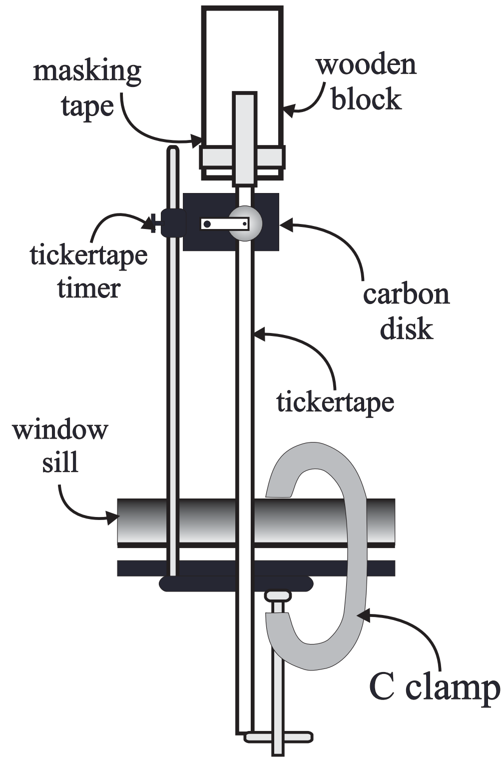
PHYSICS LAB #1 ONE DIMENSIONAL FREEFALL



Goals - The goals of this lab are:

a. to develop a set of equations which can predict the **position**, **velocity** and **acceleration** of a freefalling object.

b. to learn how to derive information from the **slope** of and **area** under a graph.

c. to learn how to apply error analysis.

Procedure -

1. Acquire a tickertape timer and a short piece of tickertape [about a meter], replace the carbon in the timer, place the tickertape through the timer with the ink side of the carbon facing [upward] the tickertape!
2. Turn the timer on and then quickly pull the tickertape through the timer. Check the quality of the dots that appear on the tickertape. The dots should be clear and dark. If the dots appear as streaks or are very dim, see the teacher for possible adjustment or replacement of the carbon disc.
3. Mount the tickertape timer on a tall ring stand as shown to the right. Measure out approximately 4-5 meters of tickertape [about the width of the Physics classroom].
4. Thread the tickertape through the timer [under the metal plate but on top of the carbon paper] and then attach the tickertape to a wooden block as shown to the right. Attach one piece of masking tape along the length of the tickertape and a second piece perpendicular to the first.
5. Extend the ring stand, with the mounted tickertape timer out the window as shown above, clamping the base of the ring stand to the window sill. Stretch out the tickertape across the room making sure that there are no twists in the tape. While holding the tickertape with one hand release the wooden block and wait until the block stops swinging.
6. Turn on the tickertape timer and then release the tickertape allowing the wooden block to fall to the ground outside. Turn off the tickertape timer. [Record the frequency setting on the timer - 10 Hz [preferred], 40 Hz. or 60 Hz]
7. After the block strikes the ground below, remove the remaining tickertape from the tickertape timer and then pull up the wooden block. If the tickertape breaks inform the teacher, get a pass and then go outside into the courtyard through the door adjacent the first floor elevator.
8. After recovering the tickertape, mark the beginning and end of the tickertape. Make sure that the marks on the tickertape are clearly visible. If they are not, replace the carbon disk with a new carbon disk and repeat the procedure from the beginning.
9. Determine the first distinct dot on the tickertape and draw a short line through the center of the dot, perpendicular to the length of the tape. If the timer was set to 10 Hz. draw a short line perpendicular to the length of the tickertape through each dot. If you had set the time to 40 Hz., count out every fourth dot and draw a short line through each until the dots start to get closer together. [That is, skip four spaces - since the dots are 1/40 the of a second apart, marking every fourth dot or every four spaces results in a time interval of 1/10 the of a second, making all calculations much easier!]
10. Label the first dot that you marked on the tickertape 0.0 seconds, label the second mark as 0.1 seconds, the third mark as 0.2 seconds etc.
11. Measure the distance between the 1st mark and the 2nd mark and record the measurement directly on the tickertape, then measure the distance between the 1st and the 3rd mark and record, then measure the distance between the first dot and the 4th dot, etc. The measured distance is the **cumulative** distance between the first and each mark [every 1/10 the second] thereafter.
12. Using the data recorded on the tickertape go to a computer, double click on the **AppleWorks** icon and select **Drawing** from the options menu. Click on the spreadsheet icon and then click in the drawing window and drag a spreadsheet four columns wide and about 15 rows long. [See top of next page!]
13. In the first column of the spreadsheet record your TIME by tenths of a second.
14. In the second column record the total **DISPLACEMENT** of the block as a function of time.
15. In the third column calculate the average **VELOCITY** $[(x_2 - x_1)/(t_2-t_1) = \Delta x/\Delta t]$ of the block during each time interval. [Note, that if you have 10 data points in each of the first two columns there should only be 9 points in the third column - ten data points can only generate 9 differences, etc.]

Type in formula =(B3-B2)/(A3-A2)

Click and hold here to change the width of a column.

Enter data from ticker tape

Type in formula =(C4-C3)/(A4-A3)

	A	B	C	D
1	**Time [s]**	**Displacement [m]**	**Velocity [m/s]**	**Acceleration [m/s^2]**
2	0.0	0.000	-	-
3	0.1	0.044	0.44	10.1
4	0.2	0.189	1.45	9.8
5	0.3	0.432	2.43	7.3
6	0.4	0.748	3.16	9.6
7	0.5	1.160	4.12	8.8
8	0.6	1.660	5.00	6.4
9	0.7	2.224	5.64	10.2
10	0.8	2.890	6.66	-

No data are to be typed into these three cells

Click on C3 and hold. Drag the mouse down until you have highlighted cells 3 through C10. Press the left apple button plus D to copy the formula down through each of the highlighted cells

Click on D4, highlight D4 through D10 and then press left apple + D.

16. In the fourth column calculate the average **ACCELERATION** [$(v_2 - v_1)/(t_2-t_1) = \Delta v/\Delta t$] of the block during each time interval. [Note, there are only 8 points in this column!]
17. Save your work in the appropriate class file before proceeding. Click on **File**, select **Save As**, type in a convenient name for your file and then click on **Save**. {Note that this is an Apple computer and you can therefore use long file names. There is no reason not to fully describe your file!}
18. After you have completed and saved your data table, your next task will be to make the following graphs; **VELOCITY vs. TIME**, **DISPLACEMENT vs. TIME** and **ACCELERATION vs. TIME**. In each case note that **TIME** is the independent variable and is always plotted on the x - axis while the **DISPLACEMENT**, **VELOCITY** and **ACCELERATION** are variables that depend on **TIME** and are therefore plotted on the y - axis. From these graphs you will develop the equations describing the position, velocity and acceleration of the freefalling block, you will determine the meanings of the slopes and areas of each graph and you will learn how to account for and use the experimental error to demonstrate these relationships.

VELOCITY GRAPH

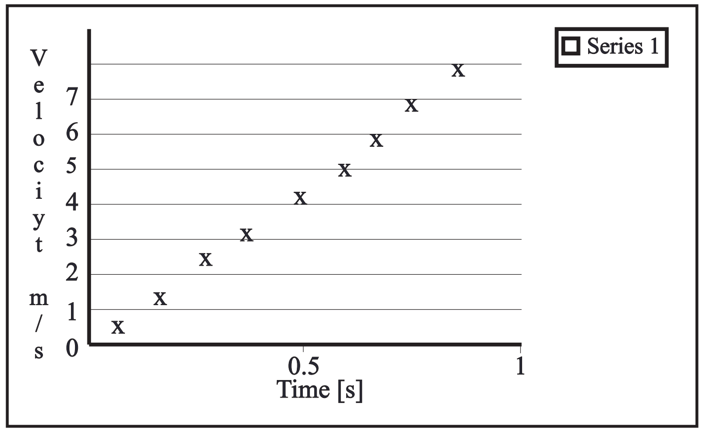
	A	B
1	Time [s]	Velocity [m/s]
2	0.00	0.00
3	0.05	0.44
4	0.15	1.45
5	0.25	2.43
6	0.35	3.16
7	0.45	4.12
8	0.55	5.00
9	0.65	5.64
10	0.75	6.66

Size "handle"

19. To make your **VELOCITY vs TIME** graph begin by clicking on **Format** and selecting **Document**. Click on **size - pages across** and change the number of pages in your document to at least 5 and then click on **OK**. Finally click on **Windows** and select **Page View**.
20. Highlight the first column by clicking A1 and then holding as you scan to the bottom of your data, and then press **Left Apple + C** to copy this first column to the **Clipboard**.
21. Click on the drag bar at the bottom of the page and slide the bar to page 2 of your document.
22. Click on the **Spreadsheet icon** to activate it and then click on the **drawing page** and drag a spreadsheet window into your document. Clicking on and holding the **"handle"** in the bottom right corner of the spreadsheet window, drag the window until it is exactly 2 columns wide and long enough to include all of your data. Single click on cell A1 and then press **Left Apple + V** to Paste your time data into the spread sheet. Return to page one of your document. Click on **C1** drag and highlight all of your data in column C and then again press **Left Apple + C** to copy your velocity data. Return to page 2 and click on cell **B1** to select it. Click on the **Edit** menu and then select **Paste Special** - select the option **Paste Values Only**. Adjust the widths of the columns if necessary by clicking and holding the dividing line between the cells. At this point column width can be changed by dragging the dividing line to the right or left as necessary. To adjust the format of the numbers appearing in the data cells, highlight the cells whose appearance you wish to change, click on **Format** and then **Number**. Select the numerical format you would like to use for your data and then press OK. [I suggest you use **Fixed** combined with the appropriate number of decimals

called **Precision**.] Adjust the time column so that the times are in the center of the interval since these velocities are average and should be treated so. At this point your data should look like the spreadsheet above.

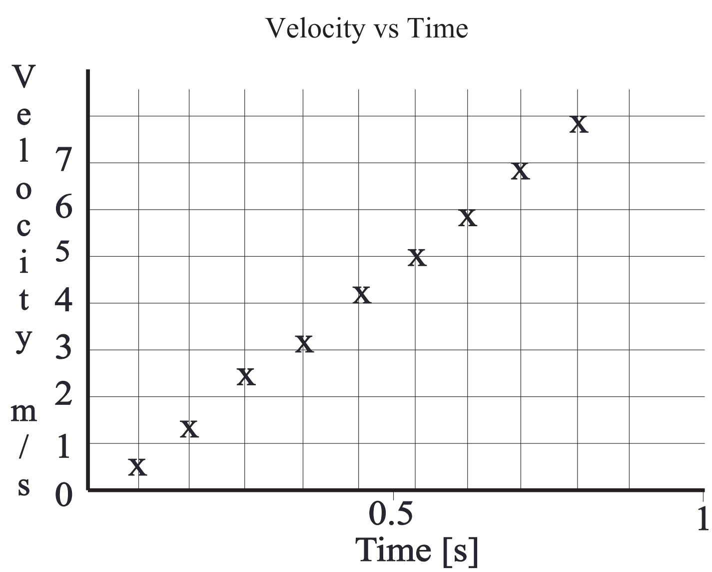
23. The next step is to make the graph of **Velocity vs. Time**. Highlight both columns **including the labels** [the labels will automatically become the labels for the axes of your graph!] at the tops of each column. Click on **Options** and then on **Make Chart**. You will be presented with the graphics menu. Select **X - Y Scatter**. The result will be a graph that appears much like the graph to the right. Click anywhere on the graph and drag it to a convenient position on the paper.



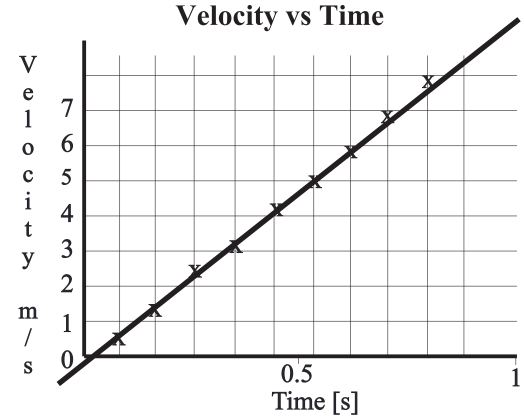
The next step will be to format the appearance of the graph.

24. Click anywhere on the graph to activate it. Go over to the tools at the left. click on the **line width** icon and select **None**. This will eliminate the border around the graph. Do the same for the spreadsheet window.
25. Click and activate one of the cells in the spread sheet then click on **Options** and then **Display**. Click and **turn off Cell Grid**, **Column headings** and **Row headings** and finally click on OK.
26. Click on and activate your graph, and then double click on the graph again. This should return you to the **Chart Options** menu. [If this doesn't work click on **Options** and then on **Modify Chart**.] Click first on **Labels** and **uncheck** the box next to **Legend**. Click on **OK**. This will make the graph larger and get rid of the **legend** which was taking up so much space.
27. Again, activate the graph, double click to bring up the **Chart Options** menu. Click on the **Axes** button and then check the **X axis** box. [Note that the **Label** space is already filled in] Click on the **Grid box** and then select the **Minimum** box. Type in 0.0 as your minimum x value, click on **Maximum** and type in 0.80, click on **Step** and type in 0.1. [The exact number values given here are for example purposes only. Your data will almost certainly be different!]
28. Now click on the **Y axis** box and repeat. Click on the **Grid** box and then select the **Minimum** box. Type in 0.0 as your minimum y value, click on **Maximum** and type in 7.0, click on **Step** and type in 1.0 .
29. Click on the **Label** button and then select **Title** and then type in the title of the graph **"Velocity vs. Time"**. Click on **OK** and your graph and spreadsheet should now appear as shown below. The next step will be to determine the equation for this line.

Time [s]	Velocity [m/s]
0.0	-
0.05	0.44
0.15	1.45
0.25	2.43
0.35	3.16
0.45	4.12
0.55	5.00
0.65	5.64
0.75	6.66



30. First click on the line tool icon and then draw a line which **BEST** fits the points plotted on the graph. You can easily adjust the position of the line by clicking and holding either end of the line and then move it about until it seems right.
31. Since this is a straight diagonal line, the equation of this line follows the relationship:

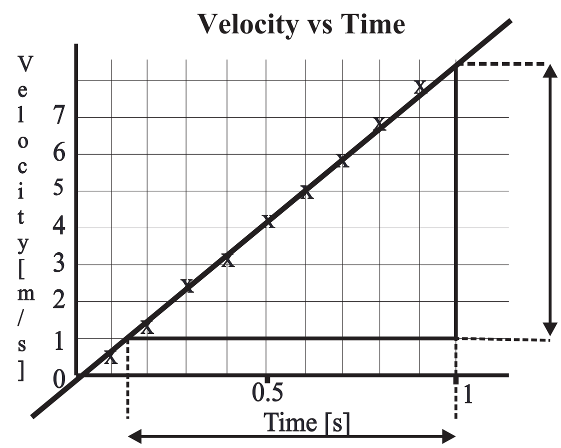


$$Y = mX + b$$

32. where **Y** is the velocity, **x** is the time and **b** is the y intercept. And so the equation will take on the form:

$$V = mt + b$$

33. The next step will be to determine the constants **m** and **b**. To determine **b** just look at your graph and determine where your line intercepts the y axis. In this case the value of the y intercept is approximately **b = -0.3 +/- .1 m/sec**.
34. Next determine the slope **m** of your line. To do this complete a right triangle as shown. It is best to make the triangle as large as is practical. It is not necessary that your line have any connection with the points drawn on the graph. [At this point you are seeking the equation of the best fit line you have drawn and you are not currently concerned with any particular point.] After drawing in the triangle determine the **Rise** by reading the two endpoints from the graph and take their difference as shown. Do the same thing for the **Run**. Note that these point have both units and errors! At this point you can calculate the slope of this line by dividing the rise by the run.



Rise = (8.4 +/- .2) - (1.0 +/- .2) m/sec = (7.4 +/- .4) m/sec

Run = (1.0 +/- 0.02) - (0.15 +/- 0.02) sec = (0.85 +/- 0.04) sec

slope = m = Rise/Run
slope = (7.4 +/- .4 m/sec / (0.85 +/- .04) sec
slope = (8.3 +/- 0.9) m/sec^2

Combining these two results together the equation now becomes;

V = (8.7 +/- 0.9) m/sec^2 t + (- 0.3 +/- .1) m/sec

35. The next step will be to test this equation to see if it properly predicts the velocity of the falling object as a function of time [Go back and reread the goals of the lab procedure!]. To do this first pick a time at random from your data chart. In this case assume that you have chosen **0.65 seconds**. At this time the value for the velocity was determined to be **5.64 m/sec**. The question you might now ask yourself, is "What is the error on this velocity?" Remember that to determine this velocity you subtracted two different displacements from one another and then you divided by 0.1 seconds, the time interval between any two data points. Suppose for a moment that your best estimate of the accuracy of the displacement data was **+/- 3 mm** which is the same as **+/- 0.003 m**. Since you subtracted two different displacements, both of which had this same estimated error, the difference between these two data points will generate an error equal to the sum of the separate errors or **+/- 0.006 m**. Then you divided this number by the time difference of **0.1 seconds**. If you divided the above error by **0.1 sec.**, you will get an error of **+/- 0.06 m/sec**. And so the velocity at 0.65 seconds is **V at 0.65 sec = (5.64 +/- 0.06) m/sec** according to you data chart.

36. Now you will test to see how well the equation you developed from your graph predicts the velocity at this same time, 0.65 seconds. To do this take the equation you developed and substitute in the time value of 0.65 seconds and use it to predict the velocity.

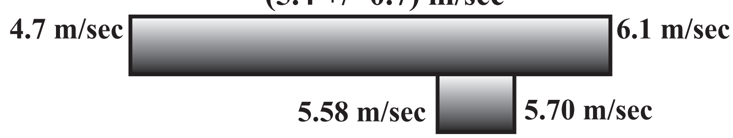
$V = (8.7 \pm 0.9)\ m/sec^2\ t + (-0.3 \pm .1)\ m/sec$

$V = (8.7 \pm 0.9)\ m/sec^2\ (0.65\ sec) + (-0.3 \pm .1)\ m/sec$

$V = (5.7 \pm 0.6)\ m/sec + (-0.3 \pm .1)\ m/sec = (5.4 \pm 0.7)\ m/sec$

37. The final step in this process will be to test these results to see how well this equation predicted the velocity. To do this you will make a **bar graph** comparing the **measured velocity at 0.65 seconds** with the **predicted velocity at t = 0.65 seconds**.

Predicted Velocity at 0.65 Seconds
(5.4 +/- 0.7) m/sec



Measured Velocity at 0.65 Seconds
(5.64 +/- 0.06) m/sec

38. You will note that the above bar graph completely overlaps. This means that the values predicted by the equation have a common solution set with the measured, experimental value. Therefore, it could be concluded that it is **highly likely** that the equation that you developed from the graph does indeed properly predict the velocity of a falling object and that you have clearly met at least part of the first goal of the lab!
39. The next step of this part of the lab is to learn how to interpret the **slope of and area** under the **velocity - time** graph. You will recall that the slope of the velocity - time graph was $(8.7 \pm 0.9)\ m/sec^2$. This slope, you will note, has units of m/sec^2. These are the units of acceleration! Is it possible that this quantity is in some way related to the acceleration of the falling object? This would seem a reasonable hypothesis and so the next step will be to test this hypothesis. To do so you will make a bar graph comparing the **slope** of the **velocity - time graph** to the **average acceleration** of the falling object.

	A	B	C	D
1	**Time [s]**	**Displacement [m]**	**Velocity [m/s]**	**Acceleration [m/^2]**
2	0.0	0.00	-	-
3	0.1	0.044	0.44	10.1
4	0.2	0.189	1.45	9.8
5	0.3	0.432	2.43	7.3
6	0.4	0.748	3.16	9.6
7	0.5	1.160	4.12	8.8
8	0.6	1.660	5.00	6.4
9	0.7	2.224	5.64	10.2
10	0.8	2.890	6.66	-
11		+/- 0.003	+/- 0.06	+/- 1.2
12		**Average**	**Acceleration =**	8.89

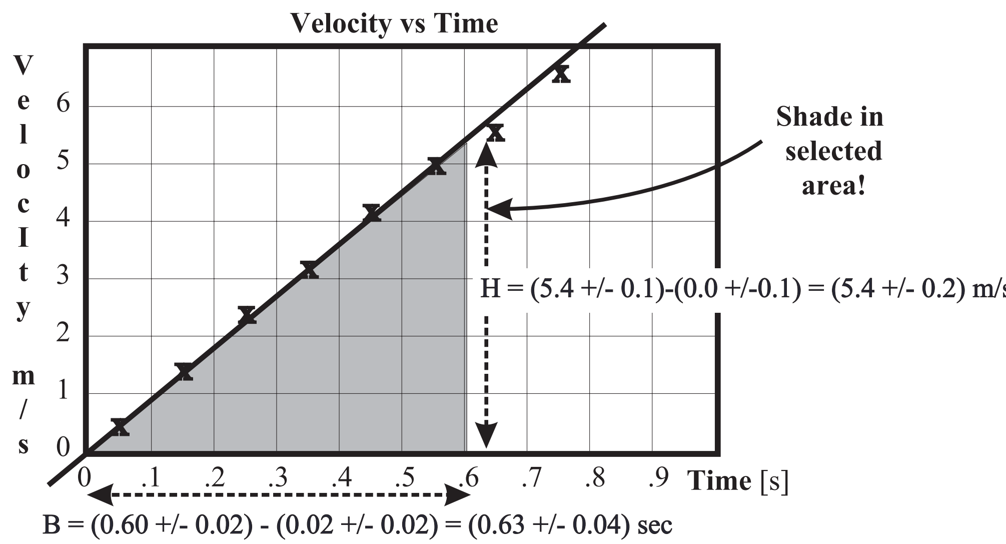
Include error estimates for each column.

Click on D12, type in =AVERAGE(D4..D10)

Click on B12, type in an appropriate label!

40. To accomplish this the first step will be to go back to the spread sheet you developed initially and then calculate the average of the acceleration data. This is relatively easy to do on a spreadsheet. [See previous page!] Click on cell D12 of the spreadsheet to activate the cell then type in the formula "**=AVERAGE(D4..D10)**". You can indicate the cells to include in the average either by tying in the first and last cell with two periods between or you can click and hold on the first cell and then drag to the last cell and release. The resulting average will probably have too many digits. Either click on **Format**, select **Number** and then select **Fixed** and click OK. or double click on cell D12 and then do the same as above. Next click on cell B12 and type in an appropriate label as shown. [By the way for purposes of alignment highlight the cells you wish to align, hold down the Left Apple key and then press **[** for left alignment, \ for center alignment and **]** for right alignment.] Now you are ready to compare the slope of the velocity - time graph to the average acceleration determined on the spreadsheet by **making a bar graph** as done above.

41. The last thing to do on this part of the lab is to determine the significance, if any, of the **area** under the **Velocity vs Time** graph. First, look at the **Velocity vs Time** graph you have made, drop a perpendicular from some point on the graph [we will choose 0.6 seconds] to the x axis. Lightly shade, color or crosshatch the area enclosed by the diagonal line, the dropped perpendicular and the x axis. Since the shaded area is clearly a triangle, the area under the graph would be given by **Area = ½ x Base x Height.** You will note that according to this formula it will be necessary to multiple the Base by the Height. The units on the Base will be **seconds** while the units of the Height will be **meters/second**. When you multiply these two quantities together the resulting unit is **meters!** From this it would seem to be a reasonable hypothesis that the **area** under the **Velocity vs Time** graph is **equal to the displacement!** Therefore the next step will be to **calculate the area under the Velocity vs Time graph** and compare that area with the **measured displacement** at the appropriate time. The height of this triangle is H = (5.4 +/- 0.1) - (0.0 +/- 0.1) m = (5.4 +/- 0.2) m/sec while the base is B = (0.60 +/- 0.02) - (-0.03 +/- 0.02) sec = (0.63 +/- 0.04) sec. From these values you can calculate the area under the **Velocity vs Time** graph. As shown in the calculations above, the area under this Velocity vs Time graph between 0.0 and 0.6 seconds is 1.70 +/- 0.11 meters while the displacement measured at 0.6 seconds is 1.66 +/- 0.03 meters. The last and final step here will be to again **make a bar graph** comparing the **Area under the Velocity - Time graph** with the **Measured Displacement.**



ACCELERATION GRAPH

42. You will now repeat what you have done for the **Velocity vs Time** graph but this time you will be making a graph of **Acceleration vs. Time**.

43. While working on your first graphics page click on **Format** and then on **Document**. After returning to your document go to page 2 by using the **slider bar** at the bottom of the document. Click anywhere on the page to activate it and then click on the spreadsheet icon and drag a new spreadsheet onto the page. Now transfer the times and acceleration values from your spreadsheet as before. After transferring the data make your graph of **Acceleration vs Time** and then format the graph as before.
    a. Determine the equation of the line using **y = mx + b** and test at some random point for which you know the acceleration. **[Make bar graph!]**
    b. Determine the significance [if any] of the **area under the graph**, develop an hypothesis and then compare this area to the appropriate physical quantity. **[Make bar graph if appropriate!]**
    c. Determine the significance [if any] of the **slope of this graph**, develop an hypothesis and then compare this slope to the appropriate physical quantity. **[Make bar graph if appropriate!]**

DISPLACEMENT GRAPH

44. You will now repeat what you have done for the **Velocity vs Time** graph but this time you will be making a graph of Displacement vs. Time.
45. Go to page 3 of your drawing document by using the **slider bar** at the bottom of the document. Click anywhere on the page to activate it and then click on the spreadsheet icon and drag a new spreadsheet onto the page. Now transfer the times and displacement values from your spreadsheet as before. After transferring the data make your graph of **Displacement vs Time** and then format the graph as before. Note that this graph is NOT a straight line. What is the shape of the curve on your graph? Based on this shape what is the relationship between the displacement and the time?
46. Go to the next page of your drawing document and make a new graph by plotting the **Displacement vs Time Squared**! Now what is the shape of the graph?
    a. Determine the equation of the line using **y = mx + b** and test. **[Make bar graph if appropriate!]**
    b. Determine the significance [if any] of the **area under the graph**, develop an hypothesis and then compare this area to the appropriate physical quantity. **[Make bar graph if appropriate!]**
    c. Determine the significance [if any] of the **slope of this graph**, develop an hypothesis and then compare the slope at a particular time to the appropriate physical quantity. **[Make bar graph if appropriate!]**

CONCLUSION

47. Finally, go back and reread the goals of the lab and write a clear, concise conclusion including each of the following;
    a. Restate each goal. [What do you hope to achieve?]
    b. State briefly how each goal was reached. [What did you do to reach these goals?]
    c. State what happened. [What comparisons were made?]
    d. Indicate whether or not you have reached each goal and how you know the you have reached each goal. [Refer specifically to your graphs, bar graphs etc as supporting evidence.]

GOAL - The goals of this lab are;

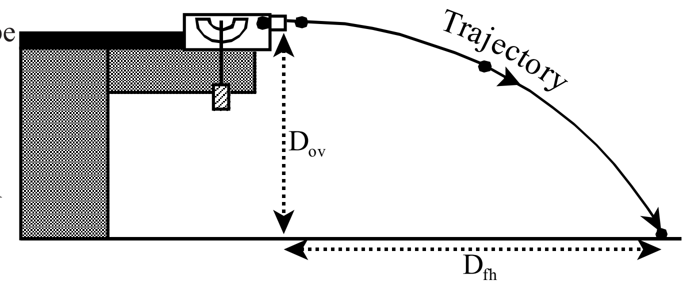
a. to demonstrate that displacement, velocity and acceleration are vector quantities.

b. to determine the relationship the range and height of a projectile fired at any arbitrary angle.

c. to determine the angle at which a projectile will achieve maximum range and maximum height.

