# REALITY PHYSICS

## Calculus Based

### Twentieth Edition Fall 2013

By
K.W. Nicholson

Central Alabama Community College

# Lab Manual

# 2013 Physics 213 Lab Manual Table of Contents

# Lab Orientation

1. Precision & Accuracy are a bit of a conundrum

Precision is a measure of how finely an instrument can make measurements.

Accuracy is indicated by something called "uncertainty" which has several levels of difficulty. We will only venture to the first level.

A LMD (length measuring device) whose smallest increment is 1 inch has a precision of 1 inch. One should be able to estimate measurements to the nearest half inch with an uncertainty of ± 1/4 inch. That is, if you estimate it to be 1 1/2 inches, it is certainly somewhere between 1 1/4 and 1 3/4. Hence, we assume the maximum distance you can be off is 1/4 inch.

Accuracy is also a measure of just how correct an experimental result is.

In some cases, the exact correct value is known, in which case the percent error in an experimental result can be calculated as $\%\text{ error} = \dfrac{|\text{experimental value} - \text{correct value}|}{\text{correct value}} \times 100$

In other cases, an actual value is unknown, in which case results are obtained by two different methods and a measure of accuracy can be obtained as

$$\%\text{ difference} = \frac{|\text{experimental value}_1 - \text{experimental value}_2|}{\text{experimental value}_1 + \text{experimental value}_2} \times 200$$

2. Things we can measure

length m
mass kg
time s
temperature C

3. Combo's

density r = mass / volume
Newton N = kg m / $s^2$
Joule J = N m
speed v = m/s
velocity **v** = m/s
acceleration m / $s^2$
momentum p = kg m/s

4. You are expected to set up you own lab equipment and put it away when you finish.

# Guide to Lab Write-up

1. Title page - must include experiment number & title, course, date, & names of people in the group.

2. Introduction- What and how?
What is our objective?
How do we plan to obtain it?

3. Data Sheet - organized, labeled with blanks to fill in, written up before class.

4. Analysis - Usually done on computer. **Results must appear here! This is the deliverable for the lab.**

5. DOA - (means Discussion of Analysis) Did we obtain expected results? If not, why not? Assessment of possible sources of error.

6. Conclusion - If we obtained our objective using the above procedure, we must put it here and give our opinion of it's validity and justification for this opinion (means state percent error, or percent difference).
**Remember, you must restate numerically the deliverables here!**

**Percent Difference between a and b =** $\frac{|a-b|}{a+b} \times 200$

**Percent error for experimentally determined value =** $\frac{|actual - experimental|}{actual} \times 100$

# Experiment 1 Measurement
## A Study of $\pi$

$\pi$ is defined to be the value of the ratio circumference / diameter of a circle and is believed to be the same value for all circles. A motion has been put forth in the US Senate (3 times in fact, the latest one in the 1980's), to assign the value 3 to this ratio. (No doubt motivated by religious zeal, see I Kings, chapter 7, verse 23 of the Holy Bible. Unfortunately, these "literalists" forgot to notice that God was speaking to people that had not yet invented fractions.)

Summoned as an expert counsultant, our job is to study $\pi$ and deliver an opinion, with data and analysis to support that opinion. Our objective, then, will be to obtain a relationship between circumference (C) and diameter (D) of any circle.
Translation: This means find a mathmatical relationship between C & D if possible.
Translation of the translation: This means find an **equation** C = some function of D.

Reasoning: If $\pi = C/D$ for any circle, then $C = \pi D$, which is a straight line through the origin of the C vs D graph whose slope equals $\pi$.

So all we have to do is take "enough" data, plot it on a C vs D graph, and see if it does appear to be a line through the origin, and if so, is three a reasonable value for this slope? Which means, if we did choose to use 3 for $\pi$, what would be our percentage error?

- So, first let's discuss measuring with rulers to the best accuracy of the instrument.

- Next let's take some data - What data would you suggest?

- Then let's analyze this data and see what it suggests.

- And finally, let's write a report ending with our conclusion.

**My Title Page**
**Experiment 1: Measurement**

**August 17, 2009**

**Principle Investigator:  Me**
**Co PI # 1  Fred**
**Co PI # 2  Martha**

# Introduction

# Exp. 1 Data Sheet

1. Data of Circumference and corresponding Diameter Values.

# DOA

# Conclusion

# Experiment 2 Velocity
# Determine average Speed of the Car

**1. By measuring time and distance.**

The plan:

a. Beginning at a point of origin, you will start the car and drop a bean bag every 5 seconds beside the car's current position.

b. Make a chart with colums for clock reading (t) and locations (x).

c. Plot this data using GA and create new columns delta t, delta x, and velocity (v) = delta x / delta t

d. Obtain plot of x vs t and the line of best fit.

e. Obtain plot for v vs t and compare the slope of the x vs t with the average value of v.

## Deliverable # 1:

The speed of the car using Graphical Analysis. (this will go in your conclusion.)

**2. By using the motion detector and Logger Pro.**

Place the motion detector on the floor behind the car .
Start the car and also click **collect** to start the program.

Use the distance vs time graph to determine the speed.
Use the velociy vs time graph to determine the speed.

## Deliverable # 2:

The speed of the car using Logger Pro. (This too will go in your conclusion.)

**3. Find the percent difference** between the value of velocity obtained in parts 1 & 2.

# Experiment 2:  Kinematics I

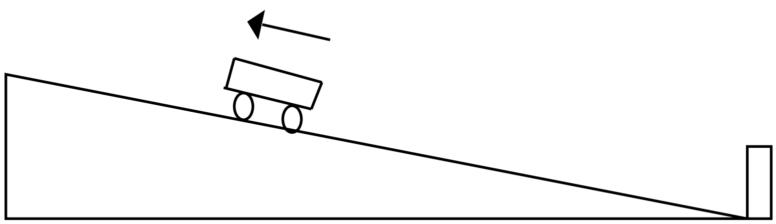
**Deliverable:** (means what you must deliver)  The equation for a vs t, v vs t and x vs t using first one end ot the ramp as the origin, (motion detector (MD) at the top of the ramp), then using the other end (MD at the bottom of ramp) as the origin.

Note:  You will analyze the motion beginning at the instant of release from your shove.

**Part I.   Motion detector at the top of the ramp:**

**Procedure:**

- Place the cart on an incline, with the motion detector at the top of the ramp, ( see figure).
- Give the cart a shove up the plane and allow it to return to the bottom of the ramp.
  **Note:  The cart must stop a minimum of .5 m from the MD on it's way up!**
- Use Logger Pro to obtain the a vs t, and the v vs t and x vs t graphs and then use these graphs along with CURVE FIT to obtain the requested relationships for the cart.



**Part II.   Motion detector at the bottom of the ramp:**

**Procedure:**

Place the motion detector at the bottom of the ramp and again give it a shove up the ramp.
Again use Logger Pro to obtain the requested equations.

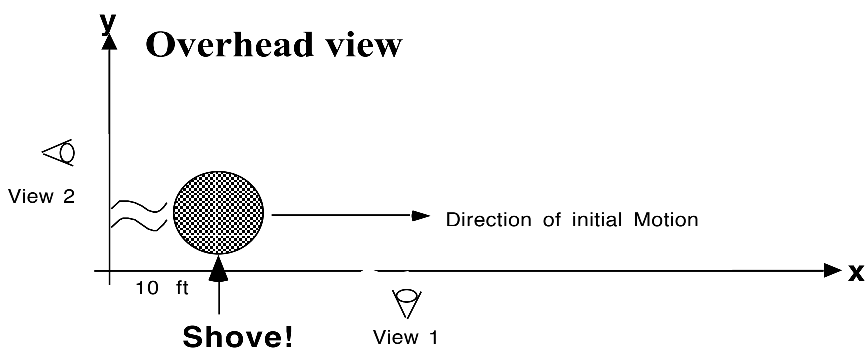
# Experiment 3a: StudyingTwo-Dimensional Motion

**OBJECTIVE:** This lab is part observation and part analysis. I want you to be able to predict the trajectory (path) of an object moving in two directions at once, given any combination of a shove and a constant force in the two directions. So your objective is to both analyze the motion mathematically and know what the motion diagrams and the trajectory look like. Predictions are an important learning tool for this lab so make sure you draw them clearly and neatly as they happen, **Turn them in before we do the lab!** They will be checked and returned, so you can compare with your results. Get a page and make two columns, one for predicted trajectories, x and y motion diagrams, and one for observed trajectories, x and y motion diagrams. Try to get **all** of them on the same page to turn in.

**APPARATUS:** Hovercraft, 25 lb spring scales, tape measure or a metersticks, bean bags, Computers and at least 2 (human) bodies.

## Write up Predictions and turn in BEFORE we do the activities.

**Motion 1: Object is initially moving with constant velocity in the x direction. then after moving 10 feet or so, it is suddenly given a shove in the y direction.**




1. Draw an overhead view of the path you think the rolling Hovercraft will take if you start it moving in a straight line then give it a sudden single shove sideways as shown ? (Use a dashed line)

2. Also draw a predicted a motion diagram for the craft in both the x and y directions.

3. Establish a line in the direction which the craft will receive it's initial shove, (x axis) and another line perpendicular to this line (y axis) so you can record the coordinates of the craft at each bean bag in a table.

4. Next place a bean bag on the x axis at the location where the two axes come together and another at the point at which the craft will receive it's sideways shove.

5. Then line up the Hovercraft with the x axis about 10 feet behind the point where it is to receive it's sideways shove, then give it a **gentle** shove in the x direction.

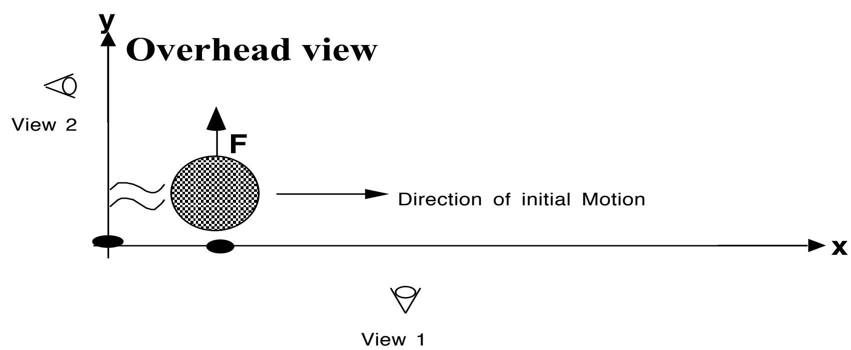
6. Make sure the designated BBD (Bean Bag Dropper) begins counting the instant the craft arrives at the **origin**. Also, get someone quick, we need bags dropped **every** second.
7. Have someone standing at the designated bean bag to give the Hovercraft a shove the instant it gets there.

8. Allow the craft to travel 30 feet or so after the second shove to get a good motion diagram.

9. Measure distances in both x and y directions to each point and record the locations in a time, x , y, chart.

10. Make a sketch of the observed trajectory.

11. Next hunker down behind the y axis and look at the bean bags so you can see the motion diagram in the y direction and draw that beside the y axis for this motion.




12. Then do the same for the motion diagram in the x direction.

13. Discuss differences between predicted and observed drawings if their are any.

14. **Question:** Does the craft begin to leave the x axis immediately after the shove sideways or is there a delay before the shove takes affect ?

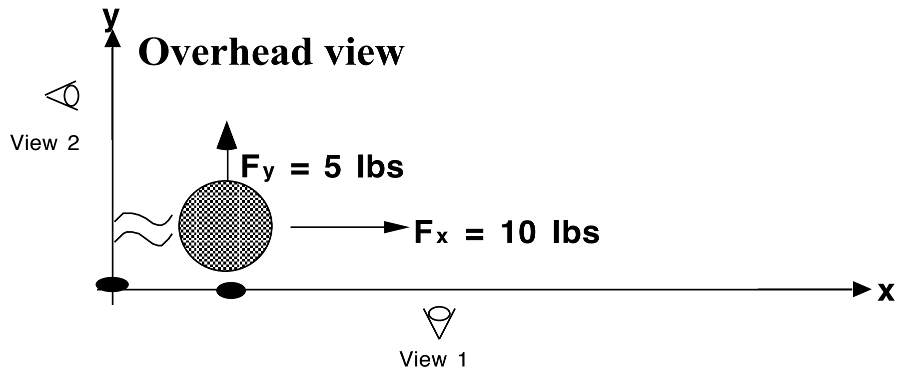
15. Analysis: Back in the lab, put the data into GA. Type in data for x distance (in meters)and y distance (in meters). Create a new column and name it Time (in seconds). Then create 2 more new comumns for velocity in both y and x directions, in m/s. To define velocity, in the bar at the top type vx=delta(x)/delta(t) for vx and vy=delta(y)/delta(t) for vy. Be careful, these values are case sensitive. Finally, obtain distance vs time and velocity vs time graphs in both the x and y directions. Also obtain a y vs x graph

**Motion 2: Hovercraft is initially moving in the x direction for about 10 feet, then at the bean bag someone suddenly begins to apply a constant force F = 5 lbs parallel to the y axis.**

Repeat steps 1 - 15 above for this motion.


Supported by NSF grant # 9352046

**Motion 3. Object is at rest at the origin when it is given a constant force of 10 lb in the x direction and a constant force of 5 lbs in the y direction.**




Repeat steps 1 - 15 above. Once you have obtained all your data and graphs, study these graphs and discuss them with your partners and other groups. There are some rather bizarre consequences you should notice and record in your conclusions about 2-D (and hence, 3-D) motion as well.

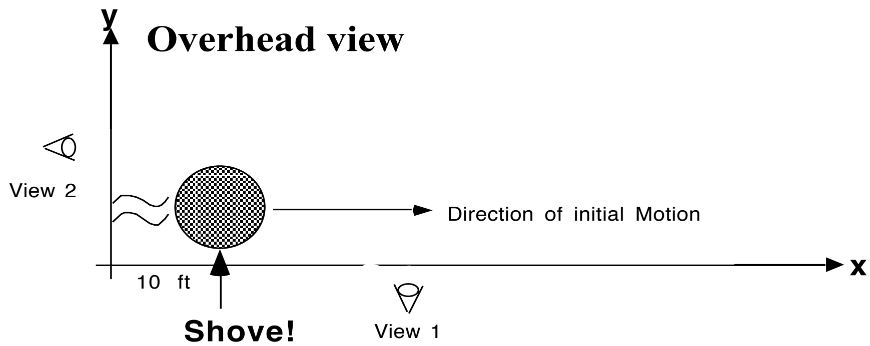
# Experiment 3a: StudyingTwo-Dimensional Motion

**Lab Sheets**

**Motion 1: Object is initially moving with constant velocity in the x direction. then after moving 10 feet or so, it is suddenly given a shove in the y direction.**

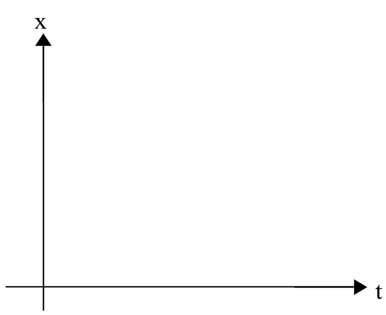
**Use a dotted line to predict the path taken by the hovercraft.**

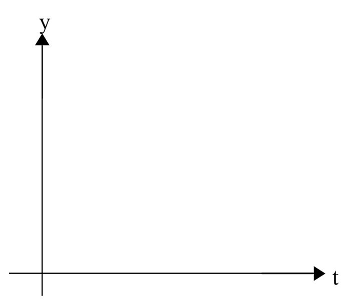
y - Motion diagram

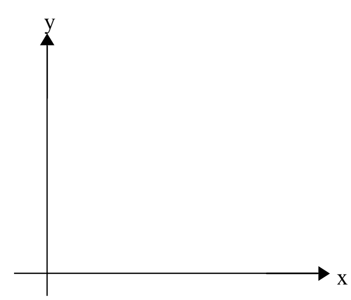


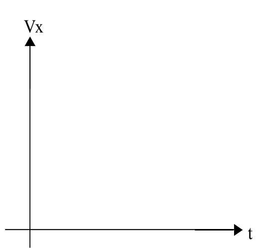

x - Motion diagram:

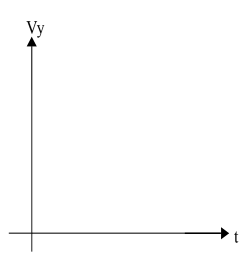
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| x | 0 | | | | | | | | | |
| y | 0 | | | | | | | | | |
| t | 0 | | | | | | | | | |



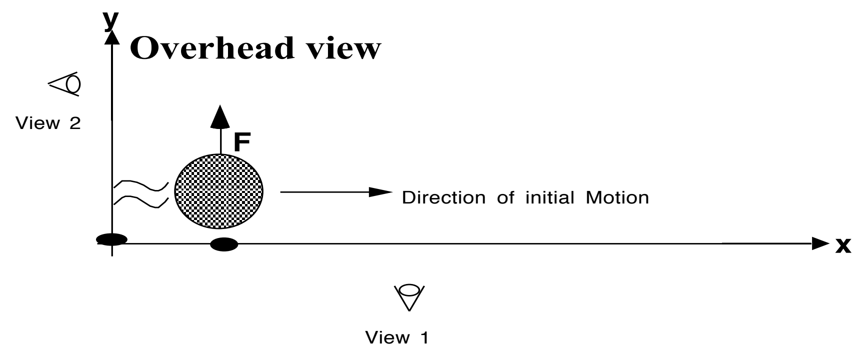


Supported by NSF grant # 9352046

**Motion 2: Hovercraft is initially moving in the x direction for about 10 feet, then at the bean bag someone suddenly begins to apply a constant force F = 5 lbs parallel to the y axis.**

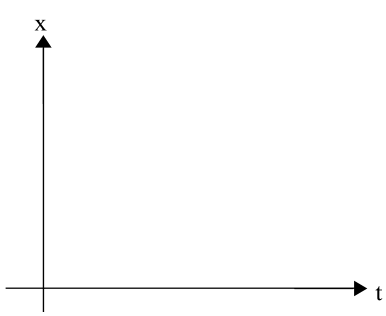
**Use a dotted line to predict the path taken by the hovercraft.**

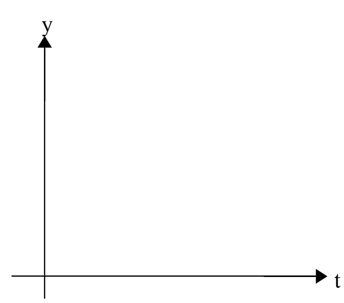
y - Motion diagram

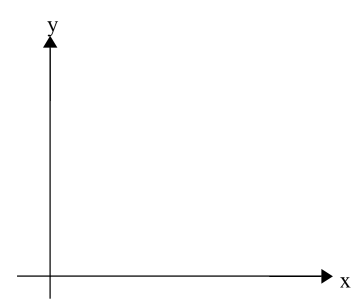


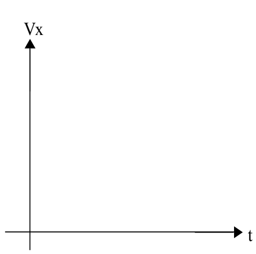

x - Motion diagram:

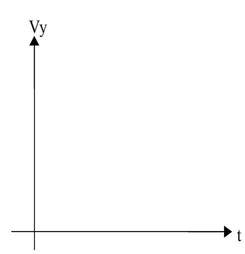
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| x | 0 | | | | | | | | | | |
| y | 0 | | | | | | | | | | |
| t | 0 | | | | | | | | | | |



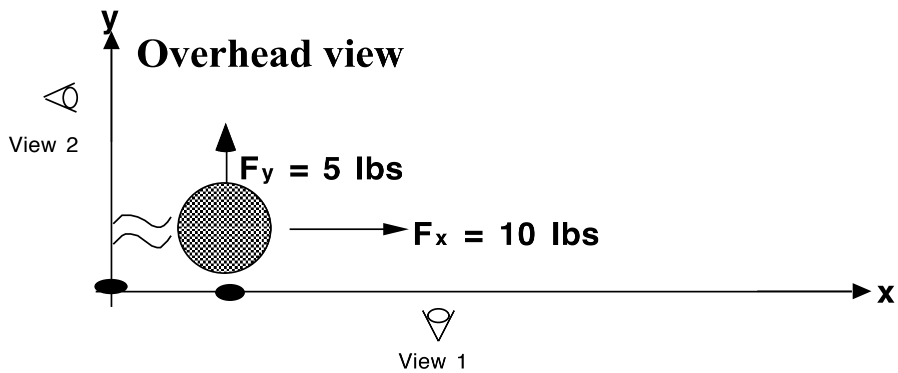



Motion 3. Object is at rest at the origin when it is given a constant force of 10 lb in the x direction and a constant force of 5 lbs in the y direction.

