PHYSICS I LABBOOK

PHY201 & 221

York Technical College

Rock Hill SC

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Lab Report Guidelines

Lab is an important part of a Physics class. It lets you get your "hands on the material" and see it really work. These are things I hope you get from participating in lab:

- An understanding of the principles we discuss in class
- An understanding of how scientists approach and solve problems, and how you can solve problems by careful study, measurement and problem solving skills
- A curiosity about the world and how it works
- Computer skills – a valuable job skill
- Writing skills – a valuable job skill
- Problem solving skills – a valuable job skill
- Some fun

A good lab report should convey information quickly, accurately and neatly. People who read your reports (including me) will want to know first what you were trying to do and what you found. Our lab reports will be submitted via D2L. Here are the steps:

- Go to https://d2l.yorktech.edu/
- Enter your username and password as described on the link above
- Click the link for PHY 201 221
- The quizzes/lab reports should be in a list on the main class page, click that week's lab.
- Answer the questions and hit submit.
- You will have a week from each lab to get the lab report done. After that D2L will block you from seeing/submitting the questions.
- When you hit submit, D2L will grade the multiple choice type questions and show you a grade so that you know it accepted your work. However, I will have to go in after the due date and grade the conclusion or any long answer type questions by hand. Your grade will be low until I get the grading finished. Relax!

The questions in the report/quiz will be a combination of the following:

- **Conclusion –** a statement of the findings of the lab, answering the objective, with a discussion comparing your results with the expected results (were there errors or equipment faults or what could have been done differently or better.) **The conclusion should prove or disprove the objective.** The conclusion does not describe the steps you took, but what you discovered.
- **Procedures –** a quick overview of the experimental equipment and steps taken. Someone should be able to replicate your work from your explanation.
- **Results/Data questions** – a check to see how accurate your results were
- **Concept questions –** questions that test your understanding of the underlying principles.

Lab 1: Measurement and Graphing

Objective Learn about measurement and numbers used in Science.

Materials	Ideas
• vernier caliper	• Significant figures
• ruler	• Scientific notation
• small PVC cylinder	• Graphing
• small glass vial	• Reading caliper
• paper	• Area of circle
• thread	• Volume of cylinder
• scissors	• Percent error
• plastic wrap	• Percent difference
• graduated cylinder	
• balance	

Procedures

1. and 2. Do exercises 1 and 2 on the datasheet regarding significant figures and scientific notation.

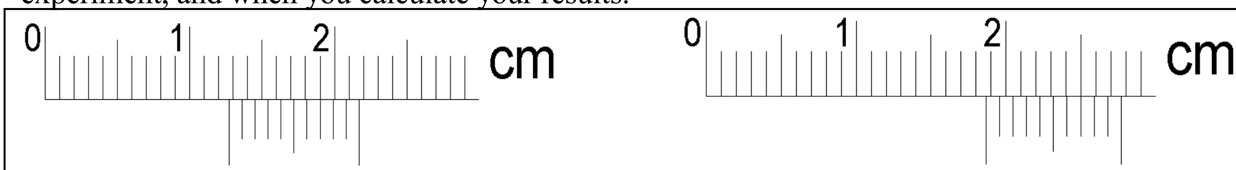
3. Graphing

The advance of a right-hand screw is proportional to the number of complete turns. Given the following data, plot a graph of advance (y-axis) versus number of turns (x-axis). Use your graph to determine the number of turns required to advance the screw 27.5 mm.

Number of turns:	16	32	48	64	80	96
Advance, millimeters (mm) :	5	10	15	20	25	30

1) Select any two points on the graph and calculate the value of slope.
2) Determine the y - intercept from the graph.

4. Measuring Pi - Pay attention to significant figures read from the instruments used in this experiment, and when you calculate your results.



Examples of measuring with a Vernier caliper

A. Value of Pi, First Method

- Use the Vernier caliper to make three measurements of the **outer** diameter of the PVC cylinder. (An attempt should be made to make measurements at different locations on the cylinder so possible errors due to the cylinder being out of round or tapered can mostly be averaged out.)
- Place a light pencil mark on the outside of the cylinder. (Please erase the mark after this exercise)
- Next, make a mark near one end of a sheet of paper.

- Then place the cylinder on the sheet of paper so the marks line up with each other.
- Roll the cylinder along the paper until the mark on the cylinder again contacts the paper.
- Make a second mark on the sheet of paper to indicate this point of contact.
- Use a ruler to measure the distance between the two marks on the paper. The distance is the circumference of the cylinder. Each team should **repeat this step three times** on their datasheet to account for possible slipping between the cylinder and paper and for differences in judging exactly where the marks line up.
- Average these results. Label the sheet of paper with the marks on it as part 4.A, and attach the sheet to your report.
- Divide the average circumference by the average diameter to obtain the value of pi.

B. Value of Pi, Second Method

- The diameter of the PVC cylinder has already been recorded.
- Wrap a thread around the cylinder to determine the circumference.
- Measure the length of the thread with a ruler to determine the circumference. Each team should **repeat this step three times** and the threads should be taped to the sheet of paper submitted for part 4.A.
- Average the results.
- Divide the average circumference by the average diameter to obtain the value of pi.

5. Finding Volume

A. Interior Volume of a Glass Vial, First Method

- Use the vernier caliper to measure **inner** diameter, D , of the small glass vial.
- Measure the height, h inside the glass vial with the probe part of the caliper.
- The interior volume of the vial can be found with the formula:

$$V = \frac{\pi D^2 h}{4}$$

B. Interior Volume of a Glass Vial, Second Method

- Fill a graduated cylinder with water to the full-scale mark on the graduate and record the amount on the data sheet.
- Carefully pour water from the graduated cylinder into the glass vial until it is full of water.
- Read the scale on the graduated cylinder and record the amount of water remaining.
- The difference in the two readings is the amount of water that has been poured into the cylinder. Note that one cubic centimeter equals one milliliter,

$$1 \text{ cm}^3 = 1 \text{ ml} = 1 \text{ cc}$$

<u>Questions</u>

1) Why do we like to measure things more than once? For example, in 4A we measure the outer diameter three times and then average. How does this apply to science?
2) Why do we like to measure quantities in more than one way? For example, in 5A we measure the volume one way and in 5B we use a different method to get the same measurement. How does this apply to science?
3) Why do we make measurements with significant digits? How does this apply to science?
4) Make a list of some features of all good scientific graphs and briefly tell why these should be included in your graphs.

Datasheet for Lab 1

1. Significant Figures

A. How many significant figures are in each of the following values?

5.0	0.0025	3.00×10^{6}	400.2	0.400	2.62×10^{-2}	0.008

B. Perform the computation indicated and round your answer to the correct number of significant figures:

$\frac{(34280)\ (265)}{(5347)\ (12)}$ $\frac{65.431}{3.1416}$ $\frac{26}{5280}$ $\frac{2.3 \times 10^{4}}{2.000}$ $\frac{3425}{2.0000}$ $(5 \times 10^{5})(3 \times 10^{2})$

___________ _________ ________ __________ _________ _____________

2. Scientific Notation

A. Express the following values in scientific notation and normal form:

Normal form	Scientific Notation
300,000	
468,900,000	
-0.0004	
0.000000561	
-695	
	-7×10^{-3}
	8.6×10^{3}
	5.28×10^{4}

B. Calculations

Expression	Value
$(-2.4 \times 10^{2})^{3}$	
$(1.4 \times 10^{-3})^{2}$	
$(5.58 \times 10^{3}) + (4.001 \times 10^{3})$	
$(5.58 \times 10^{5}) - (4.001 \times 10^{4})$	
$(5.58 \times 10^{3}) \cdot (4.001 \times 10^{3})$	
$(5.58 \times 10^{5}) / (4.001 \times 10^{4})$	

4. A. Value of Pi, First Method

	Trial 1	Trial 2	Trial 3	Average
Outer Diameter				
Circumference				

Calculated value of pi _______________

Actual value of pi _______________

% Error $\left(\frac{\text{actual} - \text{calculated}}{\text{actual}} \times 100\%\right)$ _______________

4.B. Value of Pi, Second Method

	Trial 1	Trial 2	Trial 3	Average
Circumference				

Calculated value of pi _______________

% Error $\left(\frac{\text{actual} - \text{calculated}}{\text{actual}} \times 100\%\right)$ _______________

5.A. Interior Volume of a Cylinder, First Method

	Trial 1	Trial 2	Trial 3	Average
Inner Diameter				

Internal height of cylinder ________________

Calculated interior volume of cylinder _________________

5.B. Interior Volume of Cylinder, Second Method

Volume of water to fill vial _____________________

% difference $\left(\frac{\text{first value} - \text{second value}}{\text{average value}} \times 100\%\right)$ in volumes _______________________

Lab 2: Constant Acceleration Due to Gravity

Objective Determine a value for the acceleration of gravity.

Materials	Ideas
• Behr free-fall apparatus • spark source • spark-sensitive tape • Meter stick • power supply (6 volts)	• Displacement • Velocity • Acceleration

CAUTION

- **Make certain that a ground wire is connected to the battery charger/power supply, the high- voltage spark source and the free-fall apparatus. All three devices must share a common ground.**
- **Do not stand too close to the free-fall apparatus. If the apparatus is not level, the falling object might bounce onto the floor and cause foot injury.**
- **When working around any high-voltage equipment, it is good practice to use one hand only. Keep your other hand away from any equipment or ground by placing it in your pocket or against your hip.**

Background

The velocity of freely falling objects increases when they are subjected to the pull of gravity. As long as air resistance is negligible, velocity will continually increase and acceleration will be constant. However, air resistance near the Earth's surface must be considered as velocity continues to increase. Ultimately, a terminal velocity is reached which depends on drag exerted on the object by air.

The major item of equipment used in this experiment is the Behr free-fall apparatus. The falling object is a tapered wood cylinder with a steel rod pressed axially into the cylinder and a metal ring attached to the outside of the cylinder. The cylinder can be suspended at the top of the apparatus by an electromagnet. When power to the electromagnet is interrupted the cylinder falls downward between two bare, parallel wires. A high voltage across the wires causes a spark to jump from one of the wires through the metal ring on the falling object and into the other parallel wire. The high voltage is pulsed so that a spark will jump across the falling object 60 times a second. A spark sensitive tape adjacent and parallel to the inside wire records the point where each spark jumps through the falling object as it descends.