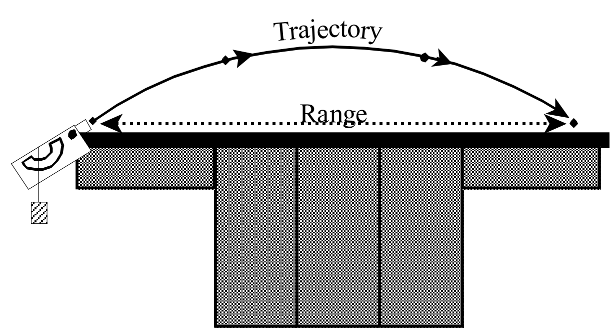
PROCEDURE

PART I - Before measuring the range and height of a projectile you will first need to determine the initial velocity of the steel marble as it leaves the launching device.



1. Mount the projectile device on the edge of the lab table with a C-clamp as shown in the diagram to the right. The device should be mounted so that the center of the launched ball lines up with the edge of the table top.
2. With a 5/8" steel marble placed in front of the piston, measure the vertical distance $\mathbf{D_{ov}}$ from the bottom of the marble to the floor.
3. At this point you **MUST** put on a pair of safety goggles which can be found in the goggles cabinet.
4. Press the steel marble into the launching device to the 2nd notch with the eraser end of a pencil or other appropriate device. [Note! There should be a number on the launching device. Be sure to **record this number** so that you can be sure to use the same device in each step of the lab! The devices may look the same, but they are slightly different.!] Lift the launching lever so as to project the steel marble onto the floor. Note where the marble strikes the floor and then tape a piece of white paper with two small pieces of masking tape on opposite corners of the white paper. On top of the white paper place a piece of carbon paper with the carbon side down. Do not tape the carbon paper down.
5. Again, place the steel marble in the launching device and fire the marble onto the carbon paper. The marble should strike the carbon paper and leave a mark on the carbon paper. If there is no mark, adjust the position of the white paper and repeat. Fire the marble until a **minimum of 5 marks** are on the white paper.
6. Next, hang a small mass on the end of a string from the center of the ball [as indicated on the apparatus] to the point on the floor immediately below to determine the initial horizontal position of the projectile. Mark this point on the floor with a pencil.
7. Measure the straight line, horizontal distance between mark indicating the initial horizontal position of the ball and the center of the group of dots caused by firing the marble. Use the scattering range of the group to determine your **error estimate** for the horizontal displacement.
8. From the height $\mathbf{D_{ov}}$ measured above, calculate how long it will take for the steel ball to reach the floor.
9. From the horizontal $\mathbf{D_{fh}}$ displacement measured above, calculate the average, horizontal velocity of the marble as it leaves the launching device. This result is $\mathbf{v_o}$ and is **the only piece of information** to be passed on to the next part of the lab!

PART II - Measuring the range and height of the projectile at various angles.



10. Mount the launching device on the edge of the table with a C - clamp as shown in the diagram to the right.
11. With a small weight attached to the end of the string which passes through the center of the protractor, adjust the angle of the launching device until the device makes an angle of 15^o with the horizontal. [The weight and string provide a "Plumb" line and define the vertical.]
12. Adjust the vertical position of the launcher until the bottom of the ball is even with the table top as it leaves the launching device. [This is to assure that Do in the vertical direction is zero!]
13. At this point you **MUST** put on a pair of goggles.
14. Press the steel marble into the launching device to the **2nd notch** with the eraser end of a pencil and fire the marble onto the table top. Note where the marble strikes the table top, tape a piece of white paper to the table and then place a piece of carbon paper on top of the white paper.
15. Fire the marble onto the carbon paper at least 5 times and then measure the **Average Horizontal Displacement** [Range!] traveled by the marble. [The distance between the center of the ball just as it leaves the launching device and the center of the 5 dots on the carbon paper.] Don't forget to record the **error estimate** as indicated by the distribution of the 5 dots!

16. Determine the approximate midpoint of the **Horizontal Displacement** and at that point place a vertically oriented board. Make a test shot at the board, note where the marble strikes the board, tape a piece of white paper to the board and then lightly tape a piece of carbon paper over the white paper.
17. Fire the steel marble at the vertical board at least 5 times and then measure the average **Height** [the vertical displacement] of the marble at the highest point of its path. [This path is called the **"trajectory"**!] Don't forget the **error estimate**.
18. Repeat for angles of 30^o, 45^o, 60^o, and 75^o.
19. For 90^o fire the marble straight up at a target mounted on a ring stand. Adjust the position of the target on the ring stand until the marble just barely strikes the target and then record this as the height for 90^o. At this point you may remove the safety goggles.
20. Make a graph plotting the **Range** of the projectile as a function of the **angle** and from this graph determine the relationship between the range of a projectile and the angle at which the projectile is fired. From the graph determine at the angle at which maximum Range occurs.
21. Make a graph plotting the **Height** of the projectile as a function of the **angle** and from this graph determine the relationship between the height of a projectile and the angle at which it is fired. From this graph determine the angle at which maximum Height occurs.
22. Select one set of data for one angle from above and using the velocity v_o from Part I of the lab predict the **Range** and **Height** of the projectile. On a bar graph compare the **calculated Range** at the angle you have selected with the **measured Range** for that angle and compare the **calculated Height** with the **measured Height**.

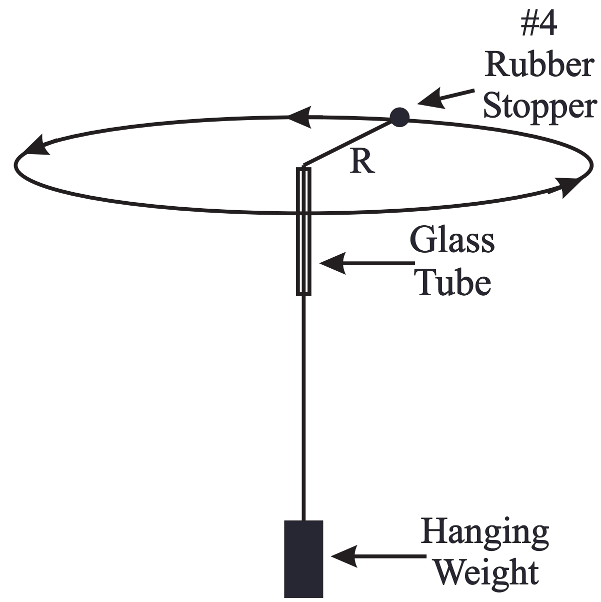
GOAL - The goals of this lab are;

a. to determine the relationships between the centripetal force acting on an object and the three independent variables; mass, velocity and radius.

b. to demonstrate the importance of running a controlled experiment allowing only a single variable in a lab to vary at a time.

PROCEDURE -

A. Centripetal Force vs. Mass



1. The apparatus for this procedure consists of four #4 single hole stoppers, a glass tube, braided nylon fishing line, a stopwatch, weight set and a meter stick.
2. Measure out approximately 2.5 meters of braided nylon string.
3. Thread the string through a 3/8 inch diameter glass tube and tie one end of the string to one of the #4 single hole stoppers.
4. Tie the other end of the string into a loop and hang a 100 gram mass from it.
5. At this point you **MUST** put on safety goggles and you **MUST** wear the goggles as long as anyone in the classroom is performing the lab! **No exceptions will be tolerated!**
6. Measure out a distance of 1.0 meters **from the center** of the rubber stopper to the top of the glass tube. Take a piece of masking tape and place it around the string at a point approximately 0.5 cm from the bottom of the glass tube. [The end which has the 100 gram mass attached to it.]
7. Holding the glass tube over your head, with the 100 gram mass hanging straight down, start to spin the rubber stopper over your head in a horizontal circle. The speed with which you spin the stopper must be sufficient to support the weight of the 100 gram mass with the masking tape "flag" approximately 0.5 cm below the bottom end of the glass tube.
8. After the system has reached equilibrium measure the time [t] required for the stopper to complete 10 revolutions.
9. Calculate the velocity of the rubber stopper based on the circumference of the horizontal circle and the time [t/10] required for each revolution. [Remember that velocity = $\Delta d/\Delta t$!]
10. Measure the mass of one #4 single hole rubber stopper on a balance. Record and tabulate the number of stoppers, the total mass rotating, the total mass hanging down, the weight of the mass hanging down, the time required for 10 revolutions, the radius of the circle and the resulting velocity of the rubber stopper. [Note! Make up a neat, well organized data table!]
11. Replace the single rubber stopper with two #4 single hole stoppers and then repeat steps #6 through #10. **As you add additional stoppers the weight hanging down will have to be changed to reinstate equilibrium**. If equilibrium is reached the velocity and radius will remain constant throughout this part of the lab.
12. Repeat steps #6 through #10 for 3 and 4 stoppers.
13. Make a graph plotting the **Centripetal Force** [the weight hanging down] acting on the rubber stoppers as a function of the **Mass** of the stoppers, and from the graph determine the relationship between **Centripetal Force** and the **Mass** of the stoppers spinning in the circle.

B. Centripetal Force vs. Velocity.

14. Return a single stopper to the end of the string, and re-measure the radius to 1.0 meters as before and repeat steps #6 through #10 for weight hanging down of 200 grams, 300 grams and 400 grams.
15. Make a graph plotting the **Centripetal Force** [the weight hanging down] as a function of the **Velocity** of the rubber stopper and from the graph determine the relationship between the **Centripetal Force** and the **Velocity** of the rubber stopper.

C. Centripetal Force vs. Radius

16. Again starting with a single stopper, reduce the radius of the circular path to 2/3 of a meter. Rotate the stopper overhead again and adjust the weight hanging down until equilibrium has again be reestablished. Note, that in order to keep the velocity of the rubber stopper constant as the radius is reduced, it will be necessary to reduce the time for 10 revolutions in direct proportion to the new radius!
17. Repeat step #15 for radii of ½ meter and 4/3 of a meter. [Remember! In this part of the lab both the mass of the stoppers and the corresponding velocities must remain constant!]
18. Make a graph plotting the **Centripetal Force** as a function of the **Radius** of the circle. From the shape of the graph, determine the relationship between the **Centripetal Force** [the weight hanging down] acting on the rubber stopper and the corresponding **Radius** of the circle in which the stopper is rotating.

D. Final Analysis

19. Combine the results of the three graphs above and determine the relationship between **Centripetal Force** [the dependent variable] and the **Mass**, **Radius** and **Velocity** of the rotating stoppers [the independent variables].
20. At random, select any single data set from above and demonstrate that your relationship properly predicts the **Centripetal Force**. **Make a bar graph!**

PHYSICS LAB #4 — FORCES AT EQUILIBRIUM

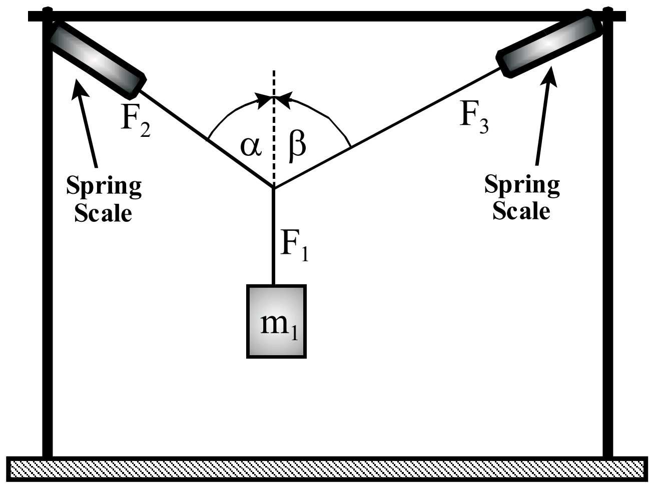
GOAL - The goals of this lab are;

a. to demonstrate that force is a vector quantity.

b. to show that when a system is at equilibrium that opposite forces must be equal.

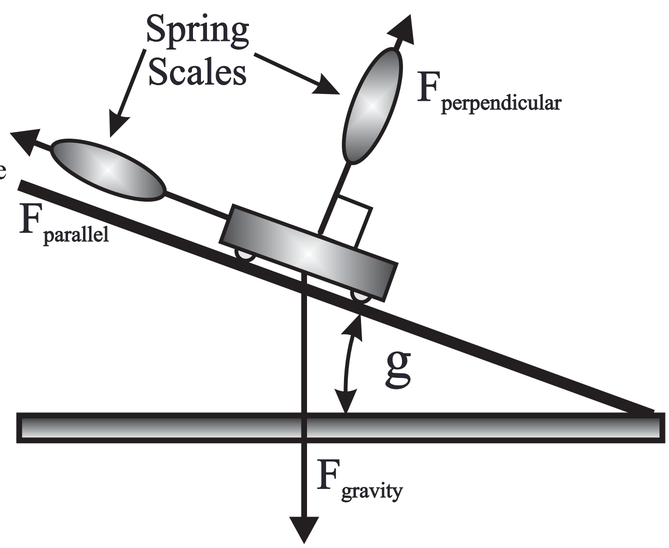
PROCEDURE

A. Three Concurrent Forces



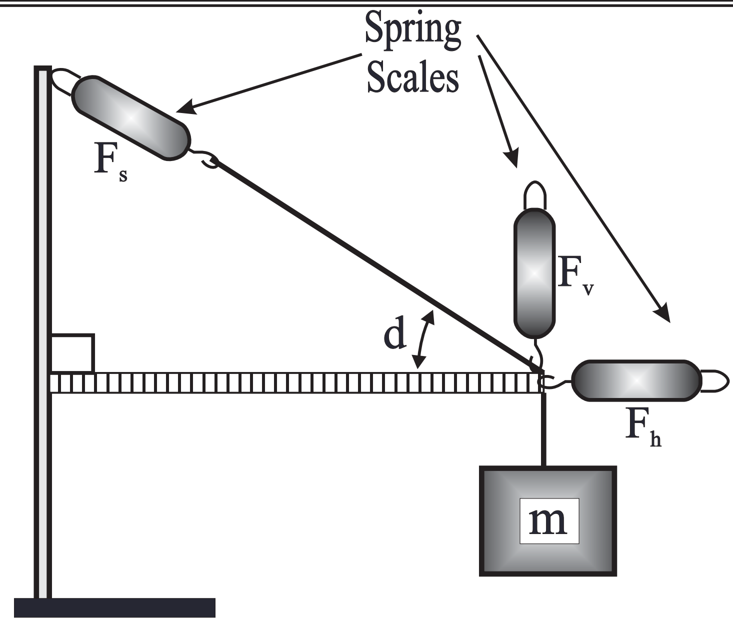
1. The apparatus for this procedure consists of three strings tied together. Two of these strings are attached to two spring scales as shown while the third string is attached to a mass m1.
2. Measure and record the mass [in kilograms] of the weight hanging down.
3. Measure and record the angles α & β.
4. Record the magnitude of the forces F_2 and F_3 from the spring scales. [Be sure that you calibrate the scales before taking any measurements!]
5. Using the angles α & β calculate the components of F_2 and F_3 that are directly opposite F1 and show that the sum of these components is equal and opposite to the force F_1 downward.
6. Show that the horizontal components of F_2 and F_3, that are perpendicular to F_1, are also equal and opposite.

B. Inclined Plane



7. The apparatus in this procedure consists of a three wheeled cart sitting on an inclined plane. A string is tied to one end on the cart. The other end of the string is attached to a spring scale which is in turn attached to a C-clamp at the top of the incline. A second string is tied through the center of the cart.
8. Measure and record the angle [γ] of the incline. [Be sure that you are using the protractor properly!]
9. Measure and record the weight of the cart.
10. Using the spring scale mentioned in step #1 above to determine the force required to keep the cart from rolling down the incline. [This is F parallel!]
11. Using a second spring scale [of the appropriate range] determine how much force needs to be applied to the cart at right angles to the incline in order to just barely lift the cart off the incline. [All wheels must lift off the incline simultaneously! This is F perpendicular.]
12. Calculate the component of the cart's weight parallel to the inclined plane and show that your calculated Force parallel is equal to the measured Force parallel.
13. Calculate the component of the cart's weight [$F_{gravity}$] perpendicular to the inclined plane and show that it is equal to the measured Force perpendicular.
14. Show that the square of the measured Force parallel added to the square of the measured Force perpendicular is equal to the square of the weight of the cart.

C. Hanging Street Sign



15. The apparatus in this third part of the lab consists of a tall ring stand, a meter stick, a string, a spring scale and a suspended mass.
16. First be sure that the meter stick meets the ring stand at a 90^o angle.
17. Measure the angle (δ) between the meter stick and the string.
18. Measure and record the magnitude of the force in the diagonal string (F_s).
19. Attach a second spring scale to the end of the meter stick by inserting the hook end of the spring scale through the hole in the end of the meterstick.
20. Apply a horizontal force to the second spring scale until the meter stick just **barely** pulls away from the ring stand. [It is advisable to either have a lab partner hold the ring stand in place or clamp the ring stand firmly to the table with a C - clamp.] Record this reading as Force horizontal (F_h).
21. Again, with the second spring scale attached to the end of the meter stick, detach the diagonal string from the first spring scale and lower the string until it is parallel to the meter stick, while at the same time support the end of the meter stick with the second scale.
22. Apply an upward force to the end of the meter stick with the second scale so as to support the system and record the vertical force (F_v) exerted by the second spring scale on the end of the meterstick.
23. Using the reading (F_s) on the diagonal spring scale and the angle (δ) between the string and the meter stick, calculate the horizontal and vertical components of the diagonal force.
24. Compare each of the above calculated forces with the corresponding measured forces.
25. Show that the square of the measured vertical force (F_v) added to the square of the measured horizontal force (F_h) is equal to the square of the measured diagonal force (F_s) .

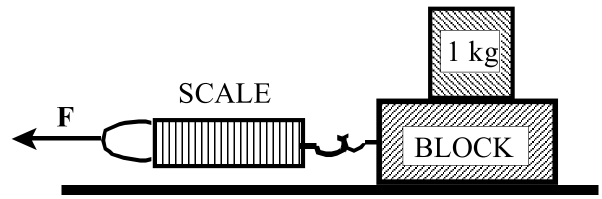
PHYSICS LAB #5 FORCE OF FRICTION

GOAL - The goals of this lab are;

a. To learn how to determine the coefficient of friction between two surfaces.
b. To determine what characteristics affect the frictional force between two surfaces.

PROCEDURE - Coefficient of Friction

A. Kinetic vs Static Coefficient



1. Determine the weight **W** of a hooked block of wood and then place it on the lab table with the **narrow** edge contacting the table. Add an additional 1.0 kg mass on top. Attach a 10 N spring scale the block of wood as shown
2. Gradually increase the force applied to the scale until the block just barely begins to move. Record the maximum force reading **F** on the spring scale.
3. Divide the maximum force reading **F** by the normal force $\mathbf{F_N}$ [$\mathbf{F_N}$ = **W** + 9.8N] and thus determine the coefficient of static friction μ_s between the block of wood and the table top.
4. Now apply a force **F** to the scale so as to pull the block across the table top at an approximately constant speed and record the average force **F** required.
5. Divide the average force reading **F** by the normal force $\mathbf{F_N}$ [$\mathbf{F_N}$ = **W** + 9.8N] and thus determine the coefficient of kinetic friction μ_k between the block of wood and the table top.
6. Compare the coefficient of static friction μ_s to the coefficient of kinetic friction μ_k.
7. What can you conclude about the relationship between the **kinetic** and **static** **coefficients of friction**?

B. Surface area

8. Repeat the procedure above to determine the coefficient of kinetic friction μ_k but this time place the block on the table so that the **wide** surface of the block is in contact with the table.
9. Calculate and compare the coefficient of kinetic friction μ_k with the narrow surface in contact with the table with the coefficient of friction μ_k with the wide surface in contact with the table.
10. Determine the wide and narrow surface areas of the friction blocks.
11. What can you conclude about the effect of **surface area** on the **coefficient of friction**?

C. Speed

12. Repeat the procedure again, this time pulling the block along the surface at two different speeds, slow and fast [within reason!].
13. Calculate and compare the **coefficient of friction** slow with the coefficient of friction, fast.
14. How does the coefficient of friction depend on the **speed** with which the block moves along the surface?

D. Normal Force

15. Repeat the procedure again, this time increase the mass sitting on the block to 2 kg.
16. Calculate and compare the **coefficient of kinetic friction** with different normal forces being applied.
17. How is the coefficient of friction affected by the magnitude of the **normal force**?

E. Contact Material

18. Repeat the procedure again, this time pull the block along a surface of wood, glass and then sandpaper.
19. Calculate and compare the **coefficients of friction** between the block of wood and the four surfaces; table top, glass, wood and sandpaper,
20. How is the coefficient of friction affected by the **physical characteristics** of the surface being contacted?

Goal - The goals of this lab are:

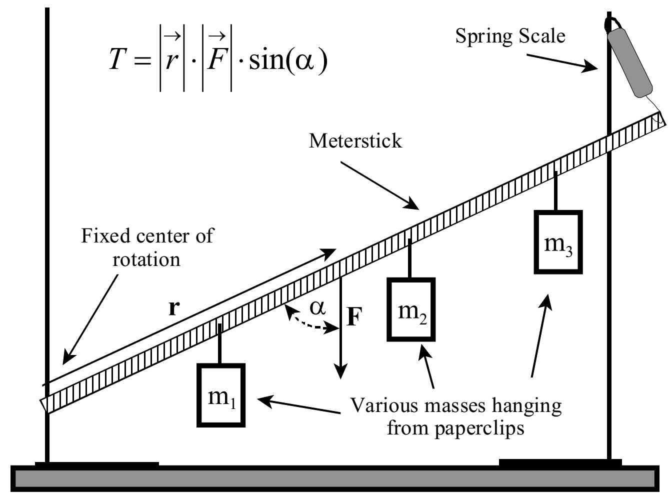
a. To show that the torque acting on system can be calculated by taking the product of the perpendicular distance between the point of application of an applied force and the magnitude of that force.

b. To demonstrate that for a system to be completely at equilibrium opposite torques, as well as opposite forces, must be equal.

$$\vec{T} = \vec{r} \times \vec{F}$$

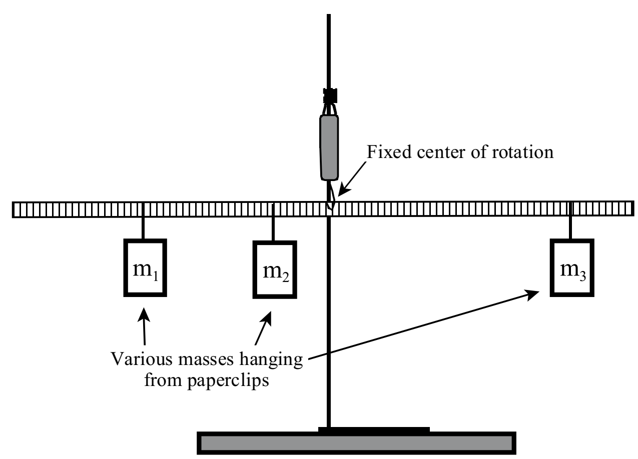
Procedure A -

1. First assemble the equilibrium system illustrated at the right.
2. A nail, secured to a ring stand with a perpendicular clamp, sticks through the left end of the meter stick. The right end of the meter stick is attached to a spring scale attached to the right hand ring stand with a second right angle clamp.
3. Three different masses are hung from the meterstick on the ends of three large paper clips at various positions along the meterstick. Record the masses of each weight [don't forget to include the mass of the paper clips - about 2 grams each] and their exact positions along the meterstick.
4. Measure and record the mass of the meterstick.
5. Record the force exerted on the scale by the right end of the meterstick.
6. Measure and record the angle a between the meterstick and the horizontal.
7. Calculate the torque exerted by each weight on the meterstick about the left center of rotation, the torque exerted by the weight of the meterstick itself and the torque exerted by the spring scale about the same center of rotation. [Remember that **r x F** means multiply the magnitude of **r** by the magnitude of **F** by the **sine** of the **angle** α between them!]
8. Compare the clockwise and the counterclockwise torques about the center of rotation and show that the sum of the torques acting on this system is zero while at equilibrium.



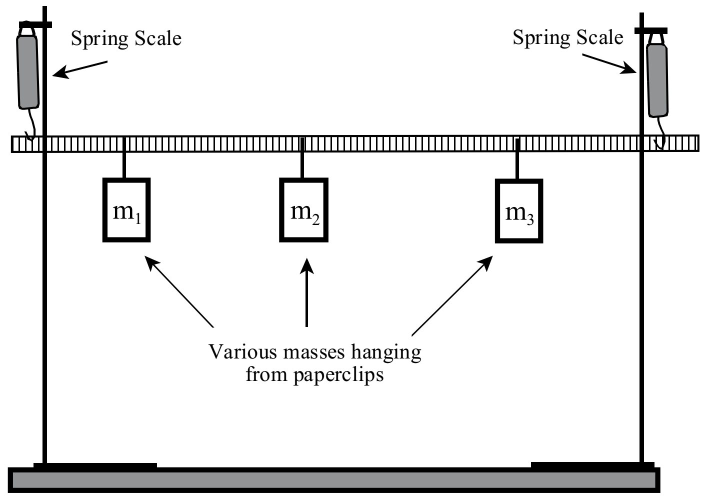
Procedure B -

9. Assemble the diagram to the right.
10. The center of the meter stick is pivoted on a nail attached to the ring stand with a right angle clamp.
11. Hang three different weights at various positions along the meterstick with large paper clips until the system is balanced. Record the mass [including paper clips] of each weight and the exact position of each along the meterstick.
12. Remove the balanced assembly from the nail and weigh the entire system with a spring scale.
13. Calculate the clockwise and counterclockwise torques about the fixed center of rotation and show that the sum of the torques is zero.
14. Show that the sum of the upward forces is equal to the sum of the downward forces.



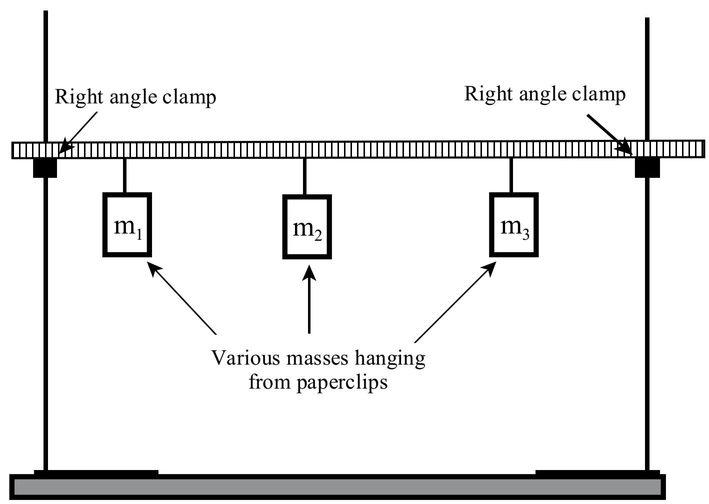
Procedure C -

15. Assemble the apparatus shown at the right.
16. Attach each end of the meterstick to a spring scale which is in turn attached to the ring stand with a perpendicular clamp.
17. Suspend three different weights from the meterstick with large paper clips at various positions along the meterstick. Record the mass and position of each weight. Record the exact position and reading on each of the spring scales. [Make sure the scales are properly calibrated!]
18. Select an appropriate center of rotation and calculate the clockwise and counterclockwise torques about the center you have chosen. [Don't forget the torque generated by the mass of the meterstick!]
19. Show that the sum of the clockwise torques is equal to the sum of the counterclockwise torques.
20. Show that the sum of the upward forces is equal to the sum of the downward forces.