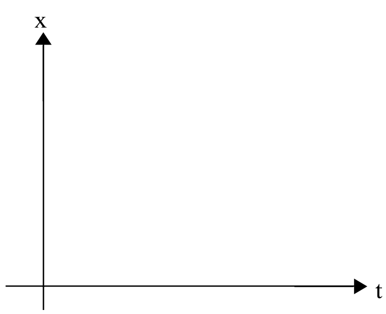
**Use a dotted line to predict the path taken by the hovercraft.**

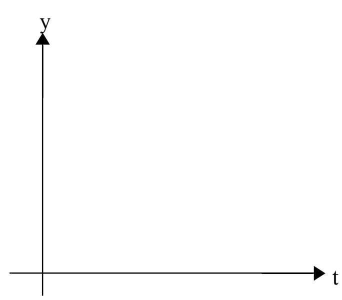
y - Motion diagram

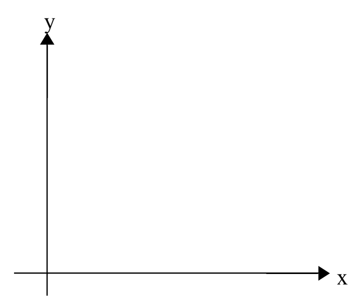


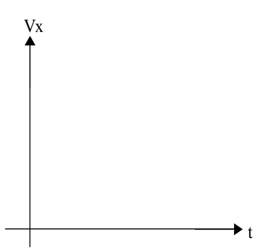

x - Motion diagram:

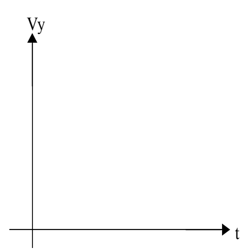
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| x | 0 | | | | | | | | | |
| y | 0 | | | | | | | | | |
| t | 0 | | | | | | | | | |



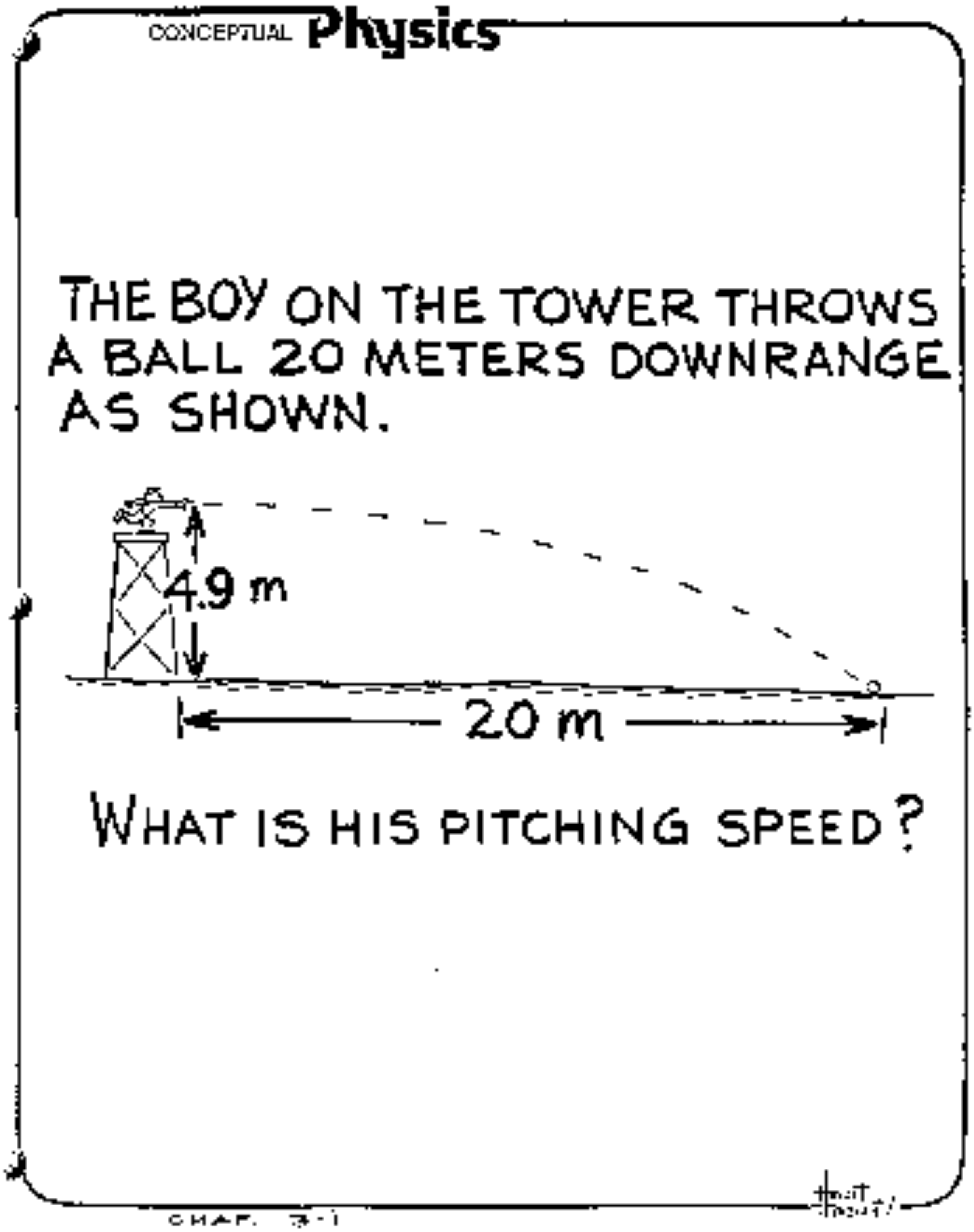



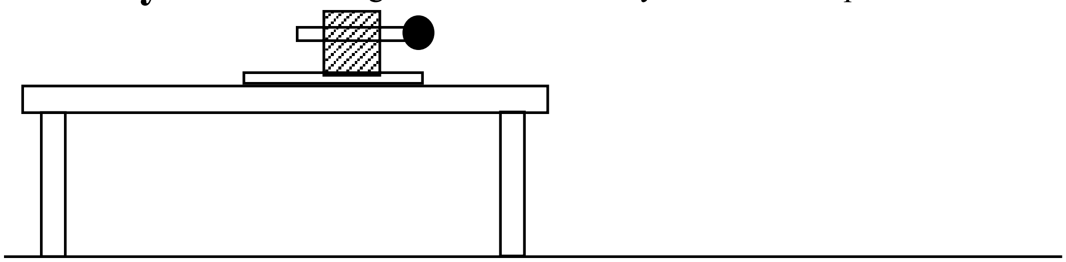



# Pre-lab Warmup



# Experiment 3: Projectile Motion

**Activity 1:** Determining the "muzzle velocity" of a ballistic pendulum.



What measurements must be taken ? Record measurements.
Calculate initial speed $v_o$ of the ball. Show calculations.

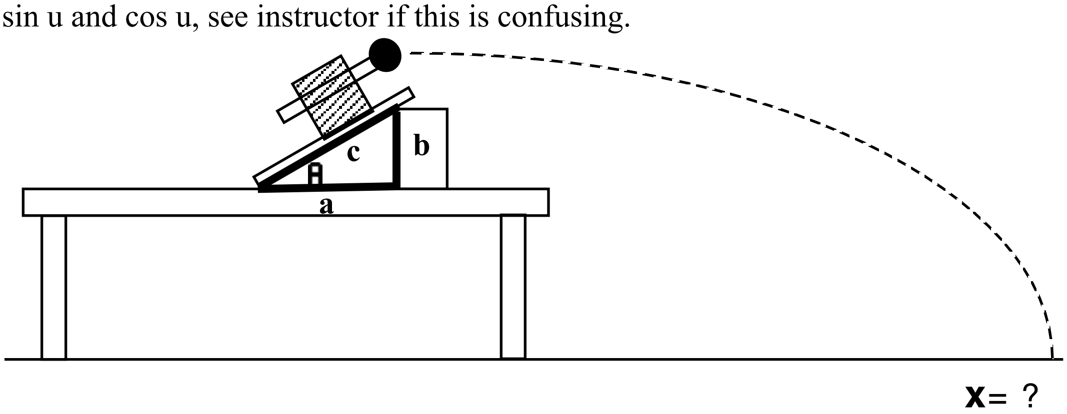
## Deliverable Before doing this experiment:

An equation for $v_0$ in terms of $y_0$ , $x_1$ , and g must be on your data sheet turned in before beginning the lab.

**Activity 2**: Predicting location of impact. (Which means you must calculate the location **before** launching the ball.) Use the muzzle velocity obtained in Activity 1 to predict the impact location of the ball.

**Deliverable BEFORE doing this experiment:** An equation , showing all calculations, for $x_1$ in terms of $y_0$, $v_0$, g , a, b, and c must be on the data sheet turned in before beginning the lab.

**Note:** If you use the sides of the triangle to find u, and **then** use the calculated u to find sin u and cos u, round off error will eat you alive. Instead, simply use the measured sides of the right triangle to determine sin u and cos u, see instructor if this is confusing.




What measurements must be taken? Show all data.
When you are ready, ask the instructor to place a piece of 8 1/2 x 11 paper over your predicted impact location.

**Failure to hit the sheet of paper in 3 tries costs you three points off the lab score.**

# EXPERIMENT 4 The Fan Cart Exp Problem

## Objective

The point of this experiment is to obtain the force supplied by a fan cart to a PASCO cart by experimental means, then use this information to determine the angle of inclination of a ramp upon which the fan cart would remain stationary. You will then place the cart on the ramp at the predicted angle to see if your prediction is correct. If not, you will adjust the angle until the cart does remain stationary and give the percent difference between predicted and actual angle.

You will decide what data is required to determine the force supplied by the fan cart. You will organize data and calculations, and whatever graphs used from Graphical Analysis or Logger Pro, you used to make your predictions.

The experiment must be divided into two distinct parts. Part I is obtaining the force. Part II is testing your results and measuring accuracy (finding percent difference between the predicted angle and actual angle.)

**Part I . Find the Force .** Steps

1. List the quantities to be measured. (In your introduction you will describe how measurements are taken using what apparatus.)

2. Do the experiment and take measurements. Make sure you write measurements down neatly and clearly on a data sheet(s).

3. Analyze data and determine the force produced by the fan. Show all calculations necessary .

**Part II. Find the Angle.** Steps

1. Determine the angle of inclination of the ramp. Hint: Start with a FBD.

2. Start the fan cart and place it on the ramp and see if it remains stationary.

3. If it doesn't , raise or lower the ramp and try again. Continue this process until the cart does remain stationary, then record data necessary to obtain this angle.

4. Calculate percent difference between predicted and actual angles.

**Notes:**
**Don't play around with the fan cart too much, because the strength of batteries will decrease so much your prediction will fail because the batteries have weakened too much.**

**Put equipment up when you finish.**

# Fan Cart Lab Data Sheet

**Part I. Find force**

**Quantities**

| Name | Value | Source |
|---|---|---|
| Mass of cart M (kg) | | POGMMD |
| Accleration a (m/s) | | Logger Pro / motion detector |
| Fan Force (N) | | F = M a (this value also goes in the conclusion) |

Show adequate data here or on a print out to indicate where / how you obtained acceleration.

**Part II. Find the Angle**

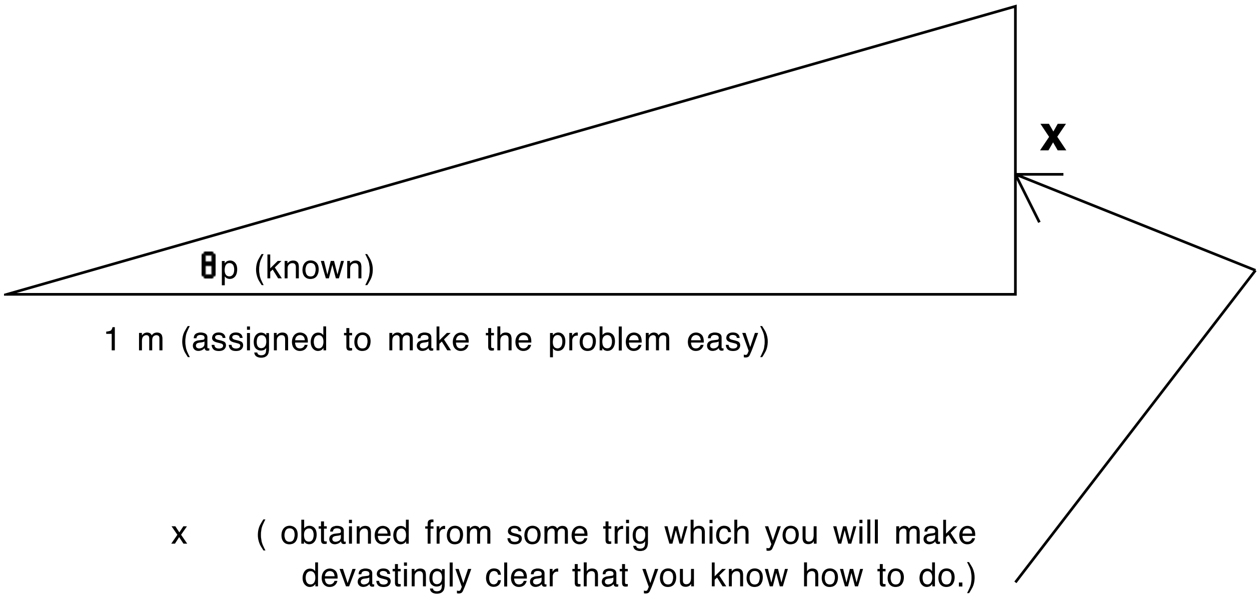
Draw a clearly and accurately labeled FBD here from which to obtain :

$\sum F_y =$

$\sum F_x =$

do some scribbling here to convince me that you really understand why $u_p = \sin^{-1} (a / 9.8)$, obtain it's value, write it down here and also include it in your conclusion **since it is the major objective** of this experiment.

Next we will determine the value of height to raise the ramp 1 m from the pivot end so the ramp will be at the predicted angle with the horizontal.




Next we will try the experiment and **record here** what happened.

If the cart remains stationary, we are finished, % difference is zero.
If the cart does not remain stationary, we will adjust the ramp until it does, then obtain that angle using clear and concise trig, and record that angle $u_{actual}$ here.

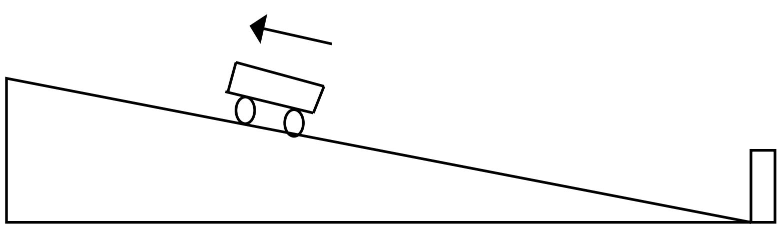
Finally, we will obtain the % difference between these two angles =[ $| u_p - u_{actual} |$ / $(u_p + u_{actual})$ ] x 200 and also put this in the conclusion too!

# Experiment 5: Force II: Rolling Friction

**Deliverable:** (means what you must deliver) The rolling friction force of a PASCO cart.

**Method:**

- Place the cart on an incline, with the motion detector at the bottom of the ramp, ( see figure).
- Give the cart a shove up the plane.
- Analyze the velocity vs time graph to obtain the acceleration up the plane, $a_{up}$ and the acceleration down the plane, and. Use these two different values of acceleration along with the mass of the cart to obtain the rolling friction force of the cart.



**Procedure:**

1. Before doing this lab, **each of you individually** must turn in a sheet containing the following:

-FBD of the cart when traveling **up** the ramp, including x and y axes. (Make up the ramp positive)
-Equation of sum of forces in both x and y directions.

-FBD of the cart when traveling down the plane, including x and y axes. (Make up the ramp positive)
-Equation of sum of forces in both x and y directions .

-Algebra solving the above equations for $F_R$ , the rolling friction of the cart.
-This equation will include **only** symbols $F_R$ , m, for mass of the cart, $a_{up}$, acceleration of the cart when moving up the plane, and $a_{dn}$, acceleration of the cart when moving down the plane.

PS: The algebra must be very convincing.

2. Now get into groups and actually shove the cart up the plane to obtain values of $a_{dn}$ and $a_{up}$. Plug these into your formula for $F_R$ , do a brief write up and turn it in <u>today</u>.

# Alternate Method:

Find the component of gravity $F_{gx}$ in the direction of the plane and use it to obtain the rolling friction force. (What data must be taken in order to find $F_{gx}$ ?) And, you've still godda show the algebra.

# <u>Experiment 5b  Passive Forces</u>

## Friction:  What you godda know

**First** there is a **normal force** imposed by the surface.  It is exactly like a spring actually. The **Really Big Deal (RBD)** about normal forces is that the <u>direction</u> of a normal force is <u>always</u> perpendicular to the surface. (In fact, the word **normal** means "perpendicular to" in mathematics.)

**Second** there are **friction forces**, two kinds, actually, static and kinetic.

**Static Friction** is not constant but has a maximum value.

**Kinetic Friction** remains constant.  (For our purposes.)

In this activity you will (hopefully) observe that static friction has a maximum value but not a fixed one, and that kinetic friction has a fixed value for any two objects rubbing together that, up to a point, is independent of speed.

So how are these forces determined?  Well, the normal force and the friction force are related.  This makes sense because when you press your hands together harder you can feel more resistance to rubbing your hands together.  To help you remember this relationship and to give you a concrete idea of how they are obtained, you get to obtain this relationship for both the static and kinetic friction forces between two materials right now.

# FORCES OF FRICTION

**Note: In this lab, the normal force is denoted by N**

## Objective

The purpose of this experiment is to determine the coefficients of static and kinetic friction between two surfaces.

## Method

A method of checking the proportionality of $F_k$ and $N$ and of determining the proportionality constant $\mu_k$ is to have one of the surfaces in the form of a plane placed horizontally with a pulley fastened at one end. The other surface is the bottom face of a block which rests on the plane and to which is attached to a cord that passes over the pulley and attached to a hanger which is dangling in the air and upon which weights can be hung. These are varied until the block moves at constant speed after having been started with a slight push. Since there is thus no acceleration, the net force on the block is zero, which means that the frictional force is equal to the tension in the cord which in turn equals the weight of the hanger plus the weights attached to it.

**Finding Kinetic Friction Coefficient.**

The normal force between the two surfaces will, in this case, be equal to the weight of the block and can be increased by placing weights on top of the block. Thus corresponding values of $F_k$ and N can be found, and plotting the points $(N,F_k)$ will show whether $F_k$ and N are indeed proportional. (i.e. is the graph linear ?) The slope of this graph will be the proportionality constant $\mu_k$, since

$$F_k = \mu_k N.$$

**Finding Static Friction Coefficient Method I.**

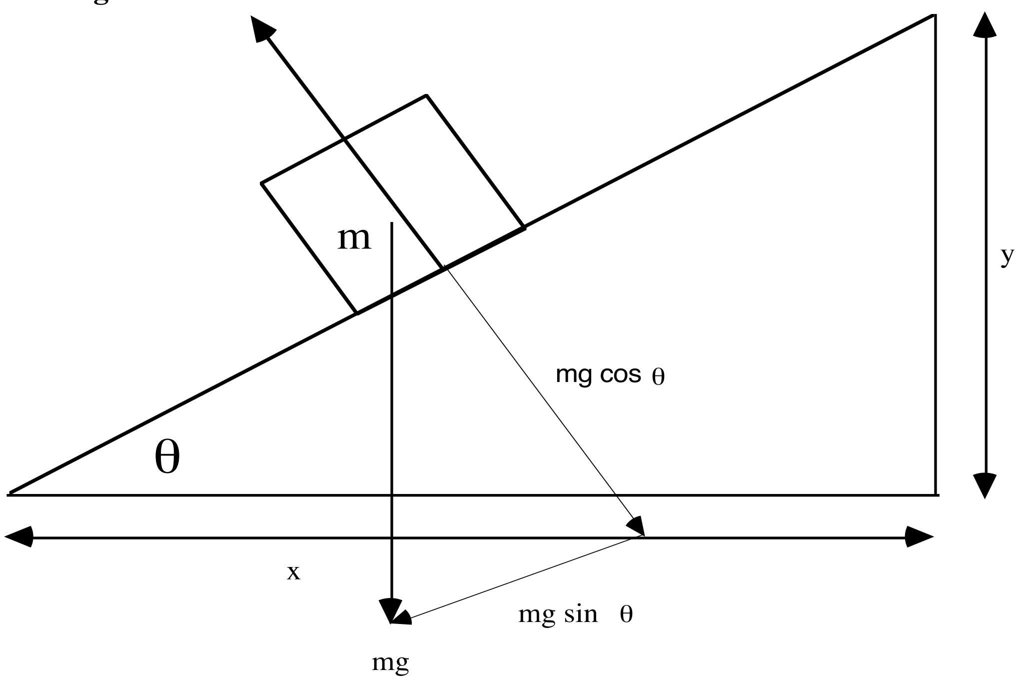
In the static case (body at rest) the frictional force automatically adjusts itself to keep the body at rest up to a certain maximum; but if static equilibrium demands a frictional force larger than this maximum, static equilibrium conditions will cease to exist because this force is not available and the body will start to move. This situation may be expressed in equation form as

$$F_s \leq \mu_s N \quad \text{or} \quad F_{s\,max} = \mu_s N \qquad (32)$$

where $F_s$ is the frictional force in the static case, $F_{s\,max}$ is the maximum value this force can assume, and $\mu_s$ is the coefficient of static friction. It is found that $\mu_s$ is slightly larger than $\mu_k$, which means that a somewhat larger force is needed to break a body away and start it sliding than is needed to keep it sliding at constant speed once it is in motion. THIS IS WHY a slight push is necessary to get the block started FOR THE MEASUREMENT OF $\mu_k$.


Supported by NSF Grant # 9352046

**Finding Static Coefficient Method II**




Inclined Plane with Block

A second way of investigating the case of static friction is to observe the so-called "limiting angle of repose", defined as the maximum angle to which an inclined plane may be tipped before a block placed on the plane just starts to slide. The arrangement is illustrated in Fig. 6-1. The block has weight W=mg whose component W cosq (where q is the plane angle) is perpendicular to the plane and is thus equal to the normal force N. The component W sin q is parallel to the plane and constitutes the force urging the block to slide down the plane.

