = 3; m=2 and m = 3 overlap.

Procedure:
1. Align the beam of light from the slit through the grating and through the telescope. The plastic marker on the base should be aligned with the zero degree. (this is usually done for you by the laboratory instructor).

2. Using the Mercury tube, measure the angle for each color of light moving the viewing telescope clockwise (as many as you can see - sometimes you are not able to see the red). Record the angle. Then measure the angle when turning the viewing telescope counter clockwise. Find the average value of the angles. The angles should be between 13° and 25° for the first order. The pattern will repeat again at larger angles for m = 2 and m = 3. You need **do only m = 1.**

3. Calculate the wavelength for each angle. Compare (find the % difference) with the accepted values for mercury.
Violet 404.7 nm, Blue 435.8 nm, Green 546.1 nm, Yellow 579.0 nm, Red 690.7 nm

4. Repeat for the Hydrogen tube.

5. Repeat using the sodium lamp.
Blue 466.9 nm, Green 498.3 nm , Green 514.9 nm , Green 515.3 nm, Green 568.8 nm, Yellow-orange 589.0 nm, Yellow-orange 589.6 nm, Orange 615.4 nm, Orange 616.1 nm.

6. Compare your results to the theoretical values for the wavelengths.

7. Make a table of your data with results.

Millikan Oil Drop Experiment

Objective:

The objective of the experiment is to determine the elementary charge possessed by an electron. This will be accomplished by measuring the velocity of a plastic sphere with a charge, q, as it falls due to gravity alone and then measuring the velocity of the plastic sphere when it rises due to an electric field which produces a force greater than gravity. Then when the electric force is aleigned with gravity driving the sphere downward. If the electric field produces a force equal to gravity, the sphere will remain suspended between the upper and lower plates.

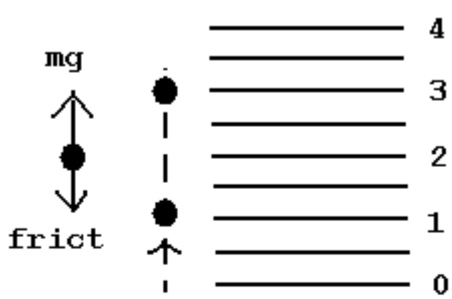
Theory:

The elementary charge carried by an electron is a well known constant, 1.6 x 10^{-19} Coulombs. A plastic sphere can have an excess of many electrons. In this experiment, a plastic sphere is ejected between two horizontal parallel metal plates (Capacitor). Three measurements are necessary: the time the sphere takes to travel two divisions (1) free fall, (which is actually upward when viewed in the telescope), (2) with an electric field directed down, and (3) with an electric field directed up.

(1) In free fall, the viscous frictional force, f = K R v, increases quickly to counterbalance the gravitational force, F_g= mg.

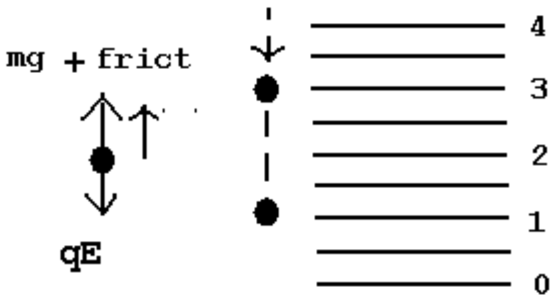
So, : **mg = K R v** (**equation A**)

where K is a constant, R is the radius of the sphere and v is its velocity. (Mass= 5.7 x $10^{-16}\,kg$, R = 0.505 x 10^{-6} m)



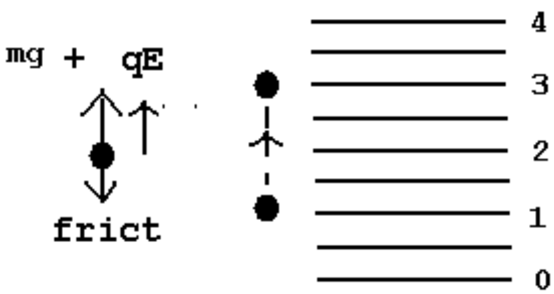
(2) when the electric field is directed in such a way as to make the sphere move upward (in the telescope it looks like it is going downward). the electrical force, F_{el}= qE,, must equal F_g + f when the sphere reaches terminal velocity. F_{el}= F_g + f

So, **qE = mg + K R v** (**eq B**)



(3) When the electric field is reversed, the electric force joins with the gravitational force to increase its velocity until the frictional force balances it. $F_{el} + F_g = f$

So, **$qE + mg = K R v$** **(eq C)**



If Equations B and C are added, $2 qE = K R (v_{up} + v_{down})$.

The Electrical field can be determined by the voltage and distance between the metal plates ($d = 4 \times 10^{-3}$ m). $E = \frac{V}{d}$. Hence, the charges on the sphere can be determined from $\mathbf{q = \frac{K}{2} \frac{R}{E} (v_{up} + v_{down})}$.

When many values for the charge on the sphere have been determined, all of these charges should be an integer multiple of a certain small amount of charge, **q = n e ,** where n is some integer and e is the elementary unit of charge found on an electron. Hence, the value for e can be calculated by dividing each value of q by some integer between 1 and 20. (Hint: first find **n'** using our advanced knowledge of the value of **e**
n' = q/e, n' can be rounded off to the nearest integer).

Procedure:

1. Check the focus of the eyepiece of the microscope by pushing the nozzle of injection system into the viewing chamber as far as possible and focusing on the tip of the needle.
2. Back up the needle until it is out of the viewing system.
3. Connect the high voltage power supply to the red and black binding posts (positive to the red and negative to the black). Adjust the voltage to 200 volts. Set the reverse switch on the Millikan apparatus to the center.
4. Squeeze the bulb gently, spraying a few spheres into the chamber (they will appear as small glossy dots).
5. Adjust the eye piece to focus on a single particle. Move the reverse switch up and down to observe the effect on the particle. With the reverse switch in the center the particle is in free fall and should move upward as

viewed through the microscope. The particle singled out should move like the majority of particles (avoid the ones that fall too fast or too slow as they could be clumps of spheres or fragments of spheres).

6. Measure the time for your particle to fall two divisions upward as seen through the microscope; move the reverse switch so as to bring the sphere back to the starting position. Repeat three times. If you lose sight of one sphere, select another ...anyone will do. You are measuring the effect of gravity and viscous friction, to find the value for K.

7. Measure the time for a sphere to move down two divisions with the electric field, then reverse the switch and measure the time for the sphere to move two divisions upward. Here you need to get both measurements on the same sphere before it disappears).

Repeat 20 times (approximately 5 sets of measurements on 4 different spheres).

Analysis of Data:

1. The mass of a sphere is 5.7 x 10^{-16}kg, the radius is 0.505 x 10^{-6} m, and the spacing between the plates is 4.x 10^{-3}m.

2. Use the data for free fall to calculate the value of K. K = mg/Rv

3. Use the data for the velocity with the Electric Field (v_{up} and v_{down}) to determine tha mount of charge on each sphere.

4. Estimate the appropriate value for n and calculate an experimental value for the elementary charge, e. Find the average value for e and the standard deviation.

Conclusion

State your value for the elementary charge, including the standard deviation.

Discussion of Data:

Comment on the difference between your experimental value and the accepted value for e. What measurements do you consider to have been most critical in contributing to your percent error? Give reasons.

Table I Free Fall

sphere	time	velocity	K
number	free fall	(up)	

Table II With Electric Field average value of K = __________ (from table I)

sphere	voltage	time	velocity	time	velocity	q	n'	e
number	(volts)	(up)	(up)	(down)	(down)			

Determination of Planck's Constant

Abstract: Photoelectrons are emitted from a metallic surface when the surface is illuminated with light having a frequency greater than some critical value. The photoelectrons constitute a photoelectric current which is proportional to the intensity of the light. Einstein explained this phenomena using photons, small packets of light, each photon has an energy, E = h. The energy of a photon is transferred to a single electron who uses some of the energy to escape from the surface of the metal and the rest becomes its Kinetic Energy. This Kinetic Energy is converted into Potential Energy, PE = q V bring the electron to a stop and thus the current to zero. By measuring the stopping voltage for different frequencies of incident light, the value of planck's constant, h, can be found.

Theory: When a quantum of light of frequency, , is incident upon a surface, it can transfer its energy, h, to an electron allowing the electron to be emitted from the metal. The work done by the electron in overcoming the attractive force of the surface is , the work function for the metal - each type of metal requires a different amount of energy to release the electron. Hence, the maximum Kinetic Energy of the emitted electron is KE = hf - ø.