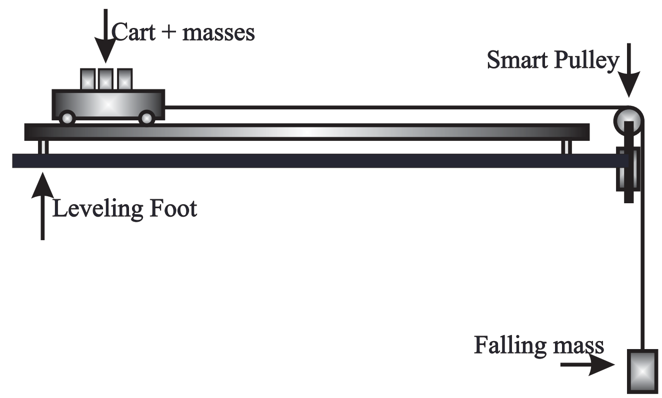
Procedure D -

21. Assemble the apparatus as shown to the right.
22. A meterstick is sitting on two right angle clamps attached to two ring stands.
23. Attach three different weights with large paper clips to various points along the meterstick. Record the mass of each weight, including paper clips, and their positions along the meterstick. Record the mass of the meterstick.
24. Using this information and the concepts of rotational and translational equilibrium, calculate the position along the meterstick where a single, upward force could be applied so as to produce equilibrium.
25. Pick up the entire, balanced meterstick assembly and balance this system on the top of a ring stand. Record the position along the meterstick where this balance occurs.
26. Compare the measured position for equilibrium with your prediction.



GOAL - The goal of this lab is to verify Newton's Second Law of Motion: "Whenever an unbalanced force F is applied to a mass m the result is an acceleration that is directly proportional to the force, inversely proportional to the mass and in the same direction as the accelerating force.

PROCEDURE -



1. First assemble Pasco low friction track, dynamics cart, string, "Smart Pulley", and weights as shown in the diagram at the right.
2. Measure and record the mass M of the dynamics cart.
3. Balance the low friction track. To do this place the cart on the center of the track and adjust the "feet" of the track until the cart remains substantially at rest.
4. Load up the supplied "Science Workshop" software and set up the smart pulley to measure average acceleration.

Part A - Acceleration vs. Force

5. Select and place 50 grams of mass to the dynamics the cart, attach a thin string to the front of the cart, stretch the string over the table clamp pulley and attach paper clips to the end of the string hanging over the pulley until the cart barely moves at a constant speed when gently pushed. This small mass compensates for the frictional force acting on the cart and any additional weight will now be responsible for any acceleration that occurs.
6. Remove 10 grams of mass m from the dynamics cart and attach it to the end of the string hanging over the "Smart Pulley" [leaving the above paper clips attached!].
7. Activate the timing program by clicking on the record [REC] icon.
8. Release the cart allowing the system to accelerate and then press STOP just as or slightly before the falling mass m reaches the floor. [So as to avoid as much extraneous data as possible.]
9. Using the computer program determine the average acceleration of the cart by clicking on the "statistics" icon S, skip the first couple of data points and then highlight the next 10-15 data points. Record the average acceleration and for error record 2x the standard deviation.
10. Repeat steps 7 through 9. If your acceleration is the same go to the next step. If your values are significantly different repeat a third time and take the average.
11. Remove an additional 10 grams from the cart and add it to the string hanging over the "Smart Pulley". [There should now be 20 grams on the end of the string (plus some paper clips) and 30 grams still sitting in the cart.] Why did you remove the mass from the cart rather than just add an additional 10 grams?
12. Repeat steps 7 through 10.
13. Continue to transfer 10 grams from the cart to the string and repeat steps 7 through 10 until no more mass remains on the cart.
14. At this point you should have 5 different applied forces with their corresponding accelerations. Plot a graph of Acceleration as a function of the Force applied. **From the shape of the resulting graph** determine the relationship between the acceleration of an object and the magnitude of the applied force.
15. Record the total mass accelerating during the first procedure. [The cart, the masses, the paper clips etc] Since you are performing a controlled experiment this total mass should, of course, remain constant throughout the first procedure!

[Continued on opposite side]

Part B - Acceleration vs. Mass

16. Add an extra ½ kg mass to the cart, stretch the string over the table clamp pulley and attach paper clips to the end of the string hanging over the pulley until the cart barely moves at a constant speed when gently pushed. As above, this small mass compensates for the frictional force acting on the cart and any additional weight will now be responsible for any acceleration that occurs. Attach 50 grams to the end of the string hanging over the pulley. Release the falling mass. Determine and record the acceleration of the cart.
17. Increase the mass on the cart by ½ kg. and repeat step 16.
18. Add one more ½ kg mass and repeat step 16 until the cart has a total mass of approximately 2.0 kg.
19. At this point you should have at least four different data points. Plot a graph comparing the Acceleration of the cart as a function of the Mass of the cart. [Don't forget to include ALL of the mass that is accelerating including the falling weight and paper clips!]
20. **From the shape of the resulting graph** determine the relationship between the Acceleration of an object under the influence of a constant force and the Mass of the object.
21. Record the total mass accelerating during each procedure. Note that the force applied to the cart remained constant throughout this procedure thus keeping it a controlled experiment.

Part C - Final Analysis

22. Combine the results of the two graphs above into a single relationship. Determine the value of any appropriate constants and develop an equation relating the acceleration of an object, the object's mass and the magnitude of the applied force.
23. Test your equation at a random data point and make an appropriate bar graph.

GOAL - The goals of this lab are:

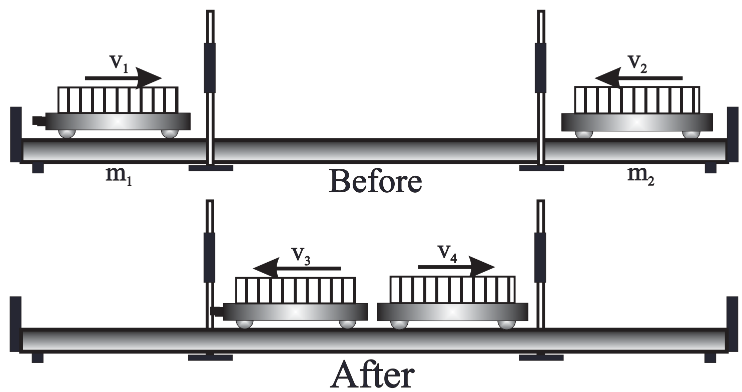
a. to show that in a closed system, a system in which there are no outside forces, the total vector momentum remains constant.

b. to compare elastic collisions, inelastic collisions and explosions.

PROCEDURE - In this lab you will be looking at three different types of collisions: elastic, inelastic and explosions. In the elastic collision you will bounce one dynamics cart off of another, in the inelastic collision two carts will collide and stick together and in the explosion the two carts will push each other apart.

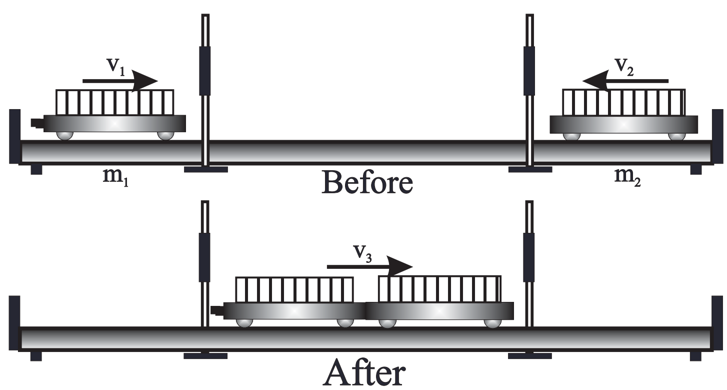
1. For each procedure first set up the dynamics track as shown below.
2. The **Science Workshop** program should be used to activate two separate digital timers which will be used to measure the velocities of your two carts before and after the collision.
3. Make sure that the dynamics track is completely **level** and that the carts move along the track freely without a noticeable decrease is speed.
4. Measure and record the masses of m_1 and m_2 [m_1 and m_2 should have **different** masses! Add an extra ½ kg to one of the carts.].

A. ELASTIC COLLISION



5. Beginning with m_1 at the left end of the track and m_2 at the right end of the track, give each a gentle push so that the carts pass through the appropriate timers, collide elastically with one another, and then rebound back their respective timers.
6. Record the velocities v_1 and v_3 for cart m_1 and the velocities v_2 and v_4 for cart m_2, before and after the collision.
7. Calculate the **total vector momentum** of this system before and after the collision and then compare.
8. Calculate and compare the **total kinetic energy** of this system before and after the collision.

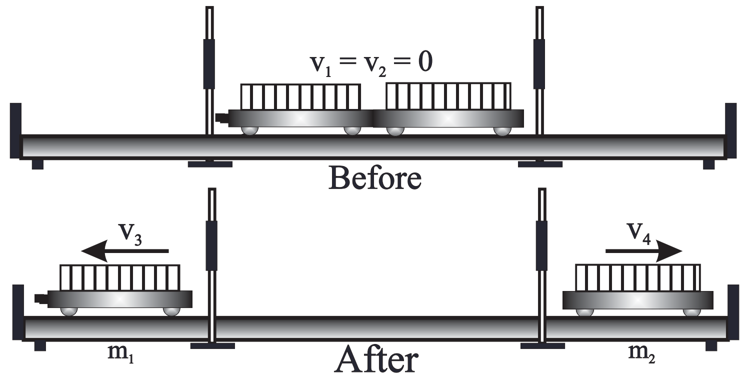
B. INELASTIC COLLISION



9. Beginning with m_1 at the left end of the track and m_2 at the right end of the track, adjust the orientation of the carts so that the velcro strips are facing one another.
10. Reset the timing program, give each cart a gentle push so that the carts pass through the appropriate timers, collide inelastically and stick together, and then pass together through the appropriate timer.
11. Record the velocity v_1 of cart m_1 through the first timer, the velocity v_2 of cart m_2 through the second timer and the velocity v_3 [$v_3 = v_4$] of both carts after the collision.
12. Calculate the **total vector momentum** of this system before the collision and the total vector momentum of this system after the collision and then compare.
13. Calculate and compare the **total kinetic energy** of this system before and after the collision.

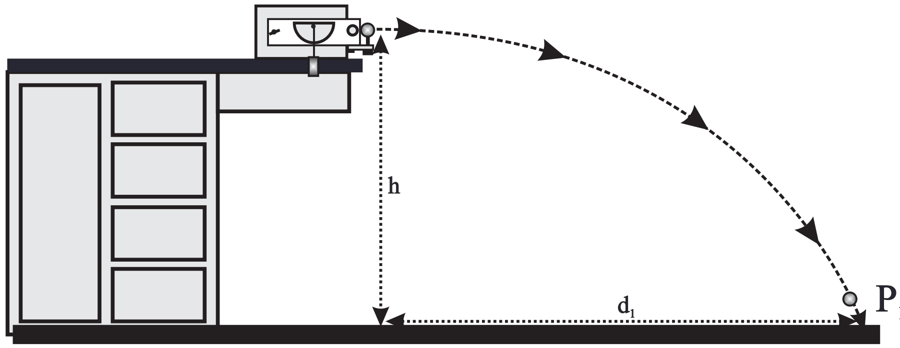
C. EXPLOSION

14. Place both carts between the two timers with the spring compressed between them.
15. Reset the timing program, turn on the dynamics track and then **carefully** tap release knob. Each cart should move readily through the appropriate timer.
16. Record the velocities v_3 and v_4 for each cart after the explosion. [v_1 and v_2 are, of course, each zero!]
17. Calculate the **total vector momentum** of this system before and after the explosion and then compare.
18. Calculate and compare the **total kinetic energy** of this system before and after the collision.



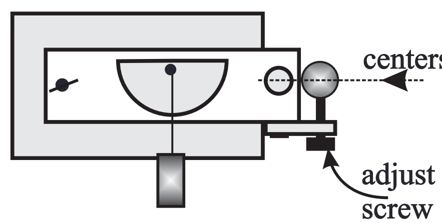
[Note! One way to determine the approximate error throughout this lab is to give one of the carts a gentle push so that it passes through both timers. If there was no friction the velocity would remain the same. But because of the frictional force the cart **wil**l slow down. By measuring the velocity of the cart through both timers separately you can determine the approximate error on the velocity.]

GOAL - The goal of this lab is to demonstrate the vector nature of momentum in a two dimensional collision.



PROCEDURE - In this lab you will be looking at the conservation of momentum in a two dimensional collision. In this collision you will fire a steel marble, using the projectile launcher, into a second steel marble, which has a different mass and radius.

1. Mount the projectile launcher to the lab table using a C clamp. Using the built in plumb line make sure that the launching device is exactly horizontal.
2. Measure and record the masses, m_1 and m_2, of the two different steel marbles.
3. Measure and record the distance h from the bottom of the marble as it is being launched to the floor below. Using this distance and kinematics calculate the time that it will take for the marble to reach the floor.
4. Insert the smaller marble into the launching device and push it into the launcher to at least the second notch. [Record which notch you use!]
5. Use a plumb line to locate the position on the floor where the marble goes into freefall. Mark this point on the floor with a dry erase marker or pencil and label this point at your origin.
6. Launch the single marble to the floor, note where it strikes the floor, and then place a piece of carbon paper at the approximate location on the floor. Again fire the marble onto the carbon paper several times and then mark and label the position on the floor where the marble strikes with a dry erase marker.
7. Measure the horizontal distance [d_1] between the point on the floor immediately below the launch point of the marble and the point where the first marble strikes the floor. From this distance and the time to the floor determined above calculate the velocity v_1 of the first mass m_1.
8. Reinsert the smaller steel marble, m_1, into the launcher and again push it in to the second or third notch as above.
9. Place the second, larger steel marble on the adjustable screw platform and then adjust the screw until the center of the second ball is vertically matched with the center of the first ball. The platform should be offset so that as the first ball is launched it strikes a glancing blow to the second ball.
10. Again, using a plumb line, mark and label the position on the floor immediately below the point where the two balls are going to collide.
11. Fire the first ball into the second ball and note where the two balls strike the floor. Place two pieces of carbon paper on the floor where the two balls struck the floor and then repeat firing the first ball into the second ball several times. Using a dry erase marker or pencil mark and label the points on the floor where each of the balls strikes the floor.



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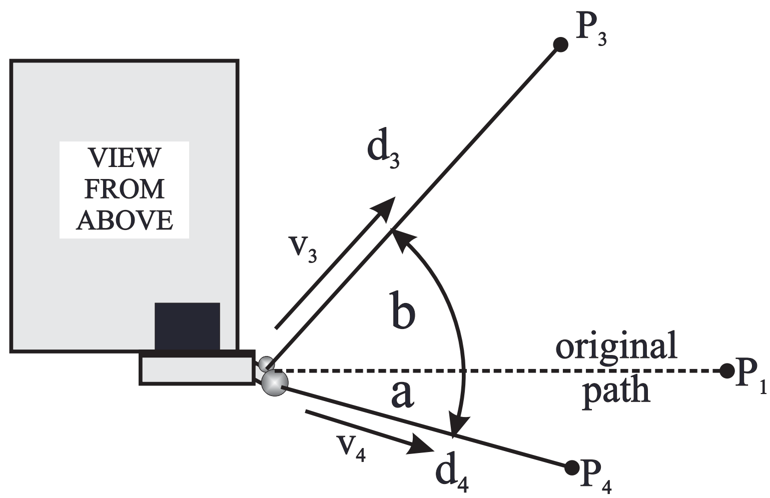
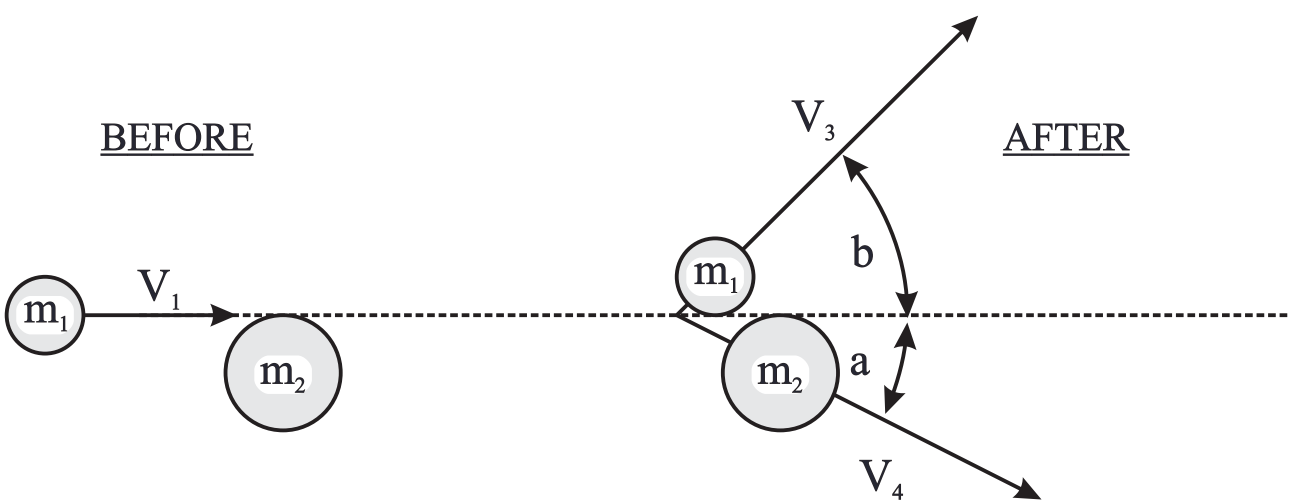


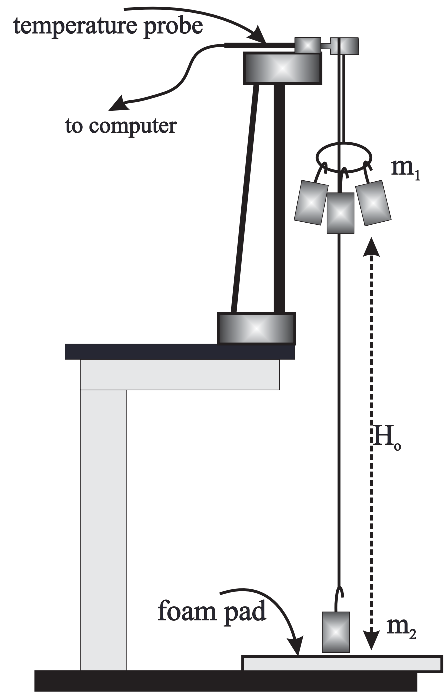
12. Measure the distance [d_3] between the point where the first ball is launched and where it strikes the floor. Measure this distance and combine it with the time determined above to calculate the velocity V_3 of the first ball after the collision.
13. Repeat the above procedure for the second ball and calculate the velocity V_4 of the second ball after the collision.
14. Determine the angles, α and β, between the velocities, V_3 and V_4, and the original path of motion of the first ball.
15. Calculate the momentums of m_1 and m_2 both before and after the collision.
16. Calculate the components of these momentums parallel to the original path of motion of the first ball before the collision. Compare the total momentum in the X direction before and after the collision. Make an appropriate bar graph.
17. Calculate the components of these momentums perpendicular to the original path of motion. Compare the total momentum in the Y direction before and after the collision. Make an appropriate bar graph.



PHYSICS LAB #10 WORK & GRAVITATIONAL ENERGY

GOAL - The goal of this lab is to measure the work done by a falling mass and thus gain an understanding of gravitational potential energy, the ability to work due to the height of an object. [GPE]

PROCEDURE -



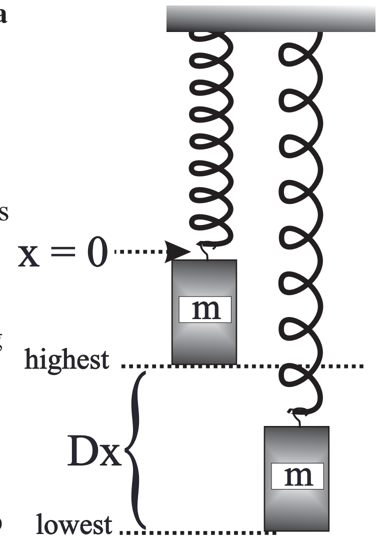
1. Assemble the system, shown at the right, consisting of a stand mounted to the lab table with a C-clamp. An aluminum cylinder is mounted between two blocks which are held together with two bolts. A piece of monofilament fishing line is strung over and around the aluminum cylinder with masses m1 and m2 attached to opposite ends of the fishing line as shown.
2. The aluminum cylinder will have a small hole in it with a diameter of about 4-5 millimeters. Clean out this hole [A Bic pen cap will work nicely!] and then insert a small amount of new clay. Measure the mass m of the aluminum cylinder and clay.
3. After weighing the cylinder firmly insert the temperature probe into the hole with the clay.
4. Mount the probe - cylinder combination between the two wooden blocks and then firmly tighten the two carriage bolts.
5. Obtain a piece of monofilament fishing line. Each end of the fishing line should have a loop tied in it. Wrap the fishing line around the cylinder twice and then hang a 1.0 kg mass on each end of the fishing line.
6. Adjust the string until one of the kilogram masses is sitting on the floor while the other kilogram mass is suspended near the aluminum cylinder. Add a 200 gram counter weight [plus an extra 1.0 kg mass to keep the counter weight on the floor until you actually begin the experiment] to the end of the string sitting on the floor and add two or three kilogram masses to the end of the fishing line near the cylinder. [Note that the mass of the counter weight will depend on your individual equipment! 200 grams is just a starting point.]
7. Carefully, remove the 1.0 kg mass from the end of the string nearest the floor and then allow [or give a slight push if necessary!] the other masses to slowly fall to the floor. It should take about 10 to 20 seconds for the masses to fall to the floor. If the masses fall too quickly increase the magnitude of the counterweight. If the masses fall too slowly decrease the magnitude of the counterweight. In any case you want the masses to fall to the floor without any apparent acceleration
8. Repeat step 7 until you can reliably get the masses to fall to the floor in 10 to 20 seconds without accelerating.
9. Return the 3.0 kg to the top and the counter weight to the floor. Measure the temperature of the cylinder and compare this to the room temperature. If the cylinder is above room temperature [as seems likely!] you need to cool the cylinder off before proceeding. To cool the cylinder take an ice cube in a plastic bag and place the ice into direct contact with the cylinder. If you over cool the cylinder, use the warmth of your hand to warm up the cylinder. The cylinder must be dry before you proceed. [Each gram of evaporating water will take 80 calories of heat with it!]
10. Record the masses, m_1 and m_2, of your system, the initial height H_o of m_1 above the floor, and record the initial temperature T_o of the aluminum cylinder. Remove the extra kilogram mass from the end of the string on the floor and allow the masses to fall to the floor. Measure the final temperature T_f of the cylinder.
11. Determine the temperature rise [$\Delta T = T_f - T_o$] of the aluminum cylinder.
12. Repeat the procedure, but this time cool the cylinder off until the initial temperature of the cylinder is ½ the expected rise in temperature below room temperature to compensate for natural cooling/heating. [$T_o = T_{room} - \Delta T/2$] Repeat 3x and then calculate the average temperature increase ΔT.
13. Calculate the net work done by the gravitational force. [Work done by gravity on the falling masses minus the work done on the rising counterweight!]
14. Calculate the heat gained by the aluminum cylinder [$Q = mc\Delta T$ where $c_{aluminum} = 0.901$ Joules/gm^{o}C]
15. On a bar graph compare the **heat gained** by the aluminum cylinder with the **net work done** on the falling masses by the gravitational force.

PHYSICS LAB #11 HOOKE'S LAW & ENERGY CONSERVATION

GOAL - The goals of this lab are;

a. to develop and verify **Hooke's Law** for springs - **The amount that a spring stretches or compresses is directly proportional to the magnitude of the applied force.**

b. to demonstrate the **Law of Energy Conservation - The total mechanical energy in a closed system [a system where there are no unaccounted for outside forces] remains constant, although the energy can change from one form to another.**



PROCEDURE - A. Developing Hooke's Law

1. Using two parallel clamps attach a meterstick to a tall ring stand with the 0.0 cm end of the meterstick **upward**. Attach a small C-clamp to the top of the meterstick and from this clamp hang a coiled spring.
2. With **NO** weight attached to the spring record the position of the bottom end of the spring.
3. Determine how much mass must be attached to the end of the spring to stretch the spring to the table top.
4. Divide this maximum mass into even intervals [For example, suppose that 1200 grams stretches the spring to the table top, then divide this into 200 grams, 400 grams, etc. up to 1200 grams.].
5. Beginning with the lightest mass, suspend the masses from the end of the spring. Record the mass added and the corresponding position of the end of the spring until the table top is reached.
6. Calculate the weights added to the spring [**F**] and calculate the amount the spring has been stretched [**ΔX**] as a result of the application of the weight. Plot a graph comparing the **Force [F]** applied to the spring versus the amount the spring has been stretched **[ΔX]**.
7. Determine the equation of this line, the **spring constant [k]** and then show that your equation successfully predicts the force exerted by the spring as a function of the amount the spring has been stretched.

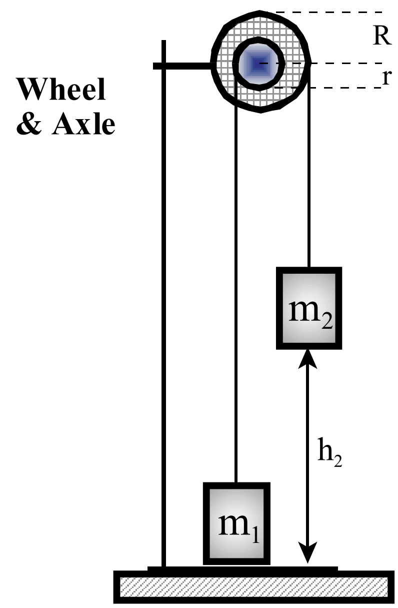
B. Demonstrate energy conservation.

8. Referring back to step #3 above take approximately ½ the minimum mass necessary to lower the spring to the table top. [Round this number down to some convenient amount!]
9. Attach this median mass to the lower end of the spring. With the spring unstretched release the mass and determine the lowest point reached by the falling mass. [Remember to read from the bottom of the spring's hook!]. This can be achieved by "grabbing" the mass when it reaches the lowest point.
10. Using this lowest point as your h = 0.0 point calculate;
    a. the **GPE** of this system at the highest point.
    b. the **EPE** of this system at the highest point.
    c. the **KE** of this system at the highest point.
    d. the **GPE** of this system at the lowest point.
    e. the **EPE** of this system at the lowest point.
    f. the **KE** of this system at the lowest point.
11. Compare the **total energy** of this system at the **highest point** and the **total energy** of this system at the **lowest point** and demonstrate that the total energy of this system is constant at the highest and lowest points.