Procedure 1 - Using the Apparatus to Produce Tapes

- Marks on the tape will indicate the location of the object every 1/60 second as it falls.
- The apparatus must be level and the wires must be correctly spaced. This is critical to the success of the experiment.
- Check that unmarked tape extends the length of the apparatus.
- Turn on the power supply for the electromagnet.
- Position the metal point of the object against the electromagnet so it is suspended at the top of the apparatus.

- Turn on the spark source but do not press the high-voltage toggle switch downward.
- Appoint one member of the team to pull the plug on the electromagnet power supply and one member of the team to press the high voltage toggle switch. The two members should work together so at an agreed-upon time, high voltage will be applied and within the next second the plug will be pulled on the electromagnet power supply. Sparks should appear continuously as the object descends.
- As soon as the object lands in the pit, release the high-voltage toggle switch.
- Turn off the high-voltage supply.

Procedure 2 - Obtaining Data from the Tape

- Identify the marks on the tape. The marks will serve as data points. The distance between points will gradually increase, and if there are any missing points, it should be obvious where the points are missing.
- If there are any missing points, place an X where it appears the points should have appeared.
- Label the first point at the top of the tape 0. This is the reference point for all length measurements that will follow.
- Then, consecutively number each of the points that follow, 1, 2, 3, 4, 5, etc. Include any missing points labeled X in the numbering sequence. The idea is to identify where the object was every 1/60 second during its fall even if the location has to be estimated.
- Measure the distance **from the zero or reference point to each of the points** and record these distances on the datasheet.
- **Prepare a graph** of distance in centimeters (y-axis) versus time in sixtieths of a second (x-axis). Since the points are produced at intervals, 1/60 second, 2/60 second, 3/60 second, etc., it is convenient to scale the x-axis in integers to save time and aid readability. Thus, a scale of 1,2,3,4, etc., along the x-axis represents 1/60 second, 2/60 second, 3/60 second, 4/60 second, etc. The graph serves as an excellent check on the data and the measurements of distance from the reference point. There may be gaps on the graph where marks were missing on the tape. Nevertheless, a line connecting the points should be smooth with no discontinuities.

Procedure 3 - Calculating Velocity of the Falling Object at each data point

- Calculate the change in position of the object at each data point except the first (reference) and last point by using the positions of the points before and after the point. For example, the change in position at point 7 is the position at point 8 – the position at point 6.
- Velocity at each point is the change in distance divided by the time required to fall that distance. The elapsed time is 2/60 or 0.03333 second. This can be written

$$v_n = \frac{\Delta y}{\Delta t} = \frac{y_{n+1} - y_{n-1}}{t_{n+1} - t_{n-1}} = \frac{y_{n+1} - y_{n-1}}{0.03333\,s}$$

Procedure 4 - Determining Acceleration

- **Plot a graph** of velocity in cm/s (y-axis) versus time (x-axis) with the same scale for the x-axis as the first graph. Leave an inch or two on the left side of the graph.
- Draw a best fit line through the data points.
- Find the slope and intercept of the best fit line.
- Convert the units of acceleration to International System units by multiplying the slope by 60. This is the acceleration due to gravity in m/s^2.

Spark #	Distance y_n (cm)	Elapsed Time (s)	Δy $y_{n+1} - y_{n-1}$ (cm)	Δt (s)	Velocity Δy/ Δt (cm/s)
0	0	0	-	-	-
1		1/60		0.03333	
2		2/60		0.03333	
3		3/60		0.03333	
4		4/60		0.03333	
5		5/60		0.03333	
6		6/60		0.03333	
7		7/60		0.03333	
8		8/60		0.03333	
9		9/60		0.03333	
10		10/60		0.03333	
11		11/60		0.03333	
12		12/60		0.03333	
13		13/60		0.03333	
14		14/60		0.03333	
15		15/60		0.03333	
16		16/60		0.03333	
17		17/60		0.03333	
18		18/60		0.03333	
19		19/60		0.03333	
20		20/60		0.03333	
21		21/60		0.03333	
22		22/60		0.03333	
23		23/60		0.03333	
24		24/60		0.03333	
25		25/60		0.03333	
26		26/60	-	-	-

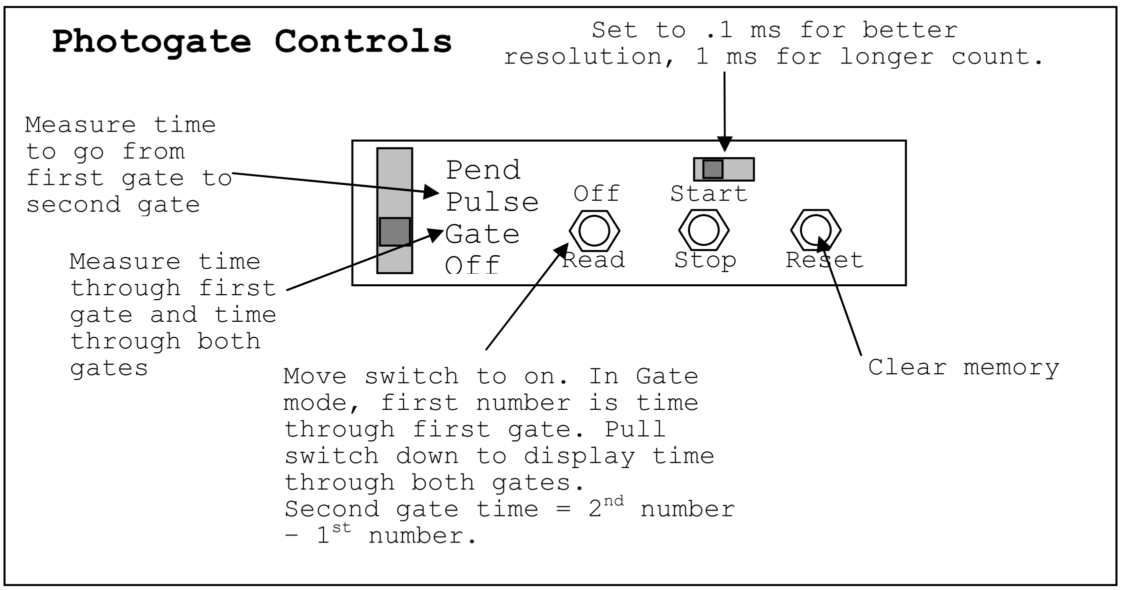
Lab 3: Velocity and Acceleration

Objective To verify the relations: $s = v_o t + 0.5\ a t^2$ and $v^2 = v_o^2 + 2 a s$

Materials	**Ideas**
• Air track and accessories • Glider • Photogates • Wood block	• Velocity • Acceleration • Experimentally verifying equations

Operation of the Air Track

The air track provides a nearly frictionless surface for the glider. The glider is equipped with a flag that passes through photogate electronic timing devices. The photogate with the electronic display is called the master photogate. The other photogate is called the remote photogate. Note that a red light on top of the photogate illuminates whenever the beam is interrupted.

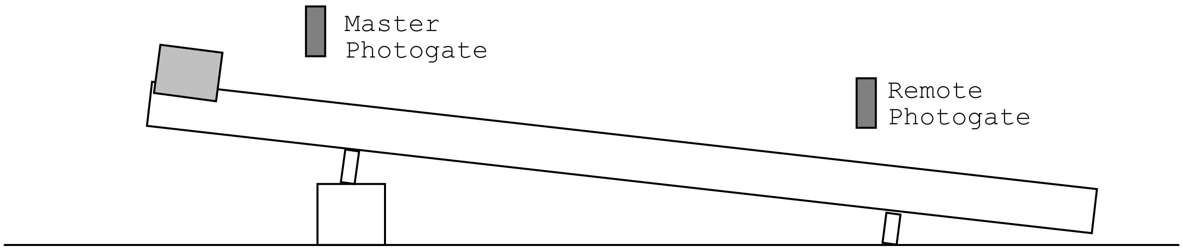


In pulse mode the timer starts when the flag goes through the first gate and stops when the flag goes through the other photogate. Pulse mode measures the time to travel from one photogate to the other. In gate mode the timer counts how long it takes to pass through the first gate, and memory will record the time it takes to pass through both gates. Since velocity = distance/time, gate mode allows you to calculate the velocity of the glider at any two spots on the track.

$$\text{velocity} \qquad v_0 = \frac{\text{flag width}}{\Delta t} \qquad \text{Equation 3}$$

Procedure 1

- Place a wood block under the air track so that one end is inclined above the table so the end with one support is on the block and the end with two supports is on the bench.
- Install the rubber-band bumper at the bottom of the track.



<u>Procedure 2</u> - Determining Time to travel between the two photogates

- Set the master unit to "pulse" mode. Position the small slide switch to 1.0 ms.
- Orient the flag so it is pointed directly down the track. The full width of the flag must be detected by each photogate for the measurements to be accurate.
- Place the leading edge of the glider 20 cm from the top of the air track. This is x_o in the equations listed under Objective and will be recorded on line 1. on the data sheet.
- Carefully position the master photogate so the leading edge of the flag interrupts the beam. The red light on top of the photogate turns on when the beam is interrupted. (You may need to support the photogate with a box or book so it clears the glider.)
- Without disturbing the master photogate, reposition the glider 70 cm from the top of the air track. Carefully position the remote photogate so the leading edge of the flag interrupts the beam. This is x in the equations listed under Objective and will be recorded on line 2. on the data sheet.
- The distance between the two photogates should be 50.0 cm or 0.500 m. This is s in the equations listed under Objective. The value of s appears on line 3. on the data sheet.

<u>Procedure 3</u> - Determining Elapsed Time

- Appoint someone to catch the glider after it passes through the remote photogate. It is best not to rely on the rubber-band bumper to prevent damage to the track or glider.
- Set the photogate to pulse mode.
- With air supplied to the track, place the glider at the very top of track. Hold the glider for several seconds until the air pressure is constant.
- Release the glider and record the time required for it to go from the master photogate to the remote photogate. This is the elapsed time $t - t_o$ in Equation 1. Since the initial time t_o is zero, this is also time t in the first equation under Objective. Elapsed time is recorded on line 4. on the data sheet.

Do not disturb the photogates. They must remain in the same locations for the next part of the procedure.