It is opposed by the frictional force $F_s$ and as long as the block remains at rest $F_s$ must be equal to W sin q . If the plane is tipped up until at some value $q_{max}$ the block just starts to slide, then $F_{s\ max}$ = Wsin $q_{max}$. But $F_{s\ max} = \mu_s N = \mu_s W \cos q_{max}$. Hence, $W \sin q_{max} = \mu_s W \cos q_{max}$ or

$$\mu_s = \frac{\sin \theta_{max}}{\cos \theta_{max}} = \tan \theta_{max} = \frac{y}{x} \qquad (33)$$

Thus if the plane is gradually tipped up until the block just breaks away and the plane angle is then measured, the coefficient of static friction is just equal to the tangent of this angle. It is interesting to note that W canceled out in the derivation of Equation 33, so that the weight of the block doesn't matter!

## APPARATUS

Pulley- cab 5A, ramp-beside bookshelf on west wall, rod and stand, should be some put together on cabinet top on North wall of lab, wood block w/cord attached-cab 5B, glass block-cab 3C, slotted wt set


Supported by NSF Grant # 9352046

and weight hanger-cab 5C, dust cloth-PS 21, POGMMD-G/3.

## References

Serway's Physics for Scientists and Engineers Chapter 5
Serway and Faughn's College Physics Chapter 4

## PROCEDURE

**Part I. Finding the kinetic coefficient of friction $\mu_k$**

1. **Finding weight of the Block.** Weigh the wood block and record it's mass (m), then calculate and record it's weight as $N_1 = mg$.

2. **Finding $\mu_k$.** Place the ramp on the laboratory table with its pulley projecting beyond the table's edge. Be sure that the surfaces of both the board and the wood block are clean, dry and free of dust and grit. Wipe them off if necessary with a clean dry, lintfree cloth or paper towel. After this has been done, do not touch these surfaces with your hands. Handle the block with the cloth or wiper and set it down only on the clean board. Begin the experiment by setting the block on the board with its largest surface in contact with the board's surface. Run the cord attached to the block over the pulley and attach it to the weight hanger. Place some weights on the hanger and slowly increase the load until it is just sufficient to keep the block sliding slowly with constant speed after it has been started with a very small push. Obtain the actual mass using the POGMMD. Calculate the weight of this load and record it as $F_1$.

3. Repeat Procedure 2 placing masses of 200, 400, 600, 800, and 1000 grams successively on top of the wood block. Calculate and record the weights of these masses as $N_2$ thru $N_6$, and record the load needed for each as $F_2$ thru $F_6$ respectively.

4. Plot $F_k$ (vertical axis) versus $N_k$ (horizontal axis) using Graphical Analysis. Draw the line of best fit and find the slope, which will be $\mu_k$, the kinetic coefficient of friction. Show these calculations on the graph <u>and put a box around $\mu_k$,</u> since it is your really big deal result. (You may use Graphical Analysis to do this step if you so desire.)

5. Turn the wood block on its side and repeat Procedure 2 through 4.

6. Find the percent difference between the two $\mu_k$'s obtained above.

**Part II. Finding the coefficient of static friction $\mu_s$.**

1. **Finding $\mu_s$, first method.** Again turn the wood block with the largest surface in contact with the

plane. Gradually increase the load on the hanger until the block just starts to move, without any initial push. Be careful to place the weights on the hanger gently so as not to jerk the cord. Notice whether this time the block moves with uniform speed or whether it is being accelerated. Again record $N_1$ and $F_1$ like you did in steps 2 thru 4 of Part I.. Next add the same masses to the block as you did in step 3, and for each mass, obtain the mass ($M_h$), added to the hanger, necessary to just start the block moving. Again graph $F_s$ versus $N_s$, and use the line drawn to find the coefficient of static friction $\mu_s$. Label this result as method 1 $\mu_s$, and put a box around it.

2. **Finding $\mu_s$, second method.** Adjust the board as an inclined plane. Place the wood block on the plane with its largest surface in contact, and gradually tip the plane up until the block just breaks away and starts to slide down. Be very careful to tip the plane slowly and smoothly in order to get a precise value of the angle with the horizontal at which the block just breaks away. This is the limiting angle of repose. Measure the tangent of this angle and record as $\mu_s$. Record the result obtained in three separate trials and use the average as your $\mu_s$. These trials should be independent, meaning that in each case the plane should be returned to the horizontal, the block placed on it, and the plane carefully tipped up until the limiting angle of repose is reached. Again, appropriately label and box your $\mu_s$.

3. Find the percent difference between the two values of $\mu_s$ obtained in steps 1 and 2.

4. Possiblility: Repeat procedure of Part II step 2 using other combinations of surfaces glass on glass, wood on glass, etc. Record the tangent of the limiting angle of repose obtained in three independent trials and again take the average to obtain $\mu_s$ for this new combination. How does this value compare to that of wood on wood?

## QUESTIONS

1. Explain in your own words why it is necessary that the block move at constant velocity in Procedures 2-4.

2. a) How does the coefficient of friction depend upon the normal force between the surfaces in contact?
   b) How does it depend upon the area of the surfaces in contact?

3. How does the coefficient of static friction compare with the coefficient of kinetic friction for the same surfaces, areas, and normal forces.

4. Calculate the force needed to pull a mass of 20 kg. at a uniform slow speed up a plane inclined at an angle of 30 degrees with the horizontal if the coefficient of kinetic friction is 0.20 .

***********************************************************

BONUS QUESTION:(5 points) You are pushing this block of steel across the floor at a constant speed. You decide to turn the block on end, reducing the surface area in contact with the floor by half. In this new orientation, to push this same block across the same floor with the same speed, the force that you must apply is: (Feel free to try it and see!)

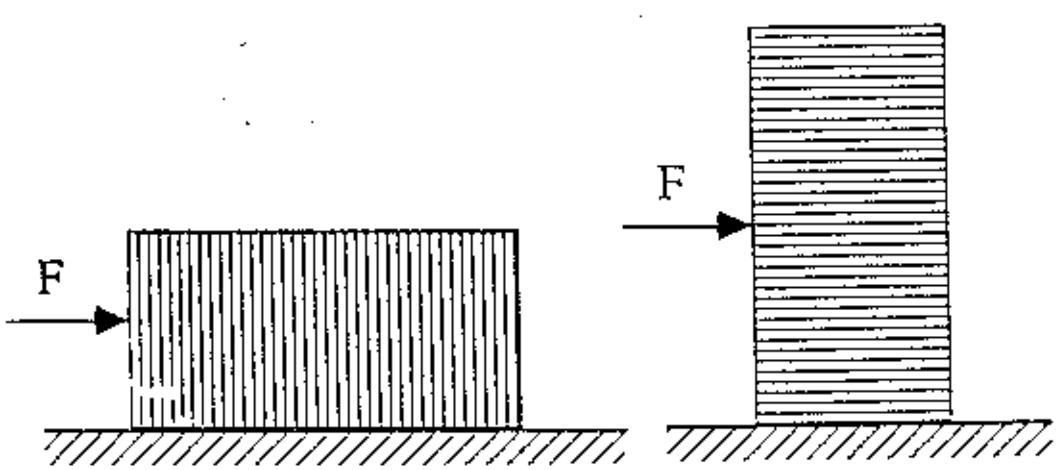
1. about four times as big as before

2. about twice as big as before

3. about the same as before

4. about half as big as before

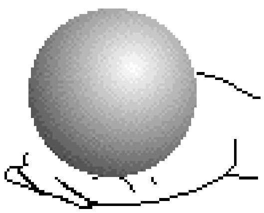
5. about one fourth as big as before



# EXPERIMENT 6 Force, work & Power

## Part I. Measuring the Horsepower in Your Arms

(a) Place a bowling ball in a double plastic grocery bag and use a Viking Jr. scales or bathroom scales to obtain its weight. Plug the motion detector into Port 2 on the ULI , lay the motion detector on the floor, turn on the ULI, start MacMotion, hold the bowling ball in the bag approximately .5 m above the motion detector, click on start, when you hear the clicking sound, lift the bowling ball through a distance of at least 1 meter as fast as possible. Click on ANALYZE and highlight Analyze Data A. Select a region of fairly uniform motion, measure the time and height of the lift and compute the work done against the force of gravity.



(b) Compute the average power, $P_{avg}$, you expended in hp. How does this compare to the horsepower of your favorite automobile? If you're not into cars, how do you stack up against a horse?

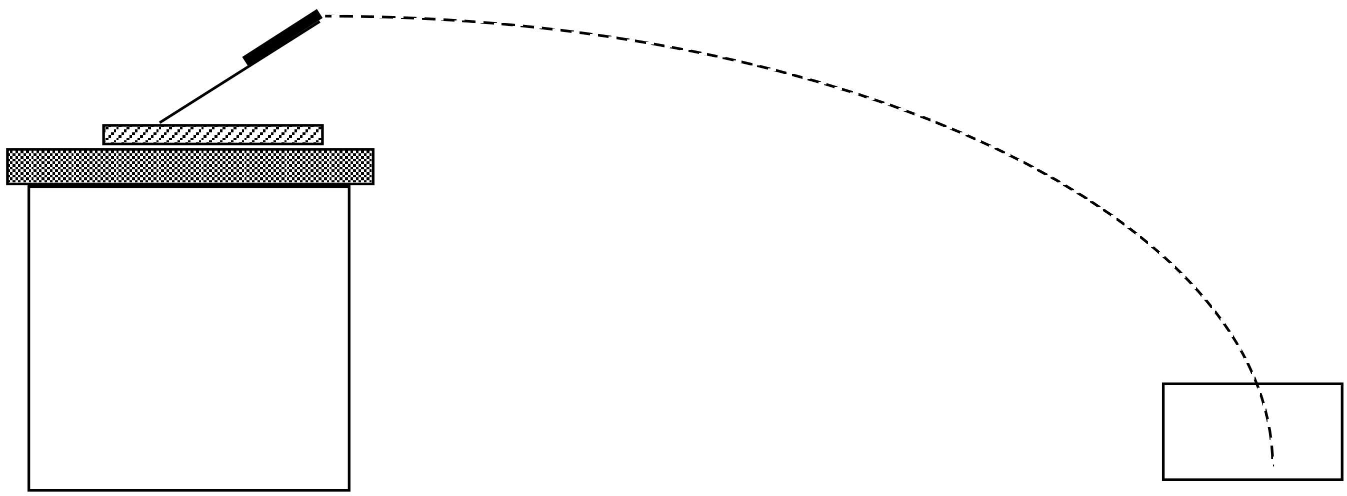
## Part II. Rate the Horsepower in Your legs. Are you fast enough to make it into the HORSE POWER CLUB?

We'll do this all together. We'll measure the angle of inclination of the stairs going up the hill across the street from the library, then measure the distance up the hill, and use some trig to obtain the change in height , all of which, together with your own mass (converted to kgs), and the time it takes you to get to the top of the hill will enable you to calculate your own power, which if turns out to be greater than 1 when divided by 746, will make you an official member of the HORSE POWER CLUB.

Ok, this has been a fun lab, but it is a lab. So make sure you make up data tables in advance, and plan you write up carefully. That will really help it go more smoothly, and enable us to get it all done.


Supported by NSF Grant # 9352046

# Experiment 7
# Energy, Kinematics, and Projectile Motion



## Introduction

Here is your chance to find out if you can put everything we've learned so far together.

## Objective

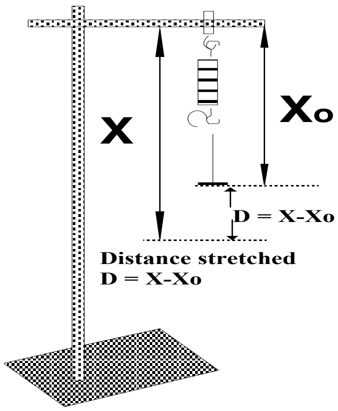
Determine how to analyze the apparatus properly and tell me how far back to pull the spring so that , when released, it will go into the box. I'll give you free of charge that you may ignore the mass of the spring, (which means the gravitational potential energy due to height is nominal compared to the spring potential ) and the friction of the rod on the spring.

**The Plan:** You are the boss with the brains, I am the flunky. You tell me what measurements you need that will enable you to calculate the distance the spring must be stretched in order to give it enough uumph to make it into the box when released. Pretend this is like a shuttle launch. Each launch costs 60 Billion Dollars, and we can't afford to try it a half a dozen times until we get it right by trial and error.

Remember the data sheet I made up for you for Experiment 4? You must make up a data sheet for this lab like that one including equations, so that, as soon as you have the values , you can simply put them into the formulas and they will produce the required numbers. How many parts must this lab have?

# The Plan, Expanded

**Part I. Finding the Spring Stiffness Constant $k_s$**




**1.**

| x | $D = x - x_o$ | m | F = mg |
|---|---|---|---|
| $x_o$ | 0 | 0 | 0 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

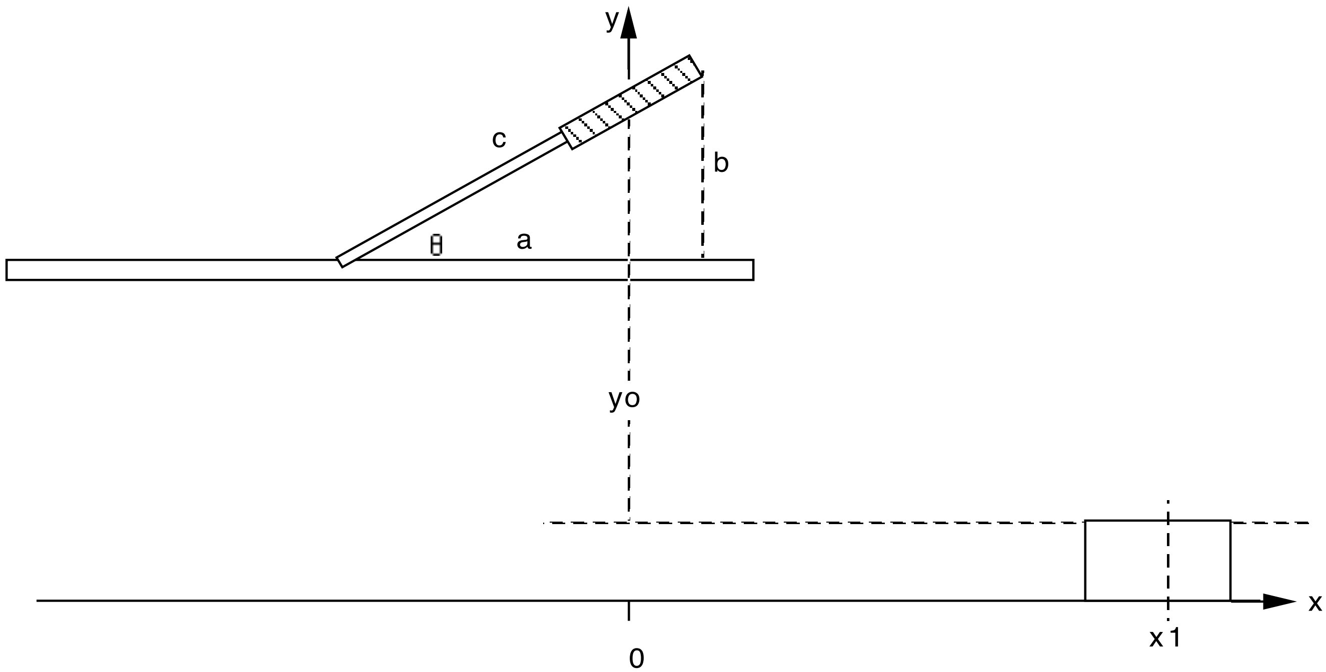
$x_o$= ______________

**Graph F vx D and find slope of line of best fit, which will be $k_s$.**

**Part II. Find the initial velocity $v_o$ of the spring as it leaves the rod** (in terms of $k_s$ , mass of spring $m_s$, gravity g, and distance stretched, Ds).

$m_s$ = ________________
Energy stored in the spring = initial kinetic energy

**Part III. Do the projectile motion problem to find the distance Ds required to stretch the spring (in terms of $m_s$ , $k_s$ g, a, b, c, $y_o$ and $x_1$ ).**




a = ________ b = ____________ c = ____________ yo = ___________ $x_1$ = ___________

# Physics 201 & 213 Experiment 7b

# Work, Rolling Friction, & Spring Potential Energy

## Introduction

It's time we began to put all these work concepts together. Be sure to put down all measurements in a nice, neat table. In this lab you work for a unscrupulus toy manufacturer who wishes to copy a competitor's new toy and manufacture it in China and make millions. So, among other things, we must obtain the spring stiffness constant for the spring used to propel the toy truck.

## Objective

The objective of this lab is to take the data and make the calculations necessary to obtain the spring stiffness constant of the spring in the toy. One requirement is that we do this without dismantling the toy.

**The Plan:** Well, that is part of the job. You have to design and carry out an experiment that will enable one to determine the spring stiffness constant for any toy of this design.

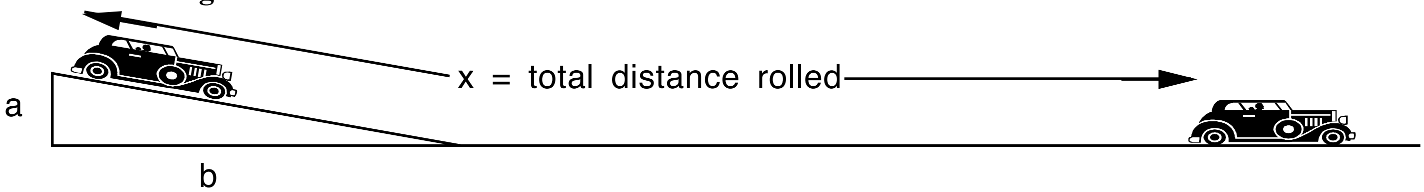
So, how can we check our answer to see whether or not we are correct?

**The Proof:** We will build a ramp. Its height and length will be known. We will calculate, according to the spring stiffness constant we have obtained, where on the ramp the toy should be placed, and how much its spring should compressed, so that when released, the toy should stop right at the top of the ramp!

Good Luck, measure carefully!

# The Plan, Expanded

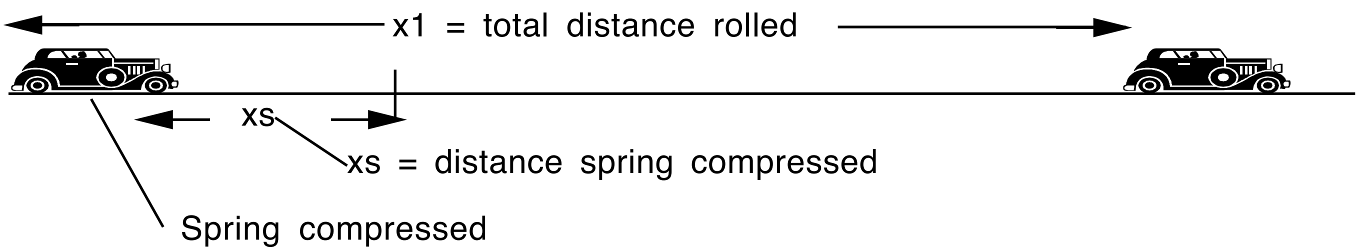
**I. Find Rolling Friction Force**




a =________________ b =________________ x = _______________ mass = __________

Equation $F_R$ = ___________________

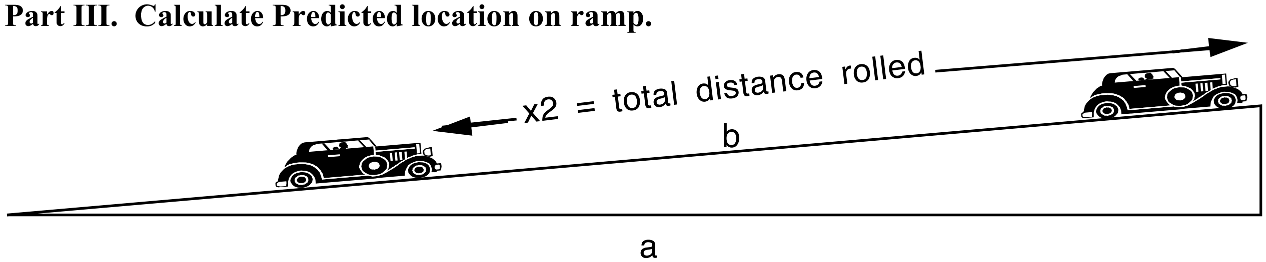
**Part II. Find Spring Stiffness Constant**




$x_1$ = ______________________ $x_s$ = ______________________

Equation $k_s$ = ________________

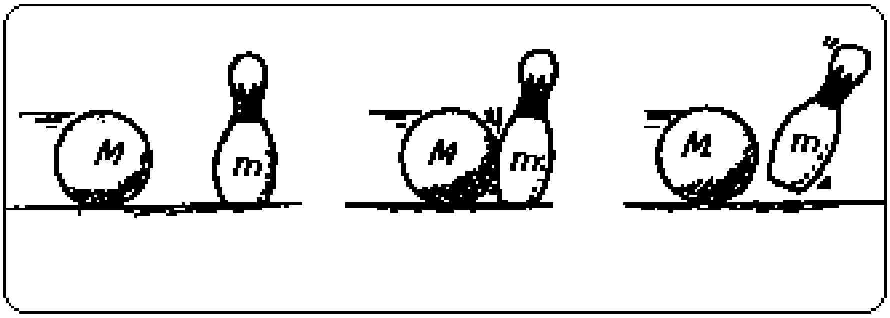
**Part III. Calculate Predicted location on ramp.**




a = ______________ b= _______________

Equation $x_2$ = ______________

# Experiment 8 : Newton's Third Law




To every action there is always opposed an equal reaction, or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.
If you press a stone with your finger, the finger is also pressed by the stone. If a horse draws a stone tied to a rope, the horse (if I may say so) will be equally drawn back towards the stone . . . .