GOAL - The goals of this lab are:

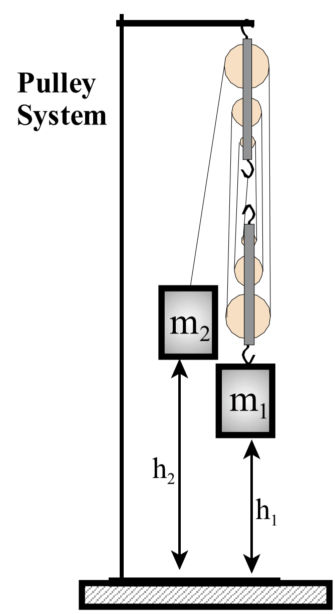
a. to measure the Actual Mechanical Advantages [**AMA**] of three simple machines.
b. to measure the efficiencies [**EFF**] of three simple machines.
c. to measure the Ideal Mechanical Advantages [**IMA**] of three simple machines.
d. to demonstrate that the **IMA** of a simple machine multiplied by the **EFF** of the simple machine will be equal to the **AMA** of the simple machine.

PROCEDURE A - WHEEL AND AXLE



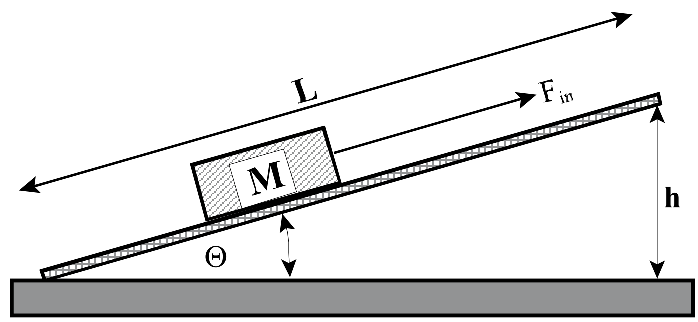
1. Mount the "Wheel and Axle" assembly on a ring stand with a perpendicular clamp at a height of approximately 70 cm above the table top as shown to the right.
2. Attach a 1.0 kg mass m_1 to the string wrapped around the inner wheel (called the axle). This mass should be sitting on the base of the ring stand.
3. Add mass m_2 to the string wrapped around the outer wheel of the Wheel and Axle until a slight push causes mass m_2 to move toward the tabletop slowly without accelerating. Record each mass.
4. From these two masses determine the ratio of the force output of this machine F_{out} and the force input F_{in} of this machine and determine the **AMA** of this machine.
5. Measure the radius R_1 of the axle and the radius R_2 of the wheel. From these values determine the **IMA** of this simple machine.
6. Measure the initial height h_2 of the mass m_2 before it falls to the tabletop. From this height calculate the work Win done on the wheel and axle by mass m_2 as it falls to the tabletop.
7. Measure the height to which the mass m_1 is lifted above the tabletop as the mass m_2 falls to the tabletop. From this height calculate the work W_{out} done on m_1 as it is lifted.
8. Calculate the efficiency [**EFF**] of this machine by taking the ratio of the work output Wout of this machine to the work Win put into this machine.
9. Show that the product of the **IMA** and the **EFF** is equal to the **AMA** of the this simple machine.

PROCEDURE B - PULLEY SYSTEM



10. Assemble two triple pulleys as shown to the right.
11. Attach a 1.0 kg mass m_1 to the bottom pulley as shown and connect sufficient mass m_2 until m_2 falls slowly to the tabletop, with a slight push, without accelerating.
12. Record m_1 and m_2 and the initial height h_2 of mass m_2 above the tabletop.
13. Count the number of strings supporting the lower pulley and determine the **IMA** of this simple machine.
14. Calculate the force output F_{out} of this machine by determining how much force is needed to lift the load m_1.
15. Calculate the force input F_{in} of this machine by determining how much mass m_2 is attached to the string in order to start lifting m_1.
16. From these two forces determine the **AMA** of this machine by taking the ratio of the F_{out}/F_{in}.
17. Calculate the work put into this machine W_{in} by calculating how much work was done by mass m_2 as it falls a distance h_2 to the tabletop.
18. Calculate the work out put W_{out} by calculating how much work was done on m_1 as it is lifted to a height h_1.
19. Determine the efficiency **EFF** of this machine by taking the ratio of the W_{out}/W_{in}.
20. Show that the product of the **IMA** and the **EFF** is equal to the **AMA** of this simple machine.

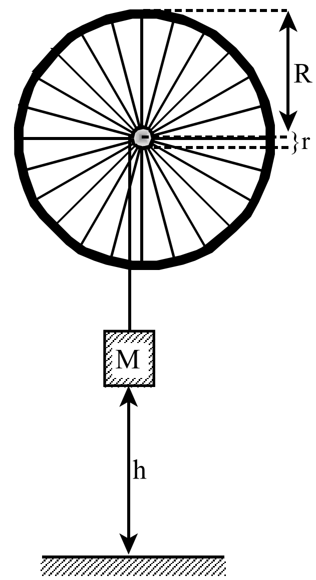
PROCEDURE C - INCLINED PLANE



21. Assemble an inclined plane system as shown to the right.
22. Measure the length L and height h of the inclined plane and from these values determine the **IMA** of this simple machine from the ratio of **IMA =** $^{L}/_{h}$**.**
23. Measure the angle Θ of the inclined plane and determine the **IMA** of this simple machine by calculating the inverse of the sine of the angle, **1/sin** Θ.
24. With a spring scale measure the force required to lift up the mass **M**. [i.e. determine the weight of the mass **M**] This is the force output F_{out} of this machine.
25. Measure the force F_{in} required to pull this mass up the incline at a constant speed.
26. Determine the **AMA** of this machine by taking the ratio of the force output to the force input, F_{out}/F_{in}.
27. Calculate the work input of this machine W_{in}, the work required to pull the mass to the top of the incline using force F_{in} as shown in the diagram.
28. Calculate the work output of this machine W_{out}, the work required to lift mass **M** to a height **h**.
29. Calculate the efficiency [**EFF**] of this simple machine by calculating the ratio of the work output of this machine to the work input of this machine, W_{out}/W_{in}.
30. Show that the product of the **IMA** and the **EFF** is equal to the **AMA** of the this simple machine.

GOAL - The goal of this lab is to show that the equations for rotational motion are of the same mathematical form as the equations for linear motion as long as each of the linear variables is replaced by the corresponding angular variable.

PROCEDURE -



1. Mount the wheel assembly firmly to the table top with a large C - clamp.
2. Determine the **mass of the wheel [M]** with the large spring scale [deduct 0.5 kg for the mass of the bracket and hub].
3. Measure the average diameter of the wheel from rim to rim and divide in half to determine the **radius [R]** of the wheel..
4. Calculate the **moment of inertia [I]** of the wheel from the mass [M] and radius [R] of the wheel assume that the wheel is a **RING**.
5. Re - mount the wheel on the table top with a large C-clamp.
6. Hook one end of the string over the nail in the hub of the wheel, wrap the string around the hub and hang a 1.0 kg mass [m] to the end of the string.
7. Measure the distance from the bottom of the mass [m] to the floor **[h]**.
8. Release the wheel and allow the 1.0 kg mass [m] to slowly fall to the floor and in the process accelerate the wheel. Immediately after the 1.0 kg mass strikes the floor measure the time **[t_1]** required for the wheel to make **2 complete rotations [Θ]** Calculate the final angular velocity **[ω_f]** of the wheel from the total angular displacement **[ΔΘ]** and the time **[t_1]**.
9. Re-wrap the string around the hub and attach the 1.0 kg mass so that it is at the same height [h] as before. Release the 1.0 kg mass and measure the time **[t_2]** required for the mass to fall to the floor, from the final angular velocity **[ω_f]** determined above, the initial angular velocity **[ω_i]** and the time **[t_2]** required for the mass to fall to the floor, determine the angular acceleration **[α]** of the wheel as the 1.0 kg mass falls to the floor.
10. Again return the 1.0 kg mass to its original height. While slowly lower the mass to the floor, measure the angular displacement **[Θ_2]** through which the wheel rotates while the 1.0 kg mass falls to the floor.
11. Measure the diameter of the hub using a caliper and then divide this number in half to determine the radius **[r]** of the hub. Using this **radius [r]** and the weight of the 1.0 kg mass [mg] calculate the **Torque [T]** applied to the wheel.
12. For each of the following linear equations, replace each of the linear variables by the appropriate angular variable [i.e. rewrite the equations using the corresponding angular variables!] and then show that each of the equations is valid using the data collected above.

$$D = {}^1/_2 at^2 \qquad F = ma \qquad KE = {}^1/_2 mv^2 \qquad W = Fd$$

13. Demonstrate that energy is conserved in this system by showing that the **total energy of the system at the beginning** is equal to the **angular work done by the falling mass** and to the **final angular kinetic energy** gained by the wheel. As above, take the appropriate linear equations and replace each of the linear variables in the equations with the corresponding angular variable as determined above. [Be sure to illustrate this in the lab background theory!]

PHYSICS LAB #14 SIMPLE HARMONIC MOTION

GOAL - The goals of this lab are:

a. to develop the concept of simple harmonic motion through the use of the simple pendulum.

b. to determine which characteristics [arc length L, length l and mass m] affect the period of a simple pendulum and how they affect this period.

c. to develop a set of equations which will predict the position, velocity and acceleration of a simple pendulum as a function of time.

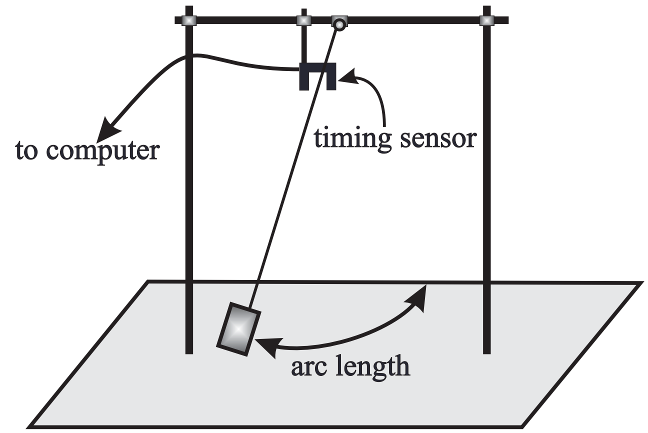
d. to measure the decay constant of a simple pendulum and use it to predict the amplitude of a simple pendulum as a function of time.

e. to demonstrate the role of hypothesis in experimentation and its relationship to experimenter bias.

HYPOTHESIS - Before you begin this procedure you are to first write three hypotheses about how each of the independent variables arc length L, length l and mass m will affect the period T of the pendulum. Be specific! [For example, how will increasing the arc length affect the resulting period of the pendulum?]

PROCEDURE -

1. Attach a 200 gm mass m to one end of a string while the other end of the string is attached to a clamp suspended by a horizontal rod as shown to the right. The 200 gm mass should be suspended about 1-2 cm above the table.



A. DETERMINE THE RELATIONSHIP BETWEEN THE PERIOD OF A PENDULUM AND THE ARC LENGTH.

2. Place a 30 cm ruler on the table so that the 200 gram mass is suspended immediately above the 0.0 cm mark of the ruler.
3. Using the Physics Workbench software drag the 1/4" plug to Channel 1 and then select the Pendulum Timer option. Then drag the Table and/or Digital output icon the channel and select the Period option.
4. Pull the pendulum back approximately 5 cm and then release. **Measure and record the period T** of the pendulum.
5. Repeat step 4 for distances of 10 cm, 15,cm, 20 cm, 25 cm and 30 cm. If there is **no effect**, you are **done**. If there is **an effect** plot a graph of the **period T of the pendulum as a function of arc length L** and **from the shape of this graph** determine the relationship between these two variables.

B. DETERMINE THE RELATIONSHIP BETWEEN THE PERIOD OF A PENDULUM AND ITS MASS.

6. Replace the 200 gram mass with a 150 gram mass and then pull the pendulum back and release. Measure and record the period of the pendulum.
7. Repeat step 6 for 100 grams and 50 grams If there is no effect, you are done. If there is **an effect** plot a graph of the **period T of the pendulum as a function of the mass m** and from the **shape of this graph** determine the relationship between these two variables.

C. DETERMINE THE RELATIONSHIP BETWEEN THE PERIOD OF A PENDULUM AND LENGTH.

8. Return the 100 gram mass to the end of the string. Measure the length L of the pendulum. [The distance between the center of the 100 gram mass and the point where the string is attached to the clamp mounted to the horizontal bar.]
9. Pull the pendulum back and release. Measure and record the period of the pendulum.
10. Shorten the length of the pendulum to 80 cm by pulling the string back through the clamp and then repeat step #9.
11. Shorten the length of the pendulum to 60 cm, .40 cm, 20 cm and 10 cm and again repeat step #9. If there is **no effect**, you are **done**. If there is **an effect** plot a graph of the **period T of the pendulum as a function of the length l** and from the **shape of this graph** determine the relationship between these two variables. [Get the equation of the line and test it!]

D. DETERMINE THE SET OF EQUATIONS WHICH WILL DESCRIBE THE POSITION, VELOCITY AND ACCELERATION OF THE PENDULUM AS A FUNCTION OF TIME.

12. Return the 200 gram mass to the end of the string with it suspended about 1 cm above the table.
13. Mount a tickertape timer on a ring stand with the time oriented horizontally. Measure out about 100 cm of tickertape. Thread the tickertape through the timer and then attach the tickertape to the top of the 200 gram mass with a piece of masking tape. Set the timer to 10 Hz.
14. Pull the 200 gm mass back about 30 cm. At this point the position of the tickertape timer on the ring stand should be adjusted until the height of the tickertape timer matches up with the height of the kilogram mass while pulled back 30 centimeters.
15. Turn on the tickertape timer and then release the 200 gram mass. Turn the timer off when the mass reaches the opposite end of its swing.
16. Remove the tickertape from the timer and from the pendulum. Match up the beginning and ending dots of the tickertape, then fold the tickertape and crease the tape. Find the dot on the tickertape closest to the crease and mark this dot as the center, x = 0.0. Count the number of intervals on each side of the center - the number of intervals should be the same on both sides!
17. Starting with one end of the tickertape find the first mark you made on the tape and label this point t = 0 and x = "the distance between this mark and the center of the tickertape". Go to the next mark on the tape and label this mark t = 0.1 seconds and x = "the distance between this mark and the center of the tickertape". Repeat for the third, fourth etc mark. Do this all the way to the opposite end of the tape. For points on the opposite side of center the positions x should be designated as negative!
18. Using the computer spreadsheet determine the position, velocity and acceleration of your pendulum as a function of time. Plot out the graphs for the position, velocity and acceleration as a function of time.
19. Determine the equations for each of the graphs and then test each at known data points.

E. DETERMINE THE DECAY CONSTANT OF YOUR PENDULUM AND THUS PREDICT THE MAXIMUM AMPLITUDE OF THE PENDULUM AS A FUNCTION OF TIME.

20. Return the 200 gram mass to the end of the string with it suspended about 1 cm above the table.
21. Place a 30 cm ruler on the table with the 0.0 mark of the ruler immediately under the 200 gram mass while sitting at the equilibrium point.
22. Pull the pendulum back 30 cm and release. Record the maximum amplitude Ao of the pendulum every ten swings until the amplitude has decreased to at least 5 cm. [Note that you can set the Data Table in the Science Workshop program to count for you!]
23. Plot a graph comparing the maximum amplitude A_o of the pendulum as a function of time t.
24. Determine the equation describing the maximum amplitude of the pendulum as a function of time. [You will need to determine two constants for this function, which is of the form $A = A_o e^{t/2t_c}$ where A_o is the y intercept of the function and where t_c is the time constant. The time constant can be found from the graph by determining how much time is required for the amplitude of the pendulum's swing to decrease to $^1/e$ [37%] of its initial value, this time will be equal to 2x the time constant t_c.]

F. COMBINE THE RESULTS OF PART D AND E ABOVE TO DETERMINE THE MOST GENERAL EQUATION DESCRIBING THE POSITION OF A DAMPED SIMPLE HARMONIC OSCILLATOR AND THEN FROM THIS EQUATION DETERMINE THE VELOCITY AND ACCELERATION OF A DAMPED SIMPLE HARMONIC OSCILLATOR AT ANY FUTURE TIME.

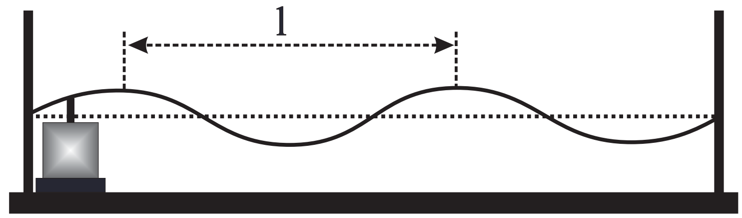
GOAL - The goals of this lab are:

a. to measure the **speed s** of a wave along a string by generating a standing wave pattern by an outside, sinusoidal source.

b. to verify that the speed of a wave can be determined by taking the product of the **frequency f** of a wave and the **wavelength λ.**

c. to verify that the **speed of a wave** can be determined by taking the square root of the ratio of the **tension in the spring T** to the **mass per unit length** of the spring μ.

PROCEDURE -



1. Attach the amplifier to the **Science Workbench** interface.
2. Connect the **Mechanical Wave Oscillator** to the amplifier with the supplied cables.
3. Tie the elastic wave cord between two firmly attached ring stands or between two poles mounted in holes in the desk top.
4. Insert the supplied banana plug into the top of the wave oscillator and then slide the elastic down the poles until the elastic wave cord slips into the top of the banana plug.
5. Turn on the Amplifier through the Science Workbench interface and then vary the frequency and amplitude of the Mechanical Wave Oscillator until resonance is reached.
6. With a meterstick or other measuring device determine and record the distance between adjacent nodes [points of no spring motion] on the spring. Make several different measurements and then take the average. From this information determine the **wavelength** λ of the standing wave.
7. Determine and record the **frequency f** of the vibration.
8. From these two pieces of information calculate the **speed s** of the wave in the elastic wave cord.
9. With a marking pen place two marks on the wave cord exactly 1.0 meters apart. Measure the entire **length L** of the wave cord and then measure the **mass of the cord** on a scale.
10. Measure the distance between the two marks you previously placed on the wave cord and determine the total stretched length of the cord.
11. Calculate the **mass per unit length** μ of the wave cord under the conditions of the standing wave pattern.
12. Hang one end of the wave cord to a ring stand and then hang weights from the other end of the cord until the stretched length between the two marks on the cord is again 1.0 meters. From this determine the tension in the string under experimental conditions. [A spring scale can also be used to make this measurement.]
13. From the **tension T** in the wave cord and the **mass per unit length** μ calculate the **speed v** of the waves in the wave cord.
14. Compare the **speed of the wave determined from the tension T and mass per unit length** μ with the **speed s determined from the period and frequency**.
15. Determine the equation which describes the displacement of this string as a function of time and position;
    a. determine the **wave number [k]**.
    b. determine the **angular velocity [ω]**.
    c. determine the **maximum amplitude [A_o]**.
16. Test your equation by using it to predict the position of at least one of the nodes from the boundary conditions above.

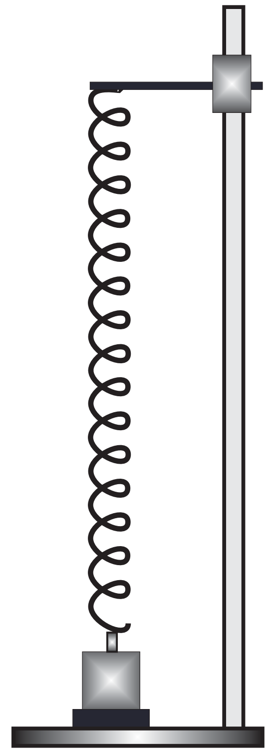
GOAL - The goals of this lab are;

a. to measure the speed of a wave along a spring by generating a standing wave pattern by an outside, sinusoidal source.

b. to verify that the speed of a wave can be determined by taking the product of the **frequency f** of a wave and the **wavelength λ.**

c. to verify that the speed of a wave can be determined by taking the square root of the ratio of the **tension in the spring T** to the **mass per unit length of the spring** μ.

PROCEDURE -



17. Attach the amplifier to the **Science Workbench** interface.
18. Connect the **Mechanical Wave Oscillator** to the amplifier with the supplied cables.
19. Attach the Mechanical Wave Oscillator to a tall ring stand as shown to the right.
20. Connect a perpendicular clamp to the ring stand.
21. Connect a coil spring between the oscillator and the perpendicular clamp.
22. Turn on the oscillator with a frequency of **20 Hz**. At this point it may be necessary to adjust the position of the perpendicular clamp as well as the dial on the power supply to achieve a stable pattern.
23. With a meterstick or other measuring device determine and record the distance between adjacent nodes [points of no spring motion] on the spring. Make several different measurements and then take the average. From this information determine the **wavelength** λ of the standing wave.
24. Determine and record the **frequency f** of the vibration.
25. From these two pieces of information calculate the **speed s** of the wave in the spring.
26. Measure the entire **length L** of the spring from the perpendicular clamp to the tickertape timer by counting the number of coils in the spring and then multiply this by the circumference of each coil.
27. Carefully, remove the spring from the apparatus and measure the **mass m** of the spring on a balance.
28. Calculate the **mass per unit length** μ of the spring under the conditions of the standing wave pattern.
29. Hang the spring from the perpendicular clamp and gradually add masses to the end of the spring until the weights have stretched the spring to the exact same length L as recorded above and from this information determine the **tension T** in the spring. [A spring scale can also be used to make this measurement,]
30. From the **tension T** in the spring and the **mass per unit length** μ calculate the **speed v** of the wave in the spring.
31. Compare the speed of the wave determined from the **tension and mass per unit length v** with the speed determined from the **period and frequency s**.
32. Determine the equation which describes the displacement of this string as a function of time and position;
    a. determine the **wave number [k]**.
    b. determine the **angular velocity [ω]**.
    c. determine the **amplitude [A_o].**
33. Test your equation by using it to predict the position of at least one of the nodes from the boundary conditions above.

Goal - The general goal of this lab is to become familiar with the various properties of waves so as to be able to identify those phenomena which are in fact waves.

The specific goals of this lab are:

a. to show that the speed of a wave is equal to the product of the wave's frequency and wavelength. [$s = f\lambda$]

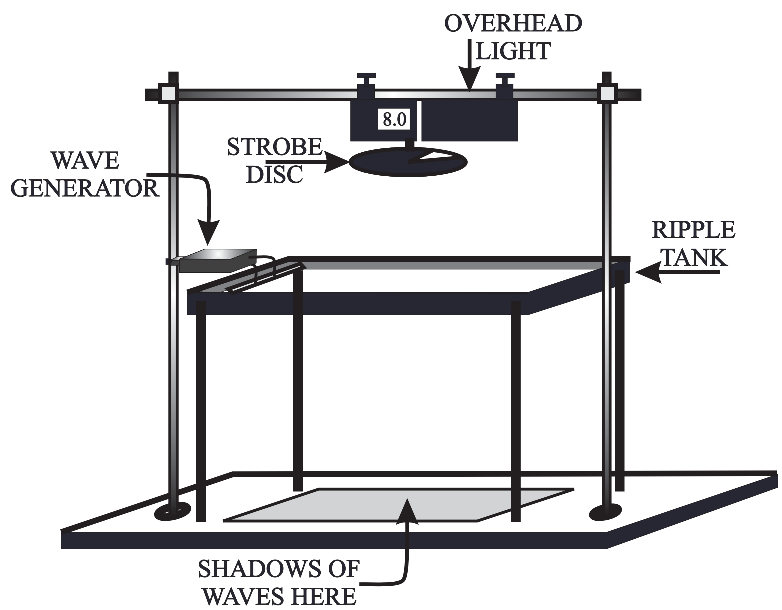
b. to show the when a wave interacts with a barrier, the wave reflects off of the barrier such that the angle of incidence is equal to the angle of reflection.

c. to show that when a wave passes through an interface from one medium into another the direction of motion of the wave changes such that the ratio of the speeds in the two mediums is directly proportional to the ratio of the sines of the angles.

d. to show that two point sources vibrating in phase generate an interference pattern according to the relationship $n\lambda = d\sin\theta$.

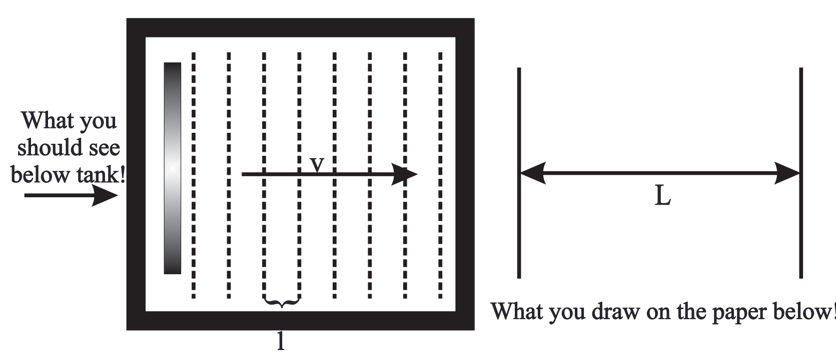
e. to demonstrate the ability of a wave to bend around the corner of an obstacle when the wavelength of the wave is large compared to the dimensions of the obstacle, by observing the diffraction patterns produced as waves of varying wavelengths pass around and through barriers arranged in a variety of ways.

General Procedure -



1. Assemble the ripple tank as shown to the right.
2. Fill the tank to a depth of approximately 0.5 to 1.0 centimeters. Check the depth throughout the tank with a plastic ruler. If the water depth is not uniform it will be necessary to adjust the screw-in feet found on the end of each leg of the ripple tank.
3. Mount the wave generator to the vertical supports as shown. The wave generator is plugged into the power supply which is in turn plugged into the power strip on the desk.
4. Turn on the overhead light and observe the waves formed on the screen of paper below the tank. If the waves are not straight and clear it will be necessary to adjust the wave generator. It is extremely important that the waves are of top quality if you expect good results from your lab experiments with the wave tank! [It is often useful to rub your finger across the front edge of the wave generator where the generator contacts the water. If this does not help, remove the bar from the generator and wash it with soap ans water to remove body oils.]
5. Adjust the wave generator until the waves are about 3 to 5 cm long and are crisp and clear.

Procedure A - Speed of water waves

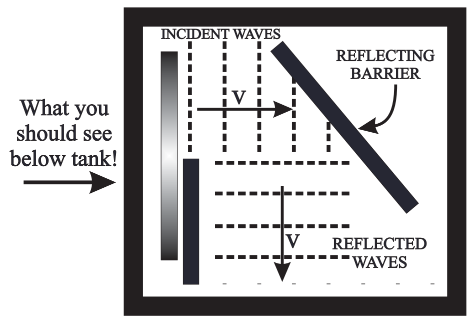


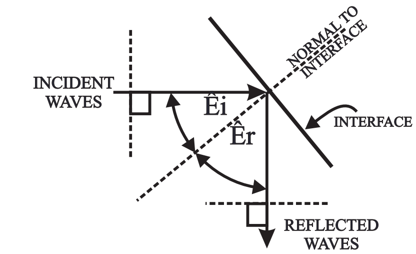
6. Generate clear waves as directed above and place a piece of construction paper [preferably yellow and about 18" square] under the tank to act as a projection screen. Attach two opposite corners of the paper to the table with two small pieces of masking tape to keep the screen from moving.
7. Insert the strobe disk between the light source and the ripple tank. Plug the strobe disk into the power supply which is in turn plugged into the power strip on the desk. Adjust the rotational speed of the disk until the waves in the tank appear to stand still.
8. After the waves are "standing still" record the frequency reading on the strobe. As long as the waves are "standing still" the frequency of the strobe and the frequency of the waves in the tank should be the same.
9. While the waves are standing still place a plastic ruler [yellow is best] under the tank on the screen. Line the ruler up with corresponding points on consecutive waves and measure the wavelength λ of the waves directly. (Sometimes when the

waves seem to drift slowly, it is best if one student moves the ruler with the drifting waves while another students actually reads the wavelength from the ruler.)