<u>Procedure 4</u> - Determining Initial and Final Velocity

- The next measurements determine the time for the glider to travel under each photogate. Set the master unit to "gate" mode, the silver toggle switch to “On” and the small slide switch to 0.1 ms.
- Place the glider at the very top of the track.
- Release the glider. Record the time required for the glider to pass through the master photogate. This is time Δt_1 and it will be recorded on line 5 of the data sheet.
- Pull the toggle switch down to “Read”. The number displayed is the total time to pass beneath both photogates. The time to beneath the second photogate is found by subtracting time Δt_1

- Use the times to calculate the initial and final velocity of the glider. V = d/t. Calculated initial and final velocity are shown on line 8. and line 9.on the data sheet.

Repeat the above measurements for displacements of 0.700 m, 0.900 m, 1.100 cm, 1.300 m and 1.400 m. Note that units on the data sheet are in SI units of meters and seconds.

Conclusion

Enter the values from the Data and Calculations sheet to confirm $s = v_o t + 0.5 a t^2$. This is the first equation listed under Objective. Then, calculate and list percent error in the observations.

Measured Displacement s (line 3)	**Predicted Value for Displacement $v_0 t + 0.5 a t^2$ (line 11 + 12)**	**Percent Error**
	Average Percent Error	

Enter the values from the Data and Calculations sheet to confirm $v^2 = v_o^2 + 2 a s$. This is the second equation listed under Objective. Then, calculate and list percent difference error in the observations.

Calc. Final Velocity Squared v^2 (line 13)	**Predicted Final Velocity Squared $v_o^2 + 2 a s$ (line 14 + 15)**	**Percent Difference**
	Average Percent Difference	

DATA and CALCULATIONS (Finish each column before moving on)

1. Initial position of glider on track (used for locating master photogate)	0.200 m	0.200 m	0.200 m	0.200 m	0.200 m
2. Final position of glider on track (used for locating remote photogate)	0.700 m	0.900 m	1.100 m	1.300 m	1.500 m
3. Displacement , s (line 2 - line 1)	0.500 m	0.700 m	0.900 m	1.100 m	1.300 m
4. Time to pass between photogates, t **(pulse mode)**	s	s	s	s	s
5. Time to pass under master photogate, Δt_1 **(gate mode)**	s	s	s	s	s
6. Time to pass under both photogates $\Delta t_1 + \Delta t_2$ **(gate mode)**	s	s	s	s	s
7. CALC. Time to pass under remote photogate Δt_2	s	s	s	s	s
8. CALC. initial velocity, v_o = flagwidth / Δt_1	m/s	m/s	m/s	m/s	m/s
9. CALC. final velocity, v = flagwidth / Δt_2	m/s	m/s	m/s	m/s	m/s
10. CALC. acceleration from Equation 1 (line 9. - line 8.) / line 4	m/s^2	m/s^2	m/s^2	m/s^2	m/s^2
11. CALC. $v_o \ t$ (line 8. * line 4.)	m	m	m	m	m
12. CALC. $0.5 \ a \ t^2$ (0.5 * line 10. * line 4. * line 4.)	m	m	m	m	m
13. CALC. v^2 (line 9. * line 9)	m^2/s^2	m^2 / s^2	m^2/s^2	m^2/s^2	m^2/s^2
14. CALC. v_o^2 (line 8. * line 8)	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2
15. CALC. $2 \ a \ (s)$ (2 * line 10. * line 3.)	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2

Lab 4: Resolution of Forces

Objective Add vectors graphically, algebraically and physically.

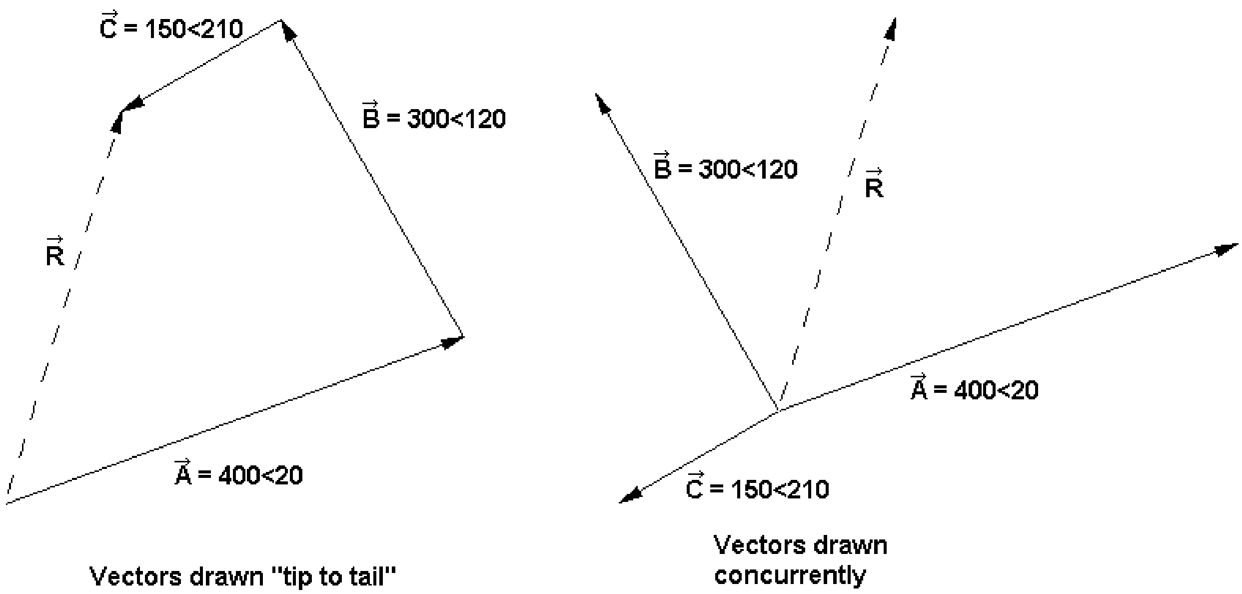
Materials	Ideas
• Force table • Mass set • Rulers • Protractors	• Vector addition • Concurrent forces

In class we have talked about and worked with vectors. Physics uses vectors to show how quantities with magnitude and direction work together. If the vectors represent individual distances traveled, the vector sum would be the distance from our starting point and which direction we would have to travel from the starting point to arrive at the end point. If the vectors represent forces on an object, then we can calculate a single net force on the object. Velocity and acceleration are two other common vector quantities used in Physics. This lab will hopefully give you some hands on experience with vectors and help you to see how they work in Physics. We will set up several vector addition problems and add each of these vectors systems three ways – by graphical methods, by algebraic methods and by "building" the problems on a force table.

As an example, if we were asked to add the three vectors

$$\vec{A} = 400\angle 20^{O} \qquad \vec{B} = 300\angle 120^{O} \qquad \vec{C} = 150\angle 210^{O}$$

we could answer the question "what is the vector sum?" by using a ruler and protractor to carefully draw the three vectors to scale "tip to tail "as in the picture on the left. **Make sure to use arrow heads to show direction of the vectors and use labels to label each of the vectors.** We would then measure the length of the resultant and the angle it makes with the horizontal.



The length of R is 336 units, and the angle measures 73.4^{O}, so $\vec{R} = 336\angle 73.4^{O}$
Another (easier) way to add the vectors is algebraically. To do this we resolve each of the vectors

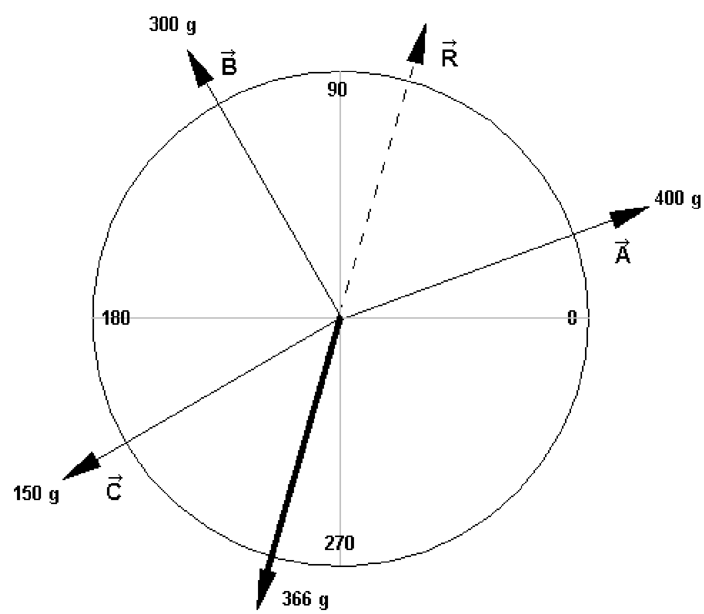
into x and y components using the formulas $A_x = A\cos\theta$, and $A_y = A\sin\theta$. Next we would need to add all of the x components to get the distance the resultant travels in the x direction, and add all of the y components to get the distance the resultant travels in the y direction. Lastly, using the two formulas $R = \sqrt{R_x^2 + R_y^2}$ and $\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$, we can find R, the length of the resultant, and θ, the angle at which we R deviates from the horizontal.

$$\vec{A} = 400\angle 20^O \qquad \vec{B} = 300\angle 120^O \qquad \vec{C} = 150\angle 210^O$$

$$R_X = 400\cos 20^O + 300\cos 120^O + 150\cos 210^O = 96 \quad \text{and}$$
$$R_Y = 400\sin 20^O + 300\sin 120^O + 150\sin 210^O = 322$$

$$R = \sqrt{96^2 + 322^2} = 336$$
$$\theta = \tan^{-1}\left(\frac{322}{96}\right) = 73.4^O \quad \text{(notice, this is in first quadrant)}$$
$$\text{so } \vec{R} = 336\angle 73.4^O$$

Lastly, we also want to build the vectors with string and weights on a force table. From above the force table will look something like the picture at the left. We place a string and weight hanger for A, B and C with 400 g, 300 g and 150 g respectively. The sum of these three vectors are shown by the dotted line labeled R. R does not show up on the force table, but a string placed along the bold line will cancel out vectors A, B and C. This line is called the equilibrant. It is the same length (or in this case, has the same mass hanging on it), but is 180^O off in the opposite direction.



Procedure

Add these vectors in the three ways described. In your conclusion, include a table showing the results for all methods.