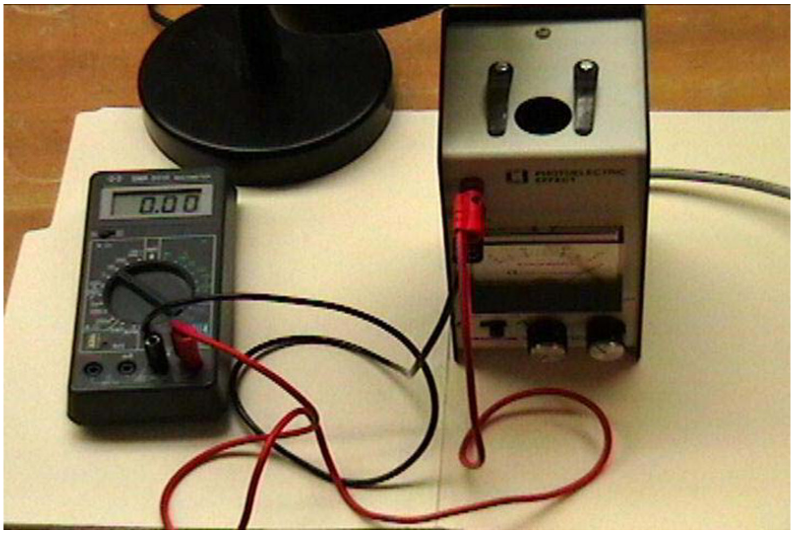
The maximum Kinetic energy depends on the frequency of light, not on the intensity. The intensity is related to the number of light quanta, photons, per unit area. If the incident light has several frequencies, the highest frequency applies.

In the photocell circuit, the ejected electrons make up a current when they reach the collecting plate (the current is very small but can be measured after it is magnified by an Amplifier). The current can be reduced to zero by a potential difference, sometimes referred to as the stopping potential, between the emitter and the collector. If the fastest electron cannot reach the collector, then its KE must be: KEmax = e Vcrit

Then, e Vcrit = hf - ø or Vcrit = (h/e) f - ø/e

The slope of V vs. frequency is equal to (h/e)

Apparatus:



Procedure:

a) Connect the voltmeter to the amplifier-photocell unit.

b) Place an opaque card over the opening on the top of the photocell unit. 

c)Zero the scale with the offset adjust knob.

d) place one of the colored filters over the photocell unit, and turn on the lamp above the unit.

e) Now increase the reverse voltage until the needle is on scale.

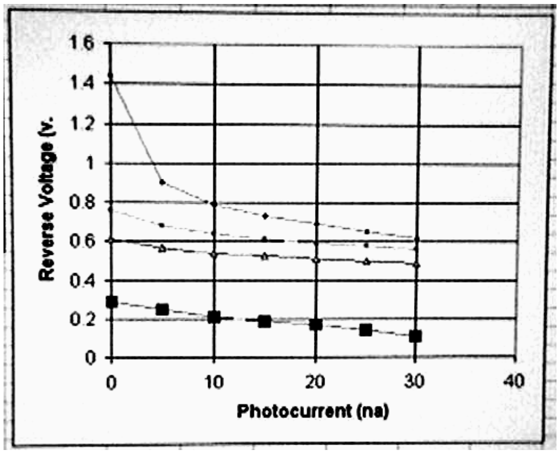
f) Record the voltage on the multimeter when the reading is at 30 nano amps.

Increase the reverse voltage to reduce the current to 25 nano amps and record the voltage and current. Repeat until the current is reduced to zero.

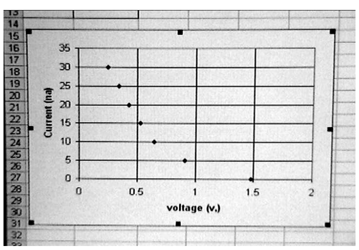
g) plot the photo current on the "y" axis and the reverse voltage on the "x axis". Determie the critical stopping voltage by extending downward the straight section of the curve to the x-axis.

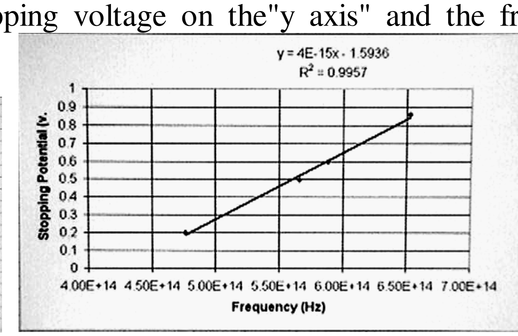
h)Change the colored filter and repeat the measurement of photo current vs. reverse voltage. for each of the colored filters (blue 460 nm, Green 510 nm, Yellow 530 nm, Red 630 nm).

i) Plot the photocurrent vs reverse voltage for each of the wavelengths. Notice that the "curve" has two sections and that you can draw a straight line for the lower section and another straight line for the upper section. Where the two sections intersect is the stopping voltage.



j) plot the critical stopping voltage on the"y axis" and the frequency of the light on the "x axis"





h/e =	4.00E-15
h =	6.40E-34

k) Solve for Planck's constant. Compare with the accepted value of h = 6.63 x 10-34 joules sec.

Microwave Optics

We have observed the wave phenomena produced by light waves passing through a double slit (Young's Double slit Experiment) and also through a single slit. We have verified the laws of reflection and refraction of light in the Ray Optics Lab. Microwaves are also electromagnetic waves which are produced by the oscillation of electrons in a small antennae in the klystron cavity. The vertical currents in the antennae produce a vertical electric field and a horizontal magnetic field which travel through the wave guide at the same frequency as the oscillations in the antennae and are radiated as plane waves by the flared horn. The waves travel at the speed of light. The microwaves are detected by an antennae in the receiver which has a power meter to measure the intensity of the microwave received.

The electric field oscillating in the vertical plane can be described by a traveling wave:

$$E_y = E_o \cos w(t - z/c)$$

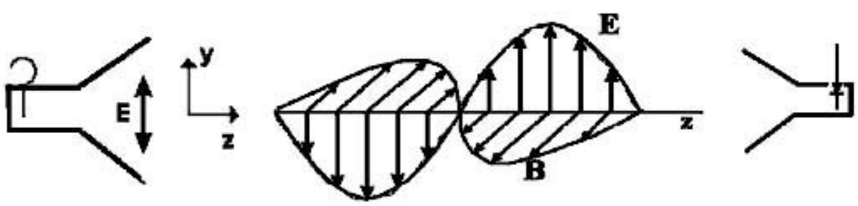


Fig. 1

Figure 1 shows the electric field oscillating in the y direction and the magnetic field oscillating in the x direction while the wave propagates in the z direction. For simplicity only the electric field will be shown from now on. Our goal is to observe with microwaves many of the phenomena previously observed using light waves.

Law of reflection: First show that for normal incident waves the reflection from a sheet of metal is as strong as a straight transmission. Set up the apparatus as shown in fig. 2. Adjust the transmitter to maximum, and show that the received signals are nearly equal.