10. Multiply the measured **wavelength** λ by the measured **frequency f** and determine the resulting **speed v** of the waves in the ripple tank.
11. Finally, measure the **speed v** of the waves in the ripple tank directly by measuring the **time t** required for the individual waves to travel **L = 50 cm** [or some other convenient distance!] on the screen below the tank. To do this use your finger to "pick up" one of the waves as it begins to travel across the screen and with a stopwatch measure how long it takes for the wave to travel a distance of L = 50 cm which you have marked on the screen. Divide the distance measured on the screen by the time and calculate the **speed v** of the water waves.
12. Compare the speed of the waves measured directly with distance and time with the **speed v** measured by taking the product of **frequency f** and **wavelength** λ.

Procedure B - Reflection of water waves

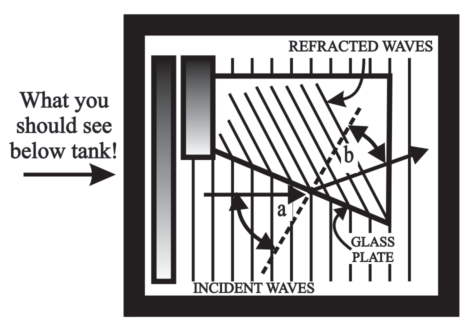


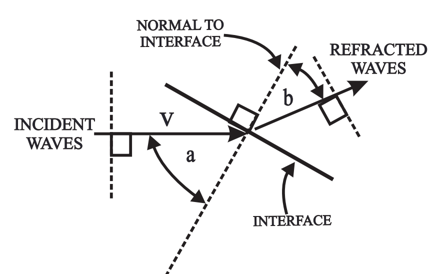


What you draw on the paper below!

13. Again generate clear waves as directed above.
14. Set one long block of wood in the ripple tank as a reflecting barrier and a second block of wood in the tank so as to produce a "shadow area" in the tank as shown below.
15. On the paper below the ripple tank draw in a line aligned with the position of the reflecting barrier.
16. Place a ruler on the paper below the tank and adjust its position so that the ruler is parallel to the wavefronts of the incident waves [the waves before they have interacted with the reflecting barrier]. Draw in the wavefront of the incident waves.
17. Move the ruler on the paper below the tank until the ruler is parallel to the wave fronts of the reflected waves [the waves after they have interacted with the reflecting barrier]. Draw in the wave fronts of the reflected waves.
18. Using a protractor, draw a line perpendicular to the incident wave front. Extend this line until it intersects the reflecting barrier.
19. Using the protractor, draw a line perpendicular to the reflected wavefront. Extend this line until it intersects the reflecting barrier at the same point as in step #6 above.
20. Using the protractor, draw a line perpendicular to the reflecting barrier [called the "normal"] at the point where the two previous lines intersected the reflecting barrier .
21. Measure the angle between the incident wave <i and the normal to the reflecting barrier [angle of incidence], and the angle between the reflected wave <r and the normal to the reflecting barrier [angle of reflection] and compare. [the "Law of Reflection!"]

Procedure C - Refraction of water waves.





What you draw on the paper below!

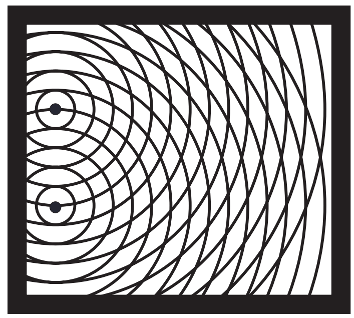
22. Remove the wooden barriers from the wave tank and place, instead, a piece of glass into the wave tank as shown below. [The glass should be either double strength glass or else use two sheets of single strength glass.]
23. The water in the tank should barely cover the glass sheet and the edge of the glass plate should be diagonal to the incident waves as shown.
24. Make sure the waves formed in both the deep and shallow water are crisp and clear.
25. Replace the paper below the wave tank and with a ruler draw in a line aligned with the interface between the deep and shallow water.
26. Draw in a line parallel to the wavefront of the incident wave and then, using a protractor, draw in a line perpendicular to the incoming wave front to the interface drawn in previously.

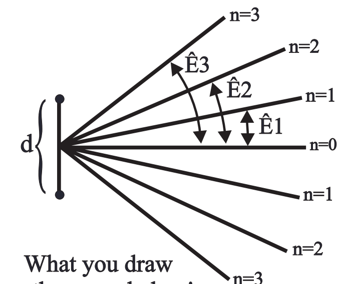
27. Draw in a line parallel to the wavefront of the refracted wave and then, using a protractor, draw in a line perpendicular to the refracted wave front to the interface drawn in previously.
28. Using the protractor draw in the normal to the interface at the point where the previous lines were drawn.
29. Measure the angle between the incident wave α and the normal to the interface [**angle of incidence**] and then measure the angle between the refracted wave β and the normal to the interface [**angle of refraction**].
30. Insert the strobe disk between the light source and the ripple tank and adjust the frequency of the strobe until the waves in the tank appear to stand still.
31. Measure the **wavelengths** of the waves in both the **deep water** λ_1 and the **shallow water** λ_2.
32. Measure the **frequencies** of the waves in both the **deep water** f_1 and the **shallow water** f_2.
33. Show that the **ratio of the speeds [s_1/s_2]** of the waves in the deep and shallow water is equal to the **ratio of the sines of the angles** of these waves **[sin α / sin β]**.

Procedure D - Two point source interference

34. Replace the bar on the oscillator with two point sources. [battery caps work quite well]
35. Adjust the height of the wave generator until the point sources are just barely contacting the surface of the water without touching the bottom of the wave tank.
36. Turn on the wave generator and adjust until you see a clear wave pattern similar to that shown below. Make sure both point sources are oscillating in phase.

What you should see below tank!





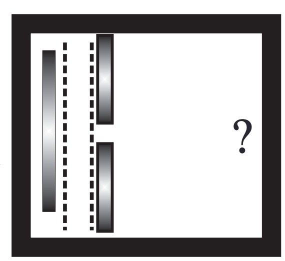
What you draw on the paper below!

37. On the paper below the tank draw in the lines as shown in the diagram above:
    a. indicate each point source.
    b. draw in a line connecting the two point sources [**d**].
    c. draw in the line perpendicular to the two point sources.
    d. draw in the lines from the centers of each antinode to the point where the perpendicular bisector meets **d**.
38. Measure the distance between the two point sources d.
39. Measures the angles [∠1, ∠2, and ∠3] between each antinode [n = 1, 2, and 3] and the perpendicular bisector.
40. Insert the strobe disk between the light source and the wave tank, "stop" the waves and measure the **wavelength** λ being produced by the point sources. [It is sometimes easier to do this with one of the point sources removed from the water!]
41. Show that the angles at which the antinodes are being produced by two point sources vibrating in phase can be predicted by $\mathbf{n\lambda = d \sin\theta}$.

Procedure E - Diffraction of waves

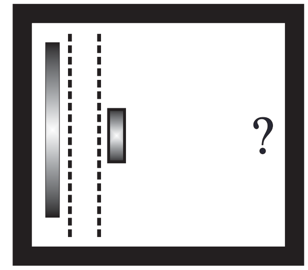
42. Remove the point sources from the wave generator and replace it with the bar again. As before, adjust the wave generator until clear straight waves are being generated.

43. Place two long wooden blocks with a space between them so as to form a **Single Slit** as shown in the diagram to the right. Vary the width of the slit from about 1.0 cm. to about 5.0 cm. and observe [sketch] the resulting wave pattern on the side of the blocks opposite the wave generator. How does changing the width of the single slit affect the appearance of the incident waves as they pass through the single slit? Explain!



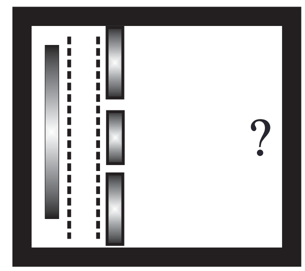
Single Slit

44. Place a single wooden block into the water as shown in the diagram to the right. Vary the wavelength of the waves from about 1.0 cm to about 10.0 cm and observe [sketch] the motion and shape of the resulting wave patterns in the area on the side of the block opposite the wave generator. How does changing the wavelength of the waves affect the degree to which the waves bend around the block of wood? Explain!



Single Block

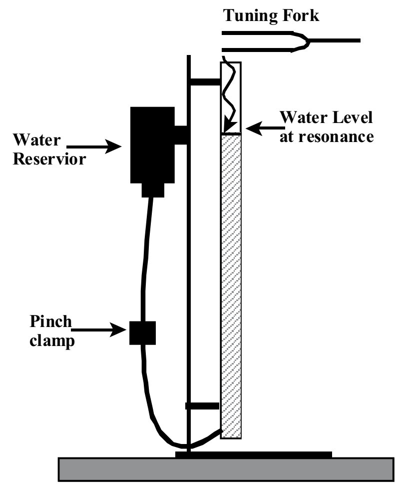
45. Replace the two wooden blocks from above with three blocks, one small and two long, as shown in the diagram to the right. Arrange the three blocks with a small block in the center with two longer blocks on either side. Vary the width of the two resulting slits from about 1.0 cm to about 5.0 cm and observe [sketch] the resulting wave patterns on the side of the blocks opposite the wave generator. What effect does the double slit have on the waves that have passed through it?
46. Your responsibility in this portion of the lab is to make it clear that you know what diffraction is and how each of the observed results above support the concept of diffraction!



Double Slit

Goal - The goal of this lab is to demonstrate the wave nature of sound by measuring the wavelength λ and frequency f of a sound and then show that the product of the this frequency and wavelength is equal to the speed of the sound wave.

Procedure A - Measure the wavelength of the sound produced by a tuning fork



1. Acquire a "resonance tube" for sound. Apply a pinch clamp to the rubber tube connecting the water reservoir with the resonance tube. Add water to the tube until the water reaches the top of the tube.
2. Select a tuning fork and record the frequency stamped into the tuning fork. Strike the tuning fork firmly with a "soft" mallet and then hold the tuning fork over the mouth of the tube as shown in the diagram to the right. The plane of the tuning fork should be vertical as shown!
3. Open the pinch clamp and slowly allow the water to flow out of the tube. Listen to the sound of the tube as you lower the water level and close the pinch clamp when you hear the volume produced by the tube suddenly get louder. (Be sure that this increase in loudness is that which corresponds to the fundamental vibrational mode of the tuning fork as the harmonics [multiples] of the tuning fork will also resonate.) It may be necessary to raise and lower the water level in the tube several times to find the exact level that produces maximum resonance. Record the distance from the top of the tube to the surface of the water in the tube.
4. Re-strike the tuning fork, hold it over the mouth of the resonance tube and continue to lower the water level in the tube until the second resonance point is reached. (What should the distance to the second resonance approximately be?) It may be necessary to raise and lower the water level in the tube several times to find the exact level that produces maximum resonance. Record the distance from the top of the tube to the surface of the water in the tube.
5. Measure and record the inner diameter of the resonance tube.
6. Calculate the wavelength λ of the sound being produced by your tuning fork for both the first and second points of resonance. Compare these values to each other and to the theoretical wavelength produced by your tuning fork at room temperature. [Note! The best value for the wavelength will be determined by measuring the distance between two consecutive nodes rather than between the top of the tube and one of the nodes.]

Procedure B - Measure the frequency of a tuning fork.

7. Connect a speaker [acting as a microphone] to the input of an audio amplifier.
8. Connect the output of the amplifier to a multimeter used as a frequency meter.
9. Strike your tuning fork with a "soft" mallet and then place the tuning fork near the speaker, with the plane of the tuning fork again perpendicular to the plane of the speaker.
10. Slowly turn up the gain of the amplifier until the frequency meter exhibits a stable reading of the frequency. Record the frequency **f**.

Procedure C - Measure the speed of sound.

11. To do this procedure you will need two friction blocks, a stopwatch and a thermometer.
12. Go outside the via the back door of the C-wing toward the student parking lot. The line of trees running parallel to the near curb of the parking lot is $\Delta\mathbf{d}$ = 101 +/- 1 meters from the C-wing.
13. Standing along the tree line strike the two blocks together firmly and listen for the return echo. [The returning echo should sound something like "clickity-click". The final "click" corresponds to the reflection off of the C-wing, while the other "clicks" come from the reflections off of the gym wing.]
14. Measure the time $\Delta\mathbf{t}$ between the two blocks being struck together and the final echo. Repeat this procedure several times, throw out any obviously extraneous data and determine the average time for the return of the final echo.
15. Calculate the speed of sound $\mathbf{s} = \Delta\mathbf{d}/\Delta\mathbf{t}$ based on the time measured above and the distance between the tree line and the C-wing. Compare the speed of sound calculated above with the theoretical speed of sound under the conditions of your measurements, with the wave speed calculated by multiplying the wavelength measured in the first part of the this lab and the frequency measured in the second part of the lab.

Goal - The goals of this lab are;

1. to show that light is a wave because it follows the **Two Laws of Reflection**.
2. to show that the position of the object, the position of the image and the focal length of a mirror are related by the equation;

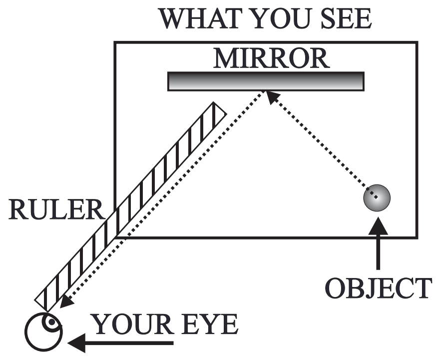
$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$$

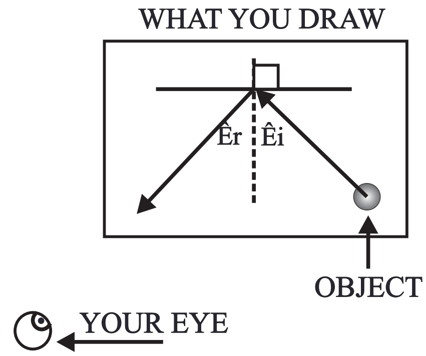
3. to learn the differences between real and virtual images.
4. to learn how to use parallax to determine the position of a virtual image.

Two Laws of Reflection

1. The angle of incidence is equal to the angle of reflection.
2. The incident light ray, the reflected light ray and the normal to the interface all lie in the same plane.

Procedure A - Plane Mirrors

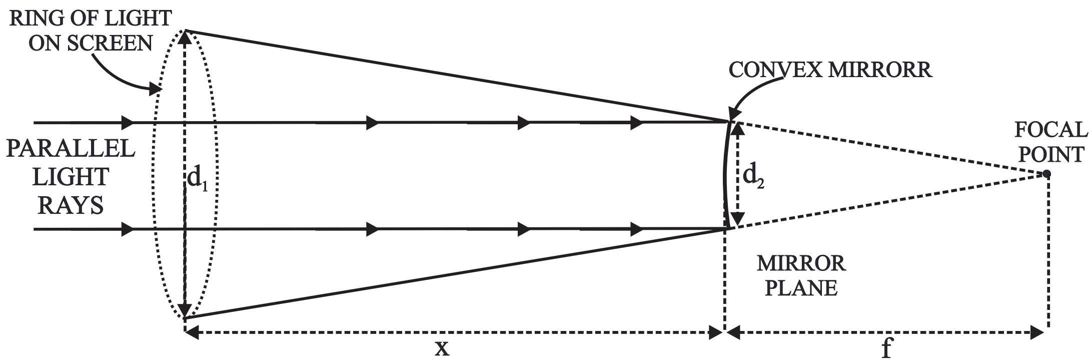




1. Place a vertical, plane mirror on a piece of white paper as shown below. On the paper draw a line which will represent the reflecting surface.
2. Move to the opposite side of the paper and sight along the edge of a ruler at the image of the "object" in the mirror and draw in the line of sight along the ruler to the reflecting surface until it intercepts the first line.
3. Draw in a line between the center of the "object" and the intersection point of the first two lines.
4. Draw in the normal to the reflecting surface at the common intersection point.
5. Measure the angle of incidence and the angle of reflection and compare.
6. Insert a pencil into a single hole rubber stopper and place the stopper with the pencil standing vertically approximately 20 cm in front of the mirror.
7. Insert a second, identical pencil into another single hole rubber stopper and place the second stopper with its pencil standing vertically as before, behind the mirror.
8. Look into the mirror at the reflection of the pencil that is sitting in front of the mirror and simultaneously look at that part of the pencil behind the mirror which sticks up above the mirror.
9. Adjust the position of the pencil behind the mirror until the pencil in front of the mirror, the image in the mirror and the pencil behind the mirror all appear to be aligned.
10. Move your head from side to side while observing the image of the pencil in the mirror and the pencil standing behind the mirror.
11. Adjust the position of the pencil behind the mirror closer or farther from the mirror until the image of the pencil in the mirror and the pencil standing behind the mirror, remain aligned at all viewing angles while you move your head from side to side.
12. When the image of the pencil in the mirror and the pencil behind the mirror remain aligned at all viewing angles, then the position of the pencil behind the mirror will be the same as the position of the image of the pencil in the mirror!
13. Measure the distance between the pencil in front of the mirror and the back side [the reflecting side] of the mirror.
14. Measure the distance between the pencil behind the mirror and the backside of the mirror.
15. Show that for plane mirrors that $\mathbf{1/d_i + 1/d_o = 1/f}$. [Hint! What is the focal length of a plane mirror?]
16. Is the image erect or inverted? Real or virtual? How do you know?

Procedure B - Convex Mirrors

17. Mount a convex mirror [The mirrored surface is the outside surface of a sphere!] in a mirror holder which is in turn mounted to a ring stand.
18. Shine a parallel light source [such as a laser or a filmstrip projector] on the mirror and reflect the light from the mirror onto a screen mounted on another ring stand. On the screen there should appear a ring of light as shown below.

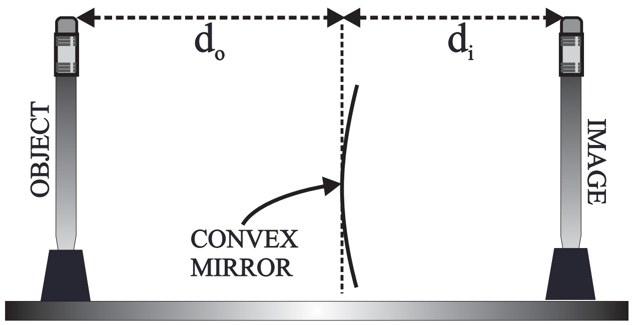


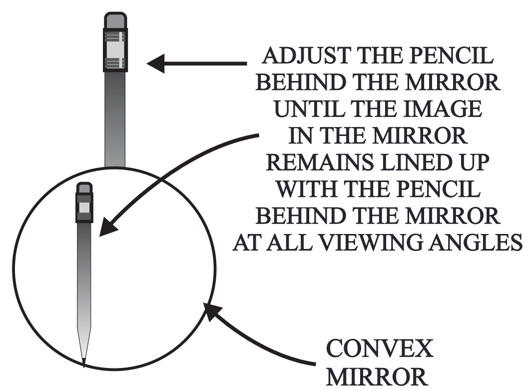
Because of similar triangles

$$\frac{d_1}{d_2} = \frac{x + f}{f}$$

Solve algebraically for f!

19. Measure the diameter of the ring of light [$\mathbf{d_1}$] on the screen, the diameter of the mirror [$\mathbf{d_2}$] and the distance between the mirror plane and the screen [**x**]. From this calculate the focal length [**f**] of the mirror. [Although this calculation will yield a positive number, since it is based on similar triangles, the actual focal length is a negative number because the focal point is behind the mirror and is therefore virtual!]
20. Insert a pencil into a single hole rubber stopper and place the stopper with the pencil standing vertically about 20 centimeters in front of the convex mirror.
21. Insert a second pencil into another single hole rubber stopper and place the second stopper, with its pencil standing vertically, behind the convex mirror.
22. Look into the convex mirror at the reflection of the pencil that is sitting in front of the mirror and simultaneously look at that part of the pencil behind the convex mirror which sticks up above the mirror.

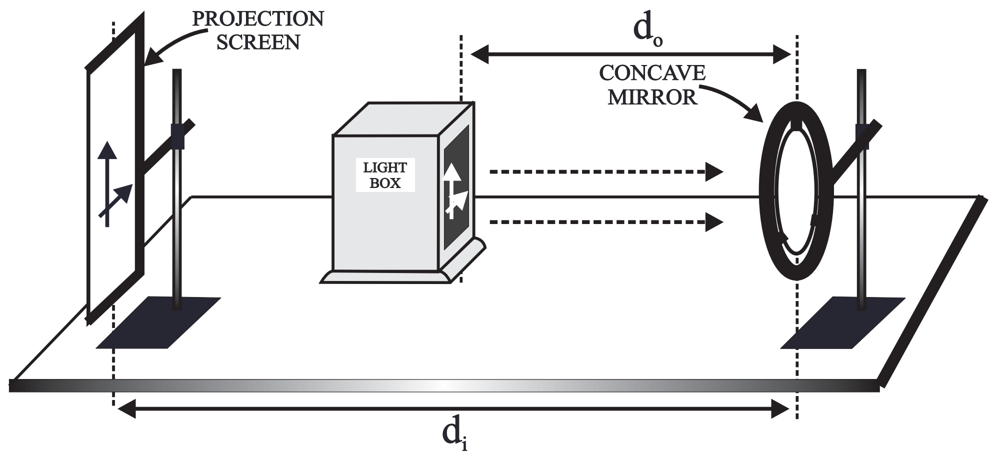




23. Adjust the position of the pencil behind the mirror until the pencil in front of the mirror, the image in the mirror and the pencil behind the mirror all appear to be aligned.
24. Move your head from side to side while observing the image of the pencil in the mirror and the pencil standing behind the mirror.
25. Adjust the position of the pencil behind the mirror closer or farther from the mirror until the image of the pencil in the mirror and the pencil standing behind the mirror, remain aligned at all viewing angles while you move your head from side to side.
26. Measure the distance between the pencil in front of the mirror and the mirror plane of the convex mirror [$\mathbf{d_o}$].
27. Measure the distance between the pencil behind the mirror and the mirror plane of the convex mirror [$\mathbf{d_i}$].
28. Show that for convex mirrors $\mathbf{1/d_i + 1/d_o = 1/f}$.
29. Place a ruler immediately in front of the mirror and measure the diameter of the image of the pencil in the mirror [$\mathbf{H_i}$].
30. Lift the ruler up slightly above the top edge of the convex mirror and measure the diameter of the pencil behind the mirror [$\mathbf{H_o}$].
31. Calculate the magnification [**M**] of this image from $\mathbf{H_i/H_o}$ and then compare this magnification to the ratio of $\mathbf{d_i / d_o}$.
32. Is the image erect or inverted? Real or virtual? How do you know?

Procedure C - Concave Mirrors

33. Mount the spherical mirror so that the concave surface [the inside surface of the spherical mirror] is facing the parallel light source. Shine the parallel light source onto the concave surface of the mirror and reflect the light onto a screen. Adjust the position of the screen relative to the mirror until the light source converges to a point. [It may be necessary to reduce the aperture of the mirror with an aperture card to reduce the spherical aberration!]
34. Measure the distance between the screen and the mirror plane [**f**].
35. Acquire a "light box" with a template of two perpendicular arrows. Plug the lightbox into the AC power source and face it toward the concave mirror at a distance d_o of approximately one meter.



36. Reflect the light from the concave mirror onto a projection screen and then adjust the position of the screen until a sharp image of the two arrows is evident on the screen. [Again it may be necessary to reduce the aperture of the mirror in order to achieve a really sharp image!]
37. Measure the distance between the light box [object] and the concave mirror plane. [$\mathbf{d_o}$]
38. Measure the distance between the screen and the concave mirror [$\mathbf{d_i}$].
39. Show that for concave mirrors $\mathbf{1/d_i + 1/d_o = 1/f}$.
40. With a ruler measure the length of one of the object arrows on the light box [$\mathbf{H_o}$] and measure the length of the corresponding arrow on the projection screen [$\mathbf{H_i}$].
41. Calculate the magnification [**M**] of this image from $\mathbf{H_i/H_o}$ and then compare this magnification to the ratio of $\mathbf{d_i / d_o}$.
42. Is the image erect or inverted? Real or virtual? How do you know?

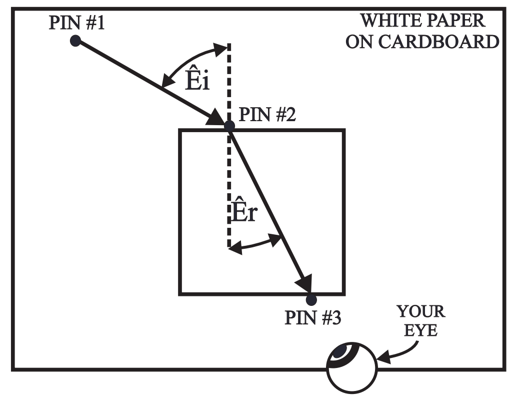
Goal - The goals of this lab are;

1. to show that light is a wave because it follows the Law of Refraction [Snell's Law] by measuring the index of refraction of a glass plate.
2. to show that the path of a light ray through a prism can be predicted using Snell's Law.