Test 1: $\vec{A} = 360\angle 90^O \qquad \vec{B} = 180\angle 180^O$

Test 2: $\vec{A} = 180\angle 162^O \qquad \vec{B} = 200\angle 250^O \qquad \vec{C} = 205\angle 10^O$

Test 3: $\vec{A} = 200\angle 80^O \qquad \vec{B} = 250\angle 120^O \qquad \vec{C} = 300\angle 210^O$

Test 4: $\vec{A} = 150\angle 90^O \qquad \vec{B} = 300\angle 30^O \qquad \vec{C} = 400\angle 250^O$

Lab 5: Projectile Motion

Materials	**Ideas**
• spring gun with metal ball • measuring tape • masking tape • photogate • cardstock	• Trajectories • Independence of x & y directions • Equations of Motion

Objective
Determine the initial velocity of a projectile, based on range and initial height of the projectile.
Predict the landing point of the projectile when fired from a different elevation.

C A U T I O N
- **Do not stand directly in front of the spring gun.**
- **Do not pull back the spring on the spring gun until everyone has been warned and is out of the way.**
- **Wear eye protection.**

Procedure 1 – Measure Initial Velocity of the Projectile
- Each team should perform the following tests with their own spring gun.
- Measure the diameter of the projectile.
- Set up the spring gun on a stable horizontal platform.
- Measure the height of the gun barrel from the floor.
- Calculate the time for the ball to freefall from this height to the floor.
- Tape a piece of cardstock on the floor to mark the spot where the projectile lands.
- Fire the projectile.
- Measure the horizontal distance from the muzzle of the gun to the landing point.
- Repeat the above test four or five times, recording horizontal distance from the muzzle to the landing point.
- Calculate initial velocity of the projectile and express velocity in m/s, miles per hour and feet per second.

Procedure 2 - Predict the landing point of the projectile when it is fired from a different elevation.
- The height of the platform will be changed.
- Measure the new height.
- Using the initial velocity determined in Procedure 1, calculate the new range (x distance)
- Mark your team's predicted landing point of the projectile.
- Fire the projectile.
- Record the predicted range, actual range and difference.
- The grade for this part of the experiment will be based on the outcome of the contest.

Procedure 3 - Predict the landing point of the projectile when it is fired at a different angle.
- The angle of the gun will be changed.
- Measure the new height.
- Using the initial velocity determined in Procedure 1 and angle, calculate the new range (x distance)

- Mark your team's predicted landing point of the projectile.
- Fire the projectile.
- Record the predicted range, actual range and difference.
- The grade for this part of the experiment will be based on the outcome of the contest.

Data for Procedure 1

Vertical height, h __________ m

Diameter of projectile __________ cm

Time to reach floor from h __________ s

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Range						

Calculated velocity based on range and height ________m/s ________miles/h _________ft/s
(Show calculations and units conversion in your calculations section.)

Data for Procedure 2

Vertical height, h __________ m

Time, t, to reach floor from h __________ s

Predicted horizontal distance traveled in t seconds ____________ m (Show calculations)

Actual horizontal distance traveled in t seconds ____________ m

% error _____________ %

Data for Procedure 3

Vertical height, h __________ m

Angle, θ ____________ ^{o}

Time, t, to reach floor from h __________ s

Predicted horizontal distance traveled in t seconds ____________ m (Show calculations)

Actual horizontal distance traveled in t seconds ____________ m

% error _____________ %
Questions

Lab 6: Friction

Materials	**Ideas**
• Inclined plane with pulley • Mass set • Rubber stopper, wood block, items to slide • String • Mass hanger	• Newton's 2nd law • Force diagrams • Friction • μ, coefficient of friction

Using Newton's second law, we can find out all sorts of things about how and why objects move. In today's lab, we will build two inclined plane type problems and study the effect of friction on an object. We will also learn about μ, the coefficient of friction, which is simply a number that tells how much friction exists between any two given materials. We will measure μ in three different ways.

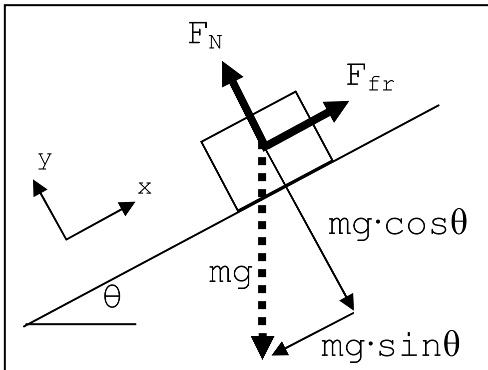


Figure 1: Block on a ramp

For the first two measurements of μ, we will simply place an object on a level surface and begin to raise one end of the surface. As shown in figure 1, the x component of the weight tries to slide the object downhill, while the friction tries to hold the object in place. At some angle, the x component of weight will exceed the frictional forces and the object will slide downhill. We can find a relationship between θ and μ. In method two we lightly tap on the inclined plane to measure the effect of vibration on μ.

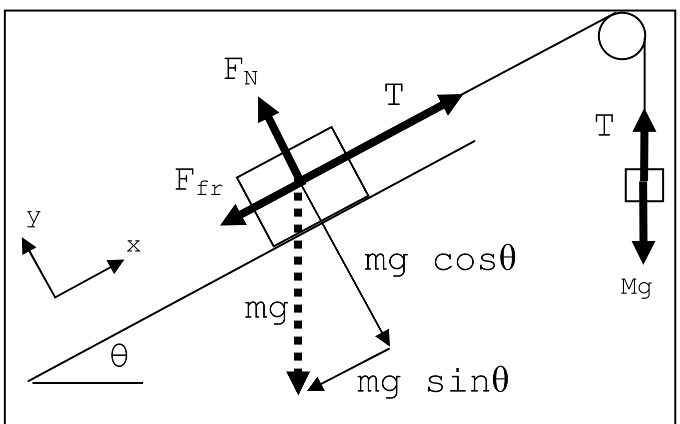


Figure 2: Block on a ramp with uphill force

For the last measurement of μ, we will use the inclined plane set to 25^{O} with a string over a pulley exerting an uphill force on the object. By adding masses to the end of the string to the point where the uphill force just overcomes the frictional forces and the x component of the weight, we can calculate μ.

Friction Datasheet

We will try to measure μ using three different methods. Show your methods of calculation and at least one example of each method on a separate page. The three methods are:

- Raising the inclined plane to find the angle necessary for the object to just begin moving **without** tapping or vibration. Record the angle necessary to move the object.
- Raising the inclined plane to find the angle necessary for the object to just begin moving **with** tapping or vibration. Record the angle necessary to move the object
- Using a pulley and weights to drag the object uphill without tapping or vibration. Set angle to 25^0. Record the mass necessary to move the object.

			Without Tapping (degrees of inclination)				**With Tapping (degrees of inclination)**				**Pulley & Weight (grams to move object)**			
Stationary Material	**Sliding Material**	**Mass**	**Trial 1**	**Trial 2**	**Av**	**μ**	**Trial 1**	**Trial 2**	**Av**	**μ**	**Trial 1**	**Trial 2**	**Av**	**μ**
Painted Steel														

Analysis - Answer in complete, grammatically correct sentences.

1. Would you expect the force of friction to be greater when the materials are vibrating or when they are not vibrating? Explain.

2. Which method would most likely present values of kinetic coefficients of friction, that is, values of μ for objects that are moving with respect to each other? Why?

3. Suggest an experimental procedure to determine the amount of friction that occurs between a moving solid and a liquid. (The procedure should be specific; include a sketch if needed.)

4. Suggest an experimental procedure to determine the amount of friction that occurs between a moving liquid and a gas. (The procedure should be specific; include a sketch if needed.)

5. **For objects made of the same material**, we derived that mass has no effect on μ ($\mu = \tan^{-1} \theta$). Do your results support that idea?

Lab 7: Uniform Circular Motion

Objective - To verify the relationship between centripetal force and the radius of rotation, mass and velocity of an object.

Materials	Ideas
• Safety goggles • Centripetal Force apparatus • Vernier calipers • Large mass hangers • Large masses • Mass set • Triple beam balance	• Centripetal Force • Rotation

Background

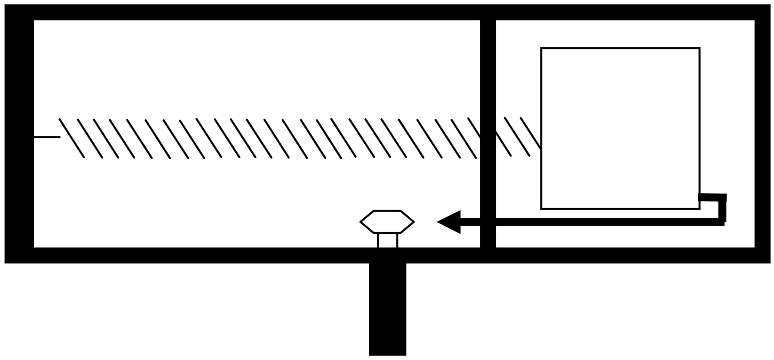
Uniform circular motion is a special case of accelerated motion. Although the magnitude of velocity is constant as an object moves around a circular path, the direction of velocity constantly changes. Since velocity changes with time, then, by definition, there must be acceleration. The force causing the acceleration is called the centripetal force. The centripetal force is directed inward toward the center of rotation. The magnitude of the centripetal force is given by $F_c = \frac{mv^2}{r}$ where r is the radius of the circular path, m is the mass of the object and v is the velocity of the object. The magnitude of this force can be measured and checked against the force of gravity to confirm the formula.

SAFETY PRECAUTIONS

- WEAR SAFETY GOGGLES OR A FACE SHIELD WHILE OBSERVING THE ROTATING POINTER ON THE APPARATUS. SAFETY GLASSES ARE NOT SUFFICIENT FOR EYE PROTECTION!
- KEEP HAIR, HANDS, SLEEVES AND JEWELRY AWAY FROM ROTATING MACHINERY.
- USE CARE WHEN ADDING LARGE WEIGHTS TO THE WEIGHT HANGER. WEIGHTS FALLING FROM THE HANGER CAN CAUSE INJURY TO THE FOOT AND TOES.