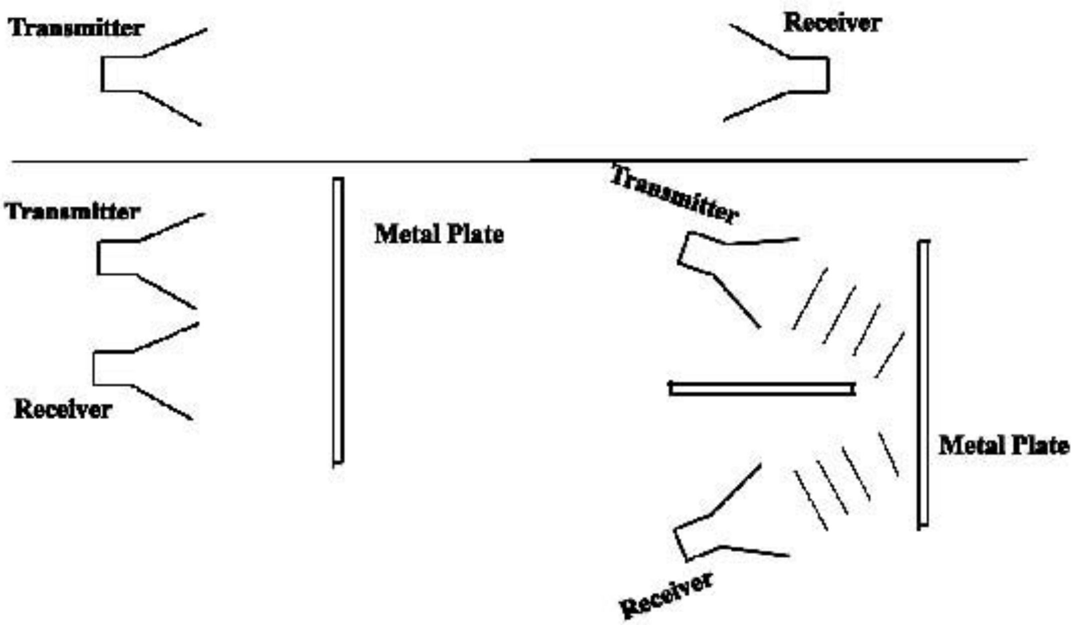


Fig. 2

Now use a partially reflecting/partially transmitting plate. These are plates with vertical slots which allow the electric field to pass. The vertical electrical field induces currents in the strips between the slots, and these currents produce electric fields which nearly cancels the original electric field in the forward direction so that only about 10% actually is transmitted in the foward direction. The electric field generated by the strips in the reverse direction accounts for the reflected wave. Set up the slotted sheet of aluminum between the transmitter and receiver and see that the transmitted wave is small. You can also check the magnitude of the reflected wave.

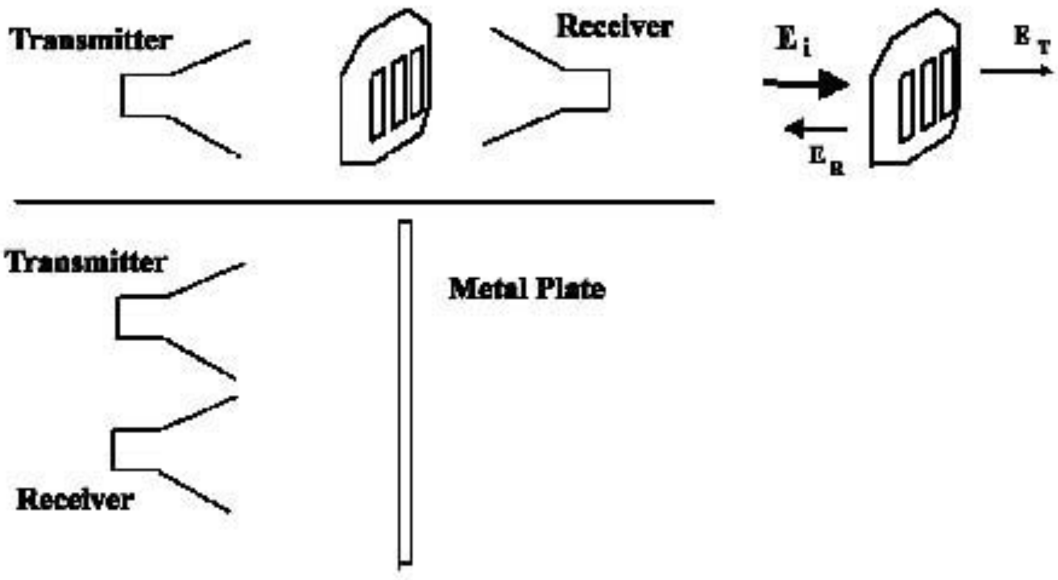


Fig. 3

Now the next setup is reminiscent of the thin film interference, when for a particular thickness of thin film, a condition for destructive interference of the reflected beam could be obtained leaving a 100% transmission of the beam. Now bring a second slotted plate with its slots also vertical (the back surface of a thin film) parallel to the first with the transmitter and receiver in the first configuration of figure 3. As you change the separation of the plates you will observe that there are periodic maxima in transmitted power. This can be explained as follows:

The incident wave was: $E_i = Eo \text{ Cos } w(t - z/c)$.

The reflected wave was: $E_R = - R \text{ Eo Cos } w(t + z/c)$.

And the transmitted wave was: $E_T = T \text{ Eo Cos } w(t - z/c)$

Finally, the power is proportional to the square of the amplitude, so that the fraction of energy transmitted is T2 and that reflected is R2. From the condition of conservation of energy, we get

$$T^2 + R^2 = 1.$$

Now to analyse the case for two plates remember every time an incident wave strikes a plate some of its amplitude is transmitted and some reflected, so there will be many reflections between the plates (see figure 4).

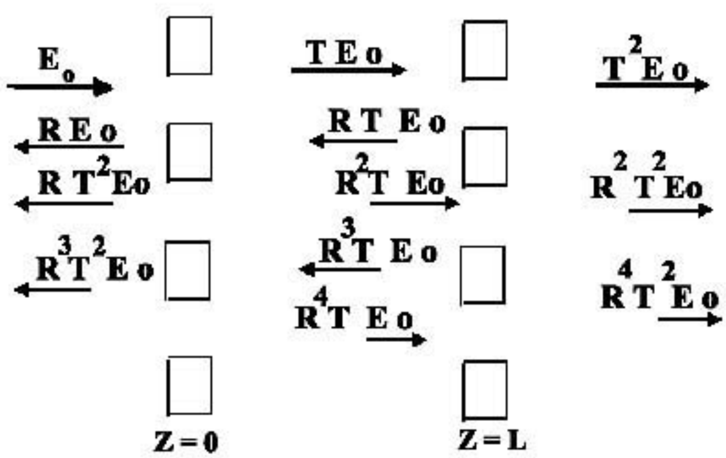


Fig. 4

The transmitted field is the sum of the terms on the right which would be:

$E_T = T^2$ Eo Cos w(t - z/c) [1 + R^2 Cos^2(wL/c) + R^4 Cos^4(wL/c) + . . .]

If we let ß = R Cos(wL/c) , then the series looks like 1 + $ß^2$ + $ß^3$ + ... = 1/(1-ß)1 .

So, the transmitted field will be given by: $E_T = T^2$EoCos w(t - z/c)/{1- R^2 Cos(wL/c)} .

When L = ½ n λo ,where λo is the wavelength, or wL/c = n pi, E_T is a maximum since the Cos (wL/c) = 1 . At these values of L, The transmitted Field becomes:

E_T = { T^2/ (1 - R^2) } Eo Cos w(t - z/c) = Eo Cos w(t - z/c) .

That means at these distances of separation the transmitted field is 100% and the reflected field is 0%.

Determine these separation distances and calculate the wavelength of the microwaves, then knowing the speed of light determine the frequency of the microwaves.

Now that you know the wavelength, repeat the Young's Double Slit expt. using microwaves. Set up the apparatus as shown in figure 5.

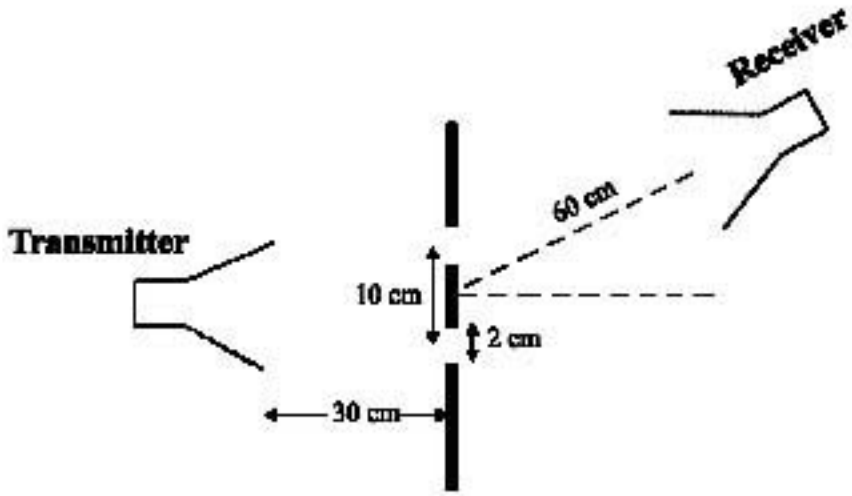


Fig. 5

Measure the intensity as a function of the angle, increment the angle by 10 degrees each time. Verify that the maximum occurs at: $m\,\lambda = d\,\mathrm{Sin}\,(\theta)$.

Finally, using the simulated crystal where the atoms are represented by steel balls, measure the separation between steel balls. Place the "crystal" in front of the transmitter and measure the angles for which you get a maximum diffraction from the crystal.