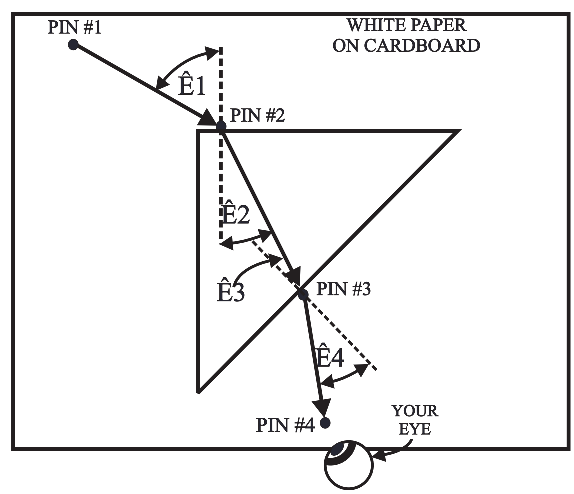
Snell's Law

$$n_1 \cdot \sin(\angle 1) = n_2 \cdot \sin(\angle 2)$$

Procedure



1. Acquire a piece of cardboard, place a piece of paper on top of it and then place a square glass plate on top of the paper and outline the glass plate on the paper.
2. Looking through the transparent edge of the glass plate, insert pin #1 into the cardboard approximately 5.0 cm back and to the left of the top left corner of the glass plate as shown.
3. With your eye positioned as shown in the diagram, look at the image of pin #1 through the front edge of the glass plate and add a second pin along the back edge of the glass plate, but in a direct line with pin #1 so as to block your view of pin #1.
4. Finally, add pin #3 along the front edge of the glass plate, aligned with the first two pins so as to block the view of the first two pins. At this point all three pins should appear to be in a single, straight line when viewed through the glass plate.
5. Remove the glass plate and with a straight edge draw a line on the paper connecting pin #1 to pin #2 and draw a second line connecting pin #2 to pin #3.
6. With a protractor, draw in the normal where the two lines above intersect the back edge of the glass plate and then **measure** the **angle of incidence [△i]** and the **angle of refraction [△r]**.
7. Using Snell's Law and the two angles measured above, calculate the index of **refraction n** of the glass plate and compare to the theoretical index of refraction of glass [1.5 - 1.7].
8. Replace the white paper on top of the cardboard and then place a right prism on the paper. As before, outline the prism on the paper.
9. Insert pin #1 into the cardboard approximately 5.0 cm in back of and to the left of the back left edge of the right prism.
10. While looking through the front edge of the prism, as shown to the right, add pin #2 along the back edge of the prism so as to block your view of pin #1.
11. Add pin #3 along the front edge of the prism and pin #4 about 5.0 cm from the front edge of the prism. When you look through the prism the four pins should all appear to lie in a single, straight line.
12. Remove the prism and connect the four points determined by the pins with three straight lines.
13. Using a protractor add the two normals as shown.
14. **Measure ONLY angle △1**. Using Snell's Law, the index of refraction previously measured for the glass plate, and basic geometry, **predict** in turn angles **△2, △3 and △4**.
15. Finally, **measure △4** and **compare** the **measured angle △4** with the **predicted angle △4**.



GOAL - The goal of this lab procedure is to measure the intensity of light transmitted from an interface where two media with different impedances meet [a wave characteristic, of course!].

$I_{reflected} = I_o\ [(n_2-n_1)/(n_2+n_1)]^2$

% reflected $= I/I_o = [(n_2-n_1)/(n_2+n_1)]^2$

% transmitted = 1 - % reflected

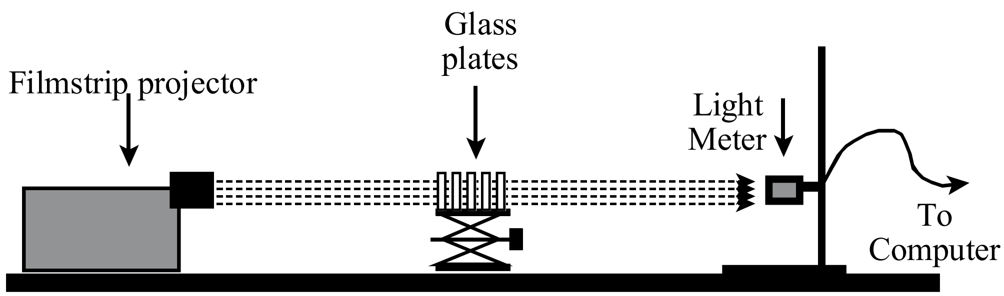
Intensity transmitted $= I_o$ (% transmitted)^N

where N is the number of reflecting surfaces [interfaces].

At each interface the amount of light reflected I_r can be predicted from the equation to the right where I_o represents the intensity of the incident light and where I_r represents the intensity of the reflected light. If you divide each side of this equation by I_o and then multiply by 100 you can predict the percentage of light energy reflected by each interface. If this percentage is then subtracted from 100 % the percent transmitted by each interface can then be predicted. If the light is to pass through N interfaces the total transmitted intensity should equal the percentage transmitted by each interface (as a decimal fraction) raised to the N^{th} power multiplied by the initial intensity I_o.

Procedure -

1. Mount the light meter on a ring stand with a clamp. Place the ring stand approximately 1.0 to 1.5 meters from the filmstrip projector.
2. Turn on the filmstrip projector and illuminate the light meter directly.
3. There should be a mask in the projector to limit the spreading of the light beam. Focus the light beam onto the light meter by rotating the front lens of the projector.
4. Measure the intensity $\mathbf{I_o}$ of the light directly illuminating the light meter.



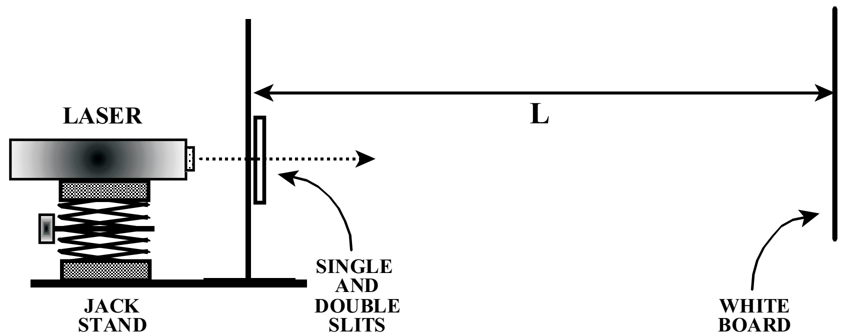
5. Count out the number of glass plates and determine the number of interfaces N (Think!). From this predict the intensity I of the light passing through all of the glass plates.
6. The glass plates should be attached together with spaces between them and should then be placed on a laboratory jackstand. Raise the jackstand until the plates are in the path of the incident light beam.
7. Using the light meter measure the intensity **I** of the light beam after it has passed through all of the glass plates.
8. Compare the predicted intensity of the transmitted light to the measured intensity **I** of the transmitted light.
9. Does this procedure demonstrate the wave nature of light? How?

Goal - The goal of this lab is to demonstrate the wave nature of light by the quantitative analysis of the diffraction pattern produced by both single and double slits. Specifically;

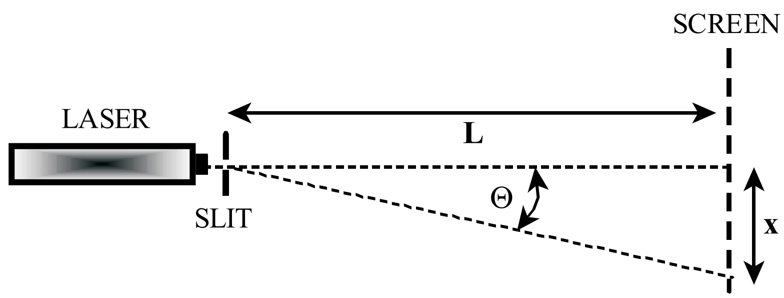
1. verify that $n\lambda = D \sin\theta$ can be used to predict the **nodes** produced by a single slit.
2. to verify that $n\lambda = D \sin\theta$ can be used to predict the **antinodes** produced by a double slit.

Procedure -

Single Slit



1. Mount the laser on a laboratory jack stand or on some other appropriate supporting structure.
2. Mount the glass enclosed negative, which contains single, double and multiple slits, on a ring stand with a clamp as shown to the right.
3. Project the laser through the single slit onto the white board acting as a screen.
4. Determine the position of the center of the central antinode and then measure the distance **x** of the Nth **node** from that center. [A labeled diagram would be useful here.]
5. Determine the distance **L** between the single slit and the position on the screen where the central antinode is located.
6. From the Measurements of **x** and **L** above calculate the angle Θ at which the Nth node occurs.
7. Determine the width **d** of the single slit from the information supplied on the glass slide.
8. Determine and record the wavelength λ of light emitted by the laser. [Hint! Look on the laser housing!]
9. Using the equation $n\lambda = d \sin \Theta$, compare $n\lambda$ with $d \sin\Theta$.
10. How does this lab procedure support the wave nature of light? Explain!



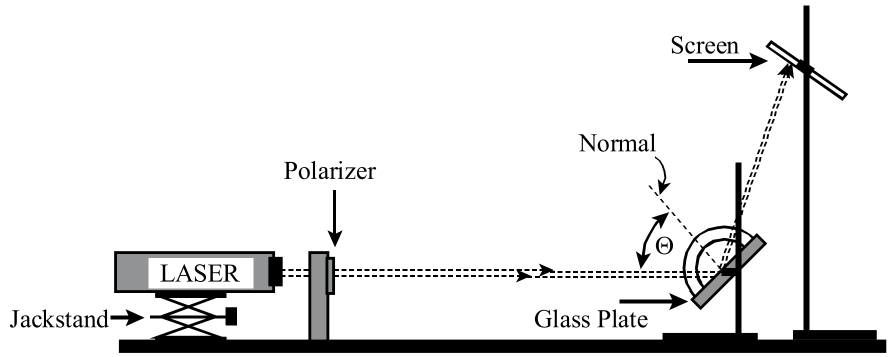
Double Slit

11. Replace the single slit with a **double slit**.
12. Project the LASER light through the double slit onto the screen.
13. Measure the distance **x** between the central antinode and the Nth **antinode**.
14. Determine the distance **d** between the slits in the double slit.
15. Using the equation $n\lambda = d \sin \Theta$, compare $n\lambda$ with $d \sin\Theta$.
16. How does this lab procedure support the wave nature of light? Explain!
17. Compare the pattern produced by the single slit with the pattern produced by the double slit.

PHYSICS LAB #22 POLARIZATION BY REFLECTION & SCATTERING

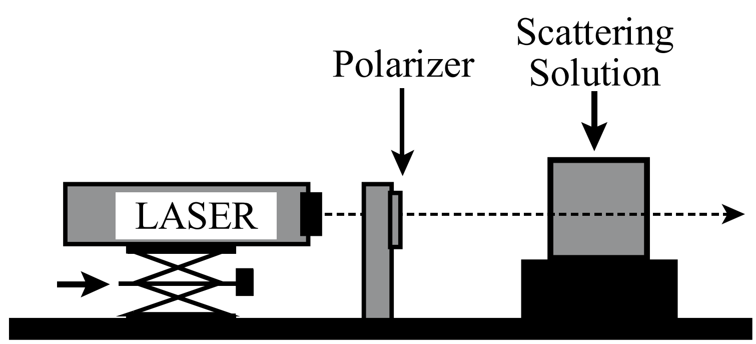
Goal -The goal of this lab is to demonstrate the wave nature of light through polarization by reflection and scattering, and to show that the index of refraction of a material can be predicted through the use of Brewster's Law.

Procedure A - Measuring Brewster's Angle.



1. Mount a glass plate with an attached protractor in a clamp attached to a ring stand and orient the glass plate as shown to the right.
2. Place a laser on a jackstand aiming the laser beam at the glass plate and then reflect the laser beam onto a projection screen mounted on another ring stand.
3. Insert a mounted polarizing filter between the laser and the glass plate.
4. Looking at the reflected beam on the projection screen rotate the polarizing filter until the intensity of the reflected beam reaches a minimum intensity.
5. Adjust the angle of the glass plate until the reflected beam on the screen blanks completely out. Repeat steps 4 and 5 if necessary. The reflected beam should almost totally disappear.
6. Measure the angle Θ between the normal to the glass plate and the incoming laser beam by moving the protractor until the laser beam intersects the protractor. [Be sure the laser beam also passes through the vertex of the protractor.
7. Calculate the index of refraction of this glass plate using Brewster's Law and compare your value to the theoretical value for crown glass.
8. How does this procedure support the wave nature of light? Explain!

Procedure B - Polarization by scattering



9. Fill the cubic container with water and add a scattering solid. [a tiny drop of milk will do]
10. Mount and insert a polarizing filter between the laser and the scattering solution.
11. Shine the laser through the polarizing filter and then through the solution. While observing the beam of light within the scattering solution from the side, at an angle of 90^o relative to the beam of light, rotate the polarizer until the scattered beam of light is at minimum brightness. At this point note the orientation of the polarizing filter.
12. Repeat step 10 observing the scattered beam of light from above.
13. Finally repeat step 10 observing the scattered light along a direction parallel to the beam of light.
14. What conclusions can you draw regarding the polarization of the scattered light, the orientation of the polarizing filter and the direction from which the scattered light is being observed?
15. How does this procedure help to support the wave nature of light? Explain!

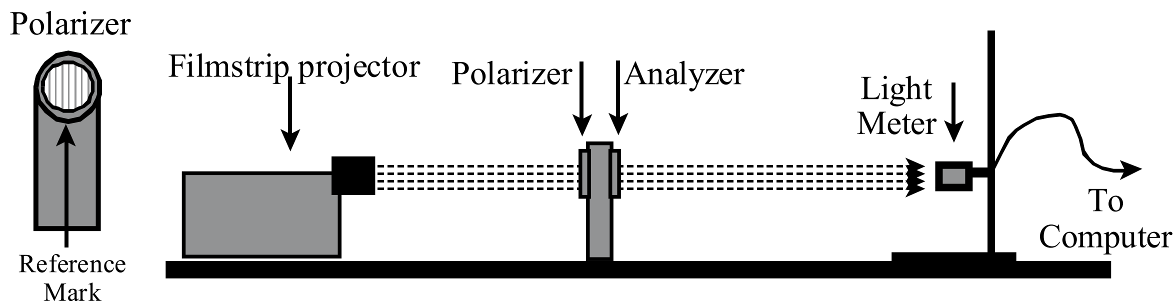
Goal - The goal of this lab is to demonstrate the wave nature of light by showing the light can be polarized by passage through a dichroic filter [selective absorption] and to show that the intensity of the light transmitted through two polarizing filters oriented at various angles can be predicted by;

$$I = I_o \cos^2\phi$$

where I_o represents the intensity of the beam transmitted when the transmission axes of the two polarizers are parallel and where ϕ represents the angle between the transmission axes of the two polarizing filters.

Procedure -

1. Mount the light meter on the ring stand with a clamp as shown below. Point the filmstrip projector [with a mask in the projector to limit the beam of light] at the light meter placed about 1.0-1.5 meters away, verify that the angle ϕ between the two polarizers is $\phi = 0^o$ and then measure the intensity of the incident light I_o.

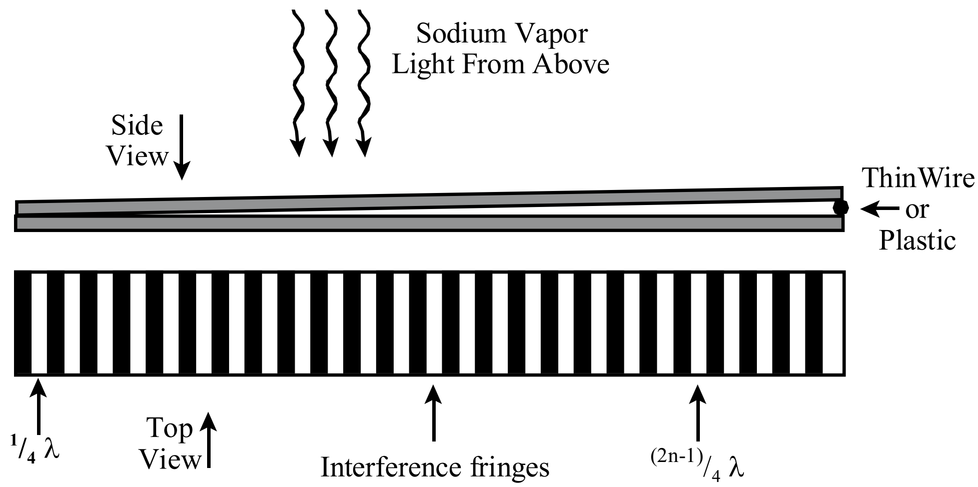


2. Adjust the second polarizer [known as the analyzer] until its transmission axis is rotated 30^o relative to the first polarizer and then measure the intensity I of the transmitted beam of light.
3. Predict the intensity **I** of the transmitted beam of light and compare this intensity to the measured intensity at 30^o.
4. Repeat for 60^o and 90^o.
5. Do your results support the assertion that light is behaving as a wave phenomenon? Explain!

Goal - The goal of this lab is to demonstrate the wave nature of light by observing the interference of light waves and by using this interference to determine the thickness of a very thin wire or piece of plastic.

Procedure

1. Turn on the Sodium vapor light [λ = 5890 Å]. [This light requires several minutes to completely warm up!]
2. Take two long glass plates, clean the plates thoroughly with tissue and use two rubber bands, one at each end, to secure the plates together.
3. Separate the plates at one end and insert a thin piece of wire or plastic parallel to the ends of the plates. [See the diagram to the right!]
4. Place the entire setup on a piece of dark blue construction paper [for contrast] and illuminate the plates from above. [Keep the incident light rays as perpendicular to the glass plates as possible!]

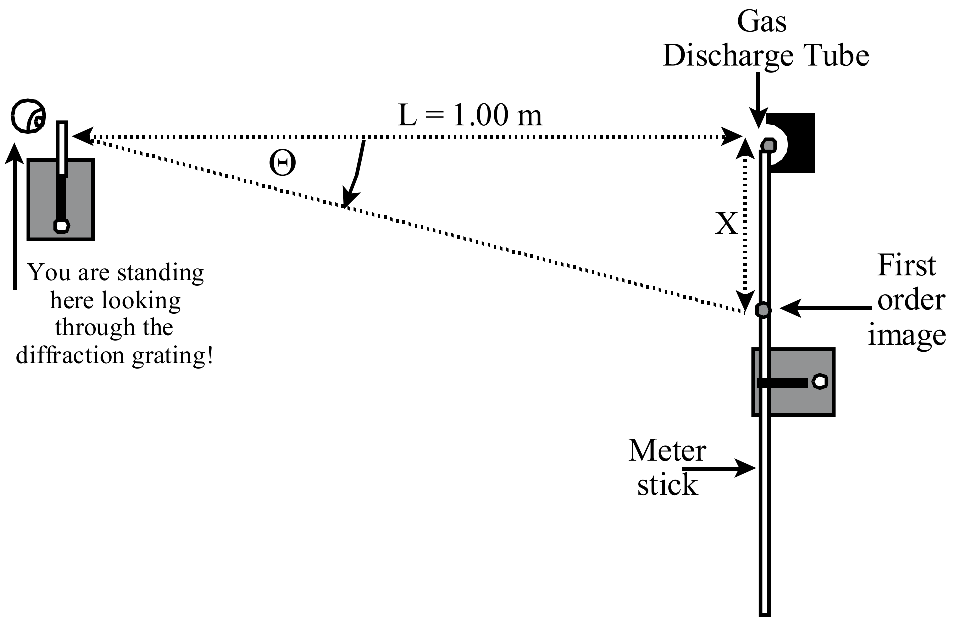


5. Observe the reflected light from above and either count the number of bright fringes from one end of the plates to the other OR count the number of bright fringes per unit length and then multiply this by the total length of the plates.
6. From these measurements calculate the thickness of the air film at the end of the plates where the wire or plastic sheet has been inserted and determine the thickness of the wire or plastic sheet.
7. Measure the thickness of the wire or plastic with a micrometer and compare this measurement to the prediction based on the fringes above.
8. Explain why the antinodes you have observed occur at odd multiples of a 1/4 wavelength.
9. Do your results support the wave nature of light? Explain!

Goal - The goal of this lab procedure is to demonstrate that light is a wave phenomena by measuring the wavelength of a light wave through the use of a diffraction grating and $n\lambda = d \sin \Theta$

Procedure -

1. Mount a gas discharge tube in the appropriate power supply. [Note that the power supply is potentially hazardous!] Note and record the type of gas contained in the discharge tube!
2. Mount a meter stick on a ring stand with a perpendicular clamp connected at the 50 cm mark so that the meterstick is horizontal and at a height approximately in the center of the discharge tube.
3. Mount a diffraction grating on another ring stand using an adjustable clamp and place the diffraction grating exactly L = 100 cm from the gas discharge tube.
4. The position of the diffraction grating, the gas discharge tube and the meterstick should form a right angle as shown
5. Turn on the power supply and look through the diffraction grating at the gas discharge tube. Looking to the right of the discharge tube you should see several images of the discharge tube, in a variety of different colors [these are called the "first order images"]. Further to the right you should see the same set of colors, in the same order [these images are the "second order images"].

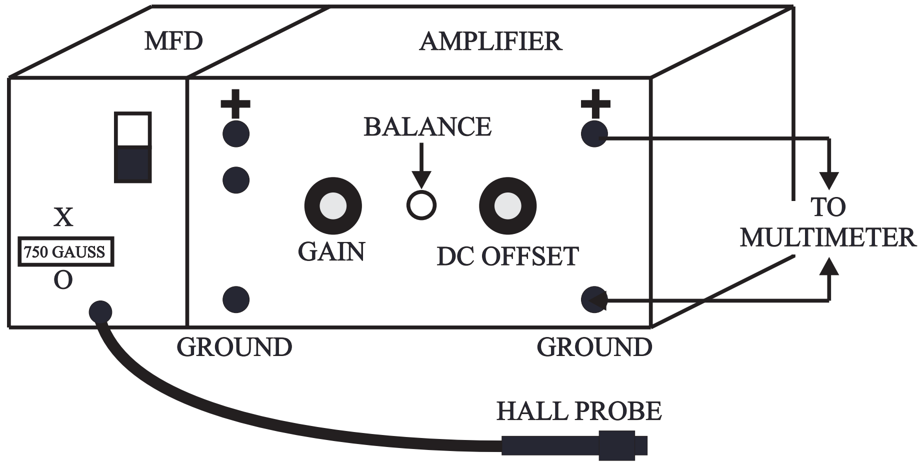


6. Select **one colored image** and then, with the help of a partner, record the position along the meter stick **x** for both the **first** and **second order images**.
7. Calculate the angles Θ_n at which each of the images above were formed.
8. Record the number of slits per unit length of the diffraction grating. Use this information to calculate the distance **d** between any two adjacent slits in the diffraction grating.
9. Make up a data table including all of your measured variables (**x**, **d**, **L**, **n**, & Θ) and then **calculate the wavelengths** corresponding to both the **first and second order images**. Look up the **theoretical value** λ for the **wavelength** of the images you have observed and compare these values to the ones you calculated in the lab. The theoretical value for the wavelength can be found in one of the color plates of a copy of Modern Physics, on the corresponding wall chart or in the Handbook of Chemistry and Physics.
10. Do these results support the wave nature of light? How?

Goal - The goal of this lab is to measure the strength of a magnetic field through the use of a Hall Effect device.

Procedure -

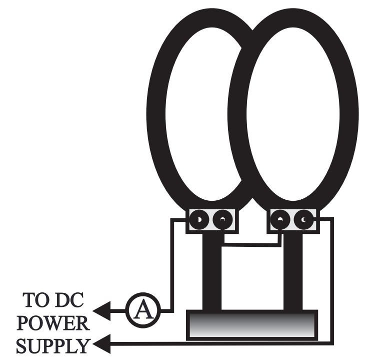
1. Connect together an ADP-101 amplifier and a multimeter by connecting the positive terminal of the multimeter to the [red] output terminal of the amplifier and the negative terminal of the multimeter to the [black] ground terminal of the amplifier. The multimeter should be set up as a Voltmeters for this procedure. See diagram below.



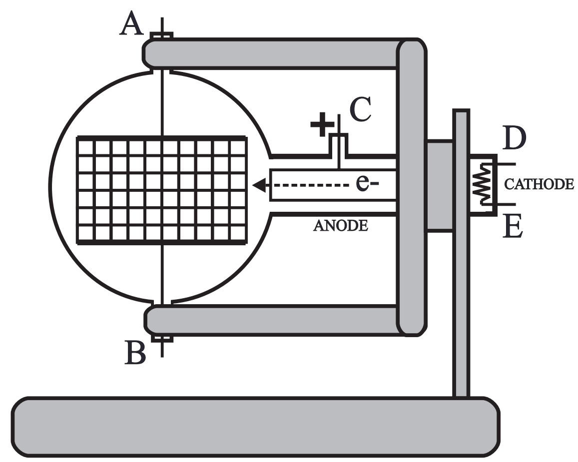
2. Perform the following step ONLY if absolutely necessary!
3. Balance the amplifier:
   a. Turn the amplifier on at least 30 minutes before balancing.
   b. Turn the amplifier gain to zero. [Counterclockwise to zero.]
   c. Carefully adjust the DC Offset until the reading on the ammeter is zero [+/- .01 Volts]
   d. Turn the amplifier gain clockwise to maximum. If the reading on the Voltmeter remains zero, skip to step 4.
   e. With a small screwdriver adjust the “Balance” control screw until the meter reads zero.
   f. Repeat steps a through e to verify that the meter is now balanced.
4. Plug the Magnetic Field Detector [MFD] module [the Hall Effect device] into the left side of the amplifier.
5. Turn up the gain on the amplifier to about 50, make sure that the Hall Effect probe is not near any substantial magnetic field source and adjust the DC Offset until the reading on the Voltmeter is zero [+/- .01 Volts].
6. Insert the Hall Effect probe into the slot in the front of the MFD with the X on top and the O on the bottom as per the symbols printed on the MFD.
7. Adjust the gain on the amplifier until the reading on the multimeter is 7.50 Volts [+/- .01 Volts]. Since the calibration source is 750 Gauss [10^4 Gauss = 1 Tesla], and since the Voltage reading across a Hall Effect device is directly proportional to the strength of the magnetic field, your apparatus is calibrated so that each Volt on the multimeter corresponds to 100 Gauss!
8. The magnetic flux passing through the Hall Effect probe will be at a maximum when the probe is oriented so that the “lump” on the end of the probe is perpendicular to the external magnetic field. [Try orienting the probe in a variety of ways near a permanent magnet until you find the maximum reading on the voltmeter and therefore the true magnetic field strength.]

Goal - The goal of this lab is to measure the effect of a uniform magnetic field on a moving beam of charged particles and to show that the magnetic force on a moving charged particle is given by F_m = qv x B.

Procedure -



1. Place the two Helmholtz coils into their respective holes in the base of the deflection tube stand.
2. Connect the two coils together in series with each other and with an ammeter and then connect this circuit to the DC power supply built into the lab table.
3. Adjust the current in the circuit until the reading on the ammeter is 0.2 - 0.3 Amperes. The exact current in this circuit is not critical, just be sure to record the value whatever it is for purposes of reproducibility.
4. Using the Hall Effect device measure the average magnetic field strength B between the two coils by varying the position in the central region between the coils. Make several measurements, record and determine an average value for the magnetic field strength that corresponds to a current of 0.2- 0.3 Amperes [or as determined before] and determine the direction of the magnetic field using the magnetic field probe. Record the current flowing through the coils and the corresponding magnetic field strength.
5. Turn off the power supply and then remove the Helmholtz coils from the stand. Carefully, insert the deflection tube into the stand and secure with the sliding clamps. [A replacement tube costs $500+.]
6. Connect up the electrostatic deflection tube as shown to the right.
   a. Connect terminals D and E of the deflection tube to the 6.3 Volts power supply.
   b. Connect terminal D to the negative terminal of the high voltage supply and connect terminal C to the positive terminal of the high voltage supply. [Terminals A and B will not be used in this procedure.]