Procedure

The apparatus contains a variable speed drive connected to a rotating platform. A metal cylinder is positioned in the platform so it can slide back and forth. The mass of the cylinder is engraved in one end of the cylinder. As rotational velocity is increased the metal cylinder will move outward, away from the center of rotation. The velocity at which outward movement occurs depends on tension in a spring that is connected to the cylinder. The tension can be varied by turning a knob on the platform at the other end from the cylinder. As the cylinder moves outward along the platform it strikes a lever and pointer which moves upward to indicate contact with the cylinder. The lever can be viewed while the platform is rotating but it is important that the viewer and those nearby wear safety goggles during this part of the experiment.



- Adjust the platform so it rotates in a horizontal plane. Do not over tighten the knob.

Measure the radius of rotation

- Unplug the motor power cord.
- Pull the string tied to the mass in the platform until the needle points to the widest part of the center pin as shown in the picture above.
- Measure the distance from the center of the pin to the scribed line around the center of the mass with a Vernier caliper. This is r, the radius of rotation.

Calculate the speed of rotation at which $F_{spring} = F_c$

- Turn the motor on and adjust the rotational speed of the platform until the pointer points at the widest part of the center pin as shown in the picture above. (Yes, this is very tricky to do… a piece of paper held behind the apparatus will make it easier to see the pointer as it reaches the neutral position.)
- Write down the number on the revolution counter.
- Using a stopwatch, engage the revolutions counter for 10 seconds.
- Take the difference between the current number on the revolution counter and the number you wrote down. This is n, the number of revolution the mass made in 10 seconds.
- Multiply the number of revolutions by $2\pi r$ and divide by t to find the speed of the rotating mass.
- Calculate $F_c = mv^2/r$

Measure the force

- Unplug the motor.
- Adjust the platform so it rotates in a vertical plane. Do not over tighten the knob.
- Hang a large mass hanger from the string and add masses until the needle points to the widest part of the center pin as shown in the picture above.
- Find the mass of the hanger and added masses using a balance and add the mass of the revolving mass within the platform. This is M, the hanging mass.
- Calculate the $F_g = Mg$

Each time a test is completed and all data has been recorded, the spring tension should be changed. This will result in a different rotational velocity for each trial, and will permit verification of the centripetal force relation over a wider range of variables.

DATA and CALCULATED RESULTS

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
Spring setting				
Radius of rotation, r				
Number of revolutions, n				
Time for revolutions, t				
Calc. Speed $v = 2 \pi r n / t$				
mass of rotating object, m				
Calc. centripetal force $F_c = m v^2/r$				
hanging mass, M				
Calc. force on spring, $F_{spring} = M g$				
% Error between F_{spring} and F_c				

Lab 8: Work and Energy

Objective - To verify the law of conservation of energy.

Materials	**Ideas**
• air track and accessories • one glider • photogate timers • block of wood • single pan balance • spring scale	• Conservation of energy • Calculating Work • Calculating PE • Calculating KE

Background - In this experiment the work needed to move a glider up an incline will be compared with the potential energy acquired by the glider when it is at the top of the incline. The glider will then be released from the top of the incline and its kinetic energy will be measured when it reaches the bottom of the incline.

Procedure

Set Up

- Place a block of wood under one leg of the air track so the track makes an incline with the bench. The end of the air track with the single support should be positioned on the block and the end with two supports should rest on the bench.
- Measure the width of a flag and place it in the cart.

Measuring Work Using the Spring Scale

- Place two 50-g masses on each side of the glider.
- Attach a spring scale to the glider and position the glider at the 50 cm mark.
- With the blower on, measure the constant force necessary to pull the sled from the 50 cm mark up to the 150 cm mark.
- The work done on the sled is: $W = F\ d$ where F is the force in Newtons and d is the distance over which the force acts.

Measuring Potential Energy

- Measure m, the mass of the glider, flag, and weights that have been placed on the cart.
- Use a meter stick to measure the height of the air track at the 50 cm mark and at the 150 cm mark.
- Find h, the difference in height between the two points.
- Calculate potential energy. $P.E. = m\ g\ h$

Measuring Kinetic Energy

- Place the photogate so that the cart will travel for one meter before it passes through the photogate.
- Release the cart from the starting point through the photogate. Try to catch the glider before it strikes the end of the track
- Determine the velocity of the glider as it passes the photogate. V = flagwidth/time
- Calculate the kinetic energy, $K.E. = 1/2\ m\ v^2$.

The experiment should be repeated for different weights on the glider, various lengths of travel along the air track, or different inclines.

Data for Work and Energy Lab

	Test 1	Test 2	Test 3	Test 4	Test 5
Work					
Force	N	N	N	N	N
Distance	m	m	m	m	m
Calc Work	J	J	J	J	J
Potential Energy					
Height	m	m	m	m	m
Mass	Kg	Kg	Kg	Kg	Kg
Calc PE	J	J	J	J	J
Kinetic Energy					
Time	s	s	s	s	s
Calc velocity	m/s	m/s	m/s	m/s	m/s
Calc KE	J	J	J	J	J

Lab 9: Conservation of Momentum

Objective - To verify the law of conservation of linear momentum: "Provided there are no external forces acting on a system, the total momentum before collision equals the total momentum after collision."

Materials	Ideas
• air track and accessories • two gliders • two master photogate timers • level • single pan balance • masking tape	• Conservation of Momentum • Elastic collisions • Inelastic collisions

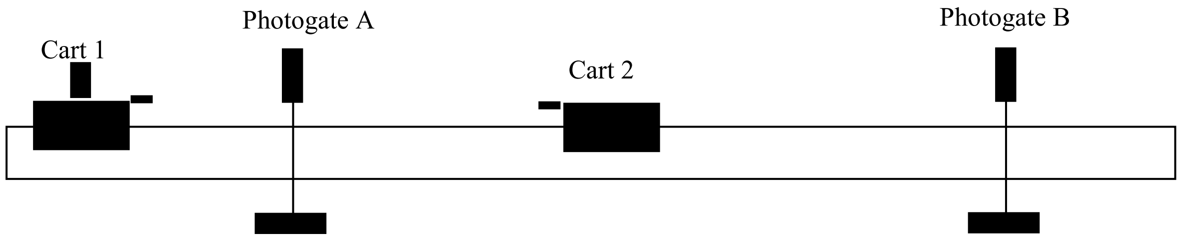
Background

Linear momentum is defined as the product of the mass of an object and its velocity. $\mathbf{p} = m\,\mathbf{v}$ Since $m\,\mathbf{v}$ is the product of a scalar (mass) and a vector (velocity), the momentum ($\mathbf{p}$) is a vector having both magnitude and direction. The law of conservation of linear momentum is not limited to two objects. It applies to three, four, or any number of objects. It is applicable in a one-dimensional coordinate system (motion along a straight line), in two-dimensional coordinate systems (motion in a plane), or three-dimensional coordinate systems (motion in space). For simplicity, a one-dimensional coordinate system and only two objects will be observed in this experiment.

The equation relating linear momentum before a collision to linear momentum after a collision is $m_1\mathbf{v_1} + m_2\mathbf{v_2} = m_1\mathbf{v_1}' + m_2\mathbf{v_2}'$ where the primes denote velocities after the collision, and the subscripts refer to objects 1 and 2.

There are several special cases of conservation of momentum in collisions that we want to look at.

Inelastic Collisions	Elastic Collisions
$v' = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$	$v_1' = \frac{m_1 - m_2}{m_1 + m_2} v_1 + \frac{2m_2}{m_1 + m_2} v_2$ $v_2' = \frac{2m_1}{m_1 + m_2} v_1 - \frac{m_1 - m_2}{m_1 + m_2} v_2$
$v' = \frac{m_1 v_1}{m_1 + m_2}$ where cart 2 is stationary	$\left.\begin{matrix} v_1' = \frac{m_1 - m_2}{m_1 + m_2} v_1 \\ v_2' = \frac{2m_1}{m_1 + m_2} v_1 \end{matrix}\right\}$ unequal masses, cart B stationary
	$\left.\begin{matrix} v_1' = 0 \\ v_2' = v_1 \end{matrix}\right\}$ where equal masses, cart 2 stationary



<u>Procedure 1</u> - Transfer of Momentum in Inelastic Collisions (carts stick together) with one cart stationary

- Level the air track. (Hint: if a cart drifts with the air on, it's not level).
- Place the photogates somewhere around 50 cm and 150 cm.
- Place the pin and putty filled receiver accessory in the carts to hold them together after the collision.
- Label a cart as "cart 2" and place it between the photogates.
- Place a flag in cart 1.
- Get the mass of cart 1 and cart 2.
- Set the photogate mode to gate and push reset on the photogate control.
- With the air on, give cart 1 a gentle push towards cart 2. Stop the carts after the flag has gone through photogate B, but before they can bounce back through photogate B.
- Calculate the initial velocity of cart 1 and the final velocity of carts 1 and 2.
- Calculate the initial momentum and the final momentum.
- Fill in the table below by changing the amount of weight on cart 1 or cart 2 or by changing the initial velocity of cart 1 and repeating the above.

Inelastic Collisions, Cart B stationary	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Units**
Mass of Cart 1, m_1						Kg
Initial Velocity of Cart 1, v_1 = flagwidth/time						m/s
Cart 1 initial momentum, $\mathbf{P_1} = m_1 v_1$						Kg m/s
Mass of Cart 2, m_2						Kg
Initial Velocity of Cart 2, v_2	0	0	0	0	0	m/s
Cart 2 initial momentum, $\mathbf{P_2} = m_2 v_2$						Kg m/s
Mass of Cart 1 and Cart 2, $m_1 + m_2$						Kg
Final Velocity of Cart 1 and 2, v'						m/s
Calculated v' from formula						m/s
Cart 1 and 2 final momentum, $\mathbf{P}' = (m_1 + m_2)\, v'$						Kg m/s
Difference in momentum $\mathbf{P_1 + P_2 - P'}$						Kg m/s

Procedure 2 - Transfer of Momentum in Inelastic Collisions (carts stick together) with both carts moving

- Place a flag in cart 2.
- Get the new mass of cart 2.
- Set the photogate mode to gate and push reset on the photogate control.
- Place cart 1 on one end of the track and cart 2 on the other.
- With the air on, give carts 1 and 2 a gentle push towards each other. Stop the carts after both carts have gone through photogate B, but before they can bounce back through photogate B.