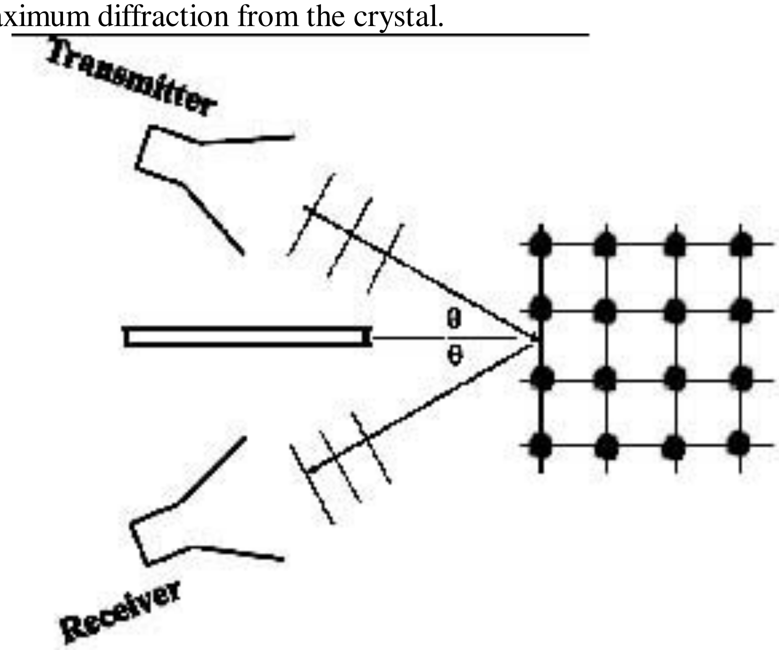


Fig. 6

Increase the angle for both the transmitter and receiver, keeping the angles equal for each measurement of intensity. Compare your results with Bragg's Law:

$$m \lambda o = 2d \sin (90 - \theta).$$

Frank-Hertz Experiment

Abstract

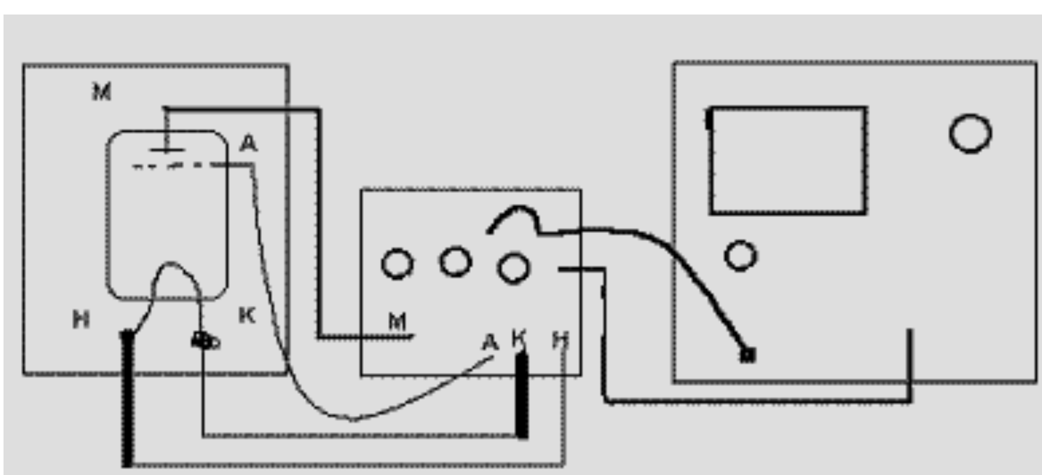
Previous experiments in spectroscopy involve the quantization of photons, James Franck and Gustav Hertz investigated the quantization of energy absorbed by an atom from the kinetic energy of an electron instead of from a photon. In this experiment an electron is accelerated from a cathode to different kinetic energies and then travels through a tube filled with gaseous Mercury atoms. If the Mercury atoms can absorb energy from the electrons, the atoms should do so in quantum amounts because it takes a quantum amount of energy for an electron of the Mercury atom to make a transistion within the atom from a lower orbit to a higher orbit. This loss of energy of the traveling electron to the atom should prevent the electron from making it to the other side of the tube so there would be a noticeable loss of current. Franck and Hertz observed that electrons with energy below 5 ev did not loose energy (did not have inelastic collisions with the Mercury atoms!). But above 5ev there was a sharp decrease in current indicating electrons were transfering Kinetic Energy to the Mercury Atoms. This occurred again at 10 v. , 15 v, 20 v,
and 25 v. This 5ev was just sufficient to bring the mercury atom to its first excited state
.

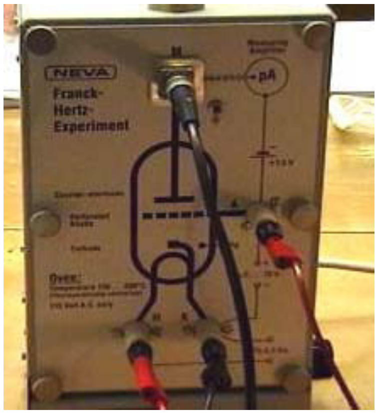
Purpose: This experiment demonstrates the quantization of energy, and thus, verifies the concepts of quantum theory with an impressive proof. Well-defined periodic and equidistant maxima and minima, revealing the quantum levels of mercury will attest to a mercury resonance line at wavelength = 253.7 nm.

Procedure:

Wire the circuit as shown in the diagram.
Plug in the heater and allow the temperature to increase to 100 °C, so the mercury is in a gaseous state.
increase the accelerating voltage, the display on the oscilloscope will be voltage on the x axis and the current on the y axis. measure the voltage of the peaks. Calculate the voltage differences and verify that the voltage differences are in agreement with the required energy for a transition to the first excited state.

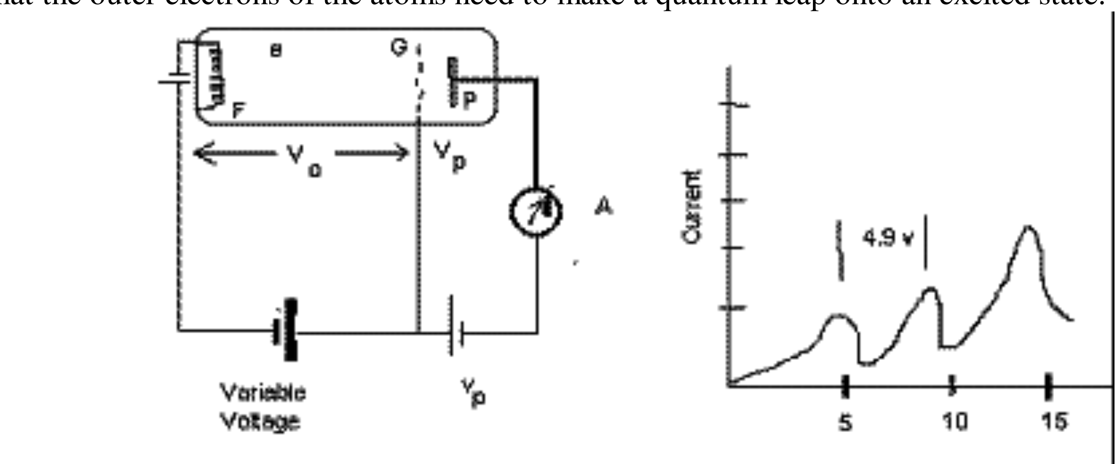
Frank Hertz Experiment





Theory:

The absorption of photons by outer electrons of atoms can only occur if the energy of the incident photon is the value that the outer electrons of the atoms need to make a quantum leap onto an excited state.



When the electrons of mercury atoms are hit by photons (or any 'bullet', be they photons, electrons, etc..) that hav eV of energy, they absorb the photons and make a jump onto the next excited state and, a short time afterwards, they r the 4.88 eV of energy and return to their ground state. The released energy is a photon (and nothing else) in the ultra range with a wavelength of 4.88 eV. The observed wavelength will be:

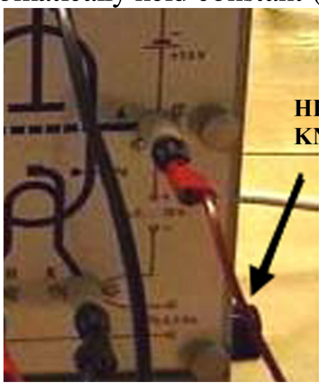
energy of hf =hc/(4.88 *1.6 x 10-19) = 253.7 nm

When a flow of particles are sent at varying voltages, a great many of them having an energy of 4.88 eV are absor mercury. If the electron current is plotted versus the varying voltages, it will be observed that several dips in the c occur with approximately 4.9 volt intervals between (the peaks or the dips); See the diagram

The voltages corresponding to the peaks in the current are called excitation potentials. When the voltage is very hi electrons may cause inelastic collisions in which the atom is completely ionized. Thus there is an additional drop current at a voltage corresponding to the 'ionization potential' voltage.