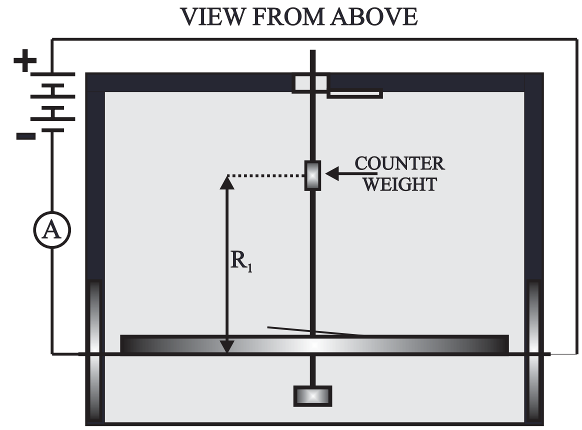


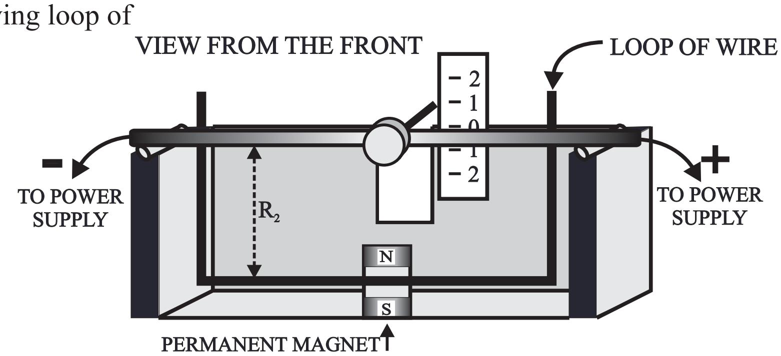
7. Carefully, reinsert the Helmholtz coils into the deflection tube stand, turn on the current to the coils and readjust the current to the coils to 0.2 - 0.3 Amperes as before.
8. Gradually, turn up the high voltage to the deflection tube to approximately 4000 Volts.
9. Record several pairs of intersection points (x,y) of the curved path on the deflection grid.
10. Calculate the radius of curvature R of the electron beam based on the above pairs of intersection points and determine the average radius of the path followed by the electrons.
11. Based on the applied accelerating potential, calculate the velocity of the electrons passing through the hole in the anode as they move into the magnetic field.
12. From the above information, calculate the centripetal force acting on the moving beam of electrons.
13. Use F_m = q v x B to determine the magnetic force acting on the beam of electrons and compare this to the centripetal force calculated above. [Why should these two be the same?]
14. Verify the cross product nature of the magnetic force by using the right hand rule. [Be sure to **support** this with a **carefully labeled diagram**.]

Goal - The goal of this lab is to determine the direction and the magnitude of the magnetic force acting on a current carrying wire while sitting in a uniform magnetic field.

Procedure -

1. Assemble the current balance kit according to the diagrams to the right.
   a. First insert the rod with the cylinder on the end through the center of the balance bar.
   b. Adjust the position of the rod until the rod points towards the zero mark on the scale at the back of the current balance kit. This adjustment is not easy, but it is important.
2. Connect the cylinder on the right side of the current balance kit to the positive end of the power supply that is built into the desk with a clip lead as shown in the diagram above.
3. Connect the cylinder on the left side of the current balance kit to an ammeter [at least 10 Amperes] with a second clip lead and then attach the other end of the ammeter to the negative end of the power supply with a third clip lead. Do NOT turn the current on yet!
4. Using the Hall Effect device, measure the average magnetic field strength B in the central area between the two poles of the permanent magnet.
5. Position your magnet such that the horizontal, current carrying loop of wire sits midway between the poles of the permanent magnet as shown in the diagram above right.
6. Turn on the power supply and adjust the current until it is approximately 5.0 Amperes. If at this point the balance bar is pulled down, flip the permanent magnet over to reverse the direction of the magnetic field.
7. Determine the direction of the magnetic field between the two poles of your permanent magnet using the magnetic field probe. Be sure to insert the probe between the poles of your magnet.
8. Determine the direction of conventional current flow through the horizontal section of the current loop, combine this information with the direction of the magnetic field between the two poles of your permanent magnet and then predict the direction of the magnetic force acting on the wire according to the right hand rule. How does your prediction compare with the actual magnetic force on the wire? Use a carefully drawn diagram to support your conclusion!
9. Add a counterweight (m) of 500 milligrams to the rod of the balance bar at a distance of approximately 15 cm from the center of rotation (R_1). Record the mass of the counterweight.
10. Turn on the current to the loop and adjust either the position of the counterweight or the current through the loop until equilibrium is reached. At this point record the distance of the counterweight from the center of rotation (R_1), the distance of the current carrying loop from the center of rotation (R_2), the current through the loop (I) and the width of the magnet (l)
11. Develop the equation describing the opposing torques acting on this loop while at equilibrium and from this equation determine the magnitude of the magnetic force (F_m) acting on the loop.
12. Calculate the magnetic force acting on the current loop based on $F_m = I\,l \times B$ and compare to the magnetic force determined from the opposing torques above.



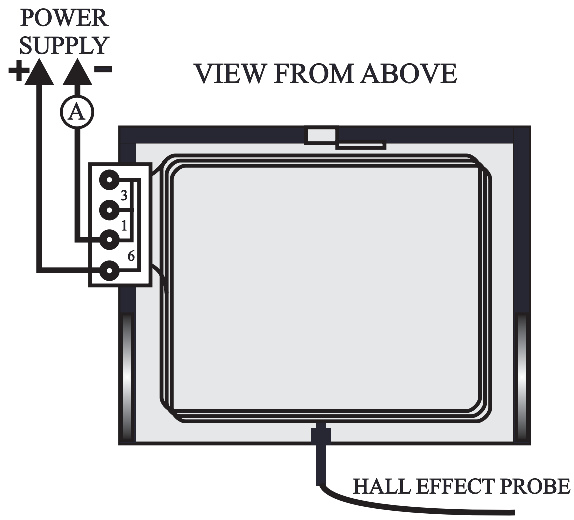


Goal - The goals of this lab are:

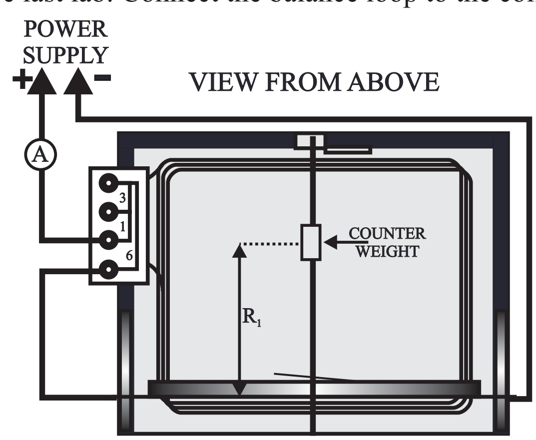
a. To determine the relationship between the magnetic field near a current carrying wire and the distance from that wire. [i.e. to verify the Biot-Savart Law and/or Ampere's Law]

b. To measure both the magnitude and direction of the magnetic force between two current carrying wires.

Procedure -



1. First connect up an ammeter and 10 of the multiple loops within the current balance kit to the voltage supply built into the desk.
2. Adjust the current to approximately 5 - 10 Amperes and then temporarily disconnect one of the leads. Record.
3. Make sure that the Hall Effect device is properly calibrated as done in lab procedure #26.
4. Reconnect the power supply to the current loops.
5. Place the Hall Effect Probe exactly 1.0 cm from the center of the wire bundle, with the probe lying flat on the base of the current balance kit.
6. Turn the current to the loops off, adjust the DC Offset of the amplifier until the reading on the Voltmeter is as close to 0.0 Volts as possible [to compensate for the effect of the Earth's magnetic field!].
7. Take the voltage reading, turn the current on, again take the voltage reading - use the difference between these two readings to determine the magnetic field strength.
8. Using the Hall Effect Device measure the strength of the magnetic field every centimeter from the current loops as shown in the diagram until the readings are too low to measure. [about 5.0 cm.]
9. Make a graph plotting the magnetic field strength as a function of distance from the wires. From the shape of the graph determine the relationship between magnetic field strength B and distance from the wire r.
10. Select one of your data points and calculate the magnetic field strength near the current carrying wires and then compare to the theoretical magnetic field strength near the wire as determined by Ampere's Law [or the Biot - Savart Law] Don't forget that you are using ten loops of wire!
11. Next, add the balance bar with the current carrying loop and balance as in the last lab. Connect the balance loop to the coils in the bottom of the box in a simple series circuit as shown to the right



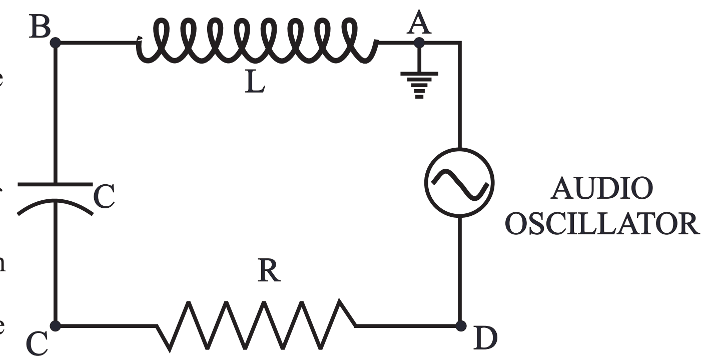
12. Adjust the distance between the ten loops in the bottom of the box and the balance loop to approximately 1.0 centimeter. Turn on the electric current and adjust to approximately 10.0 Amperes and record. This should result in the balance loop being forced away from the loop in the bottom of the box and in doing so lifting the counterbalance as in the last lab. [If the loop is pulled forward, reverse the current in either the suspended loop or the loops in the bottom of the box.] Add a counterweight of **100 milligrams** to the balance loop and adjust its position until the loop is returned to the equilibrium position. [Alternatively you can place the 100 mg mass about 15 cm from the center of rotation and then adjust the current in the circuit until you reach equilibrium!]
13. Measure and record; the mass and position of the counterweight relative to the center of rotation, the distance of the current loop from the center of rotation, the current flowing in each loop.
14. Calculate the magnetic force acting $\mathbf{F_{m1}}$ between the two wires by using the concept of rotational equilibrium.
15. Calculate the magnetic force $\mathbf{F_{m2}}$ acting between the two current carrying wires based on the equation determined in class and then compare to the force determined above.
16. Demonstrate the validity of the **right hand rule** using appropriate diagrams illustrating the directions of the currents, magnetic fields and magnetic forces acting between these two wires.

GOAL - The goals of this lab are to:

a. determine the self inductance of a solenoid through its design.
b. determine the self inductance of a solenoid by measuring the resonant frequency.
c. show that the EMF across a solenoid is 90^o out of phase with the EMF across the source.
d. show that the voltage drops across the individual circuit elements in a series RCL circuit add up geometrically to give the EMF across the source.
e. measure the impedance of an RCL circuit.

PROCEDURE -

1. Determine the self inductance [L] of a solenoid as a function of its design.
2. Measure the length [l] of the solenoid.
3. Determine the number of turns [N] contained in this coil. [A fairly difficult process! Use your previous experience with circuits to help you determine N.]
4. Measure the cross section of the solenoid.
5. Calculate the self inductance of your solenoid.
6. Determine the self inductance of a known inductor through the determination of the resonant frequency.
7. Connect up the circuit as shown to the right where R = 5000 Ω. and the capacitor is approximately C = 100 μF.



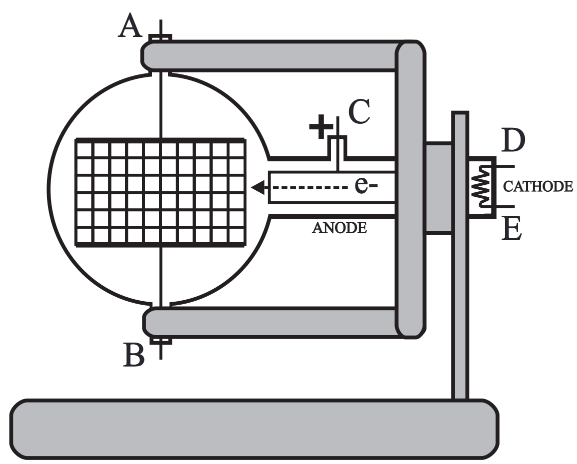
8. Attach an oscilloscope [or an AC Voltmeter] between points A and C.
9. Systematically, vary the frequency of the AC oscillator until the potential difference across the oscilloscope [or AC Voltmeter reaches a minimum. [Note! It may be useful to calculate the resonant frequency]
10. From this resonant frequency verify the rated self inductance of your inductor.
11. Repeat the above procedure on your unknown inductor and then compare this value to the inductance predicted in step 5.
12. Demonstrate the phase relationship between the EMF across the power supply and the voltage across the induction coil.
13. Adjust the oscillator to 2000 Hz and the resistance to 500 Ω .
14. Connect the vertical input of the oscilloscope between points A and D.
15. Simultaneously connect the horizontal input of the oscilloscope between points A and B.
16. Turn the input selector of the oscilloscope to Horizontal input.
17. Adjust the resistance and the gains of the oscilloscope until a circle appears on the screen.
18. Demonstrate the mathematical relationship among the EMF of the power supply, the Voltage across the inductor, the voltage across the capacitor and the voltage drop across the resistor.
19. Adjust the oscillator to some frequency significantly different from the resonant frequency.
20. Using the AC voltmeter capability of the multimeter, measure the voltage across each element of this circuit.
21. Using the theoretical relationship developed in class, show that the voltages across the inductor, capacitor and the resistor add up geometrically to the EMF of the oscillator.
22. Measure the total impedance of this circuit from the EMF of the oscillator and the AC current flowing in the circuit. Compare this value to the impedance of the circuit based on the values for resistance, inductance and capacitance.

PHYSICS LAB #31 ELECTROSTATIC DEFLECTION

Goal - The goal of this lab is to measure the effect of a uniform electric field on a moving beam of charged particles and to show that the force on a moving charged particle is given by F = Eq.

Procedure -

1. Connect up the electrostatic deflection tube as shown to the right.
2. Turn the high voltage power supply **OFF** and turn the voltage adjustment to **zero**!
3. Connect terminals **D** and **E** of the deflection tube to the **6.3 Volt** terminals of the high voltage power supply.
4. Connect terminal **D** to the **negative terminal** of the **high voltage** supply and connect terminal **C** to the **positive terminal** of the **high voltage** supply.
5. Connect terminal **A** to the **negative terminal** of the **high power supply** and terminal **B** to the **positive terminal** of the **high power supply**. [Reversing these two connections is acceptable!]
6. Turn the high voltage power supply **ON** and then, **gradually**, turn up the high voltage to the deflection tube to approximately **V = 4000 Volts**.
7. Measure and record the position **(x,y)** of the deflected beam as it leaves the deflection grid between the two horizontal plates.

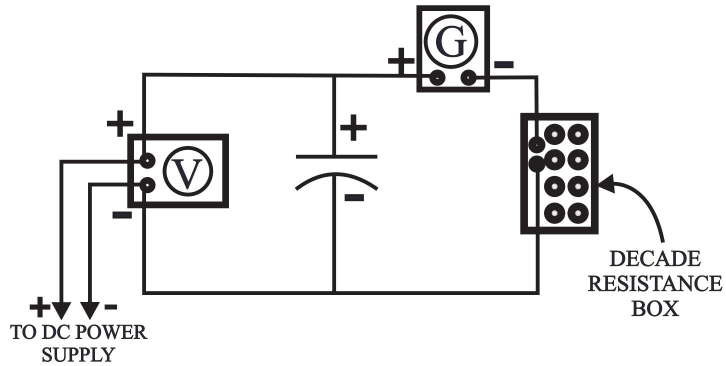


8. Based on the applied accelerating potential **V**, calculate the velocity of the electrons as they pass through the hole in the anode and into the uniform electric field. [Use energy conservation, the **work done** on the electrons by the power supply **W = Vq** should be equal to the **kinetic energy gained** by the electrons **KE = ½ mv^2**.]
9. Based on the potential applied to the horizontal deflection plates **V** and the distance between the plates **d**, determine the direction and magnitude of the **electric field strength E** between the deflection plates.
10. Determine the time t required for the electron beam to reach the position **(x,y)** measured above.
11. Calculate the direction and magnitude of the electric force acting on the electrons and from the time calculated above predict the position of the electron beam **(x,y)**.
12. Compare the actual position of the electron beam with the predicted value and thus confirm if, in fact, the electrostatic force acting on a charge particle in an electric field can be predicted by using **F = Eq**. (Be sure to explain **clearly** how your prediction of the position **(x,y)** above can be used to support your conclusion!)

GOALS - The goals of this lab are to;

a. Measure the capacitance of a parallel plate capacitor.
b. To determine the capacitance of two capacitors in parallel.
c. To determine the capacitance of two capacitors in series.

PROCEDURE -

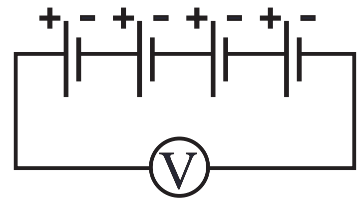


1. Connect up the circuit as shown to the right.
2. First be sure that the power supply built into the desk is turned **OFF** and the dial turned to **ZERO**!
3. Connect two clip leads to the red and black terminals of the power supply built into the desk. [Or other portable power supply as available.]
4. Connect the other ends of these clip leads to a voltmeter on top of the lab table.
5. From the voltmeter connect two other leads across a capacitor. Be sure that the polarity of the capacitor matches that of the power supply, negative to negative and positive to positive! [Electrolytic capacitors have the nasty habit of **exploding** when placed in a circuit with the wrong polarity!]
6. Now, connect another clip lead from the positive end of the capacitor to the positive terminal of the galvanometer, a second clip lead between negative end of the galvanometer and the decade box resistance and finally a third clip lead between the decade box and the negative end of the capacitor. At this point your circuit should be complete and should look like the diagram above.
7. Adjust the decade resistance box to a value of approximately R = 10,000 Ω. [This resistance may need to be adjusted up or down depending on how quickly the capacitor discharges. The purpose of the resistor is to discharge the capacitor at a controlled rate suitable for data collection.]
8. Turn the power supply **ON** and slowly turn up the power supply until the reading on the galvanometer, with the third button depressed, has reached 500 μAmperes. [It is a bit confusing , but the actual reading on the Galvanometer will be "50" when the current flow is 500 μAmperes.] A digital multimeter may be substituted for the galvanometer - using the microamp scale.
9. At this point the system is at equilibrium. That is, the capacitor is discharging through the decade resistance box at the same rate at which it is being recharged by the power supply.
10. Record the reading on the Voltmeter $\mathbf{V_o}$ and then disconnect one of the clip leads attached between the capacitor and the Voltmeter.
11. Record the reading on the Galvanometer **every 5 seconds** until the reading falls below 20 μAmperes. [Remember that 20 μAmps will correspond to "2" on the galvanometer scale!]
12. Repeat step 11. If the reading are substantially the same you have completed this portion of the lab procedure.
13. Make a graph plotting the current flowing out of the capacitor as a function of time. From this graph determine the total charge stored in the capacitor either by determining the area under the curve by **counting the number of blocks** under the curve and then multiplying this number by the area of each block, and by **determining the equation of the line** and then determine the **area by integrating between zero and infinity**. Compare these two values.
14. Calculate the capacitance of the capacitor $\mathbf{C_m}$ by taking the ratio of charge stored to the voltage applied.
15. Compare this value to the given capacitance. Make the appropriate bar graph comparing the **capacitance value printed on the capacitor C** with the **measured capacitance $\mathbf{C_m}$ of this capacitor**.
16. Remove the above capacitor from the circuit and replace it by two different, but comparable, **capacitors connected in parallel**. Repeat steps 7 - 15 above until you have determined the total capacitance of two capacitors connected in **parallel**. Compare this **measured, equivalent capacitance** with the corresponding **theoretical value** for **capacitors in parallel**.
17. Remove the above capacitors from the circuit and replace them by two different, but comparable, **capacitors connected in series**. Again repeat steps 7 - 15 above until you have determined the total capacitance of two capacitors connected in series. Compare this **measured, equivalent capacitance** with the corresponding **theoretical value** for **capacitors in series**.

Purpose: The goal of this lab is to become familiar with the basic laws of electricity and to then apply those laws to simple DC circuits.

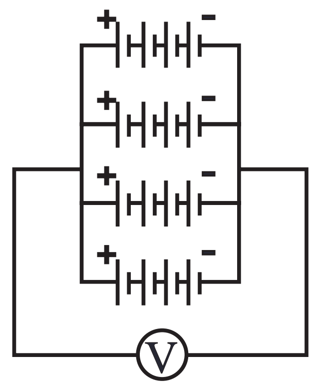
A. How is the potential difference generated by an electrochemical cell related to the number of cells connected in series?

1. Connect a single flashlight cell to a voltmeter and record the potential difference produced in volts. [Don't forget to record the estimated error!] [Note! Any time you use a meter be sure to record the meter's number and make sure that the meter is calibrated to zero before you use it!]
2. Increase the number of cells in series [positive to negative!] one cell at a time until you can determine the relationship between the number of cells in series and the potential difference produced. Support your conclusion with concrete evidence!
3. With four cells in the battery holder reverse one of the cells and measure the resulting potential difference. Reverse a second cell and again record the potential difference. Determine the relationship between the potential difference produced and the number of cells reversed.



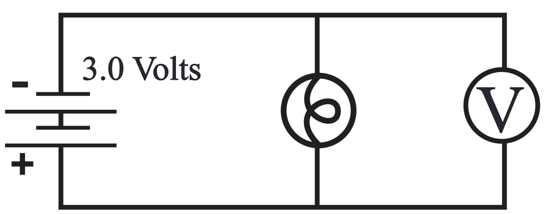
B. How is the potential difference generated by a battery [or cell] related to the number of batteries [or cells] connected in parallel?

4. Connect a voltmeter to a 6.0 volt battery and record the potential difference.
5. Connect a second 6.0 volt battery in parallel with the first battery and again record the potential difference.
6. Increase the number of batteries in parallel until you can determine the relationship between the number of batteries and the resulting potential difference. Explain!

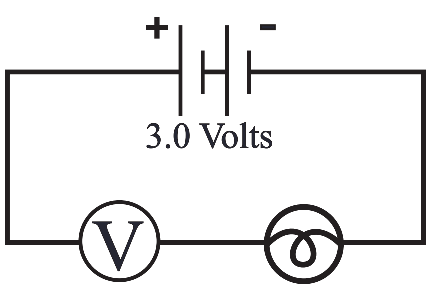


C. How should a voltmeter be connected in an electrical circuit?

7. Connect a 3.0 Volt battery to a light bulb [Make sure the light bulb lights!]. Add a voltmeter in parallel with the battery. Record the reading on the voltmeter and note if the light bulb still lights.



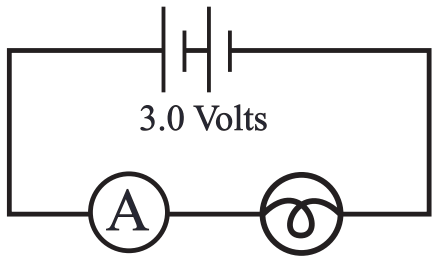
8. Connect a 3.0 Volt battery in series with a light bulb and a voltmeter. Record the reading on the voltmeter and note if the light bulb lights.



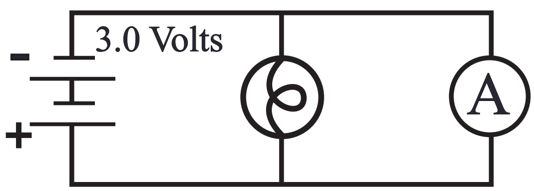
9. Which of the above configurations is the correct way to use a voltmeter? What is it about voltmeter design that accounts for the above results? Explain!

D. How should an ammeter be used in an electrical circuit?

10. Connect a 3.0 Volt battery in series with a light bulb and an ammeter. Record the reading on the ammeter and note if the light bulb lights.



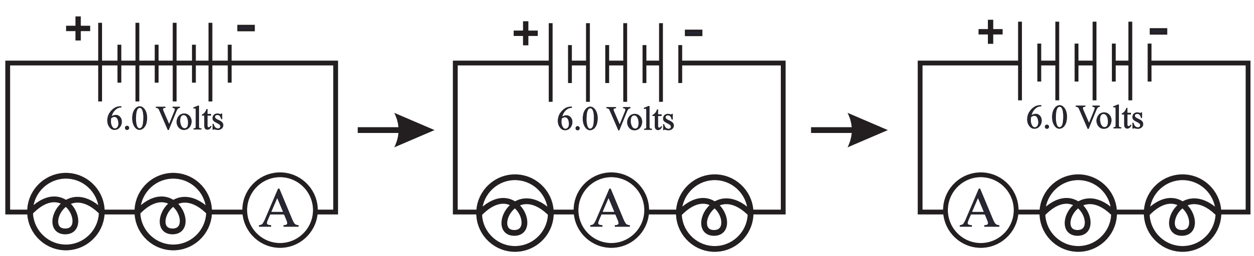
11. Connect a 3.0 Volt battery to a light bulb and note that light bulb lights. Carefully, connect an ammeter in parallel with the light bulb using the maximum current terminal only. If the meter "pegs" disconnect immediately! Determine if the light bulb lights with the ammeter connected in parallel with it.



12. Which of the above configurations is the correct way to use an ammeter? What is it about ammeter design that accounts for the above results? Explain and support with a bar graph!

E. What is the current like at different points in a series circuit?

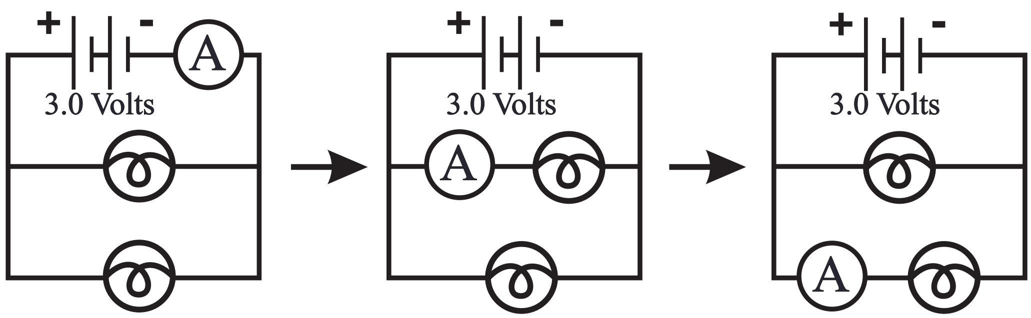
13. Connect a 6.0 Volt battery to two different light bulbs connected in series. Make sure that both light bulbs light before proceeding.



14. Disconnect the wire connecting the negative end of the battery from the light bulbs and insert an ammeter between the light bulbs and the battery. Record the current reading on the ammeter. Remove the ammeter and reconnect the circuit.
15. Disconnect the wire between the two light bulbs, insert an ammeter in the circuit between the two light bulbs and reconnect. Record the current reading on the ammeter. Remove the ammeter and reconnect the circuit.
16. Disconnect the wire connecting the positive end of the battery from the light bulbs and insert an ammeter between the light bulbs and the battery. Record the current reading on the ammeter. Remove the ammeter and reconnect the circuit.
17. How do the currents compare in each part of this series circuit? What can you conclude about the current at different points in a series circuit? Why is this so? Explain and support with a bar graph!