- Calculate the initial velocity of cart 1 and the final velocity of carts 1 and 2.
- Calculate the initial momentum and the final momentum.
- Fill in the table below by changing the amount of weight on cart 1 or cart 2 or by changing the initial velocity of cart 1 and repeating the above.

Inelastic Collisions	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Units**
Photogate A Time						s
Photogate A Memory Time						s
Photogate B Time						s
Photogate B Memory Time						s
Mass of Cart 1, m_1						Kg
Initial Velocity of Cart 1, v_1						m/s
Cart A initial momentum, $\mathbf{P_1} = m_1v_1$						Kg m/s
Mass of Cart 2, m_2						Kg
Initial Velocity of Cart 2, v_2						m/s
Cart 2 initial momentum, $\mathbf{P_2} = m_2v_2$						Kg m/s
Mass of Cart 1 and Cart 2, $m_2 + m_2$						Kg
Final Velocity of Cart 1 and 2, v'						m/s
Calculated v' from formula						m/s
Cart 1 and 2 final momentum, $\mathbf{P}' = (m_1 + m_2)v'$						Kg m/s
Difference in momentum $\mathbf{P_1} + \mathbf{P_2} - \mathbf{P}'$						Kg m/s

<u>Procedure 3</u> - Transfer of Momentum in Elastic Collisions (carts bounce) with one cart stationary

- Replace pin and putty filled receiver accessory on cart 1 and 2 with the rubber-band bumper accessory in the carts to make the carts bounce after the collision.
- Place a flag in cart 2.
- Get the mass of cart 1 and cart 2.
- Place cart 2 between the photogates.
- Set the photogate mode to gate and push reset on the photogate.
- With the air on, give cart 1 a gentle push towards cart 2. Stop cart 2 after its flag has gone through photogate B, but before it can bounce back through photogate B. Cart 1 will either come to a stop between the photogates, bounce back through photogate A, or continue on through photogate B depending on the ratio of the masses of cart 1 and 2.
- Calculate the initial velocity of cart A and the final velocity of carts 1 and 2.
- Calculate the initial momentum and the final momentum.
- Fill in the table below by changing the amount of weight on cart 1 or cart 2 or by changing the initial velocity of cart 1 and repeating the above. For one trial cart 1 and cart 2 should have equal masses. For another trail the mass of cart 1 should be greater. For another trial the mass of cart 2 should be greater.

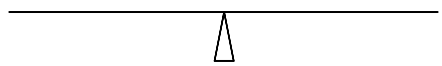
Elastic Collisions, Cart 2 stationary	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Units**
Mass of Cart 1, m_1						Kg
Initial Velocity of Cart 1, v_1						m/s
Cart A initial momentum, $\mathbf{P_1} = m_1v_1$						Kg m/s
Mass of Cart 2, m_2						Kg
Initial Velocity of Cart 2, v_2	0	0	0	0	0	m/s
Cart B initial momentum, $\mathbf{P_2} = m_2v_2$						Kg m/s
Final Velocity of Cart 1 , v_1'						m/s
Calculated v_1' from formula						m/s
Final momentum of cart 1, $\mathbf{P_1}'$						Kg m/s
Final Velocity of Cart 2, v_2'						m/s
Calculated v_2' from formula						m/s
Final momentum of cart 2, $\mathbf{P_2}'$						Kg m/s
Difference in momentum $\mathbf{P_1 + P_2 - P_1' - P_2'}$						Kg m/s

Lab 10: Torque and Equilibrium of A Rigid Body

Materials	Ideas
• Meter stick • Balance stand • Mass hangers • Spring scales • Triple-beam balance • Protractor	• Torque • Equilibrium • Statics

<u>Procedure 1</u> - Center of Gravity of a Meter Stick

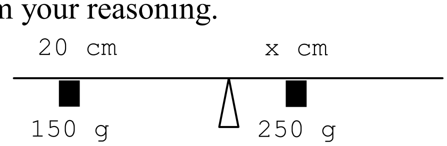
- Find a straight meter stick and place a mass hanger near the center of the stick
- Place the mass hanger on the balance stand to support the meter stick
- Find the point where the meter stick balances – this is called the center of mass



Balance point of meter stick ____________ (This is center of mass of the meter stick.)

<u>Procedure 2</u> – Balancing two Masses with the Balance at the Center of Mass

- Suspend a 150-gram mass from the meter stick at the 20-cm mark.
- Pivot the meter stick at the balance point found in step 1.
- Mathematically calculate the position required for a 250-gram mass so that the system will be in equilibrium.
- Determine the equilibrium position for the 250-gram mass experimentally.
- Compare the experimental result with the predicted result.
- If the results do not agree within 2 mm, suggest what might be the cause of the error. Repeat the experiment to confirm your reasoning.



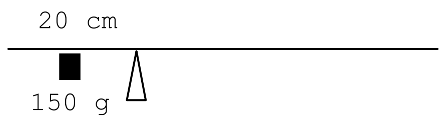
Show Calculations to Determine Equilibrium Position of 250-gram Mass

Predicted Position of 250-gram Mass for Equilibrium ____________

Actual Position of 250-gram Mass for Equilibrium ____________ % Error ____________

<u>Experiment 3</u> - Find the Mass of the Meter Stick

- Suspend a 150-gram mass suspended at the 20-cm mark
- With no other masses on the meter stick, move the mass hanger at the center of mass of the meter stick to find the point at which the meter stick will balance.
- Using the distance from the center of mass to the new balance point, mathematically determine the mass of the meter stick.
- Use the triple-beam balance to determine the actual mass of the meter stick.
- Compare the two experimental results.
- If the results do not agree within 2 grams, suggest what might be the cause of the error. Repeat the experiment to confirm your reasoning.



Balance point of the meter stick with 150-gram mass _____________

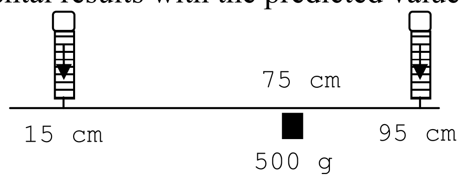
Show Calculations to Determine the Mass of the Meter Stick

Predicted mass of the meter stick, __________________

Actual mass of the meter stick, from balance __________________ % Error ____________

Experiment 4. Forces on a System

- Suspend the meter stick from two spring scales at the 15-cm mark and the 95-cm mark, and suspend a 500 g mass from the 75-cm mark, as shown below.
- Calculate what the scale readings will be for both spring scales. Include the actual mass of the meter stick.
- Set up the meter stick as shown and determine the actual scale readings.
- Compare the experimental results with the predicted values.



Show Calculations to Determine Scale Readings

Predicted reading of spring scale at 15 cm mark ________________

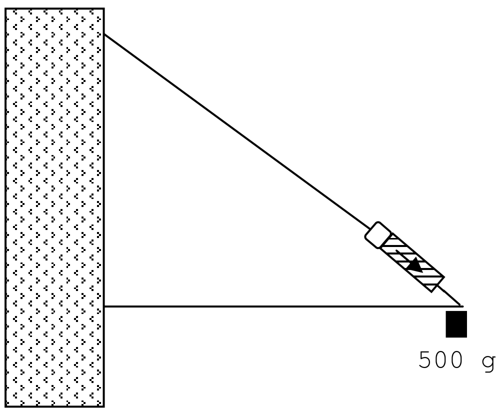
Actual reading of spring scale at 15 cm mark ________________ % Error ____________

Predicted reading of spring scale at 95 cm mark ________________

Reading of spring scale at 95 cm mark ________________ % Error ____________

Experiment 5 - Load Suspended from a Boom

- Support a meter stick at one end using a string and spring scale.
- Place a 500 gram load will be placed at the end of the meter stick. (Don't let the load fall on you or others.)
- Measure the angle between the string and meter stick
- Observe the actual scale reading.
- Calculate what the scale should read. Include the actual mass of the meter stick as well as the load and hangers in your calculations.
- Compare the experimental result with the predicted result.
- If the results do not agree within 20 grams, suggest what might be the cause of the error. Repeat the experiment to confirm your reasoning.



Calculation to Determine Reading of Spring Scale

Predicted reading of spring scale ________________

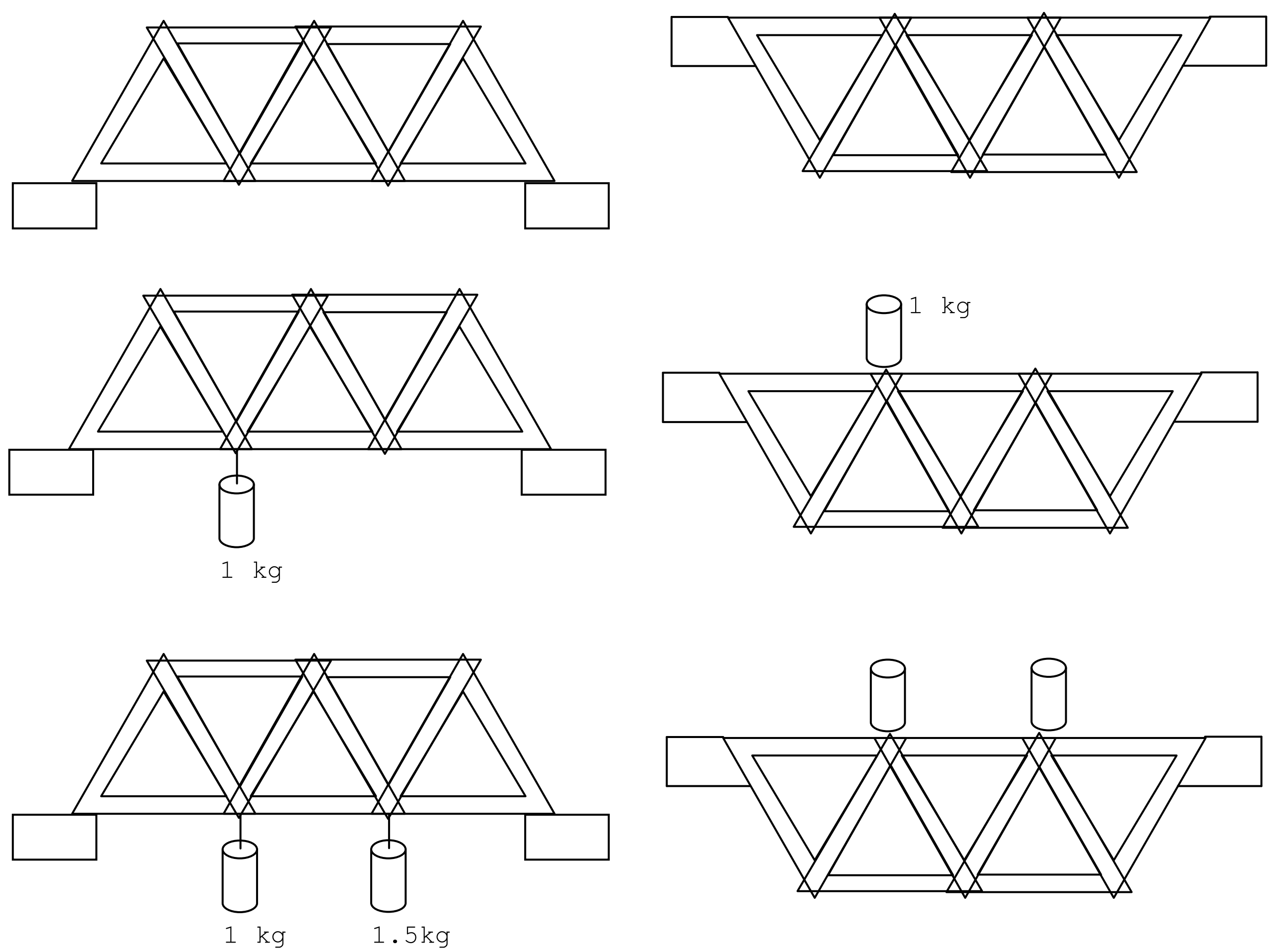
Actual reading of spring scale ________________ % Error ____________