Isaac Newton Principia (1686)

# OBJECTIVES

To examine the consequences of Newton's Third Law as applied to interaction forces between objects.

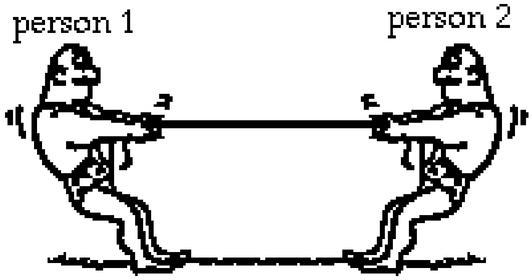
**OVERVIEW**

Since interactions like collisions and explosions never involve just one object, we would like to turn our attention to the mutual forces of interaction between two or more objects. This will lead us to a very general law known as Newton's Third Law which relates the forces of interaction exerted by two objects on each other.
As usual you will be asked to make some predictions about interaction forces and then be given the opportunity to test these predictions.
Note: This is a lab, but you do not have to do a write-up. Just do the lab and respond to the questions.

# Investigation 1: Newton's Third Law

There are many situations where objects interact with each other. In this investigation we want to compare the forces exerted by the objects on each other. What factors might determine the forces between the objects? Is there some general law which relates these forces?
We will begin our study of interaction forces by examining the forces each person exerts on the other in a tug-of-war. Let's start with a couple of predictions.

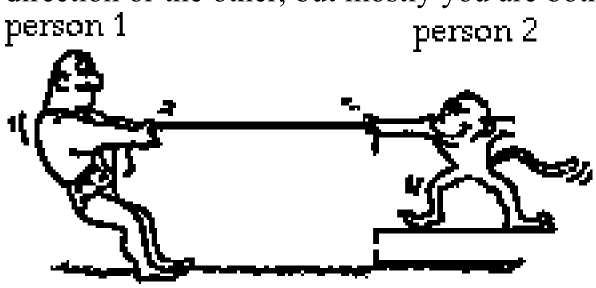
**Prediction 1-1:** Suppose that you have a tug-of-war with someone who is the same size and weight as you. You both pull as hard as you can, and it is a stand-off. One of you might move a little in one direction or the other, but mostly you are both at rest.




Predict the relative magnitudes of the forces between person 1 and person 2. Circle your prediction!

person 1 exerts a larger force on person 2
the people exert the same force on each other
person 2 exerts a larger force on person 1

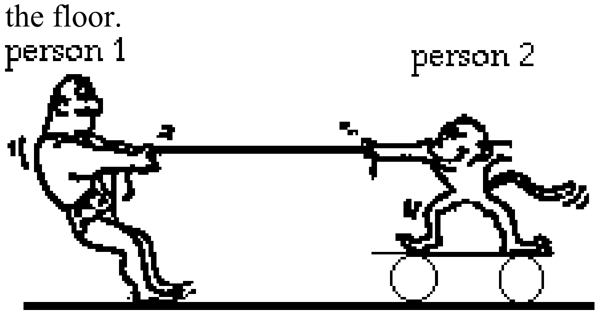
**Prediction 1-2:** Suppose now that you have a tug-of-war with someone who is much smaller and lighter than you. As before, you both pull as hard as you can, and it is a stand-off. One of you might move a little in one direction or the other, but mostly you are both at rest.




Predict the relative magnitudes of the forces between person 1 and person 2. Circle your prediction!

person 1 exerts a larger force on person 2
the people exert the same force on each other
person 2 exerts a larger force on person 1

**Prediction 1-3**: Suppose now that you have a tug-of-war with someone who is much smaller and lighter than you. This time the lighter person is on a skateboard, and with some effort you are able to pull him or her along the floor.




Predict the relative magnitudes of the forces between person 1 and person 2. Circle your prediction!

person 1 exerts a larger force on person 2

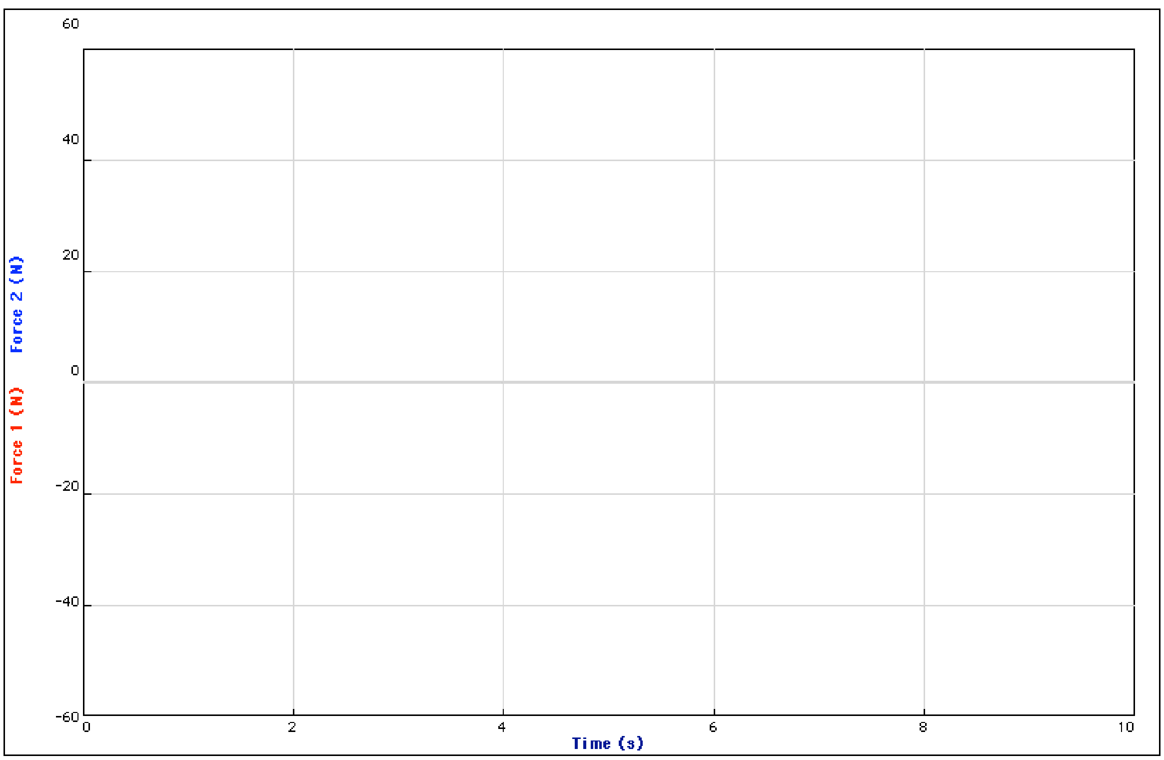
the people exert the same force on each other
person 2 exerts a larger force on person 1

# To test your predictions you will need the following:

- o Two force probes and a LabPro
- o Logger Pro
- o A skateboard(use the round red skateboard) and string
- o Two Spring Scales
- o Two Pasco Carts with force probe holders attached
- o Masses to place on the carts to increase mass

**Activity 1-1: Interaction Forces in a Tug of War**

1. Plug the two force probes into Channel 1 and 2 of the LabPro. Put the eyehooks (top of red box) on the force probes. Make sure both force probes are switched to the same range.
2. Open the Logger Pro. You should see two graphs on one coordinate axis, like the ones on the next page.




3. When you are ready to start, Zero both of the force probes. (Click on Zero under the Experiment menu) Then hook a short loop of string between them, hit Start and begin a gentle tug-of-war. Pull back and forth while watching the graphs. Do not pull too hard, since this might damage the force probes. It may be more instructive to make one of the forces negative so you can see them both. If so, under the Experiment menu, go to Setup Sensors, LabPro 1,Ch 1, Reverse Direction.

4. Repeat with different people pulling on each side.

5. Sketch one set of graphs on the axes above, or print the graphs and affix them over the axes.

**Question 1-1:** (a) How did the two pulls compare to each other? (b) Was one significantly different from the other? (c) How did your observations compare to your predictions?

**Activity 1-2**: Interaction Forces Pulling Someone Along
In this activity you will test your prediction about the interaction forces when you are pulling someone on roller skates or a skateboard along the floor.
1. You will use the Spring Scales and the roller cart (or your own skates) for this part. Do not use the Force Probes, you will damage them. Make sure you zero the scales. Hook the two Spring Scales together and pull someone along on the board.

**Question 1-2:** (a) How did the two pulls compare to each other? (b) Was one significantly different from the other? (c) How did your observations compare to your predictions?
Comment: The fundamental law governing interaction forces between objects is Newton's Third Law. which can be stated: If one object exerts a force on a second object, then the second object exerts a force back on the first object which is equal in magnitude and opposite in direction to that exerted on it by the first object.

**Question 1-3:** Do your observations in Activities 1-1 and 1-2 support Newton's Third Law of motion?

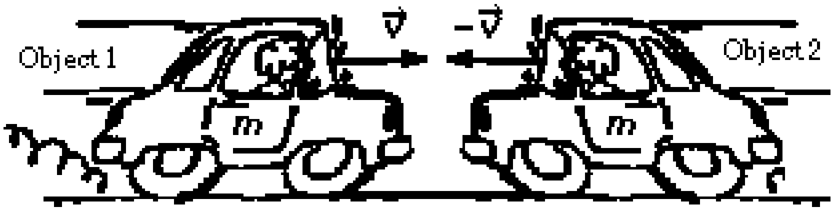
**Question 1-4:** When you pull on an object with a force probe, does the probe measure the force it exerts on the object or the force exerted on the probe by the object? (Does this distinction have any meaning?) Explain.

Comment: Newton actually formulated the third law by studying the interaction forces between objects when they collide. It is difficult to fully understand the significance of this law without first studying collisions.

**Investigation 2: Forces between interacting Objects**
There are many situations where objects interact with each other, for example, during collisions. In this investigation we want to compare the forces exerted by the objects on each other. In a collision, both objects might have the same mass and be moving at the same speed, or one object might be much more massive, and they might be moving at very different speeds. What factors might determine the forces between the objects? Is there some general law which relates these forces?

**Activity 2-1: Collision Interaction Forces**
What can we say about the forces two objects exert on each other during a collision?

**Prediction 2-1:** Suppose the masses of two objects are the same and that the objects are moving toward each other at the same speed so that m1 = m2 and v1 = - v2 (same speed, opposite direction).

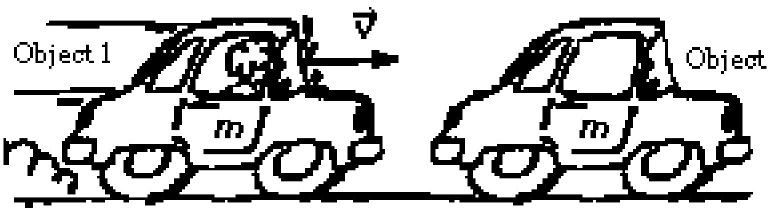



Predict the relative magnitudes of the forces between object 1 and object 2 during the collision. Circle your prediction!

object 1 exerts a larger force on object 2
the objects exert the same force on each other
object 2 exerts a larger force on object 1

**Prediction 2-2:** Suppose the masses of two objects are the same and that object 1 is moving toward object 2, but object 2 is at rest.

$$m1 = m2 \text{ and } v1 > 0, \; v2 = 0$$

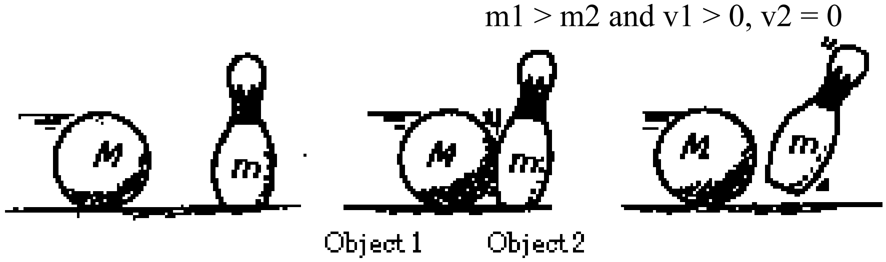



Predict the relative magnitudes of the forces between object 1 and object 2 during the collision. (Circle one)

object 1 exerts a larger force on object 2
the objects exert the same force on each other
object 2 exerts a larger force on object 1

**Prediction 2-3:** Suppose the mass of object 1 is greater than that of object 2 and that it is moving toward object 2 which is at rest.

$$m1 > m2 \text{ and } v1 > 0, \; v2 = 0$$

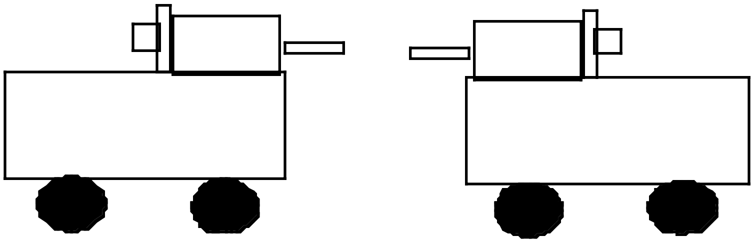



Predict the relative magnitudes of the forces between object 1 and object 2 during the collision. (Circle one)

object 1 exerts a larger force on object 2
the objects exert the same force on each other
object 2 exerts a larger force on object 1

What are the circumstances under which you predict that one object will exert a greater force on the other object?

1. Set up the apparatus as shown in the following diagram.



The force probes should be securely fastened to the carts.
The hooks should be removed from the force probes and replaced by the brown tipped bumpers (also in top of red boxes) and should be carefully aligned so that they will collide head-on with each other.

2. Open a new file. Click on File/Open/Experiments/Probes & Sensors/Force Sensors/Dual-Range Force Sensors/2-50N Dual Range.cmbl

3. Under the Experiment menu go down to Zero, then Zero all sensors to zero the probes.

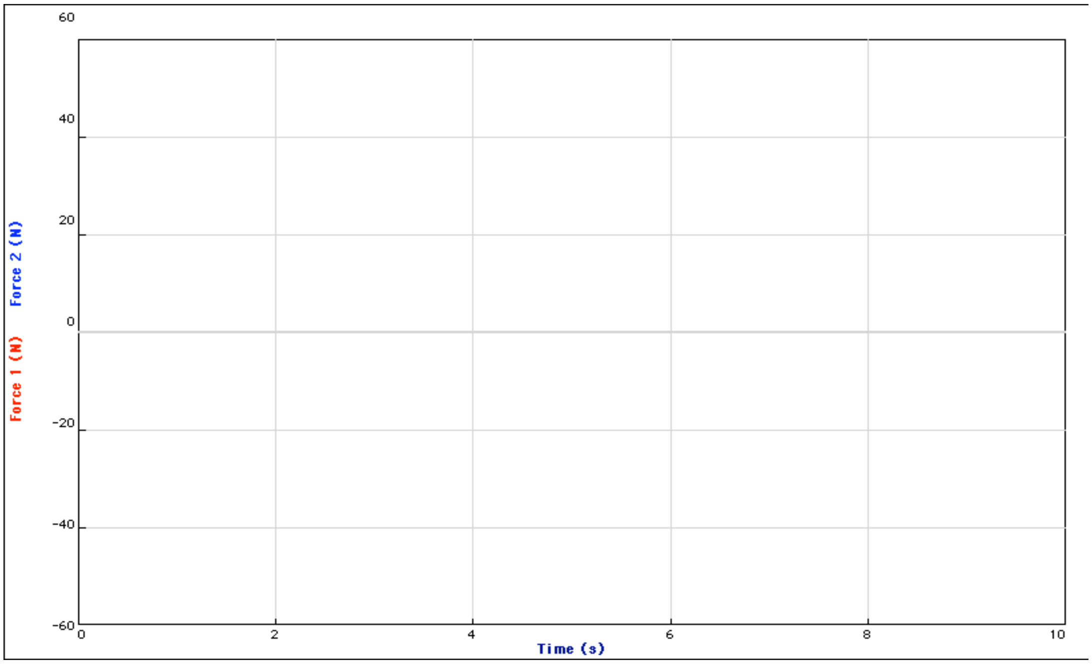
4. Use the two carts to explore various situations which correspond to the predictions you made about interaction forces. Sketch the graphs for each collision on the axes below. Be sure to label your graphs. Your goal is to find out under what circumstances one object exerts more force on another object so mark the points where one force is significantly larger than the other. You can examine the forces point by point by selecting Examine under the Analyze menu.

Try collisions (a) - (c) listed below.

Also, if the top of your curves are flat horizontal lines, that means you applied a force too large for the force probes to read.

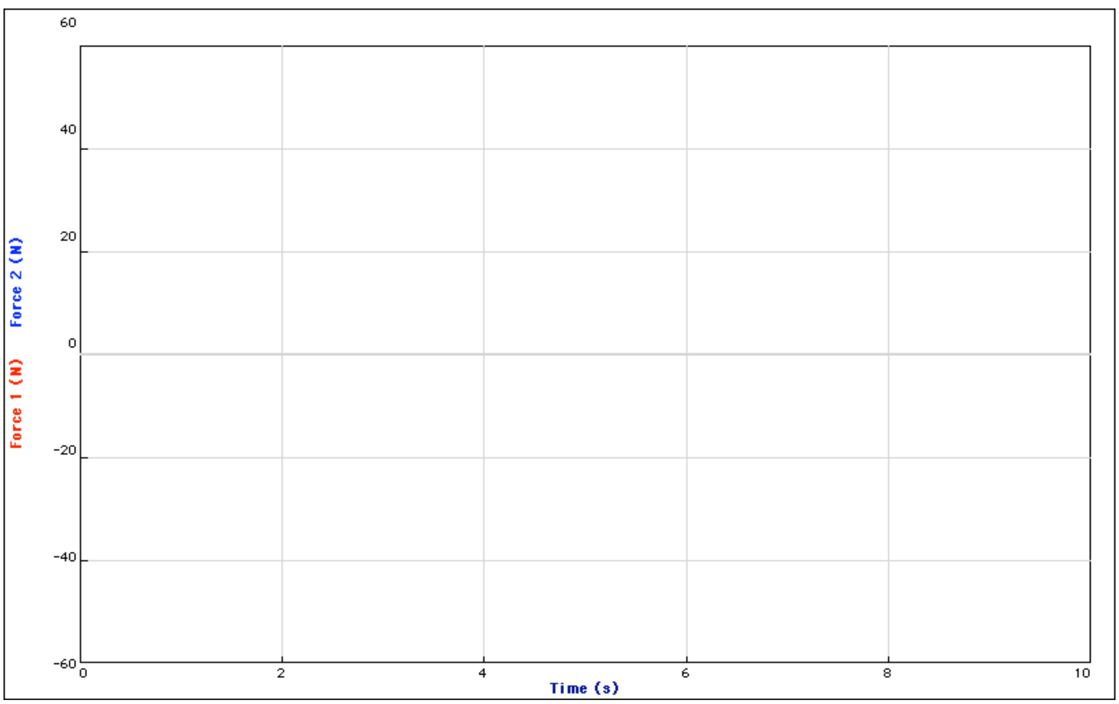
For each collision also find the values of the impulses exerted by each cart ( Impulse is the change in momentum of the object, which is also the integral or area under each force time graph). You must first select the portion of the force-time graph for which you want to find the area or integral. This is done selecting Examine from the Analyze menu. To highlight the region of the force-time graph for the area, position the cursor line at the beginning of the desired region. Press and hold down the mouse button, and slide the mouse until the cursor line is at the end of the desired region. Release the mouse button. The region should remain darkened. Next select Integral (also under the Analyze menu and read the value of area or integral on the graph. Record these values below, and carefully describe what you did and what you observed.

(a) Two carts of the same mass moving towards each other at about the same speed.