F. What is the current like at different points in a parallel circuit?

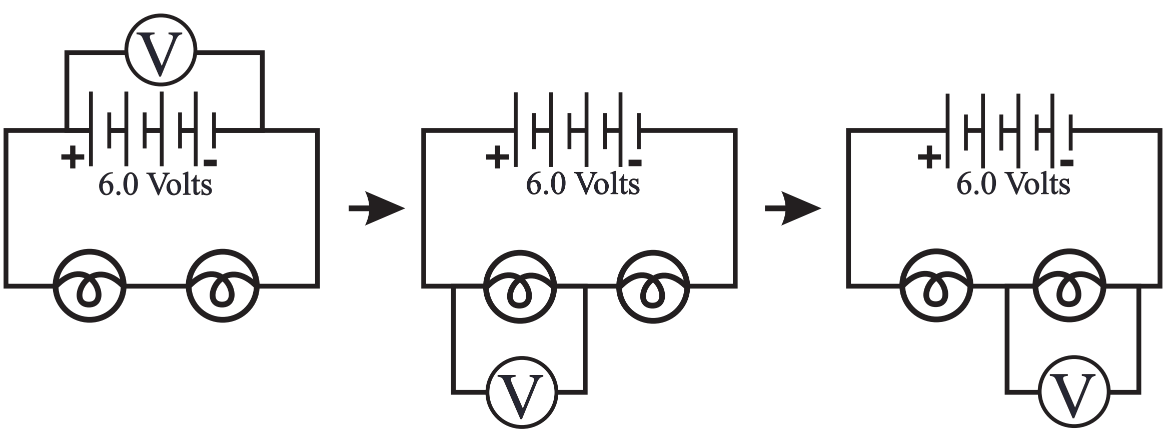
18. Connect a 3.0 Volt battery to two different light bulbs connected in parallel. Both light bulbs should light.



19. Measure the current flowing through the battery by disconnecting one of the clip leads from the battery and then inserting an ammeter in series with the battery. Record the current flowing through the battery and then remove the ammeter from the circuit. Disconnect one end of one of the light bulbs, insert an ammeter in series with this light bulb, record the current and then remove the ammeter from the circuit.
20. Disconnect one end of the other light bulb, insert an ammeter in series with this second bulb, record the current and then remove the ammeter from the circuit.
21. What is the mathematical relationship among the currents through each of the light bulbs separately and the total current flowing through the battery? Explain and support with a bar graph!

G. What is the relationship among the potential differences across each light bulb and the potential difference across the battery in a series circuit.

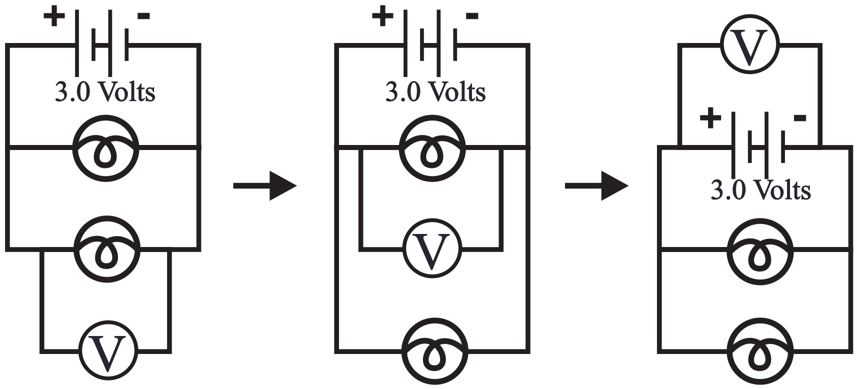
22. Connect a 6.0 Volt battery to two different light bulbs in series.
23. Connect a voltmeter in parallel with the battery, record the voltage and then disconnect the voltmeter.



24. Connect a voltmeter in parallel with the first light bulb, record the voltage and then disconnect the voltmeter.
25. Connect a voltmeter in parallel with the second light bulb, record the voltage and then disconnect the voltmeter.
26. What is the mathematical relationship among these three potential differences? Explain and support with a bar graph!

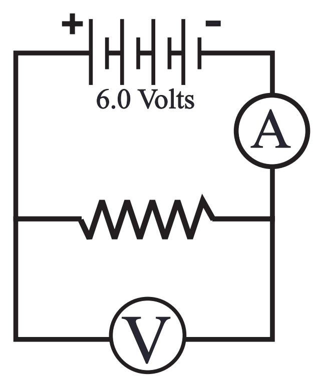
H. What is the relationship among the potential differences across circuit elements connected in parallel?

27. Connect a 3.0 Volt battery to two light bulbs connected in parallel. Make sure both bulbs light.



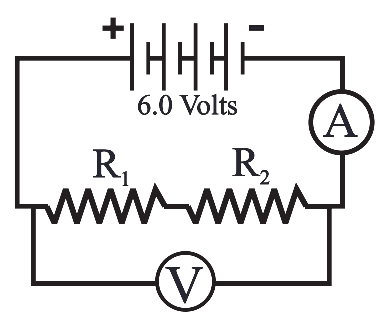
28. Connect the voltmeter across the first light bulb, record the voltage and then remove the voltmeter.
29. Connect the voltmeter across the second light bulb, record the voltage and then remove the voltmeter.
30. Connect the voltmeter across the battery, record the voltage and then remove the voltmeter.
31. What is the mathematical relationship among these three potential differences? Explain!

I. How is the current flow through a circuit related to the voltage applied and the resistance of the circuit element? [Ohm's Law]



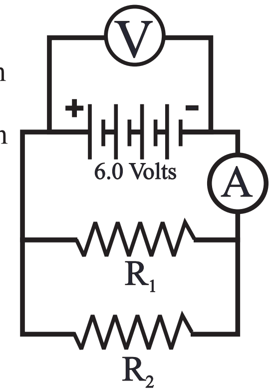
32. Connect a 6.0 Volt battery to a resistor and an ammeter connected in series. Record the reading on the ammeter before proceeding. If there is no reading on the ammeter it may be necessary to move to a more sensitive meter!
33. Connect a voltmeter in parallel with the resistor. Record the reading on the voltmeter. [When you add the voltmeter, does the reading on the ammeter change? Why?]
34. Calculate the resistance of the resistor by dividing the potential difference across the resistor by the current flowing through the resistor.
35. Remove the resistor from the circuit and then measure the resistance of the resistor using a multimeter.
36. Determine the theoretical resistance of the resistor from the resistor color code. Record the colors of each resistor as data! [Each colored band represents a number; black 0, brown 1, red 2, orange 3, yellow 4, green 5, blue 6, violet 7, gray 8, white 9. The first band represents the first digit of the code, the second band represents the second digit of the code, the third digit represents the power of ten and the fourth band represents the error: gold 5%, silver 10% and none 20%. For example the four colored bands "Brown, black, red, gold" would represent 10×10^2 +/- 5%. One exception, gold in the third band represents 10^{-1}!]
37. Compare the resistance value from the resistor code, the value from the voltmeter-ammeter method, and the value from the multimeter. Did you successfully verify Ohm's Law?

J. How is the total resistance of resistors used in series related to the separate resistances?



38. Select two resistors which have different values but are of the same order of magnitude. Connect these two resistors in series with one another and with a 6.0 Volt battery.
39. Measure the current flowing through these two resistors as well as the potential difference across both of them together and determine their combined resistance.
40. Measure the resistance of the two resistors in series with a multimeter set up to operate as an ohmeter.
41. Determine the total resistance of these two resistors in series by using the resistor code.
42. Make a bar graph comparing the total resistance determined by the voltmeter - ammeter method, by using the multimeter and by using the resistor code.

K. How is the total resistance of resistors used in parallel related to the separate resistances.



43. Select two resistors which have **different values** but are of the **same order of magnitude**. Connect these two resistors in parallel with one another and with a 6.0 Volt battery as shown to the right. Measure the current flowing through these two resistors as well as the potential difference across both of them together and determine their combined resistance.
44. Remove the two resistors from the battery and then measure their combined resistance in parallel with a multimeter set up to operate as an ohmeter.
45. Determine the total resistance of these two resistors in parallel by using the resistor code.
46. Make a bar graph comparing the total resistance determined by the voltmeter - ammeter method, by using the multimeter and by using the resistor code.

L. Every electrical circuit element has some resistance, even sources of EMF such as batteries! How do you determine the internal resistance of a battery?

47. Connect a 6.0 Volt battery to a voltmeter and determine the **"open circuit voltage"**. [The "open circuit voltage" is the EMF of the battery or the potential difference the battery is capable of generating in the absence of current flow.]
48. Briefly connect this battery to the maximum scale of an ammeter and determine the **"short circuit current"**. [The "short circuit current" is the maximum current the battery is capable of producing in the absence of any appreciable load resistance.]
49. Divide the **"open circuit voltage"** by the **"short circuit current"** to determine the internal resistance **r** of the battery.
50. Connect this battery in series with a **high power 5-10 Watt** resistor [This resistor is a small rectangular box about 1/4" x 1/4" x 3/4" in size.] and an ammeter [be sure to use the maximum scale to start!]. Record the current flowing in the circuit.
51. Measure the potential difference across the battery while attached to this load. [the **"terminal voltage"**]
52. The voltage drop across the **internal resistance** of the battery can now be calculated by taking the **difference** between the **EMF** of the battery and the **"terminal voltage"** of the battery while under load. Divide this voltage difference by the current flowing through the battery to get the internal resistance **r** of the battery.
53. Compare the internal resistance of the battery determined in step 49 above with that determined in step 52.

M. How is the resistance of a wire related to the length of the wire?

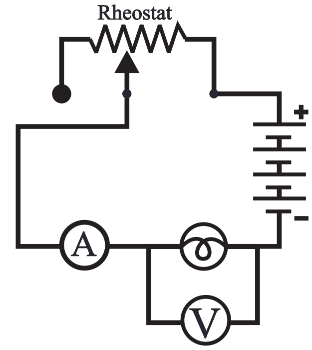
54. Take a spool of Nichrome wire and unwind about 25 cm of wire [Please, do **not** cut the wire!]. Determine the resistance of the wire using whatever procedure you prefer. [Be careful here, Nichrome wire is the resistance wire used in toasters, hair driers etc. and **the wire may get hot!**]
55. Repeat the above procedure with 50 cm, 75 cm and 100 cm of the same wire.
56. Plot a graph comparing the resistance of your Nichrome wire as a function of length and determine the relationship from the shape of the graph.
57. How is the resistance of a wire related to the length of the wire? You are expected to support your answer with **specific**, **quantitative** evidence.

N. How is the resistance of a wire related to the cross section [The cross section of a wire is the circular area exposed when the wire is cut cleanly.] of the wire?

58. Select at least three different gauges of Nichrome wire and determine the cross section of each.
59. Measure the resistances of equal lengths of these three different pieces of Nichrome wire. [50 cm would be fine.]
60. Plot a graph comparing the resistance of these three wires as a function of their cross sectional areas.
61. From the shape of the resulting graph determine the relationship between the resistance of a wire and the wire's cross sectional area.
62. Use the relationship determined from the graph to predict the resistance of one of your wires and make an appropriate bar graph.

Gauge	Diameter	Cross Section
10	2.588 mm	5.261 mm^2
12	2.053 mm	3.309 mm^2
14	1.628 mm	2.081 mm^2
16	1.291 mm	1.309 mm^2
18	1.024 mm	0.823 mm^2
20	0.812 mm	0.518 mm^2
22	0.644 mm	0.326 mm^2
24	0.511 mm	0.205 mm^2
26	0.405 mm	0.129 mm^2
28	0.321 mm	0.081 mm^2
30	0.255 mm	0.051 mm^2
32	0.202 mm	0.032 mm^2
34	0.160 mm	0.020 mm^2

O. What is the relationship between the resistance of a wire and the wire's temperature?



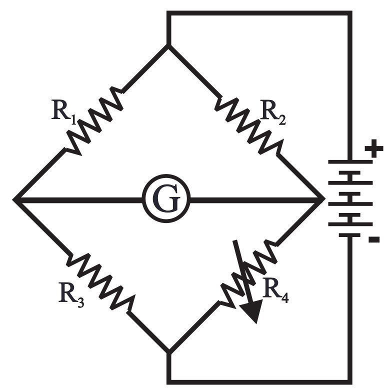
63. Connect a series circuit consisting of a 3.0 Volt battery, a light bulb, a variable slide wire resistor [rheostat] and an ammeter. Connect a voltmeter in parallel with the light bulb.
64. Adjust the rheostat until the light bulb is barely lit [cool] and determine the resistance of the light bulb.
65. Adjust the rheostat until the light bulb is very bright [hot] and determine the resistance of the light bulb.
66. How is the resistance of the light bulb filament [which is, after all, a wire] affected by the temperature? You are expected to support your answer with specific evidence.

P. How is the resistance of a conducting wire determined and what is the resistivity ρ of a material?

Material	Resistivity
Aluminum	2.82 x 10^{-8} W m
Brass	7.00 x 10^{-8} W m
Copper	1.72 x 10^{-8} W m
Gold	2.44 x 10^{-8} W m
Iron	10.0 x 10^{-8} W m
Nichrome	115. x 10^{-8} W m
Nickel	7.80 x 10^{-8} W m
Silver	1.59 x 10^{-8} W m

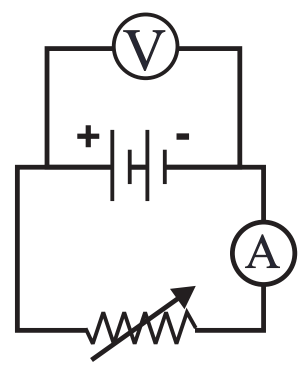
67. Measure out a 50 cm length of Nichrome wire.
68. Determine the **cross section of the wire** and then measure the **resistance** of the wire using a multimeter.
69. Calculate the **resistivity** of the wire and compare this value on a bat graph to the theoretical value of resistivity ρ for Nichrome.

Q. Using a bridge circuit [Wheatstone Bridge to be exact!] to measure the resistance of an unknown resistance.



70. Connect up the circuit shown at the right where R_1 and R_2 are equal resistance, R_3 is the **"unknown"** and R_4 is a **"decade resistance box"**. Record all resistance values including the colors! It is easiest if you first connect the fours resistors in a loop and then add the galvanometer and the battery. Being neat will make this procedure much easier!
71. To determine the value of your **"unknown"** resistance (R_3) first push button #1 on the **galvanometer** and then adjust the **decade resistance** until the needle on the galvanometer approaches zero. Then move to button #2 and repeat. Finally, move to button #3 and fine tune your adjustment to the decade box until the galvanometer reads as close to zero as possible. At this point note the value on the decade resistance box and compare to the **"unknown"** resistor R_3.
72. Repeat with a second, different "unknown" resistance to test your understanding of the procedure. Compare the "unknown" resistance with that determined by either a multimeter of the resistor code.
73. How does this circuit and this procedure enable you to determine the **"unknown"** resistance? Explain!

R. How do you measure the power delivered to the load [the part of any electrical circuit that consumes the energy!] in a circuit, under what conditions will maximum power be delivered and under what conditions will the delivery of that power be most efficient?



74. Select a 6.0 Volt battery and determine its **EMF**.
75. Connect up a series circuit consisting of this 6.0 Volt battery, a rheostat and an ammeter. Connect a voltmeter in parallel with the battery.
76. Adjust the rheostat until the reading on the voltmeter is ½ the EMF. What is the relationship between the resistance of the load **R** and the internal resistance **r** of the battery under these conditions?
77. Record the **current** and the **terminal voltage** of the battery.
78. Calculate the **power** delivered to the **load resistance**. [current through load x voltage drop across load]
79. Calculate the **power** consumed by the **internal resistance**. [current through battery x voltage drop across the internal resistance of the battery.]
80. Calculate the **total power** supplied by the battery. [the sum of 78 & 79]
81. Adjust the rheostat until the reading on the voltmeter is **2/3** the **EMF** and then repeat steps 77-80 above.

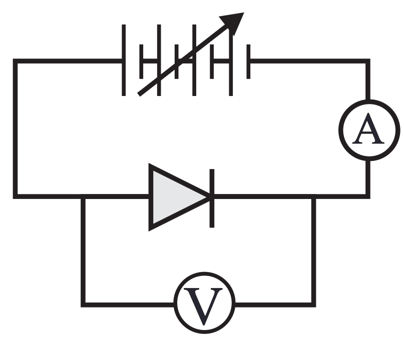
82. Adjust the rheostat until the reading on the voltmeter is **1/3** the **EMF** and then repeat steps 77-80 above.
83. Assemble the above results into a well organized data chart.
84. In which of these three cases does the **load** receive the **most power**?
85. In which of these three cases is the **largest percentage** of the **power** delivered to the **load**?
86. In which case would the battery **last the longest**?

S. What is the relationship between the heat delivered by an electrical circuit, the amount of current supplied, the voltage supplied and the time? [Joule's Law]

87. Get a Styrofoam cup which has a resistor glued into the bottom. Fill the cup with exactly 50 grams of water [use a graduated cylinder!].
88. Connect two clip leads from the power supply built into the desk to a voltmeter on the tabletop. [Use this as your power supply.] Be sure that the power supply is turned down to zero!
89. Connect the Styrofoam cup of water in series with an ammeter and the voltmeter, which is attached to the power supply. [Power is still off!]
90. Put a thermometer through the hole in the supplied Styrofoam lid and place on the cup. Record the **initial temperature T_i**.
91. Turn up the power supply to 10 Volts. **Immediately and continuously** swirl the water in the cup for a period of **200 seconds**. Record the **current flowing I** through the cup and the **potential difference V** across the cup.
92. At the end of 200 seconds disconnect the power supply and measure the **final temperature T_f** of the water in the cup. [Allow a few seconds for the heat to be transferred to the water.]
93. Calculate the **electrical work** done by the electrical current during these 200 seconds. [Joule's Law]
94. Calculate the amount of heat added to water based on the specific heat of water [$c = 4.19$ J/gm^{o}C], the mass of water and the change in temperature. **[$\Delta Q = mc\Delta T$]**
95. Compare the **heat gained** by the water with the **electrical work** done and determine if Joule's Law is valid.

T. How is the resistance of a diode, an active circuit element, different from the resistance of resistor?

96. Connect two clip leads from the power supply built into the desk to a voltmeter on the tabletop. [Use this as your power supply.] Be sure that the power supply is turned down to zero to start!
97. Connect a diode in series with an ammeter and a voltmeter.



98. Slowly turn up the power to the circuit in **increments of 0.2 Volts** until the current reaches a maximum of **2.0 Amperes** or until the voltage reaches **2.2 Volts**. For each increment record the current through the diode, the voltage drop across the diode and calculate the resulting **resistance**.
99. **Plot a graph** comparing the resistance of the diode as a function of the applied voltage.
100. Reverse the orientation of the diode and repeat steps 98 & 99.
101. How does the resistance of a diode vary with the direction and magnitude of the applied voltage? Now is this different from a resistor? Support your conclusion with **specific** evidence.

[The End!]

PHYSICS LAB #34 BACKGROUND RADIATION AND THE PENETRATING ABILITIES OF α, β, AND γ RADIATIONS

GOAL - The goals of this lab are:

a. to measure the background radiation in the classroom.

b. to measure the relative penetrating ability of three types of nuclear radiation; a, ß and g

GENERAL PROCEDURE -

1. Acquire a Geigercounter setup including; amplifier, speaker, scalar, **GM** tube and holder, and a stopwatch.
2. Plug the scalar into the amplifier, plug the **GM** tube between the 450 Volt terminal of the scalar and the positive input of the amplifier.
3. Plug in the amplifier and turn the power on. Adjust the **DC OFFSET** to approximately zero and adjust the gain to about 40-50. Set the scalar switches to **GATE** and **APS OUT**. Slide the switch on the amplifier to **AC**.
4. Place any radioactive source under the **GM** tube and note that the scalar should be counting and the speaker should be clicking.
5. Push the **RESET** button and notice that the scalar count returns to zero. Push the MANUAL button and note that the counting stops. The normal procedure during any measurement will be to;

   a. Press the **MANUAL** button to stop the counting.

   b. Press the **RESET** button to set the scalar to zero.

   c. Start the stopwatch and press **MANUAL** simultaneously.

   d. At the proper time press **MANUAL** to stop the counter.

   e. Record the number of counts , divide by the measured time and then subtract out the background count rate to determine the effective count rate.

[The following four procedures can be done in any order.]

BACKGROUND RADIATION

6. Make sure that there are no radioactive sources in the immediate area!
7. Press **MANUAL** to stop the counter and press **RESET** to set the counter to zero.
8. Start the stopwatch and press **MANUAL** simultaneously and measure the background count for **at least** 10 minutes.
9. At the end of ten minutes press **MANUAL** to stop the counter, record the number of counts and calculate the background count rate.

ALPHA DECAY

10. Acquire an **Alpha** source (Which will probably be a sample of Lead 210 present in the eye of the sewing needle!) and use a small piece of tape to fix the eye of the needle immediately below the center of the GM tube so that the sample will not move during the experiment. Be sure to leave space between the **GM** tube and the radioactive sample.
11. From the chart of nuclides look up and record; the type of decay, the radioactive half-life, the energy of the decay particles, the probability of each decay mode, the daughter nuclide produced etc.
12. Based on the information acquired above write the appropriate, balanced nuclear equation for the decay of you alpha source.
13. **CAREFULLY**, remove the red cover from the end of the **GM** tube. Be **VERY** careful! The end window of the GM tube is extremely fragile and the tube is **EXPENSIVE** to replace!
14. **RESET** the scalar to zero, set your stopwatch to zero. Start the stopwatch and press **MANUAL** simultaneously. Allow the scalar to count for exactly 100 seconds. At the end of this time interval press **MANUAL** to stop the counter, record the count, divide by the time and subtract out the background to determine and record the effective count rate.
15. Place a very thin sheet of polyethylene plastic between the **GM** tube and the alpha source. Repeat step #14.
16. Continue to add additional layers of plastic until the count rate has decreased to about 10% of the initial value.
17. Determine the mass density [in mg/cm2] of the polyethylene by dividing the mass of a sheet of polyethylene by the area of the sheet and record the mass density of the polyethylene.
18. Make a graph comparing the effective count rate as a function of the absorber thickness in mg/cm^2. From this graph determine the amount of matter needed to reduce the count rate to ½ the initial count rate. This value is the **HALF-THICKNESS** for this alpha source. [Relate this to the type and energy content of the emitted radiation!]

BETA DECAY

19. Acquire a **Beta** source (Which will probably be a sample of **Carbon 14** or **Thallium 204**.) and use a small piece of tape to fix the sample immediately below the center of the **GM** tube so that the sample will not move during the experiment. **Be sure to leave plenty of space between** the **GM** tube and the radioactive sample for the absorbers.
20. From the chart of nuclides look up and record; the type of decay, the radioactive half-life, the energy of the decay particles, the probability of each decay mode, the daughter nuclide produced etc.
21. Based on the information acquired above write the appropriate, balanced nuclear equation for the decay of your **Beta** source.
22. **RESET** the scalar to zero, set your stopwatch to zero. Start the stopwatch and press **MANUAL** simultaneously. Allow the scalar to count for exactly 100 seconds. At the end of this time interval press **MANUAL** to stop the counter, record the count, divide by the time and subtract out the background to determine and record the effective count rate.
23. Place a very thin sheet of polyethylene plastic [or a thin notecard] between the **GM** tube and the **Beta** source. Repeat step #22.
24. Continue to add additional layers of plastic [or notecards] until the count rate has decreased to about 10% of the initial value.
25. Determine the mass density [in mg/cm^2] of the polyethylene [or the notecards] by dividing the mass of a sheet of polyethylene [or notecard] by the area of the sheet and record the mass density of the polyethylene [or notecard].
26. Make a graph comparing the effective count rate as a function of the absorber thickness in mg/cm^2. From this graph determine the amount of matter needed to reduce the count rate to ½ the initial count rate. This value is the **HALF-THICKNESS** for this **Beta** source. [Relate this to the type and energy content of the emitted radiation!]

GAMMA DECAY

27. Acquire a Gamma source (Which will probably be a sample of **Barium 137m**.) and use a small piece of tape to fix the sample below the center of the GM tube so that the sample will not move during the experiment. Be sure to leave a space of **<u>at least 5 cm</u>** between the **GM** tube and the **radioactive sample**.
28. From the chart of nuclides look up and record; the type of decay, the radioactive half-life, the energy of the decay particles, the probability of each decay mode, the daughter nuclide produced etc.
29. Based on the information acquired above write the appropriate, balanced nuclear equation for the decay of your Gamma source.
30. **RESET** the scalar to zero, set your stopwatch to zero. Place a single sheet of Lead between the GM tube and the Gamma source [To eliminate all of the Beta particles!] Start the stopwatch and press **MANUAL** simultaneously. Allow the scalar to count for exactly 100 seconds. At the end of this time interval press **MANUAL** to stop the counter, record the count, divide by the time and subtract out the background to determine and record the effective count rate. [This is the first point for your graph.]
31. Continue to add additional layers of **Lead** [add 10 layers each time] until the count rate has dropped to about 10% of the initial value. Repeat step #30.
32. Determine the mass density [in mg/cm^2] of the Lead by dividing the mass of a sheet of Lead by the area of the sheet and record the mass density of the Lead.
33. Make a graph comparing the effective count rate as a function of the absorber thickness in mg/cm^2. From this graph determine the amount of matter needed to reduce the count rate to ½ the initial count rate. This value is the **HALF-THICKNESS** for this **Gamma** source. [Relate this to the type and energy content of the emitted radiation!]

GOAL - The goals of this lab are;

a. to measure the half life of a radioactive isotope.

b. to develop an equation for predicting the activity of a radioactive sample at any future time

PROCEDURE -

1. Acquire a Geigercounter setup including; amplifier, speaker, scalar, GM tube and holder, and a stopwatch.
2. Plug the scalar into the amplifier, plug the **GM** tube between the 450 Volt terminal of the scalar and the positive input of the amplifier.
3. Plug in the amplifier and turn the power on. Adjust the **DC OFFSET** to approximately zero and adjust the gain to about 40-50. Set the scalar switches to **PULSE** and **APS OUT**. Slide the switch on the amplifier to **AC**.
4. The radioactive material for this lab will be a sample of the short lived isotope Barium 137m.
   a. Fill the small plastic bottle found in the Cs 137 / Ba 137m kit with 1.0 Normal HCl solution to the fill line visible on the side of the bottle.
   b. Insert the plastic nipple into the large opening of the radioactive “cow” and insert the other end of the “cow” into a dropper bottle.
   c. Apply gentile pressure to the plastic bottle so as to force about 1 drop per second through the “cow” so as to “milk” the “cow” of the soluble Ba 137m. [The Barium is soluble in 1.0 Normal HCl while the Cesium is not.]
   d. After the bottle of HCl has all passed through the “cow”, quickly put the cap on the bottle, insert the bottle under the GM tube and immediately begin counting.
   e. **Wash your hands NOW**!
5. With the radioactive Ba 137m source under the GM tube press the RESET on both the timer and the scalar simultaneously and begin counting.
6. Record the count on the scalar every ten seconds until the counting rate falls below the background radiation. [About 10 minutes!]
7. Determine the counts for each ten second interval, divide by ten seconds and then deduct the background radiation to determine the **effective count rate**. [Note that these count rates will correspond to times of 5 sec, 15 sec, 25 sec etc.]
8. Make a graph comparing the effective count rate of the Ba 137m as a function of time.
9. From this graph determine the **Half-life** of Ba 137m. [To do this determine the initial count rate at t = 0 seconds and find out from the graph how long it takes for the count rate to drop to ½ of this initial rate. this time will be the **Half-life.**]
10. Determine the theoretical **Half-life** of Ba 137m from the chart of the nuclides and compare to the measured **Half-life**.
11. Determine the equation of the curve on your graph and test this equation by substituting in some time value for which you know the count rate and see how well your equation can predict the activity **A** of your radioactive sample at a future time.

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