Lab 11: Trusses and Bridges

Build each of the bridge systems shown below. Shade members in compression with red and shade members in tension in blue. Assume all members are the same material and size. In each picture, circle the member most likely to fail due to compression in red and the member most likely to fail due to tension in blue. Mark a vertical black line to indicate where the bridge is most likely to fail due to sheer forces.

Warren Through Truss

Warren Deck Truss



Lab 12: Simple Harmonic Motion

Materials	**Ideas**
• tapered brass spring • weight hanger and weight • base, rod and clamp to support spring • meter stick • stop watch	• Spring constant • Linear force • Acceleration of gravity

<u>Background</u>

Simple harmonic motion occurs whenever an object displaced from an equilibrium position experiences a linear restoring force. Examples of simple harmonic motion (SHM) include: sound waves, water waves, vibrating strings on a musical instrument, atomic vibrations, and a vibrating mass attached to a spring.

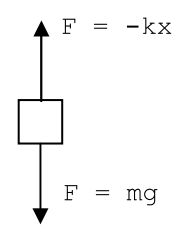
The restoring force on the object that is displaced is

$F = -kx$ where k is the spring constant, x is the displacement from equilibrium .

Note that when there is no displacement the restoring force is zero. Also, the greater the displacement, the greater the restoring force.

When a mass is suspended vertically from a spring, the force on the spring is mass times the acceleration of gravity:

$$F = m g$$



For equilibrium,

$$m g - k x = 0$$

$$k = \frac{m g}{x}$$

The period of motion, T, is the time required for the mass to move from one extreme position back to the same extreme position. Motion from one extreme position back to the same extreme position is called a cycle. Thus, period is expressed in seconds per cycle.

For a mass, m, vibrating at the end of a spring,

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Substituting for the spring constant,

$$T = 2\pi\sqrt{\frac{\not{m}x}{\not{m}g}}$$

$$T = 2\pi\sqrt{\frac{x}{g}}$$

$$T^2 = 4\pi^2 \frac{x}{g}$$

Graphing the relationship between period squared and the displacement of the spring, allows the slope to be found.

$$\frac{T^2}{x} = \text{slope} = \frac{4\pi^2}{g}$$

Since slope can be found from a graph of T^2 versus x, and the value of pi is known, it becomes possible to determine the acceleration of gravity:

$$g = \frac{4\pi^2}{\text{slope}}$$

Procedure - Obtaining Data

- Suspend the spring and carefully measure the height from the bench to the lower end of the spring. The bench top will be the reference point for all measurements of displacement. The initial measurement of height will serve as the equilibrium position of the spring and it should be recorded in the space on the first line on the data sheet.
- Place a 50-g weight hanger on the end of the spring. Record the position of the lower end of the spring. The displacement of the spring is the difference between the two positions. This displacement is called the static displacement of the spring. The force on the spring can also be calculated by multiplying the mass of the weight hanger in kilograms by the acceleration of gravity.
- The next step will be to displace the spring and mass from the equilibrium position observed in step 2. The maximum displacement should be less than one-half the static displacement.
- Pull the spring and mass downward as noted in step 3. Release the spring and mass and use a stopwatch to measure the time it takes for 20 to 50 complete cycles. The period can then be calculated by dividing elapsed time by the number of cycles.
- Add twenty grams of additional mass to the weight hanger and repeat steps 3 and 4. Continue the procedure, adding mass in twenty-gram increments, and recording mass, displacement, number of cycles and elapsed time for the total number of cycles.

Determining Spring Constant

- Make a graph of force on the spring in newtons (y-axis) versus static displacement in meters (x-axis). The plot should cover as much of the paper as possible. The scales should be in multiples of 1, 2, 5 or 10, each axis should be labeled and state units, and the graph should have a title.
- Draw a best-fit, straight line through the circled points. Use the scales on the graph to find the coordinates of the end points of the straight line.
- Calculate the slope of the straight line. The slope is the spring constant.

Determining Acceleration of Gravity

- Make a graph of period squared in seconds squared (y-axis) versus static displacement in meters (x-axis). The plot should cover as much of the paper as possible. The scales should be in multiples of 1, 2, 5 or 10, each axis should be labeled and state units, and the graph should have a title. Data plotted on the graph should be circled.

- Draw a best-fit, straight line through the points. Use the scales on the graph to find the coordinates of the end points of the straight line.
- Calculate the slope of the straight line. Observe units as well as magnitude of the slope.
- Calculate g, the acceleration of gravity from the relation derived in the background.

Conclusions

In a complete sentence report the value of the spring constant for the spring.
In a complete sentence report the acceleration of gravity at York Technical College.
Calculate the % error for the acceleration of gravity, and explain what happened.

Questions

1. Should the best-fit line on the graph of force versus static displacement go through the origin? Explain.

2. Should the best-fit line on the graph of period squared versus static displacement go through the origin? Explain.

3. Calculate a correct value of slope based on the accepted value of acceleration of gravity. Draw and label a line with this slope on your graph. Show your calculations as part 4. on your analysis sheet.

Datasheet for Lab #12

Mass on Spring	Calc. Force	Height above table	Calc. Static Displacement	Total time for cycles	# of cycles	Calc Period	Period Squared
kg	N	m	m	s	#	s	s^2
0							
.050							
.070							
.090							
.110							
.130							
.150							
.170							
.190							
.210							
.230							
.250							
.270							
.290							
.310							
.330							
.350							
.370							

The maximum load on the tapered brass spring should not exceed 0.450 kg .

Lab 13: Pulleys

Objective - Determine the ideal mechanical advantage, the actual mechanical advantage and the efficiency of several pulley systems.

Materials	**Ideas**
• Pulley support apparatus • Pulleys • Line • Spring Scale • Meter stick, rulers • Weights	• Spring constant • Linear force • Acceleration of gravity

Introduction

A pulley consists of a grooved wheel on a shaft that is attached to a frame. The frame is called the block. Pulleys can be arranged in combination, where two or more wheels are attached to the same block. Also, pulleys may be fixed or movable; the position of a fixed pulley does not change whereas movable pulleys can be raised or lowered with the load.

The actual mechanical advantage (AMA) of a pulley or a system of pulleys is the ratio of the output force to the input force,

$$\mathrm{AMA} = \frac{F_{\mathrm{Out}}}{F_{\mathrm{In}}}$$

The input force is the force applied to the system, and the output force is the resulting force on the load.

The ideal mechanical advantage (IMA) of a pulley or a system of pulleys is the ratio of the distance the input force travels to the distance the output force travels.

$$\mathrm{IMA} = \frac{S_{\mathrm{In}}}{S_{\mathrm{Out}}}$$

In this experiment, S_{in} is the length the string moves while force is applied to the string, and S_{out} is the length the load moves while force is applied to the string.

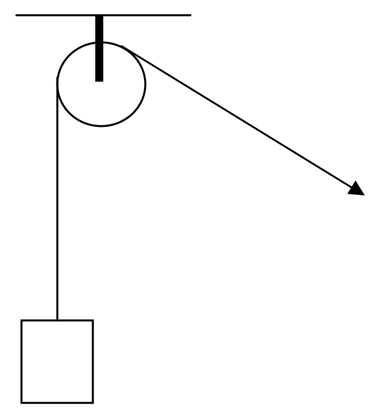
The efficiency of the pulley system is the ratio of work output to work input:

$$\mathrm{Efficiency} = \frac{W_{\mathrm{Out}}}{W_{\mathrm{In}}} = \frac{F_{\mathrm{Out}}\,S_{\mathrm{Out}}}{F_{\mathrm{In}}\,S_{\mathrm{In}}} = \frac{F_{\mathrm{Out}}}{F_{\mathrm{In}}}\frac{S_{\mathrm{Out}}}{S_{\mathrm{In}}} = \left(\mathrm{AMA}\right)\left(\frac{1}{\mathrm{IMA}}\right) = \frac{\mathrm{AMA}}{\mathrm{IMA}}$$

<u>Procedure 1</u> - Single Fixed Pulley

- Set up the single fixed pulley as shown with a load of 500 g.
- Calculate the load, F_{out}.
- Raise the weight at a uniform rate and record F_{in} , the reading of the scale, in the data table.
- Measure the distance the string moves to apply force to the pulley system, S_{in} , and the distance the load moves, S_{out} .
- Calculate ideal mechanical advantage, actual mechanical advantage, and percent efficiency.
- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.
- Try pulling the sting at different angles, does it make a difference?