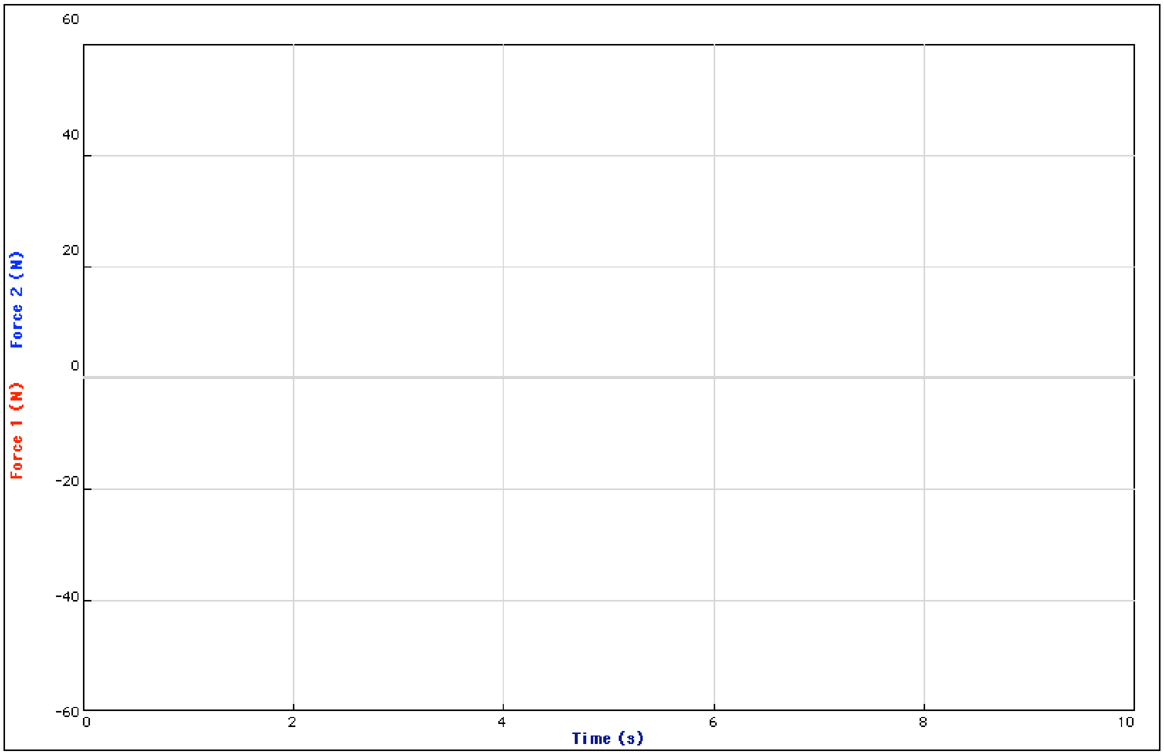

Impulse 1_______ Impulse 2____________

(b) Two carts of the same mass, one at rest and the other moving towards it.




Impulse 1_______ Impulse 2____________

(c) One cart twice or three times as massive as the other, moving toward the other cart which is at rest.

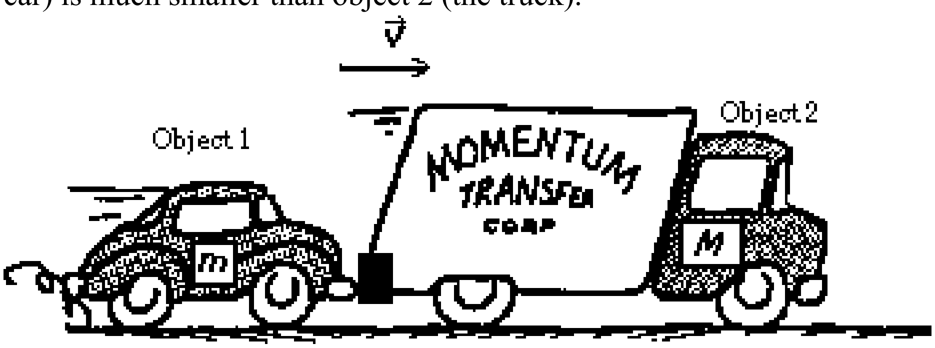



Impulse 1_______ Impulse 2____________

**Question 2-1**: Did your observations agree with your predictions? What can you conclude about forces of interaction during collisions? Under what circumstances does one object experience a different force than the other during a collision? How do forces compare on a moment by moment basis during each collision?

**Activity 2-2: Other Interaction Forces**

Interaction forces between two objects occur in many other situations besides collisions. For example, suppose that a small car pushes a truck with a stalled engine, as shown in the picture below. The mass of object 1 (the car) is much smaller than object 2 (the truck).




At first the car doesn't push hard enough to make the truck move. Then, as the driver pushes down harder on the gas pedal, the truck begins to accelerate. Finally the car and truck are moving along at the same constant speed.

**Prediction 2-4:** Place a check next to your predictions of the relative magnitudes of the forces between objects

1 and 2.

Before the truck starts moving:

the car exerts a larger force on the truck

the car and truck exert the same force on each other

the truck exerts a larger force on the car

While the truck is accelerating:

the car exerts a larger force on the truck

the car and truck exert the same force on each other

the truck exerts a larger force on the car

After the car and truck are moving at a constant speed:

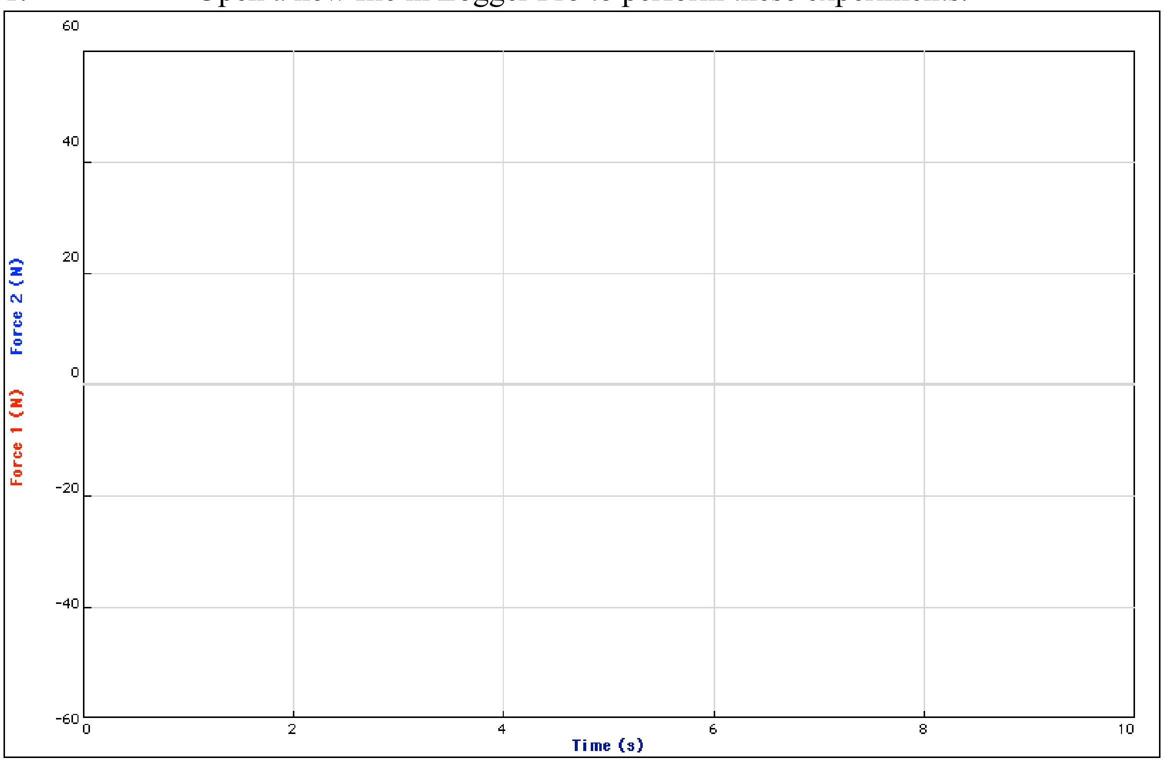
the car exerts a larger force on the truck

the car and truck exert the same force on each other

the truck exerts a larger force on the car

Test your predictions.

1. Open a new file in Logger Pro to perform these experiments.




2. Use the same setup as in the last activity with the two force probes mounted on carts. Add masses to cart 2 (the truck) to make it much more massive than cart 1 (the VW).

3. Zero both force probes .

4. Your hand will be the engine for cart 1. Move the carts so that the stoppers are touching, and then hit Start. When graphing begins, push cart 1 toward the right. At first hold cart 2 so it cannot move, but then allow the push of cart 1 to accelerate cart 2, so that both carts move toward the right.

5. Sketch your graphs on the axes on the previous page, or print them and affix them over the axes.

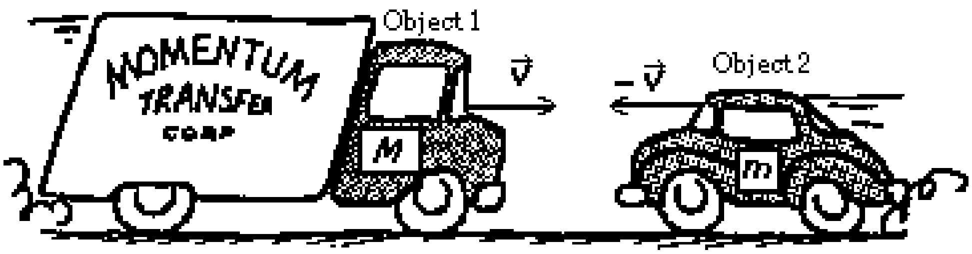
**Question 2-2**: (a) How do your results compare to your predictions? (b)Is the force exerted by cart 1 on cart 2 (reading of force probe 2) significantly different from the force exerted by cart 2 on cart 1 (reading of force probe 1) during any part of the motion?

**Activity 3-1: More Collision Interactive Forces**

Make predictions for the interaction forces in the following situations, and then use the apparatus to test your predictions if there is time left in lab. In each case describe your observations and how you made them. Include copies of any graphs you make. Compare your observations to your predictions.

Prediction 1: Suppose the mass of object 1 is greater than that of object 2 and that the objects are moving toward each other at the same speed so that

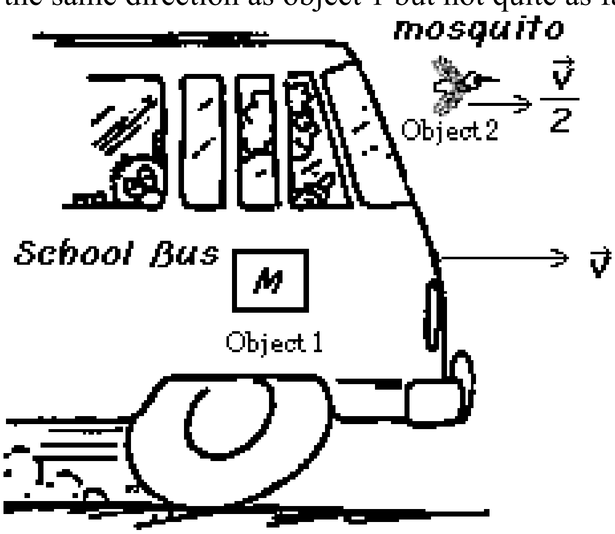
$$m1 > m2 \text{ and } v1 = -v2$$




Predict the relative magnitudes of the forces between object 1 and object 2.

object 1 exerts a larger force on object 2
the objects exert the same force on each other
object 2 exerts a larger force on object 1

**Prediction 2:** Suppose the mass of object 1 is much greater than that of object 2 and that object 2 is moving in the same direction as object 1 but not quite as fast so that




Predict the relative magnitudes of the forces between object 1 and object 2.

object 1 exerts a larger force on object 2
the objects exert the same force on each other
object 2 exerts a larger force on object 1

**Prediction 3:** Suppose the mass of object 1 is much greater than that of object 2 and that both objects are a rest until an explosion occurs so that

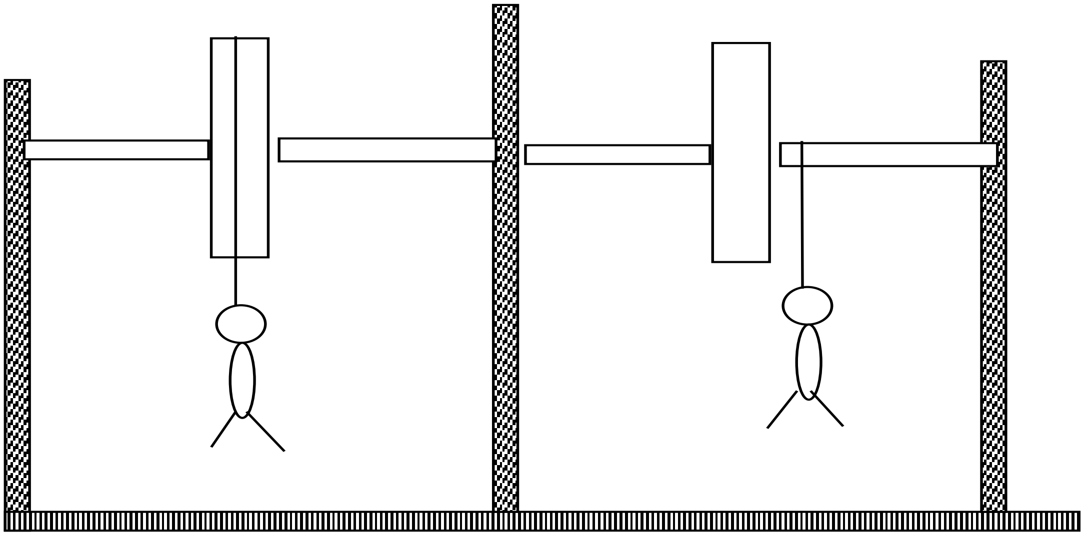
m1 >> m2 and v1 = v2 = 0


Predict the relative magnitudes of the forces between object 1 and object 2. Place a check next to your prediction! Circle one.

object 1 exerts a larger force on object 2
the objects exert the same force on each other
object 2 exerts a larger force on object 1

What is your final conclusion about forces two exert on each other?

# Experiment 9:  Rotaional Inertia



Predict speed upon impact of each object.
Then use motion detector to test prediction.

# Experiment 10 Torque

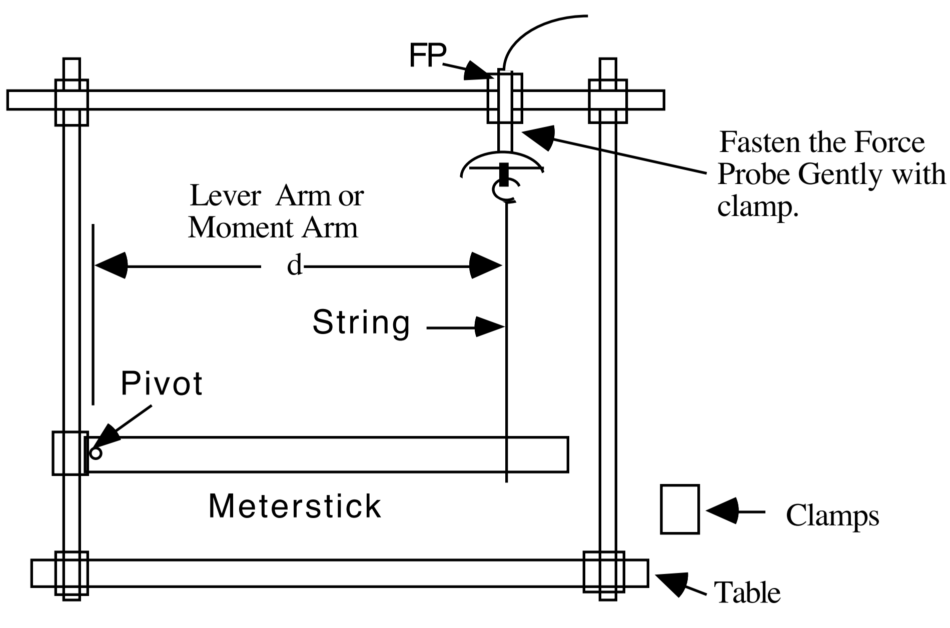
## PART I: TORQUE[1]

**PURPOSE:** To introduce the concept of torque; to investigate how force, distance, and angle are involved in the torque concept.

**APPARATUS**: Force probe, ULI interface, Macintosh computer, MacMotion 4.0 software, 1-meter sticks, 2-meter stick, string, clamps, rods, wire, and masses

**INTRODUCTION:** A relationship between force and distance will be observed and how these two quantities relate to torque. A force probe and meterstick will be used to measure force and distance.

**PROCEDURE:** Set up the "torque" apparatus as indicated in the picture below - there should be a "model" setup for you to view. Be sure that the horizontal rod and the meterstick are horizontal and that the string is vertical. BE SURE THAT YOU ZERO THE FORCE PROBE BEFORE EACH DATA RUN!




Start LoggerPro, select Force as the vertical axis by clicking on the name for the vertical axis and highlight force. Calibrate the force probe using a 500 g mass(es)Set the time scale from **0 sec to 3 sec** and force from **0 N to 5 N**. Remember to **Zero the force probe before you take data on each run.**

Activity One - Vertical Force with Horizontal Distance!

---

[1] This experiment is adapted from one written by Chuck Hollenbeck, Chaffey Community College, Alta Loma, CA

1. Set the top horizontal rod to be approximately 50 cm above the table top. Make a single loop of string around the meter stick and the hook of the force probe so that the string is vertical and the meterstick is horizontal. Place it so the string is located .90 m **from the pivot point.** You will be sliding the loop to new positions later in this activity. Before taking each reading, you must make sure the string is vertical and zero the force probe by first removing all tension in the string (lifting the meterstick), zero, and then gently lower the meterstick to its original position.

   For this activity,

   a. what force do you think the force probe is measuring?

   b. Draw a free-body diagram of the meterstick.

   c. what quantity does the distance from the pivot to the string represent?

   d. Will the force probe reading increase, decrease, or remain bout the same as the string is moved to the left, toward the pivot point?

   Why?

2. a. Run LoggerPro, obtain the average force for this run by highlighting **Analyze Data A** under the Analyze menu, then highlight part of the graph by clicking on the graph and dragging the mouse to the right or left, then , under the **Analyze** menu highlight **Statistics**. Record this average force as the Force on the meterstick due to the string at the .9 m distance in Table 1.

   b. Now repeat this procedure for string positions of 0.75 m, 0.55 m, 0.35 m, and 0.20 m from the pivot point. Make sure the string is vertical each time and that you zero the force probe for each run.

   c. How did the force change as the distance d decreased from 90 cm to 75 cm?

| Table 1 | | | | | | Average |
|---|---|---|---|---|---|---|
| Lever Arm distance d (m) | 0.90 | 0.75 | 0.55 | 0.35 | 0.20 | XXXXXX |
| Force (N) | | | | | | XXXXXX |
| F •d (Nm) | | | | | | |

3. Now calculate the product of force times distance for each of your set of measurements and record these in Table 1.

**Note 1:** this product, F•d, is **counterclockwise torque** and is denoted by the greek letter tau (read "tow", like how) t.

**Note 2:** The perpendicular distance d, from the pivot point to the line of action of the force is called the **moment arm**, or **lever arm** of the force.

How does the product F • d change as the distance d decreases?

4. Slide the string to the 50.0 cm mark. Remove the meterstick from the pivot and adjust the position of the string on the meterstick until the meterstick balances horizontally. Record the position.

Position of Balance: ____________________

a. After zeroing the force probe at this position, record the force of the meterstick's weight.

Weight of Meterstick: ___________________

b. Calculate the distance from the pivot point to the position of balance and then calculate the torque due to the weight of the meterstick. Record the value below.

"Lever Arm" Distance: ___________ m

Torque due to Weight of Meterstick: __________ N m.

c. What is the direction of the torque due to the weight of the meterstick about the pivot point?

d Compare this value for the torque to the average value of the torque found in Table 1 above. They should be close to the same value. Are they? (Percent difference $\leq 5$ % is considered close). If they are not, check your algebra, your apparatus and your procedure and retry, **then** consult with the instructor.

5. Using the same set up, calculate (using the formula for t ) where the vertical string would have to be placed to get a force readings of: Then obtain the actual values by experiment.

| **Force** | **Predicted position (m) show formula here d =** | **Actual position (m)** |
|---|---|---|
| F = 1.75 N | | |
| F = 2.80 N | | |
| F = 4.00 N | | |

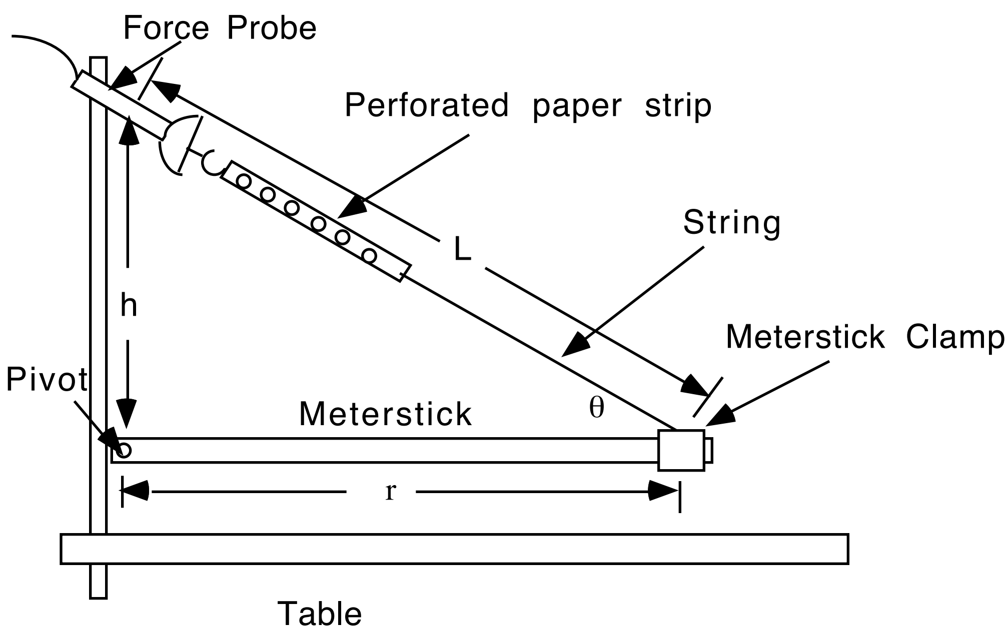
a. Show me the algebra you used to obtain the formula you used for the predicted position.

b. How good were your predictions? (Less than 5% difference between values is good.)

c. Explain any significant differences between your prediction and the measured values.