Procedure: The apparatus will be set up prior to your arrival. The following procedure was followed.

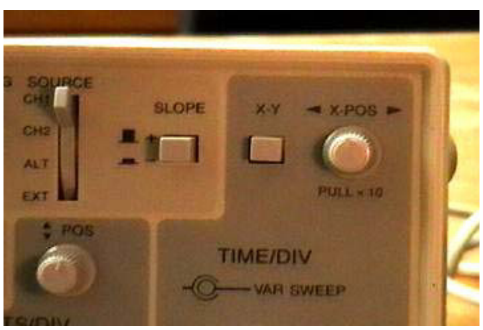
1. Connect the heating oven to a grounded AC line voltage, using the supplied main cable. Set the bimetal contact to the desired temperature (for example, 170 degrees Celcius)   The temperature can be read on a thermometer inserte the center of the oven. It should take about 10-15 minutes for the oven to warm up. The temperature set in this ma automatically held constant (even if the oven is switched off and then re-used after a long idle period.)



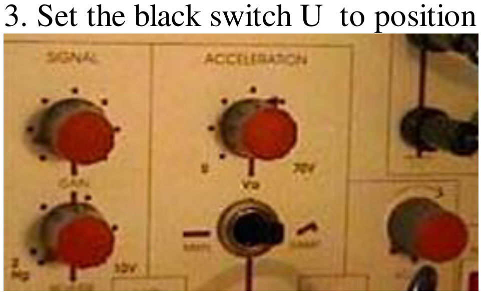
HEATER ADJ. KNOB

2. Switch on the operating unit, and the oscilloscope.

3. Set the oscilloscope for X-Y operation by pushing the button x-y in the upper right hand corner. Then set the voltage at 0.5 volts / division. The output of the control unit has been reduced by a factor of ten; so the scale on the x actually 5 volts/division.



3. Set the black switch U to position "¬"on the control unit



4. Set the middle red acceleration control knob U to zero volts.

5. Set the "adjust" (heizung) knob to about midway
6. Set the left signal "gain" (Verstarkung) knob to maximum sensitivity (turn to the right as far as it will go).
7. Adjust the right "reverse bias" (gegenspannung) knob such that the meter reading at the amplifier output is zero.

The indirectly heated cathode requires a warm-up time of about 90 seconds after you switch on the operatin Slowly increase the accelerating voltage (starting from 0 volts), while reducing the "gain" (Verstarkung) setting, to ke output reading within the meter range.

The Franck-Hertz curve appears on the cathode ray tube screen (oscilloscope). If necessary improve disp judiciously adjusting the "gain" control and the cathode temperature "heater" control. Adjust the accelerating voltag that no self-sustained discharge takes place in the tube, because the curve would be destroyed by collision ionization.

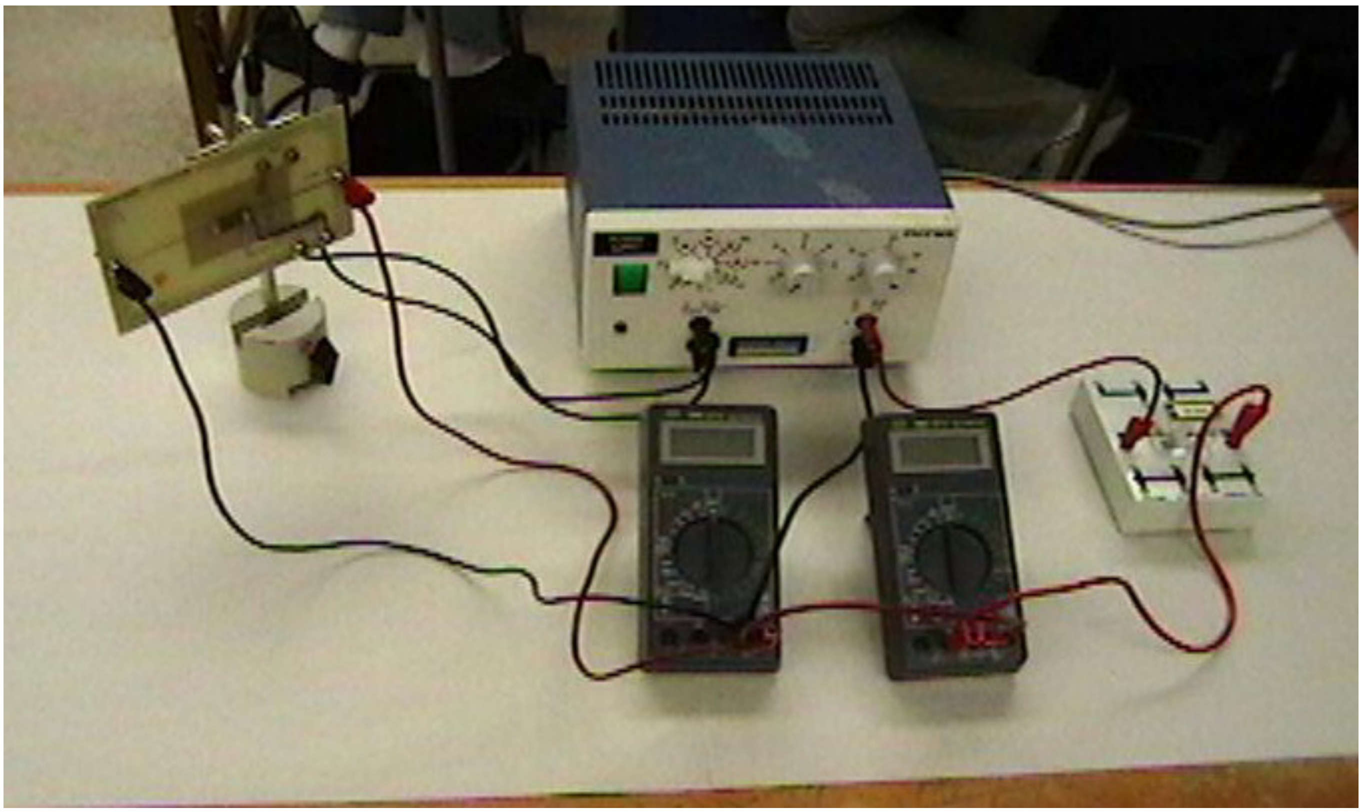
Current Peak num

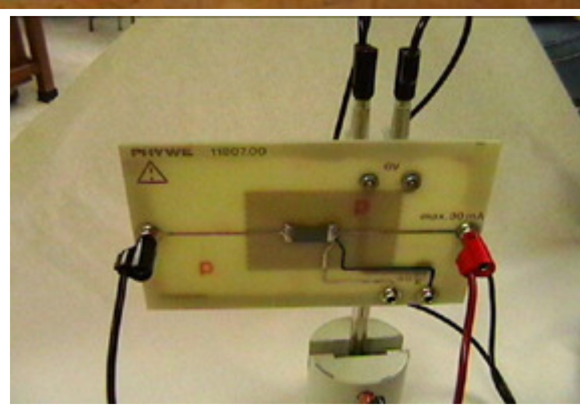
View of the oscilloscope showing current peaks Table of Voltage peaks (read x voltage)

Energy Gap in a Semiconductor

Purpose: The objective of this lab is to determine the forbidden energy gap of a germanium semiconductor. This will be accomplished by measuring the resistance of an intrinsic semiconductor sample as a function of temperature.

Apparatus:





Theory:

In an atom electrons occupy distinct energy levels. When atoms join to make a solid, the allowed energy levels are grouped into bands. The bands are separated by regions of energy levels that the electrons are forbidden to be in. These regions are called forbidden Energy gaps or bandgaps. Energy bands and the forbidden energy gap is illustrated in figure 1. The electrons of the outermost shell of an atom are the valence electrons. These occupy the valence band. Any electrons in the conduction band are not attached to any single atom, but are free to move through the material when driven by an external electric field.