Activity Two - Force and Distance at an Angle

**PROCEDURE:** Setup the torque apparatus as indicated in the picture below - there should be a "model" setup for you to view. Attach the force probe clamp to the vertical rod **approximately** 1.00 m above the pivot point. Place the meterstick clamp at 98 cm. Tie one end of a piece of string to a perforated paper strip. Put the end hole of the paper strip on the force probe hook . Attach the other end of the string to the meterstick clamp, making sure the length is adjusted so that the meterstick is horizontal. **Make sure the force probe is aligned with the string going to the meterstick clamp**.




Record the mass of the meterstick clamp: _________________

6. What do you think will happen to the force probe reading as the probe is lowered toward the pivot point? The meterstick is kept horizontal by adjusting the perforated strip on the probe hook. Will the force probe reading increase, decrease, or remain about the same. Why? (Careful explanation here please.)

7. Be sure to zero the force probe before taking each reading. Record the average force in the table below (From Statistics under the Analyze menu). Use another meterstick and measure the <u>vertical</u> distance, h, from the pivot point on the top of the meterstick to the point of intersection with the

line L . Also measure the length, L, along the string from the force probe hook to the point where the meterstick clamp is attached to the meterstick. Record both of these values in the table 2 and use them to calculate the angle q. Now, letting r represent the distance from the pivot point to the meterstick clamp, calculate and record r sin u in table 2.

a. What does the product r sinq represent? (Hint: Where's the force ?)

b. If you multiply r sinq by the force, what does the product represent?

8. Now, complete the Table 2 using the same procedure used in step 7 above to obtain values of F, h, L, u, r sin u, and Fü r sin u for h approximately equal to 0.9 m, 0.8 m, 0.7 m, 0.6 m .

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Probe Height | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

a. How does the force change as the perpendicular distance (r sin q) decreases?

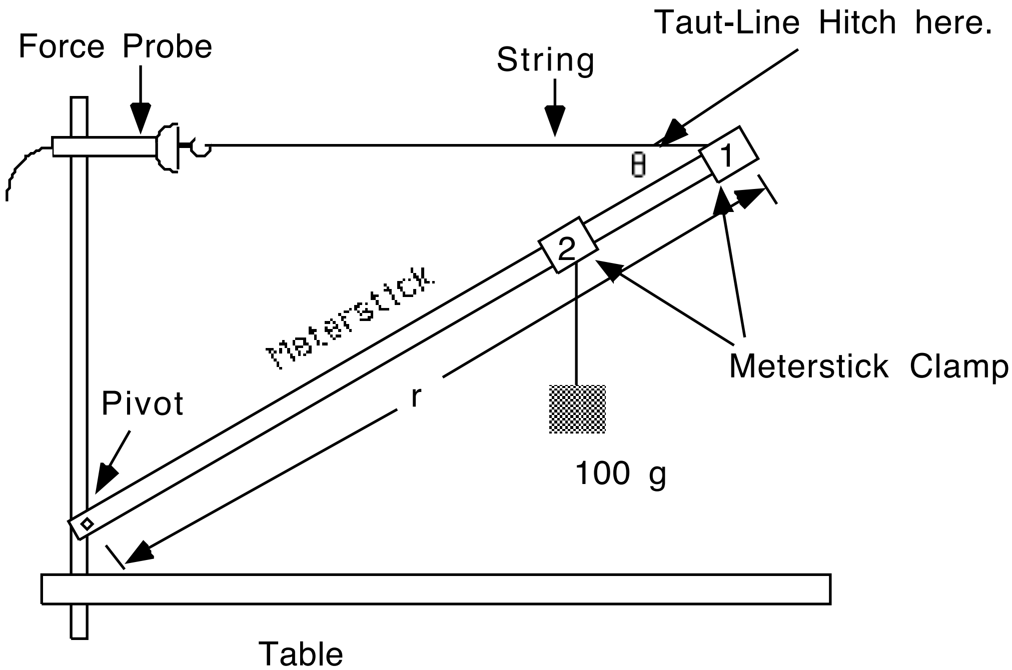
b. How does the product F • r sin q change as the distance (r sin q) decreases?

9. Draw the free body diagram for the meterstick-clamp system. (Be careful, you lose a point for each force omitted!

a. Calculate for each set of measurements, the torque on the system due to the weight of the meterstick and the weight of the clamp. Find the percent difference between this torque (clockwise torque) and the torque caused by the string (counterclockwise torque). (% difference should be less than 5 % .)

Activity Three - Predicting the Tension, Knowing the Other Forces

**PROCEDURE:** Setup the torque apparatus as indicated - there should be a "model" setup for you to view. Put meterstick clamp 1 at 0.98 m and meterstick clamp 2 at 0.70 m, tie a string to the clamp using a Taut-Line Hitch so you can easily change it's length, and attach the other end to the force probe. Make the force probe clamp approximately 60 cm above the table. Hang 100 g from meterstick clamp 2.




Record the mass of meterstick clamp 1: _________ and meterstick clamp 2: ___________

10. Draw the free body diagram for the meterstick arrangement above. On this figure show a dashed line that represents the perpendicular distance, r sin q, [Note: r and q are not the same for all forces, which torques are positive, (counterclockwise), and which are negative (clockwise)], for <u>each force</u> from the pivot point. Solve algebraically for the tension T in the string.

11. Measure and record on the previous figure any additional heights needed to calculate the angle q of the meterstick from the horizontal.

    Put numbers into your equation from step 10 above and calculate the value of the string tension T. This is your **predicted value of T**.

12. Zero the force probe, find the average force of the of the force probe. Record the tension as

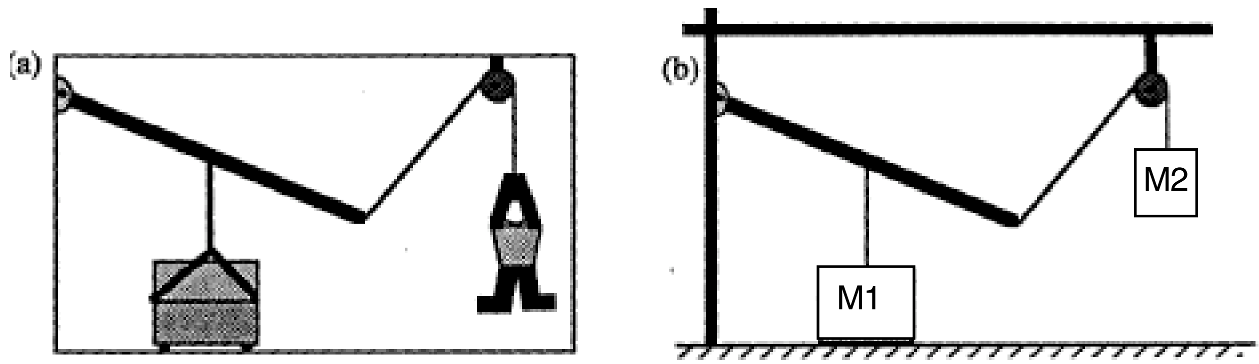
    T = ___________

    Find the percent difference between the experimental value and the predicted value of T.

# Experiment 11
# Experiment Problem for Statics

**Piano Lifter:** You are asked to develop a beam system that can lift a piano so that your mate can clean under it. You decide to use a system, such as shown below in (a). To develop your expertise, you first experiment with a miniature version. You are to decide with the miniature version, shown in (b), the minimum weight of the hanging object(M2) in order to lift the "piano"enough so that a paper can be slid under the piano. If you finish this task with time to spare, estimate the weight of the hanging object that will hold the beam in a horizontal orientation. (5 points Bonus!)

You will be provided with M1, and any lengths you find necessary.




**Instructor Guidelines: Each group must do the following in this order:**

1. (3 pts) Draw a Free Body Diagram (FBD) for the meter stick and get it checked by the instructor. If it is not correct, instructor will mark off a point and give you a hint. After two unsuccessful attempts, the instructor will give you the correct answer and you will be allowed to go to step 2.

2. (3 Pts) Write equations for the sum the forces on the meter stick in both x and y directions and them checked by the instructor. If they are not correct, the instructor will mark off a point and give you a hint. After two unsuccessful attempts the instructor will give you the answer and you will be allowed to go to step 3.

3. (3 Pts) Select the zero mark on the meter stick as the pivot and write an equation for the sum of the torques on the meter stick about this point. This must be checked by the instructor. If it is wrong, a point will be marked off and a hint given. After two unsuccessful attempts the answer will be given and you will be allowed to proceed to step 4.

4. (3 Pts) Solve the system of equations formed above for M2 in terms of measured quantities. If it is wrong, a point will be marked off and a hint given. After two unsuccessful attempts the answer will be given and you will be allowed to proceed to step 5.

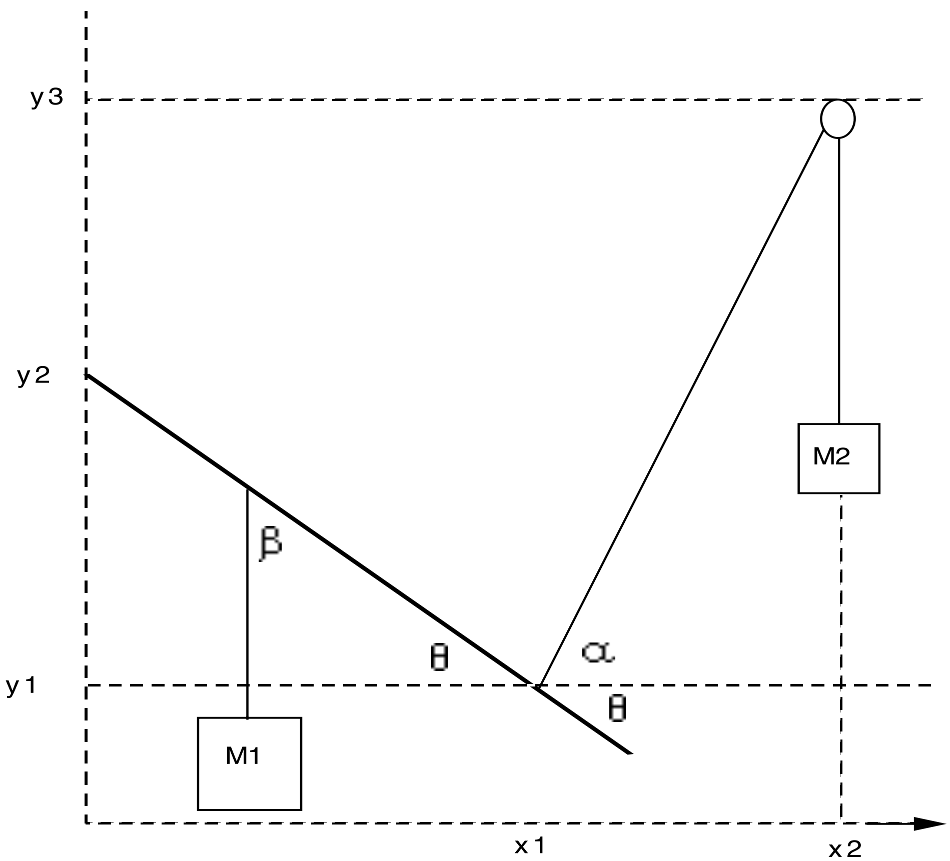
5. (3 Pts) Lab write up.

**Equipment List:**

| | |
|---|---|
| Meter stick for beam | Three right angle clamps |
| Two long rods (-80 cm) | Short thin rod that is pivot for beam |
| Pulley at end of rod | String |
| Meter stick | 500-g object (the piano) |

Standard masses and holder to hang from sting (200, 100, 50, 20, 20, 10, 5, 2, 2, 1 g)

# Experiment 11 Statics Help Sheet




sin b = cos u =

sin u =

sin a =

cos a =

sin (a + u) =

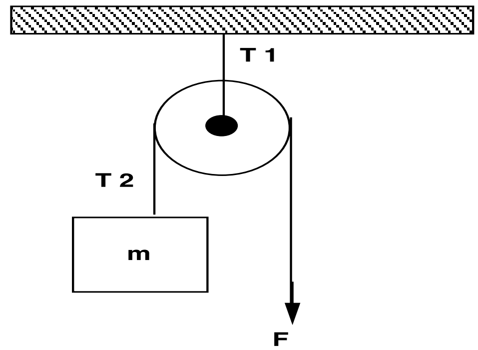
# Phy 201 & 213 Experiment 11a Statics I: Pulley's

Note 1: The mass m is "large enough" that you can treat the pulleys as if they are massless.
Note 2: These scales measure mass, you will have to calculate force by multiplying by 9.8 m/s$^2$.
Note 3: Finding F "in terms of W=mg of hanging mass means: F = C W; find C.

## Part I. The Pull Down

Predict: $T_1$ = ___________ $T_2$ = ____________

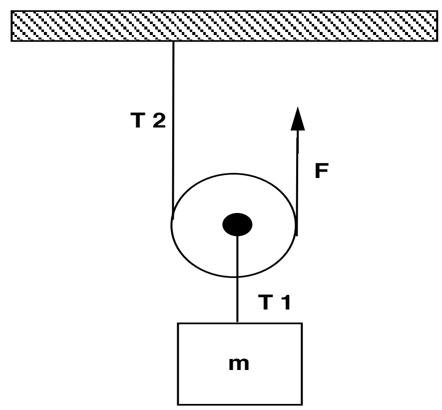
1. Find the tension $T_1$ and the force F required to hold the system stationary.
2. Find the tension $T_1$ and the force F required to hold the system stationary, in terms of the weight = mg of the mass m.
3. Find $T_2$ and then find $T_2$ in terms of m and g.




## Part II. The Pull up

Predict: $T_1$ = ___________ $T_2$ = ____________

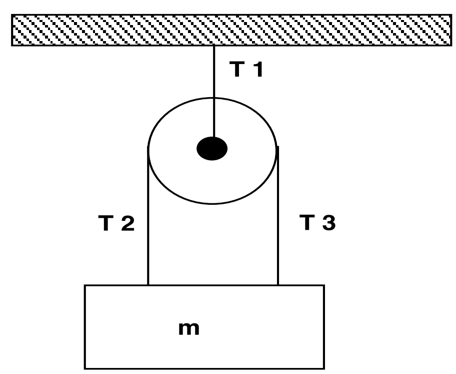
1. Find the tension $T_1$ and the force F required to hold the system stationary.
2. Find the tension $T_1$ and the force F required to hold the system stationary, in terms of the weight = mg of the mass m.
3. Find $T_2$ and then find $T_2$ in terms of the weight = mg of the mass m.




## Part III. The Double PullDown

Predict: $T_1$ = ___________ $T_2$ = ____________

1. Find the tension $T_1$ , $T_2$, and $T_3$.
2. Find $T_1$ ,$T_2$ and $T_3$ in terms of the weight = mg of the mass m.



# EXPERIMENT 12

# ARCHIMEDES PRINCIPLE

## INTRODUCTION

**Archimedes Principle states:** A body ($m_o$) wholly or partially submerged in a liquid will be buoyed up by a force ($F_B$) equal to the weight ($W_f = m_f g$) of the fluid displaced, or $F_B = W_f = m_f g$.

Density **p**: p = mass (m)/volume (V), hence m = pV!
The density of water, **$p_w$ = 1g/cm$^3$ = 10$^3$ kg/m$^3$.**

So an object's weight $W_o$ equals its mass $m_o$ times acceleration due to gravity g, or, $W_o = m_o g = p_o V_o g$
If an object floats, then the buoyant force $F_B$ equals both the weight of the object and the weight of the fluid displaced.

If an object sinks, then the apparent weight, $W_A$, of the object after submersion equals the weight of the object minus the weight of the object's volume of water.

## OBJECTIVES

Study Archimedes Principle and use it to find the densities of some liquids and solid objects.

## APPARATUS

Vernier Caliper - cab 5B, POGMMD- G/3C, metal Cylinder - cab 5C, Wooden block- G/2C, String-next to fire extinguisher, south wall, Meter stick-countertop north wall, 500 ml beaker PS-5B, Vertical support rods-corner by cab 6, Force Probe -in red box in cab PS 5

## REFERENCES

your text's chapter on Fluids

## PROCEDURE

## Part I. Determination of density by p = M/V.

1. Obtain and record mass of cylinder and wooden block using the POGMMD.

2. Using Vernier caliper, make and record on your data sheet the length (L), and diameters (D) of the cylinder. Using these values, and the volume of a cylinder formula, $V_{cyl} = \pi/4\ (LD^2)$,

calculate the volume of the cylinder and record. Finally, calculate the density of the cylinder.

3. Using a metric ruler, make and record determinations of the length, width and height of the wooden block. Finally, calculate and record the density of the block . Show whatever quantities and equations you use to obtain this value.

# Part II. Determination of densities using Archimedes Principle.

(This is the dreaded "verification of a principle" part of the lab.) You will determine the density using Archimedes Principle and compare it to the value above to (hopefully) "see" that it really works!

Note: Although our instruments are crude, your accuracy should be fairly good (meaning, your percent difference should be 15 % or less). If it is worse than that, either your lab techniques or your algebra is unacceptably awful.

l. Wooden block--very carefully and slowly lower the wooden block into a beaker of water. Now carefully remove it. The water line should be easily seen. Measure and record the depth to which the block sank in the water four different places on the block. Using the mean value of this depth along with the length and width measured in Part I, calculate the volume $V_f$ of water displaced by the block. Now, using Archimedes Principle, calculate and record the density of the block. Next calculate and record the percent difference between this value and the one obtained in Part I.

2. Brass Cylinder--attach one end of a piece of string to the brass cylinder and the other to the Force Probe (after calibrating and zeroing). **<u>The force probe must have the switch in 10 N mode.</u>** Lower the brass cylinder into a beaker of water and measure the tension in the string using the force probe. Now the tension (T) in the string plus the buoyant force $F_B$ must equal the weight of the brass cylinder $M_b g$. Or: $F_B + T = M_b g$. Use this and the fact that $M_b = p_b V_b$ to find $r_b$. Show any calculations you make.

Record this value of $p_b$. Also find and record the percent difference between this value and the one found in Part I.

# * Part III. Determination of the density of an unkown fluid.

Note: The unknown liquid is vegetable oil in bottom shelf of cabinet PS-5.

Since you know both the weight and volume of the brass cylinder, you should be able to use this fact and a procedure similar to the above to find the density of an unknown fluid! The only trouble is, the force probes are not very good at absolute accuracy, but they are pretty good at comparative accuracy. (Is that a word?) What I mean is, when compared to its own readings, **in the same trial**, its results are consistent. But when compared to some other device, the POGMMD, for instance, **or even its own readings in different trials,** it is not. So, for this part of the lab, you must use the force probes value for the weight of the cylinder. **<u>The force probe must have the switch in 10N mode.</u>** Do this, then zero, then attach the brass cylinder to a string and attach the other end to the force probe (don't forget to zero ). Start loggerPro, let it run a few seconds to record the **weight** of the cylinder in air, then bring the beaker containing solution l up to submerge the cylinder to record its weight in the fluid. Now record the weight of the cylinder in air as the $M_b g$, and the force after submersion as $T_1$. The buoyancy force should now be within your grasp, and since it must equal the <u>weight</u> of the fluid displaced by the cylinder, You should be able to find, and record, $p_1$, the density of solution 1.

# QUESTIONS (2 points each)

l. A balloon has an inflated volume of 12000 $ft^3$. If the balloon and the harness attached to it weigh 500 lbs. what payload can be lifted by the balloon when filled with helium? (Density of air = .0807 lb/$ft^3$ and the density of helium = .0111 lb/$ft^3$ at sea level.)

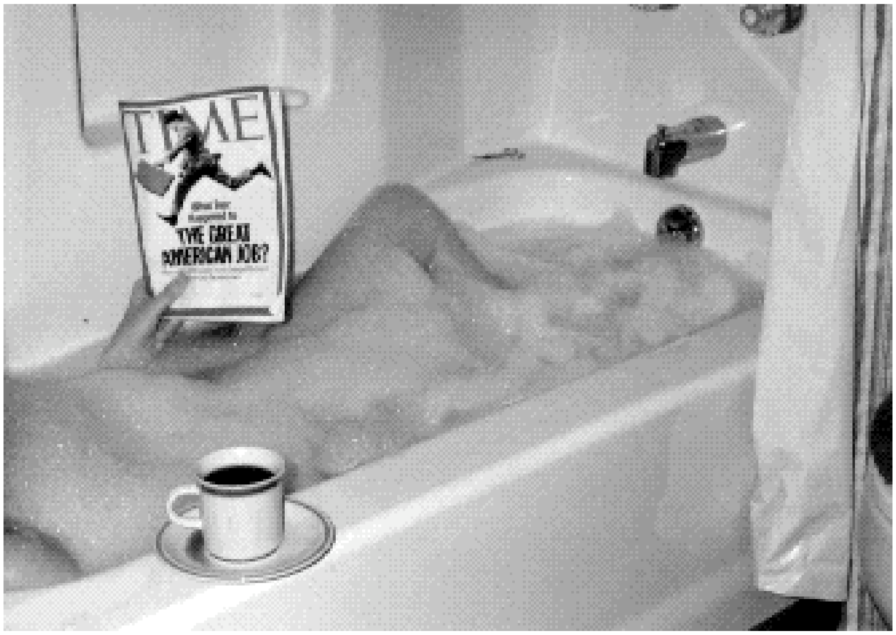
2. For <u>your</u> block, to what depth would it sink if floated in an oil of specific gravity = 0.7? (specific gravity of a substance $S_s = p_s/p_w$). a) write equation and solve for unknown, b) substitute in values for your block.

****************************************************

* if time permits.

# EXPERIMENT 13 HEAT & THERMO LAB1

# TEMPERATURE




*The coffee and the bath water are at the same temperature. Both are "hotter" than the air in the room. However, it costs much less to heat the coffee than it does to heat the bath water. Why? Aren't the words heat and temperature synonymous? Is heat a substance or what? In this unit you will learn how contemporary physicists define and use familiar terms like "heat" and "temperature" to help them understand thermal processes.*

. . . . thermometer readings alone do not tell the entire story of thermal interactions, . . . something else must be happening, and . . . an additional concept (or concepts) must be invented.

-- A. Arons

**Lab GroupNames**

**Author:** ___________________________

**Technician:**___________________________

**Analyst:** ___________________________

**Date:** ___________________________

# Part I. Temperature Scales

Suggested Reading: 201- 10-1 thru 10-3
213 - 19-1 thru 19-4

**Objective 1.** The object of this part is to convince us that the relationship between any two temperature scales ia a linear function. In other words, if an object has temperature $T_A$ using scale A, and temperature $T_B$ using scale B, then $T_B$ = (some constant)*$T_A$ + (some other constant), or, for the severely mathematically impaired, $T_B$ = (slope)*$T_A$ + $T_B$intercept.

To accomplish this formidable task we will invent our own temperature scales and take the temperature of 8 different things with our thermometer, as well as with both Centigrade and Fahrenheit thermometers. Then we will graph $T_{ours}$ vs $T_C$, $T_{ours}$ vs $T_F$, and $T_C$ vs $T_F$.

To conduct this investigation and several others in this session you will need:

- An unmarked glass bulb thermometer (Blue capped tube), cab 4D
- Masking tape for marking temperature scales, See Instructor
- A Centigrade glass bulb thermometer (Yellow Tube) Cab 4D
- Boiling Tap water, on Table 1
- Boiling Alcohol, on Table 1
- Boiling Salt Water, on Table 1
- Room Temperature Tap water, on Table 1
- Body Temperature, Yours
- Salt(NaCl)water on ice, on Table 1
- Ice Alcohol, Table 1
- Ice Tap Water, on Table 1
- Styrofoam cups w/ insulating lids, cab 4C
- Graphical Analysis

# Activity 1. How to build your own Thermometer

a) First place a 7" piece of Scotch tape lengthwise on an unmarked thermometer as directed by the instructor. Obtain two easily reproducible “fixed points” of temperature from the table below and mark these on the tape.

b) Decide what number to assign to either the top or bottom fixed point temperature and label it .

c) Decide how many units (“degree” marks) you want between the two fixed points, mark and label the other end point and at least 5 points between the two.

## Creating your own thermometer.

Choose your 2 fixed points from the following available items, and follow steps a, b, & c above to create your own thermometer.

| | | |
|---|---|---|
| Boiling water<br>boiling alcohol<br>boiling salt water<br>your own temperature (armpit) | room temperature water<br>room temperature alcohol<br>“ “ metal<br>“ “ wood | ice water<br>ice salt water<br>ice alcohol (cup of alcohol sitting in ice bed) |

1. Using thermometers marked with a Fahrenheit , Celsius(centigrade). and our scale, complete the following table.

| Item | Fahrenheit ($T_F$) | Celsius ($T_C$) | Your ($T_{ours}$) |
|---|---|---|---|
| Boiling Salt Water | | | |
| Boiling water | | | |
| Boiling alcohol | | | |
| body temperature | | | |
| room temperature | | | |
| ice alcohol | | | |
| ice water | | | |
| ice salt water | | | |

2. Use Graphical Analysis to plot a graph of $T_C$ vs $T_{ours}$. If the curve looks like a line, use automatic curve fit and click the appropriate dot to obtain the equation of $T_C$ as a function of $T_{ours}$.
Obtain a printout of your graph and include it when you hand in this activity. Be sure it is labeled clearly.

Write your equation here: $T_C$= ______________

3. Repeat for $T_{ours}$ vs $T_F$ . Write our equation for $T_{ours}$ as a function of $T_F$ here. $T_{ours}$ = ________

4. **Testing our Accuracy:** Repeat for $T_C$ vs $T_F$ Write your equation here: $T_C$= ______________

Note: your data for $T_C$ vs $T_F$ should indicate that the relationship between $T_C$ & $T_F$ is linear, but due to our crude thermometers, your equation may not be exactly right. Use the fact that water boils at $212^o$ F and $100^o$ C , and freezes at $32^o$ F and $0^o$ C , find the “correct” relationship by determining the equation of the line thru the points ($32^o$, $0^o$), & ($212^o$, $100^o$). Comment on your accuracy:

Show the algebra you used to obtain the actual formula here.

**Objective 2: Understand how change in temperature affects different materials.**

The molecules in any solid or liquid are actually vibrating at all times, in gases they actually move. This gives them a kind of kinetic energy. Temperature is actually a measure of the average kinetic energy per molecule in a substance. Bang on a penny with a hammer and it will heat up. That's because all that banging rattles the molecules in the penny causing the average kinetic energy per molecule to go up. Since they are vibrating more violently, the penny actually swells up. Different elements and compounds swell different amounts with the same amount of increased kinetic energy per molecule. Thus, different substances have different **coefficients of linear expansion.**

---

**- Discussion 1: The coefficients of linear, area, and volume expansion.**

Consult the Temperature Coefficient of Expansion table in your text for values of a
Note the formulas :

$$DL = aL_oDT$$
$$DA = gA_oDT = 2aA_oDT$$
$$DV = bV_oD = 3aV_oDT$$

---

**- Discussion 2: The Glass Bulb Thermometer**
Sketch a picture of a glass bulb thermometer. Explain how it works.

**Objective 3: Learn how to use the electronic temperature probe.**

Sensing Temperature Electronically

Next you will explore temperature measurement with an electronic temperature sensor that can be attached directly to the microcomputer at your lab station. This system has several advantages over the use of the glass bulb thermometers. The sensors usually respond more quickly to changes in temperature. You can produce a graph of temperature vs. time for one or two sensors at a time automatically. And, as usual, the data you collect can be displayed in tabular form and transferred to other programs for further analysis and display. The purpose of this activity is to become familiar with electronic temperature measurement, some of the limitations of electronic sensing, and features of the temperature measuring software.

To carry out these investigations you will need in addition to some of the other materials used earlier in this session:

- *LoggerPro* Icon - Under the Apple Menu
- a temperature probe G/S -1
- a Lab Pro - in red toolbox in PS-5 (under the glass cabinets)

To get started:

**Activity 2: Introduction to the Temperature Probe.**
1. Plug the temperature probe into the LabPro.
2. *Find the temperatures of the air around you. Open Logger Pro*. A temperature-time axis should appear on the screen with the current temperatures being read by the probe(s) at the bottom of the screen.

*Electronic vs. Glass Bulb Temperatures*
Our new temperature sensors are fairly accurate without calibration, but you may calibrate if desired.

**Caution!!** Cups will **NOT** support the thermometers !! Hold onto cup with one hand and thermometer with the other at all times!!

**Note :** You will have to use a styrofoam lid for the hot water in order to obtain a stable reading (otherwise it cools off too fast), poke the thermometer and probe thru holes in the lid.

**Activity 3: Comparing Temperatures**
(a) To determine the accuracy of the temperature probe, re-measure a couple of temperatures using both kinds of thermometers for a reality check. Try ice alcohol and boiling salt water for a check and fill out the table below.

| | Glass Bulb Therm ($^o$ C) | Electronic Therm ($^o$ C) | Difference ($^o$ C) |
|---|---|---|---|
| Ice Alcohol | | | |
| Boiling Salt Water | | | |

(b) How close is the electronic reading to your "standard"?

Note: If you are off by more than ±1 degree Celsius you should re-calibrate carefully before any session where accurate temperature readings are needed. Don't bother re-calibrating now unless you are off by 5° or more.

*Some Important Properties of Temperature Sensing*

There are a couple of things you should know about temperature sensing in order to measure temperature more accurately.

**Discussion 3: Time Delays**

(a) When a nurse pops a room temperature thermometer in your mouth to see if you have a fever, can the temperature be determined immediately? Why not?

(b) Suppose you want to measure room temperature with a thermometer that has been in ice water. Which do you predict would cause more time delay, measuring room temperature water or room temperature air? Explain the reason for your prediction.

**Note: You really should use two temperature probes to do this part and part (e). You can share with another group, or simply do each part separately. You'll need to calibrate the new temperature probe.**

Do!(c) Use the Standard Temp Probe program to verify your prediction *quantitatively* by recording how the temperature of an electronic temperature sensor changes over time when it is transferred from ice water to room air and vice versa. (You'll need to set the scales to 0 & 25 $^0$ C and 0 to 300 seconds.)

Stabilize both thermometers in the ice water, then click on Collect and place one in the room temperature water and wave the other around in the air. Continue until both stabilize at room temperature. Click on analyze to obtain the times.

Ice water to room air: $\Delta t$ (sec) =

Ice water to room temp water: $\Delta t$ (sec) =

Discuss! (d) On the basis of these measurements what should you watch out for in making temperature measurements?

Discuss! (e) The temperature difference between room temperature and ice water is about 20°C. What do you think will happen to the measured time delays if the temperature of the sensor is only a degree or two below room temperature? **Try it!** Make some cool water in a styrofoam cup, and some room temperature water in another. Place both sensors in the cool water until they stabilize. Then place one in the warm water, and wave the other one around in the air.

cool water to room air: $\Delta t$ (sec) =

cool water to room temp water: $\Delta t$ (sec) =

Compare and comment on the ratios $\Delta T/\Delta t$ for these two cases to the ones above in part (c)

---

Remember how it feels to get out of a shower on a dry day? Brrr! You need to beware of *cooling by evaporation*. Be careful not to measure air temperatures when the sensitive part of the thermometer is wet (especially with alcohol). Evaporating liquid on the thermometer can cool it. You will be in a better position to understand and explain the phenomenon of cooling by evaporation after completing the next couple of units on thermodynamics in which we study the relationship between temperature and molecular motion in a substance.


**Discussion -Can we trust our "feelings" when it comes to temperature ? Discuss this demo but do not do it.**

**Thermal Equilibrium**

Are objects lying around a room really at the same temperature? To explore this question of thermal equilibrium you can use the following:

- A piece of metal with a sensor hole Cab 1-B
- A piece of Styrofoam with a sensor hole Cab 4-C
- A piece of wood with a sensor hole C4-C
- A thermometer or MBL temperature system C4-D

**- Activity 4: Predicting Relative Temperatures**

(a) Feel the wood, metal, and Styrofoam. Predict which one actually has the highest temperature and the lowest temperature.

(b) Now measure the temperature of the three objects and record your measurements in the table below.

| | |
|---|---|
| Metal | °C |
| Wood | °C |
| Styrofoam | °C |

(c) Did your observation jive with your prediction? _______ Is your sense of touch an accurate predictor of relative temperatures? __________

(d) According to other observations you have made in this session, should the temperatures of three different materials sitting around in the same room be the same or different?

(e) On the basis of previous observations, you should be able to explain the reason why some objects feel colder than others. Hint: Is the temperature of your hand different than the room temperature? If so, what is happening when you touch an object which is at room temperature?

**Problems Assigned: (In addition to those in Chapter 19 (213) or chapter 11 (201)**

1. A 40 $F^o$ increase in temperature of an object would be what increase in $C^o$ ?

2. A 60 $C^o$ drop in temperature of an object would be what change in temperature on a Fahrenheit scale?

3. A change of 80 Kelvins on the absolute temperature scale would be what change on the: a) Centigrade scale, b) on the Fahrenheit scale?

4. At what temperature are the Kelvin and Fahrenheit scales the same?

5. At what temperature are the Centigrade and Fahrenheit scales the same?

6. At what temperature are the Kelvin and Centigrade scales the same?

7. The New River Gorge bridge in West Virginia is a steel arch bridge 518 m in length. How much will its length change between temperature extremes of -20 degrees C and 35 degrees C?

8. If a fast marble hits a random scattering of slow marbles, does the fast marble usually speed up or slow down? Which gain(s) kinetic energy and which lose(s) kinetic energy? How do these questions relate to the direction of heat flow?

9. Suppose you apply a flame for a certain amount of time to 1 liter of room temperature water and the temperature rises $2^o$ C. If you apply the same flame to 2 liters of room temperature water for the same amount of time, by how much will its temperature rise?

10. Approximately what is human body temperature on the Celsius temperature scale?_____

11. Which is better at transferring heat , water or air? How does this fact explain the length of time it takes the temperature probe to reach thermal equilibrium with the air or water it is in?

______________________________________________________

______________________________________________________

______________________________________________________

12. What effect does the evaporation of water have on the object from which it is evaporating? When has your body experienced this effect?

______________________________________________________

______________________________________________________

______________________________________________________

13. During evaporation, heat flows from something to something? What does it flow from and what does it flow to?

______________________________________________________

______________________________________________________

14. If you put a cup of hot chocolate at 80°C on a table in a room at 20°C you already know it will cool down.

a. How cool will the hot chocolate get?_______

b. If you put it outside where the temperature is 5°C, how cool will it get?_____

# EXP 14: HEAT & THERMO LAB II
# TEMPERATURE AND HEAT TRANSFER

Ever notice how some foods stay hotter longer than others? Boiled onions or pizza may burn your tongue if you try to eat it too quickly. But mash potatoes or toast may be eaten straight out of the stove.While it may take 15 minutes to heat room temperature water to boiling, it will take only 2 minutes to heat the same mass of iron to the same temperature, and less than a minute for silver. As you know by now, changing something's temperature means changing the average kinetic energy per molecule in that substance. In other words, heat is just another form of energy. In fact: **heat is defined to be energy that is transferred from one place to another because of a difference of temperature.** Futhermore, the amount of heat (energy) required to raise the temperature of a given **sample** of a particular substance by one degree Celcius is called it's **Heat Capacity, (C)** of that particular sample of the substance. **Specific Heat,** (denoted by lower case "c") on the other hand, is defined to be the amount of heat (energy) required to raise the temperture of **1 gram** of that substance by $1^{o}$ C. **In other words, SPECIFIC HEAT is heat capacity per unit mass of the substance. I**t's the "c" in the formula Q = mcDT. The introduction of this formula is the primary purpose of this lab.

**Lab GroupNames**

**Author:_________________________**

**Technician:_________________________**

**Analyst: _________________________**

**Date:_________________________**

The objective of lab 2 is to introduce you to two ideas. How much temperature changes when energy is transferred to something (like banging on the penny) depends upon two things:

Its **mass** and its **specific heat capacity.**

**Activity 1. Convincing oneself that electricity really can generate heat.**

We're going to use electricity to deliver chunks of energy so the first thing we need to do is convince you that electricity really does deliver heat. For this observation you will need the following:

- A Gencon hand-operated generator - Cab 1E
- Alligator clip leads for the generator
- A miniature light bulb and socket - Cab 1D
- An 18" (or so) length of nichrome wire - In Genecon box
- A finger
- A lab partner (need a volunteer)
- 8Volts DC (approximately) From red & black plugs under the table

a) Connect the Gencon to the light bulb and turn the crank. Does the light bulb light? Now disconnect it and turn the crank. Describe the difference in cranking before and after disconnecting the bulb.

b) Now wrap the wire loosely around your index finger, attach it to the generator and have your partner turn the crank. Do you feel the heat?

**Objective 1: Determining the relationship between heat added (Q) and temperature change (DT). In other words, proving that $Q_{in}$ = mass x heat capacity x Temp change = m c DT.** Power P=VI in J/s. So P Dt will be energy in Joules, i. e., $Q_{in}$ = VI Dt . Notice that V and I will be constants in this formula, so if we double the time we double the heat in, halving the time halves the heat in and so forth.

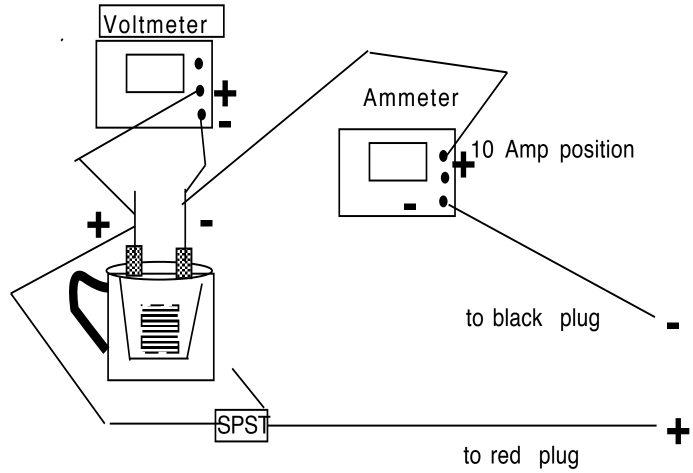
Note: There is a lot of stuff we are using here we haven't covered yet. There are two basic units of heat used in this course, calories and joules. They are related by the formula 1 cal = 4.186J. So the **division by 4.186** in the table below **is to convert the energy units to calories** so that the specific heat of water will be one calorie/C$^{o}$/g.

**Activity 2: Adding the same amount of heat to different masses of water.**

**Apparatus:** Labpro & temp probe, in the red tool box, voltmeter & ampmeter, G/3 C, heating coil, cab 4 D, wires, back wall pegboard.SPST, cab 1C, 10 V DC, under table.

**A.** We're going to have 4 setup groups, each with a different mass of water. We'll put the same amount of heat in each chunk of water. We'll obtain a Temperature (T) vs time (t) curve using the Standard

Temperature Probe (under the Apple Menu). With a little help from Excel or Graphical Analysis we'll obtain a Q vs DT curve and see what it tells us.




**Group 1:** place 125 g of room temperature water in a styrofoam cup inside the plastic cup.
**Group 2**: Place 175 g room temperature water in a styrofoam cup inside the plastic cup
**Group 3:** place 200 g of room temperature water in a styrofoam cup inside the plastic cup.
**Group 4:** place 290 g of room temperature water in the plastic cup.

**All groups:**

1. Hook up the apparatus as indicated in the diagram below.
2. Set the temperature scale to Temperature 1.
3. Set the time scale to 210 s, and the temperature scale to 0 to 100.

**Do not throw the switch until the instructor examines your setup.**

4. **Important!** Close the switch and start collecting simultaneously! Heat the water for 210 s. (change the time scale) **Stir Constantly!!**

5. One person must record the voltage V and the current I every 25 seconds.

6. After your time runs out, **open the switch.** Under Analyze, select Examine and obtain 8 values of T and t to place in a table with headings indicated below in a Graphical Analysis worksheet . **Use the average of your voltage and current values for V and I in the formula for Q in the table.**

| I | V | mass | t | $Dt = t - t_0$ | T | $DT = T-T_o$ | $Q = \frac{V*I*Dt\ (J)}{4.186(J/cal)}$ |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

7. Obtain a Q vs DT graph including line of best fit and equation of the line. Use this and information obtained from the other two groups to fill in the chart below.

| Group | Mass | slope of Q vs DT | % diff between m & slope of Q vs DT |
|---|---|---|---|
| 1 | 125g | | |
| 2 | 175g | | |
| 3 | 200g | | |
| 4 | 290g | | |

8. Include a print out of your Q vs DT data table and graph at this location in your lab writeup.

Does the slope turns out to be very close to the mass of your water sample? (It should.)

**B. Finding the specific heat of antifreeze. Repeat A steps 1 - 4 with Antifreeze.**

| I | V | mass | t | $Dt = t - t_0$ | T | $DT = T - T_o$ | $Q = \frac{V*I*Dt}{4.186}$ |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

9. Fill in the chart below. Note that if Q = mcDT and slope = k = mc , then c = ?.

| Group | Mass (m) | slope (k) of Q vs DT | c = k / m |
|---|---|---|---|
| 1 | 125g | | |
| 2 | 175g | | |
| 3 | 200g | | |
| 4 | 290g | | |

10. Include a print out of your Q vs DT data table and graph at this location in your lab writeup.

11. Discussion: Notice that the antifreeze gains more temperature than the water with the same amount of heat added. That is because it has less capacity to absorb heat without affecting its temperature than water. This c = k/m is antifreeze's ability to absorb heat as a fractional part of water's ability to absorb heat per unit mass per centigrade degree **where heat is in calories**.

**12. Question:** Based upon the information of part A,Step 5, what must be the specific heat of water according to your data? What is your percent error ?

**C. (Optional for 5 points bonus). Repeat B 1 - 6 to find the specific heat of cooking oil.**

| I | V | mass | t | $Dt = t - t_0$ | T | $DT = T-T_o$ | $Q = \frac{V*I*Dt}{4.186}$ |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

10. Fill in the chart below.

| Group | Mass (m) | slope (k) of Q vs DT | c = k / m |
|---|---|---|---|
| 1 | 125g | | |
| 2 | 175g | | |
| 3 | 200g | | |
| 4 | 290g | | |

**13. Determine the specific heat of oil.**

## Problems for Lab 2: (3 Points)

1. How much heat (in calories) is required to raise the temperature of 400 g of copper by $60^o$ ? Look up the specific heat of copper in your textbook.

2. If 3000 calories of energy raises the temperature of a substance from $40^o$ C to $55^o$ C, what is it's heat capacity?

3. 1500 calories is added to alcohol at $20^o$C. Its final temperature is $40^o$ C. What is it's mass?