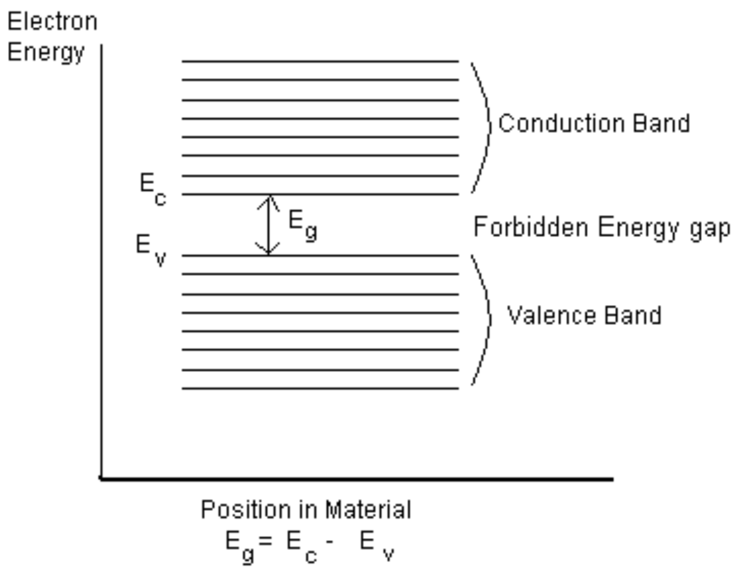


Figure 1

In a metal such as copper, the valence and conduction bands overlap as illustrated in figure 2a. There is no forbidden energy gap and electrons in the topmost levels are free to absorb energy and move to higher energy levels within the conduction band. Thus the electrons are free to move under the influence of an electric field and conduction is possible. These materials are referred to as conductors.

In an insulator such as silicon dioxide (SiO_2), the conduction band is separated from the valence band by a large energy gap of 9.0 eV. All energy levels in the valance band are occupied and all the energy levels in the conduction band are empty. It would take 9.0 eV to move an electron from the valence band to the conduction band and small electric fields would not be sufficient to provide the energy, so SiO_2 does not conduct electrons and is called an insulator. Notice the large energy gap shown in figure 2b.

Semiconductors are similiar to the insulators insofar as they do have an energy gap only the energy gap for a semiconductor is much smaller ex. Silicon's energy gap is 1.1 eV and Germanium's energy gap is 0.7 eV at 300 °K. These are pure intrinsic semiconductors. Observe the energy gap in figure 2 c.

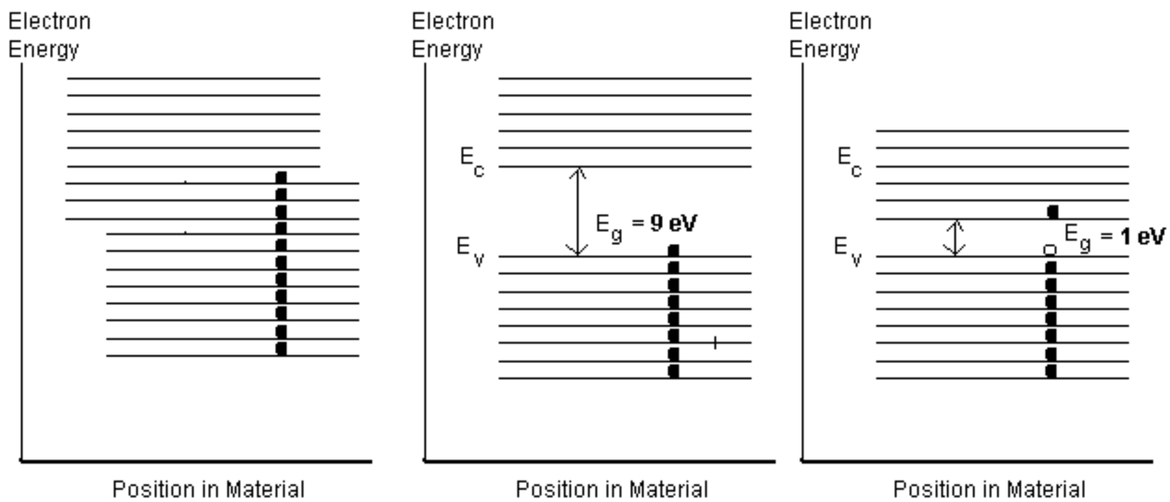
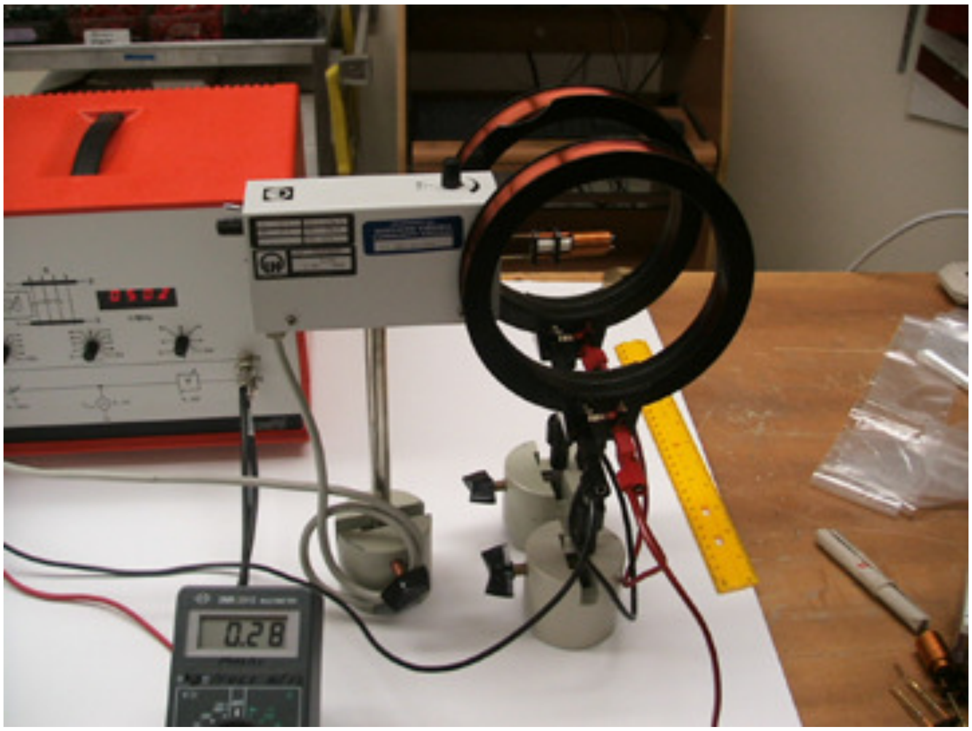


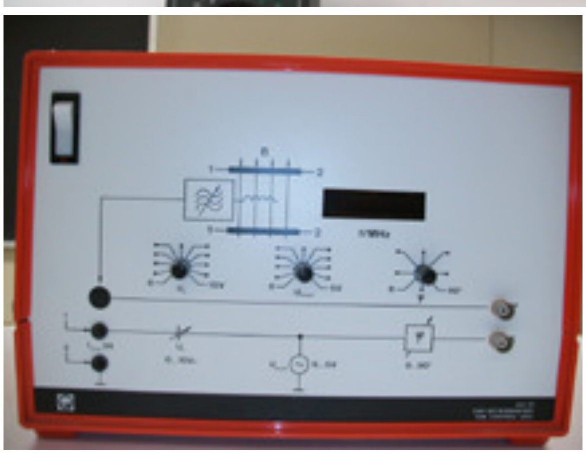
Figure 2a. Metal (Bands Overlap)

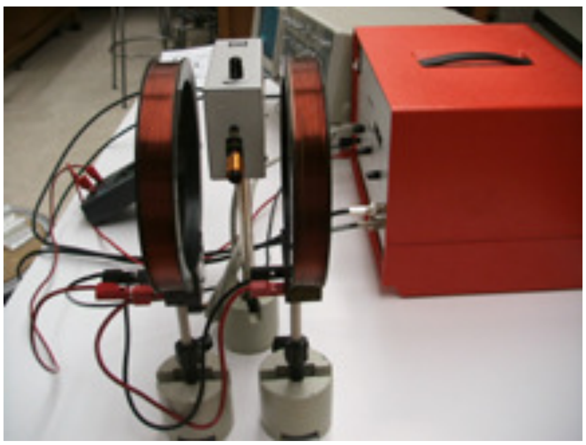
Figure 2b. Insulator (large Energy gap)

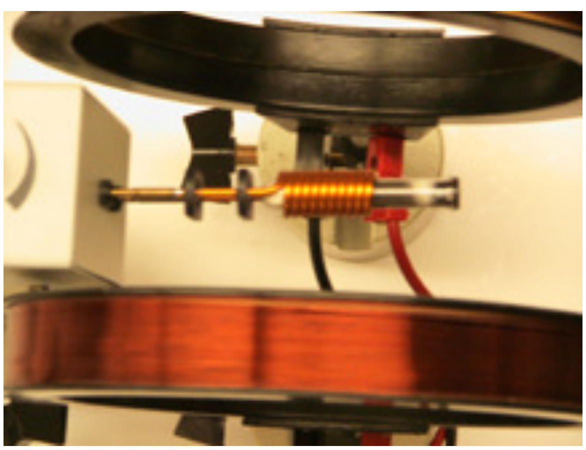
Figure 2c. Semiconductor (small Energy gap)

For finite temperatures, a probability exists that electrons from the top of the valence band in an intrinsic semiconductor will be thermally excited across the energy gap into the conduction band. The vacant spaces left by the electrons which have left the valence band are called holes which also contribute to the conduction because electrons can easily move into the vacancies. If an electric field is applied, the electrons flow in one direction and the holes move in the opposite direction. The holes act as a positive charge (deficiency of negative charge) so the direction of current (effective positive charge) is in the same direction. For pure silicon at 300 °K, the number of electrons residing in the conduction band as a result of thermal excitement from the valence band is $1.4 \times 10^{10}/cm^3$.

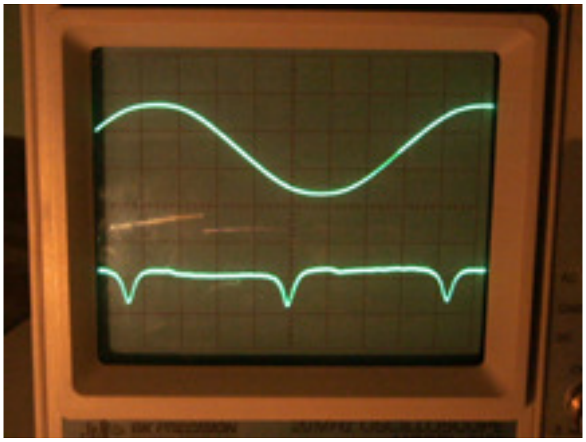

0.28





132



current	freq (M Hz)	B (mT)g	
0.41	21.00	1.73	0.87
0.8	46.00	3.38	0.97
1	59.60	4.23	1.01
1.35	77.00	5.71	0.96

GEIGER COUNTER

Purpose: To investigate the detection of beta particles using a Geiger Counter.

Theory: A Geiger tube consists of a fine wire in the center of a tube and a cylinder centered around the wire (Figure 1). The tube is filled with a gas, and a voltage is maintained between the wire and the cylinder. When a charged particle strikes the gas in the cylinder, it ionizes the gas making the gas a conductor. A surge of current flows in the circuit indicating the presence of the charged particle. After about one microsecond the gas returns to an insulator and the voltage returns to its original value ready for the next particle. The time during which the geiger counter is not ready for another particle is called its <u>dead</u> <u>time</u>.

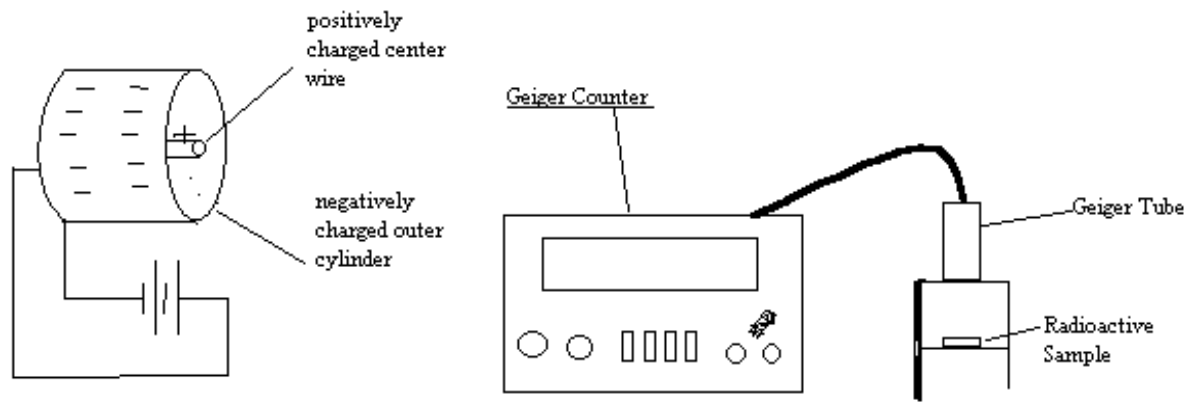


Figure 1.

All three forms of radiation:

Alpha particles (helium nuclei: charge = + 3.2 x 10^{-19} coul. mass = 6.64 x 10^{-27} kg.
Beta particles (electrons: charge = – 1.6 x 10^{-19}coul. mass = 9.1 x 10^{-31} kg.
Gamma Rays (electromagnetic waves : no charge & no mass)

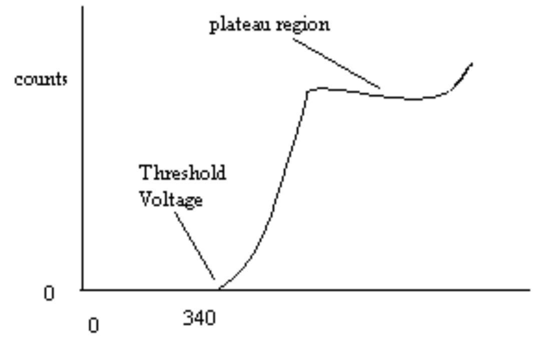
are capable of ionizing gas. The beta particles are especially efficient at ionizing the gas. So the geiger counter is used primarily for counting beta and alpha particles.

The geiger tube requires the voltage in order for it to operate. If you slowly increase the voltage from zero, there will be zero counts until you reach a minimum voltage called the <u>threshold</u> <u>voltage</u>. The geiger tube will increase in its ability to detect particles as the voltage is increased until it reaches a plateau where an increase in the voltage will not significantly increase the number of counts.

Procedure:

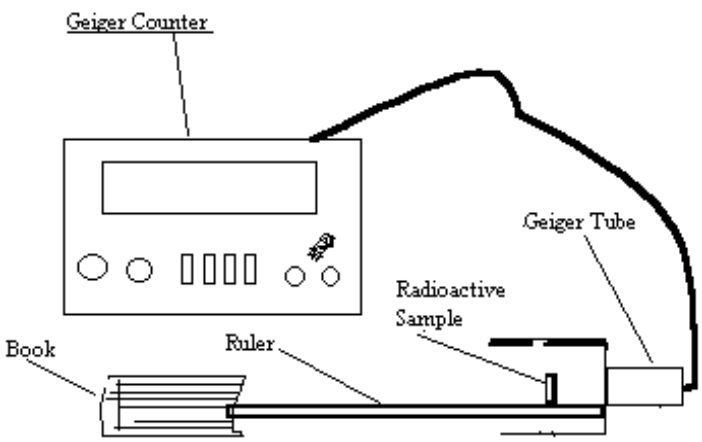
* Place a beta source on a tray on the second shelf of the geiger tube stand.
* Set the voltage (course and fine) to zero. Set the preset count interval to 1 minute.
* Press the power (on) button.
* Press the reset button (display should show zeros).

* Press the count button. This can be measured by placing a beta source below the geiger tube and increase the voltage slowly



until the counter starts counting. (this is threshold voltage- record this value).
*Increase the voltage in 20 volt increments for a total of 100 volts above threshold.
*Increase the voltage in 60 volt increments until you reach 700 volts.
*Plot the counts per minute vs. the voltage.

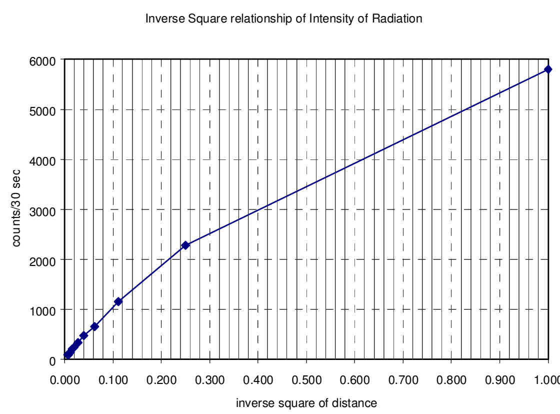
Part II Inverse Square Law:



The counts/min should decrease as $1/R^2$ as the source is moved from the detector.