# Experiment 15: H&T Lab 5 Phase Change

## Heat Transfer Without Temperature Change: Is it Possible?

**Duh,** Of course it is, otherwise why would we be doing this lab?

**Objective:** Recognize and understand conditions under which heat can be added to a mass without a temperature change.

Just in case you haven't memorized this yet, let's return to the principle of heat transfer we developed in the last unit:

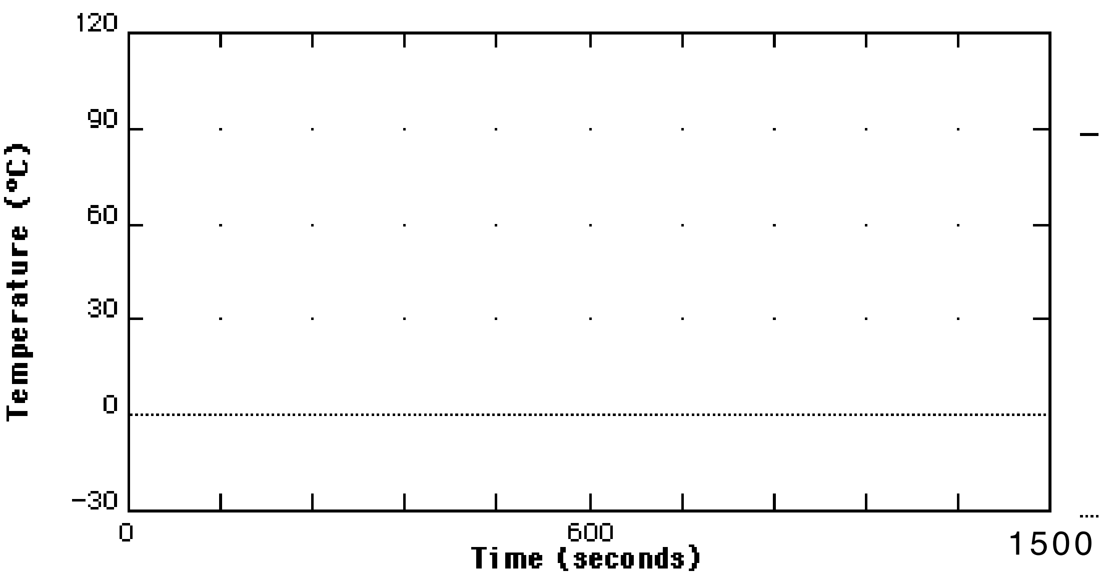
"Heat is energy in transit between two systems in thermal contact due to the temperature difference only."

Consider the heating coil, if you touch it, is very hot. It is capable of transferring a known amount of heat energy to any system having lower temperature than it has. The question is this – how is it possible for a system to absorb heat and not change temperature?

### Activity 1. Changing Ice to Water and then to Steam.

Discussion : Predicting T vs. t for Water

(1) Suppose you were to add heat at a constant rate to a container of water at 0°C (with no ice in it) for 10 minutes at a low enough rate that the water almost reaches its boiling point. Sketch the predicted shape of the heating "curve" on the graph below.




(2) Suppose that the container had a mixture of ice and water at 0°C when you started heating it at a faster rate and that the water starts boiling after five minutes (300 seconds). You keep adding heat energy at the same rate for five more minutes. Draw a *dotted line* on the graph above showing your prediction.

(3) **Determining Heats of Fusion and Vaporization for water.**

By transferring a known amount of heat energy to a mixture that is originally half water and half ice until the ice melts, we can determine the amount of heat energy needed to melt a gram of ice. This energy is known as the ***latent heat of fusion.*** By transferring a known amount of heat energy to a known amount of water at $100^0$C and then measuring what's left of the water, one can also determine the amount of heat energy needed to turn a gram of boiling water into steam. This energy is known as the ***latent heat of***

***vaporization***. It is often measured in joules per gram. We will use these units in this activity. For this activity you will need:

- A LabPro and Temperature Probe - red toolbox PS - 5
- A heating coil- Cab 4D
- A Voltmeter & an Ammeter- get 2 multimeters from Cab G/3 C
- 10 Volts DC (approximately) - R&B plugs under table
- SPST switch Cab 1 D
- A large *(plastic insulated)* cup
- Small styrofoam cups to put inside the large cup Cab 4B
- Crushed ice and paper towels
- Water at 0°C
- An electronic balance

**Notes:**

1. You should calibrate and set up the temperature sensing system to take temperature vs. time data for 25 minutes (1500 s) from one temperature sensor while the heating coil is enabled. Set the temperature scale from 0 to 120. You do not necessarily have to run the experiment for the full 20 minutes. You should continue adding heat to the system until all of the ice is melted and then keep going until the water reaches the boiling point and boils for 5 minutes or so **but not enough to cause water level to drop below the coils.**

2. *You should stir continuously during the experiment and keep the heating coil immersed at all times.*

3. ***WARNING!! DO NOT TURN ON HEAT UNLESS THE HEATER IS IN THE WATER! Leave the heating coil unplugged until you are ready to start.***

4. As with any experiment, you should record and clearly label all data necessary to obtain results included herein. **Each incidence of missing data will cost you 1 point.**

**Procedure:**

1. You must be prepared to begin this experiment immediately after you mix the water and ice together, so first set up the apparatus and calibrate your temperature probe.

2. Pre-cool the heating coil by placing it in ice-water bath.

2. Measure 80 g ice water in a styrofoam cup (which is inside one of the plastic cups). Make sure the styrofoam cup sits high enough in the plastic cup so that its rim is above the plastic cup's rim.

3. In a separate cup measure 30 g (approximately) of fresh, dry ice. Be sure to record the exact mass of ice.

4. Take both cups over to your setup. Dump in the ice then put in the coil, then throw the switch and start Logger Pro immediately!

5. Don't forget to stir constantly. Also record the voltage and current at the end of each minute, (you'll take an average over the entire time of the lab.)

6. Continue to heat the water for 5 minutes after the water begins to boil.

7. When the experiment is finished, **immediately** remove the coil and go weigh the cup and water combined. Then pour out the water and re-weigh the cup to find out how much water was left . Be sure to record the mass of the water that was vaporized. You'll need this in part B below.

**A. Determining the latent heat of fusion of water.**

1. How long did it take the ice to melt? ________

Calculate how much energy in joules was added to the mixture <u>by the heating coil</u> while the ice was melting.

Show your formula! $Q_{exp}$___________

2. Remembering how many grams of ice you started with and the fact that $Q = mL_f$, calculate the experimental value of the latent heat of fusion. Show your calculations.

$L_{f\,exp} =$ _______J/kg

3. Analyze your curve after the ice has melted and figure out how many joules it takes to raise each gram of water (after the ice has melted) by 1°C. (You may want to go back and see how you did this in H & T Lab 2. Just pick two points on your T vs t curve and use them). This is of course the specific heat $c_w$, of water. Show data used, and the formula you used to obtain:

$c =$ _______ $\frac{J}{kg\ c^B}$

**B. Determining the latent heat of vaporization of water.**

1. Record the number of seconds the water boiled. __________

2. How many grams of water turned to steam in that time?________
How much heat energy was added in that time? ________
(Show all pertinent data and calculations.)

3. Using these number and the mass of the water vaporized,find the experimental value for the latent heat of vaporization, $L_{v\ exp}$. Show your calculations.

$L_{v\ exp}$. = ___________

4. Compare the values of specific heat and latent heat of fusion to the accepted values stated in your textbook or a handbook. What % error is there in each case?

| | Exp | Accepted | % error |
|---|---|---|---|
| Latent Heat of Fusion $L_f$ (J/kg) | | | |
| Specific Heat (c) J/(kg c°) | | | |
| Latent Heat of Vaporization $L_v$ (J/kg) | | | |

5. Are your values higher or lower than the accepted values in each case? Can you think of any sources of systematic error to explain this?

6. Obtain a print out of the graph for this experiment.

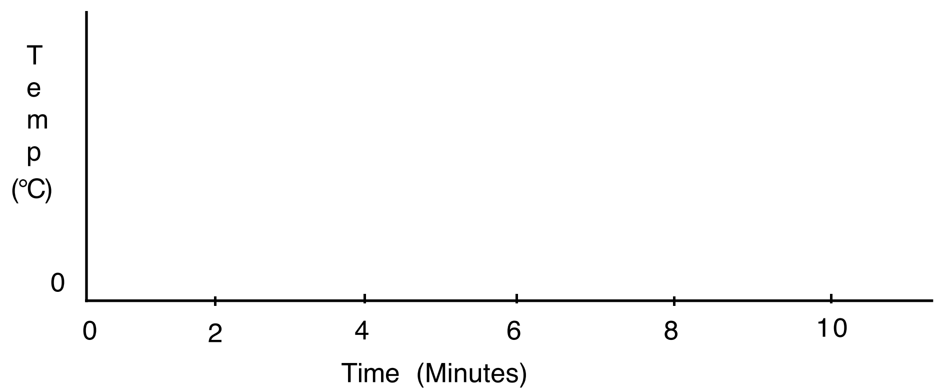
# Homework for Changing Phase:
# Ice to Water and Water to Steam

1. Describe what happens to the temperature of water when heat energy is transferred to it at a constant rate.

__________________________________________

___________________________________________

2. a) Sketch a temperature history on the axes below for Activity 1 in this lab.
   b) Describe what happens to the temperature of a water-ice mixture originally at 0°C when heat energy is transferred to it at a constant rate.
   c) Describe the location on your graph where the ice disappears.
   d) If the temperature is constant for part of your history, explain what the energy being transferred is doing.




________________________________________________________________

_________________________________________________________________

__________________________________________________________________

3. Convert your value for the *Latent Heat of Fusion* of ice from joules per gram to calories per gram. Show your calculations.

___________calories/gm

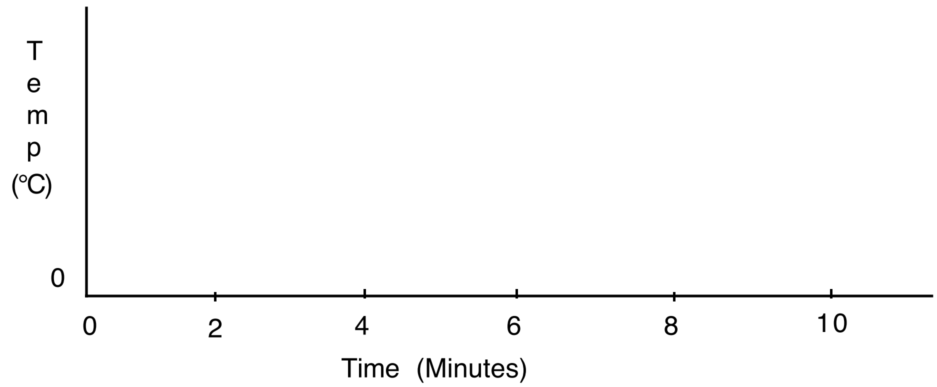
4. Suppose you start with 250 grams of ice at 0 °C. Calculate the amount of energy that must be transferred to melt the ice. (Use 335 joules/gram for the Latent Heat of Fusion of ice.) Show your calculations.

_____________joules

5. A mixture of 150 grams of ice and 300 grams of water is at 0 °C. How many joules of heat energy must be transferred to bring this mixture to a final temperature of 75 °C ? Assume the heat lost to the room is very small. Show your calculations. (Use 335 joules/gram for the Latent Heat of Fusion of Ice and 4.18 joules/gram °C for the Specific Heat Capacity of water.)

__________joules

6. Describe what would happen to the water in Question 2 if you continue to transfer heat at a constant rate even after the ice has melted. Sketch the temperature history on the axes below. Indicate on your sketch where the water begins to boil. If the temperature is constant for part of your history, explain where the energy being transferred is going.




7. Convert your value for the Latent Heat of Vaporization of water from joules per gram to calories per gram. Show your calculation.

___________calories/gm

8. Suppose you start with 250 grams of ice at 0 °C. Calculate the amount of heat energy which must be transferred to convert the ice to steam at 100 °C. Show your calculations. (Use 335 joules/gram for the Latent Heat of Fusion, 2250 joules/gram for the Latent Heat of Vaporization and 4.18 joules/gram °C for the Specific Heat Capacity of water.)

__________joules .

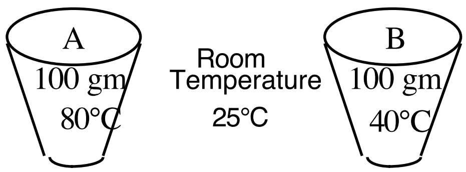
# Heat & Thermo Lab 4

## Activity 1. Cooling Rate: Is temperature a factor?

Suppose you had two cups of coffee, identical cups, same amounts, only one at 80°C and one at 40°C. Which will cool fastest ? That is, which will have the greatest temperature change in 60 s ?

## Predict:

Cups A and B contain the same amount of water (100 gms). The cups are placed in a room where the temperature is 25 °C. The water in cup A is initially at 80°C, while that in cup B is initially at 40°C.

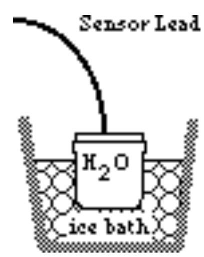



______1. Initially, which cup will cool down at a faster rate?
**A)** A will cool faster **B)** B will cool faster **C)** they both will cool at the same rate
**D)** not enough information is given to determine the answer

______2. Which cup will reach its final temperature most quickly?
**A)** Cup A **B)** Cup B **C)** Both take the same time
**D)** not enough information is given to determine the answer

To Find out the Truth you'll need:

- 200 ml Aluminum beaker - Cab 4D
- 1 plastic cup - Cab 4C
- 1 Temp Probe - G/1 B
- 1 ULI Cab 2A




On the computer, double click on the Standard Temperature Probe.
Click on the label on the vertical axis and change it to Temperature 1 only.
Click on the right end number of the horizontal axis and change it to 100 s.
Fill the plastic cup 1/2 full of ice.
Put 50 g of water into the aluminum beaker from the coffee pot.
Place the probe into the beaker for a minute to allow it to reach thermal equillibrium with the water.
Place the beaker in the cup of ice and start the program. **Stir constantly**
When finished, under Data select Data A -> Data B.
Now replace the ice in the plastic cup.
Put 50 g of 40° water in the aluminum cup and put probe in it.
Place the aluminum cup in the ice and start the program.
Measure the temperature difference for both curves using Analyze (under the Analyze menu) from 20s to 50s.

For the hottest water the change in temperature was ___________________.
For the coolest water the change in temperature was ___________________.

**Note: Please transfer your temperature data to a spreadsheet and SAVE IT as you will need it for homework. (Phy 215 only)**

So, of all things affecting cooling rate, temperature difference between object and surroundings is the primary factor.

# What else affects cooling rate? Discussion:

Think about a glass cup of coffee sitting on a glass table.
Think about a glass cup of coffee sitting on a wooden table.
Think about a glass cup of coffee sitting on a styrofoam placemat on a wooden table.

Burn the paper wrapped around the steel rod and the wooden rod.

Think about a styrofoam cup of coffee sitting on a glass table.
How about a saucer filled with coffee?
What about a saucer filled with coffee with a fan blowing on it?

Think about heat going through a small single paned window.
How about heat through a large single paned window?

How about a double paned window vs a triple paned window.

How about a double paned window on an Alabama winter day of $25^0$F vs a triple paned window on a Michigan winter day of $-25^0$ F ?

Would more heat go through an open window and why?

Think about the black pavement and the white line on it.

Which has the most heat going through it each second, a big window or a small one?

Which would conduct heat the fastest, a thick rod or a thin one, a thin one or a short one?

**Discuss forms of heat transfer: conduction, convection, & radiation**

**Heat lost due to conduction/s = H =** $\dfrac{kA\Delta T}{L} = \dfrac{A\Delta T}{\frac{L}{k}} = \dfrac{A\Delta T}{R}$

**Heat lost due to convection/s = H = hA$\Delta$T, h = convection coefficient, see your text.**

**Heat lost due to radiation/s = Power =P =** $\sigma Ae(T^4 - T_0^{\,4})$

**HOMEWORK**

**Phy 215: Read Section 20 - 7 & do Problems pg 556 - 53, 55, 59, 61, 62.**
**Phy 205: Read Sections 12-5,6,7 & do problems pg305 - 25,26,27,29, 32,33**
**Let's take a Break!**

**Phy 205 Text Pg 304: Do 4, 8, 12. Assign - Quest 1-22, Problems 5,9,10B,11,13.**

**Phy 215 Text Pg 553: Quest. 1-26, Probs 3,5,7,9.**

## • *Homework for Intro. to Heat and Temperature*" (attached) [10 pts]

(Due Monday, 4-10-95) Turn in by groups.

**1)** [10 pts] Suppose you pour hot coffee for your guests, and one of them chooses to drink the coffee after it has been in the cup for several minutes. In order to have the warmest coffee, should the person add the cream just after the coffee is poured or just before drinking? Explain.

**2)** An 80-kg weight-watcher wishes to climb a mountain to work off the equivalent of a large piece of chocolate cake rated at 700 (food) Calories. How high must the person climb? Note: One food calorie = 1000 physicist's calories.

3. Approximately what is human body temperature on the Celsius temperature scale?_____

4. Which is better at transferring heat , water or air? How does this fact explain the length of time it takes the temperature probe to reach thermal equilibrium with the air or water it is in?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

3. What effect does the evaporation of water have on the object from which it is evaporating? When has your body experienced this effect?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

4. During evaporation, heat flows from something to something? What does it flow from and what does it flow to?

______________________________________________________________________

______________________________________________________________________

5. If you put a cup of hot chocolate at 80°C on a table in a room at 20°C you already know it will cool down.

a. How cool will the hot chocolate get?_______

b. If you put it outside where the temperature is 5°C, how cool will it get?_____

c. Compare the initial rates of cooling in (a) and (b). Are they the same or is one larger? Explain.

______________________________________________________

d. Where does the heat go as the hot chocolate cools down?

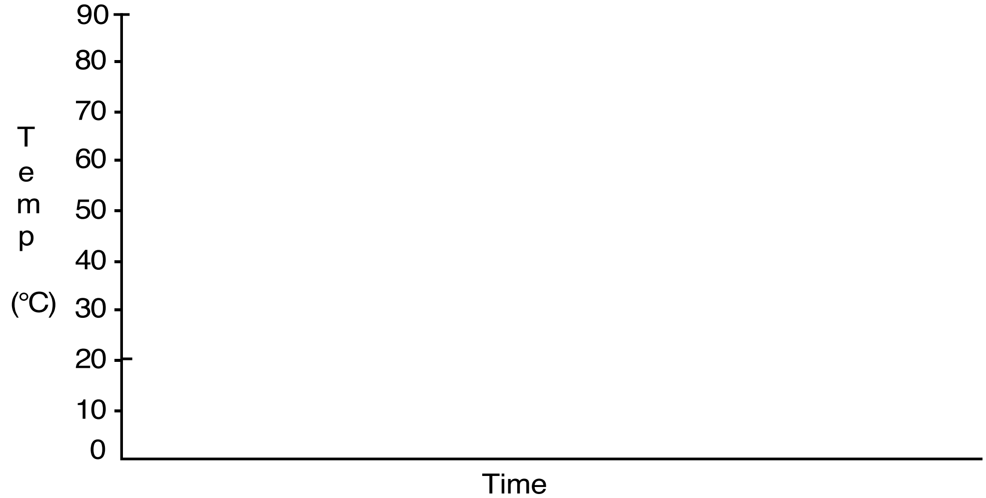
______________________________________________________

e. On the axes on the below, sketch a graph of the temperature of hot chocolate vs. time if the hot chocolate starts at 80°C and is placed outside on a cold day where the temperature is 0°C.

f. Explain the shape of the graph, especially changes in the rate of cooling as the hot chocolate cools down, in terms of your observations in this lab.

_______________________________________________

_______________________________________________




6. **(215 only)** Newton discovered an observational law which describes the rate at which most objects cool and heat. The Law is as follows: *At any given time the rate at which an object cools (or heats) is proportional to the temperature difference between the object and its surroundings*.

In this problem you should see if you can verify Newton's Law of Cooling by analyzing the data you obtained from the **coolest** cooling water sample in Activity 1 of Lab 4. By using a spreadsheet you can find the approximate rate of cooling at two successive moments in time by noting that

$$R_c = \frac{dT}{dt} \approx \frac{\Delta T}{\Delta t} \qquad \text{Eq. 1}$$

where $\Delta T = (T_i - T_{i-1})$ is the temperature change **<u>between one reading and the next</u>** and $\Delta t = (t_i - t_{i-1})$ is the time interval **<u>between successive readings</u>**. (Note: You will have less distortion by round-off error if you select about 20 points with time interval approximately $\Delta t = 5$ s.) The temperature difference between the object and its surroundings is given by the difference between the final room temperature and the current temperature of the object, so that $\Delta T = T - T_s$ where T is the current temperature of the object at time t and $T_s$ is the temperature of the surroundings.

[5 pts] (a) Show graphically that

$$\frac{dT}{dt} \approx \frac{\Delta T}{\Delta t} = -k(T - T_s) \qquad \text{Eq. 2}$$

**Hint**: Transfer your cooling curve data (use a nice smooth subset) to a spread sheet and calculate the values of

$$\frac{\Delta T}{\Delta t} \text{ and } T - T_s$$

for each time at which a temperature has been recorded. Graph the results, determine whether the graph is linear, and, if so, find k by performing a simple fit to the data using **Trendline** in Excel.

[5 pts] (b) Solve the differential equation of Eq 2 above to obtain temperature T as a function of time t.

[5 pts] (c) Use Excel to obtain a graph of T vs t, and **Trendline** to obtain T as a function of t. Compare the coefficient of t in the exponent to the one obtained in (a) above.