Procedure:

* Place the geiger tube horizontal; place a ruler with a groove down the middle parallel to the geiger tube so that the sample, when placed on the ruler, will be centered in front of the geiger tube window.
* Set the geiger tube at 600 volts. Set the preset count to 0.5 min.
* Start at 2 cm and count the radioactivity.
* Increase the distance in 2cm increments until 16 cm.
* Plot the Counts/.5min vs. $1/R^2$; you should obtain a straight line.
* Turn the voltage to zero then turn off the geiger counter.

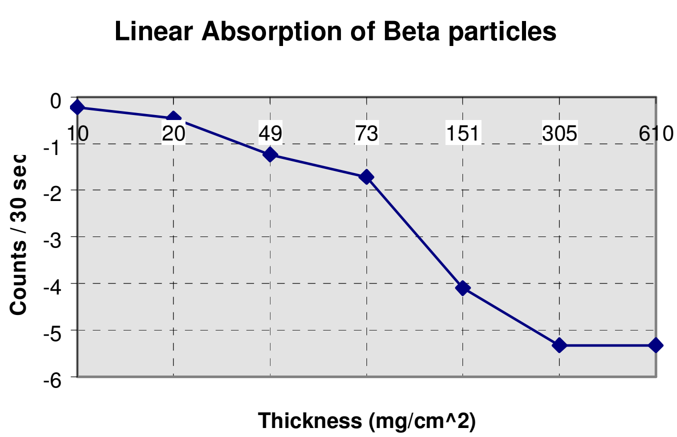


Part III. Absorption of Beta Particles

Beta particles are removed from the beam as they are absorbed by the material. The amount absorbed is proportial to the intensity and the thickness of the material: $-dI \;\; \alpha \;\; I\,dx \;\; or \;\; dI = -\mu\,I\,dx$ where μ is the proportionality factor, called the linear absorption coefficient. Solving this equation yields an exponential dependence on the distance, x.
$I = I_o\, e^{-\mu x}$ Hence, taking the natural log of both sides: $\mathrm{Ln}(I/I_o) = -\mu$ x.
The linear coefficient of absorption depends on the energy of the incident radiation and the nature of the absorbing material. The product $\mu\,x$ must be dimensionless. To avoid the dependence on the difference in density of different materials, the product $\mu\,x$ is often written as: (μ/ρ) $(\rho$ x) or μ_m $(\rho$ x) where μ_m is called the mass absorption coefficient; and the absorber thickness $(\rho$ x) has units mass/cm^2.

Set up the geiger tube and counter as in Part I and place an absorbing sheet of plastic over the sample in the holder. Measure the counts/30 sec for each of the plastic absorbing sheets of different thickness.

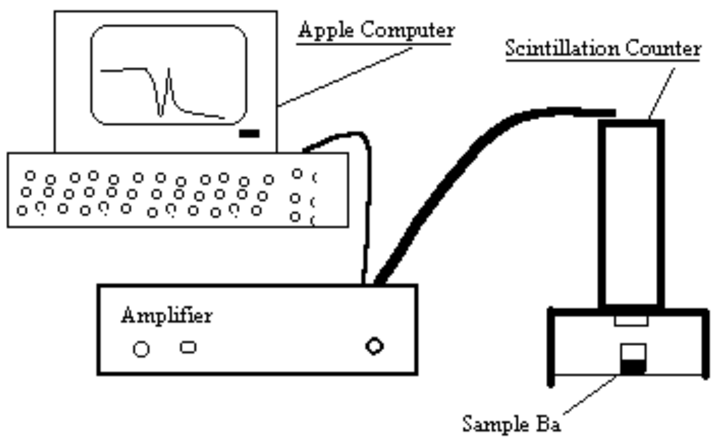
disk	counts/30sec	ln(I/Io)
10 mg/cm^2		
20		
49		
73		
151		
305		
610		



HALF LIFE OF $^{137}Ba^m$

Purpose: To determine the halflife of a radioactive isotope. $^{137}Ba^m$ has a half life of 2.552 minutes.

Apparatus:



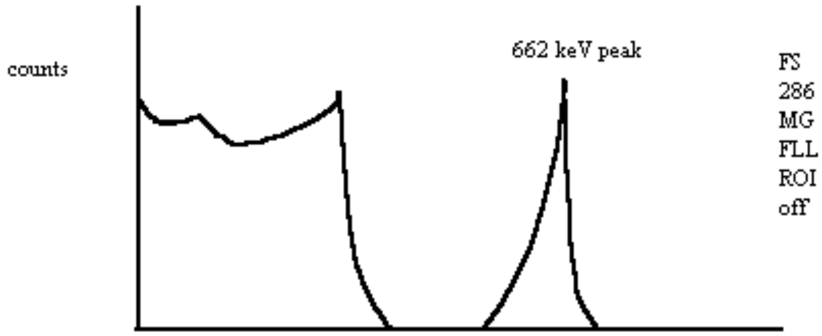
Theory: ^{137}Cs decays to $^{137}Ba^m$ (the m stands for metastable state) by emitting a beta particle. The $^{137}Ba^m$ then decays to a stable form of Ba with the emission of a gamma ray with an energy of 662 keV. A scintillation counter is used to detect the gamma rays. The number of nuclei that decay in any given minute depends on the number of radioactive nuclei present in the sample. As the number of radioactive nuclei decreases due to the radiactive decay process, the decay rate (counts per minute) decreases. (Decay Rate=Activity) $R = \lambda N$ where λ is the decay constant and N is the number of nuclei **still** radioactive.
The decay rate, $R = -\frac{dN}{dt} = \lambda N$.

Solving this equation yields $N = N_o e^{-\lambda t}$ or $R = R_o e^{-\lambda t}$.

Taking the natural logaritm of both sides: $\text{Ln } R = -\lambda t + \text{Ln } N_o$ which is a linear equation with Ln R (y-axis) and t (x-axis) where $-\boldsymbol{\lambda}$ **is the slope**.

The half life can be found from $\boxed{T = \frac{\text{Ln } 2}{\lambda} = \frac{.693}{\lambda}}$.

Procedure:
* Turn on the Apple computer, use the multichannel analyzer disk.
* Boot-up the Apple.
* Power on (gently pull the lever outward then switch the power on).
* Wait 45 sec then turn on the high voltage.
* Place the γ- ray source (^{137}Cs red disk) on a tray below the detector.
* Press "**A**"; the computer should start collecting data. The display is a histogram, where the number of γ-rays with an energy E $\pm$ .5 keV is plotted vertically and the energy horizontally.
* When the display appears similiar to Figure 2, press "D" which stops the collection of data.



CHL 000   CI 000   PT 000
KEV: GI 000   TR 000

Figure 2.

* Use the arrow keys to move the cursor to the beginning of the 662 keV peak (see Fig. 2)
* Press "R" (Region Of Interest) ; look to the right of the graph - the ROI should say "ON" then press the space bar, move the cursor to the right of the peak and press the "R" the ROI should say "SET" then press the space bar again.
* Below the graph in the middle of the screen the total number of counts within the peak is displayed GI =______.
* Press "**T**" to set the time, type 20 and "**Enter**".
* Hold down the "**Control**" key while pressing the "**C**" key to clear the screen.
* Press "**A**" - It should count for 20 sec and stop.
* "**Control-C**"

* * Remove the calibrated sample (red disk) from under the detector.
* The instructor will now give you a sample of $^{137}Ba^{m}$, by dissolving the Ba in HCl acid (the Cs does not dissolve).
* Press "A" and start your stop watch.
* When the 20 sec are up, write down the total number of counts and clear the screen with "control-c".
* At 30 sec on the stopwatch, press "A" for a new count. Repeat at 60 sec, 90 sec, etc.
* Continue until the count is less than 1/20 of the first count.

** Turn off the High Voltage.
* Turn off the power on the Analyser
*Turn off the Apple computer
* Calculate Ln R. You may wish to use Excel on the IBM PCs.
* Plot Ln R vs. time.
* Find the slope, from the slope determine λ, from λ find the halflife of Ba.
* Calculate the % error.

Time start end	Counts (20 sec)	Time	ln (counts)
0 - 20		10	
30 - 50		40	
60 - 80		70	

BIBLIOGRAPHY

[1] Bibliography entry text. Define a bookmark for this entry at the beginning of the entry text (after the tab).

Frank-Hertz Experiment