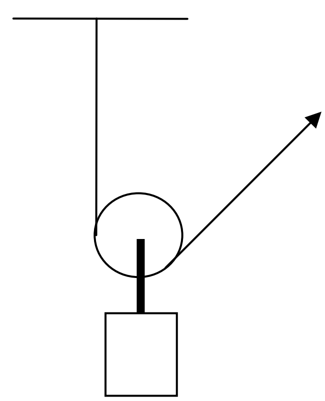
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 2</u> - Single Moveable Pulley

- Set up the single moveable pulley as shown with a load of 500 g.
- Calculate the load, F_{out}.
- Raise the weight at a uniform rate and record F_{in} , the reading of the scale, in the data table.
- Measure the distance the string moves to apply force to the pulley system, S_{in} , and the distance the load moves, S_{out} .
- Calculate ideal mechanical advantage, actual mechanical advantage, and percent efficiency.
- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.
- Try pulling the sting at different angles, does it make a difference?

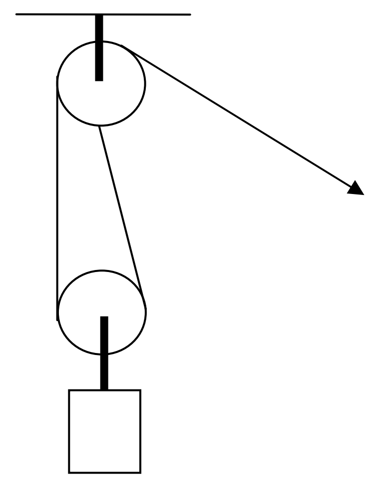
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 3</u> – One Fixed and One Moveable Pulley

- Set up the pulley system as shown with a load of 500 g.
- Calculate the load, F_{out}.
- Raise the weight at a uniform rate and record F_{in} , the reading of the scale, in the data table.
- Measure the distance the string moves to apply force to the pulley system, S_{in} , and the distance the load moves, S_{out} .
- Calculate ideal mechanical advantage, actual mechanical advantage, and percent efficiency.
- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

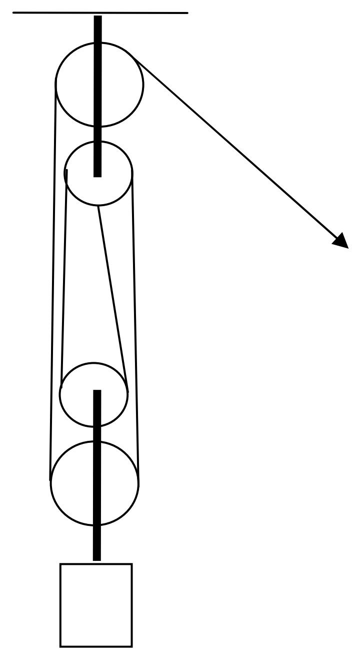
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



Procedure 4 – **Two Double Pulleys**

- Set up the pulley system as shown with a load of 1 kg.
- Calculate the load, F_{out}.
- Raise the weight at a uniform rate and record F_{in} , the reading of the scale, in the data table.
- Measure the distance the string moves to apply force to the pulley system, S_{in} , and the distance the load moves, S_{out} .
- Calculate ideal mechanical advantage, actual mechanical advantage, and percent efficiency.
- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

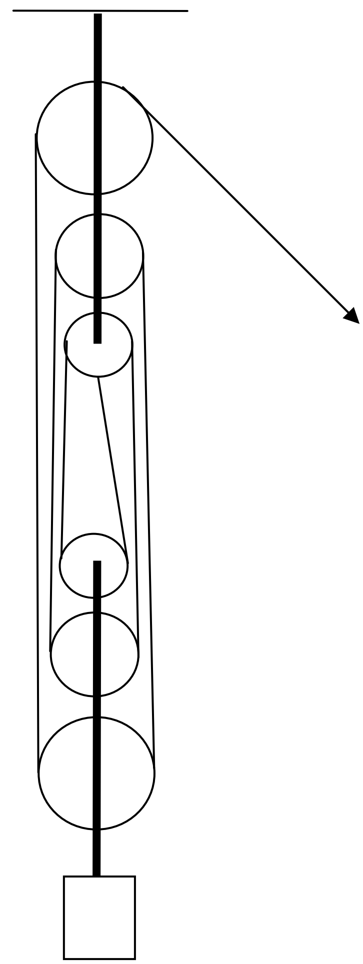
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 5</u> – Two Triple Pulleys

- Set up the pulley system as shown with a load of 1 kg.
- Calculate the load, F_{out}.
- Raise the weight at a uniform rate and record F_{in} , the reading of the scale, in the data table.
- Measure the distance the string moves to apply force to the pulley system, S_{in} , and the distance the load moves, S_{out} .
- Calculate ideal mechanical advantage, actual mechanical advantage, and percent efficiency.
- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

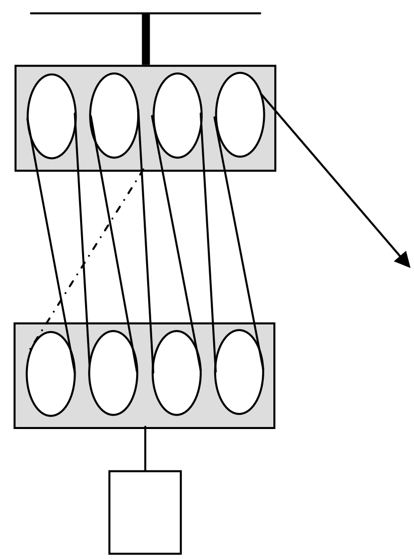
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 6</u> – Two Quadruple Pulleys

- Set up the pulley system as shown with a load of 1 kg.
- Calculate the load, F_{out}.
- Raise the weight at a uniform rate and record F_{in}, the reading of the scale, in the data table.
- Measure the distance the string moves to apply force to the pulley system, S_{in}, and the distance the load moves, S_{out}.
- Calculate ideal mechanical advantage, actual mechanical advantage, and percent efficiency.
- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



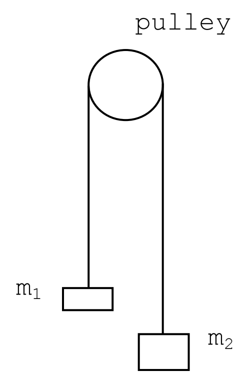
Make a table listing pulley system, ideal mechanical advantage, actual mechanical advantage and efficiency.

<u>Analysis</u> - Answer the questions in complete sentences on a separate sheet of paper.
1. What would be a reason for using a system consisting of a single fixed pulley?
2. Did the angle of the string make any differences in procedures 1 and 2? Why or why not?
3. Discuss how the ideal mechanical advantage of a system of pulleys can be determined based on the number of ropes that support a load.
4. For every system of pulleys discuss how the ideal mechanical advantage can be determined by observing distances that force and load move.
5. Make a neat, clear sketch showing a system of pulleys that could be used to raise a 100 kg load using an ideal applied force of 196 Newtons.

Lab 14: Force Diagrams and Newton's Laws

Today we will build a couple of systems that require the use of force diagrams and Newton's laws to solve. We will solve for the accelerations mathematically, and then will measure the acceleration experimentally. Since it is difficult to accurately measure time and velocity and acceleration using only a stopwatch, and because our mathematical solution leaves out the friction and inertia of the pulley, **expect some difference** between the mathematical and experimental accelerations.

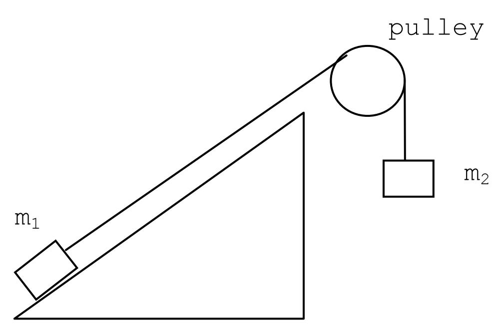
Atwood's Machine - Atwood's machine is nothing more than a pulley (or pulleys), string(s), and masses. When there is a difference between m_1 and m_2, the masses will accelerate. In the diagram at the right, and below: Draw the forces on m_1 and m_2



Procedure 1 - Using Newton's second law, calculate the acceleration for a system where $m_1 = .050$ kg and $m_2 = .055$ kg. Show your work on a separate sheet of paper.
a = ____________________

Procedure 2 - Build the system so that one of the masses will reach the floor or table when the other is close to the pulley
Raise m_2, so that m_1 is on the floor or table. Measure x, the height from the floor or table to the bottom of m_2.
x = __________________
Release m_2 and let it run several times to get an average value of t, the time for m_2 to fall to the table
t = __________________
Since $x = v_0t + ½ at^2$, calculate a. Show your work on a separate sheet of paper.
a = ____________________

Inclined Plane with Pulley - Using the inclined plane, build the system shown at the right. Find m_1 and m_2, so that m_1 accelerates up the ramp. (Slower is better, since we will eventually have to measure t). In the diagram at the right, and below, draw the forces on m_1 and m_2



Procedure 1 - Using Newton's second law, calculate the acceleration for your system. Show your work on a separate sheet of paper.
a = ____________________

Procedure 2 - Release m_2 and let it run several times to get average values for x, the distance m_1 moves and the time, t.
x = __________________
t = __________________
Since $x = v_0t + ½ at^2$, calculate a. Show your work on a separate sheet of paper.
a = ____________________

Questions

1) How far off were the values of a in the first system? Why?

2) How far off were the values of a in the second system? Why?

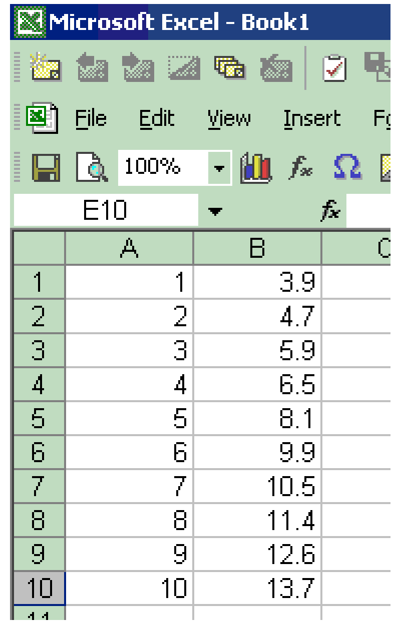
3) What is a better way to measure a in these two systems?

4) How do the force diagrams help solve these problems?

5) What is the tension in the string in the first system? Show your work on a separate sheet of paper.

6) What is the tension in the string in the second system? Show your work on a separate sheet of paper.

Excel 2003 Graphing

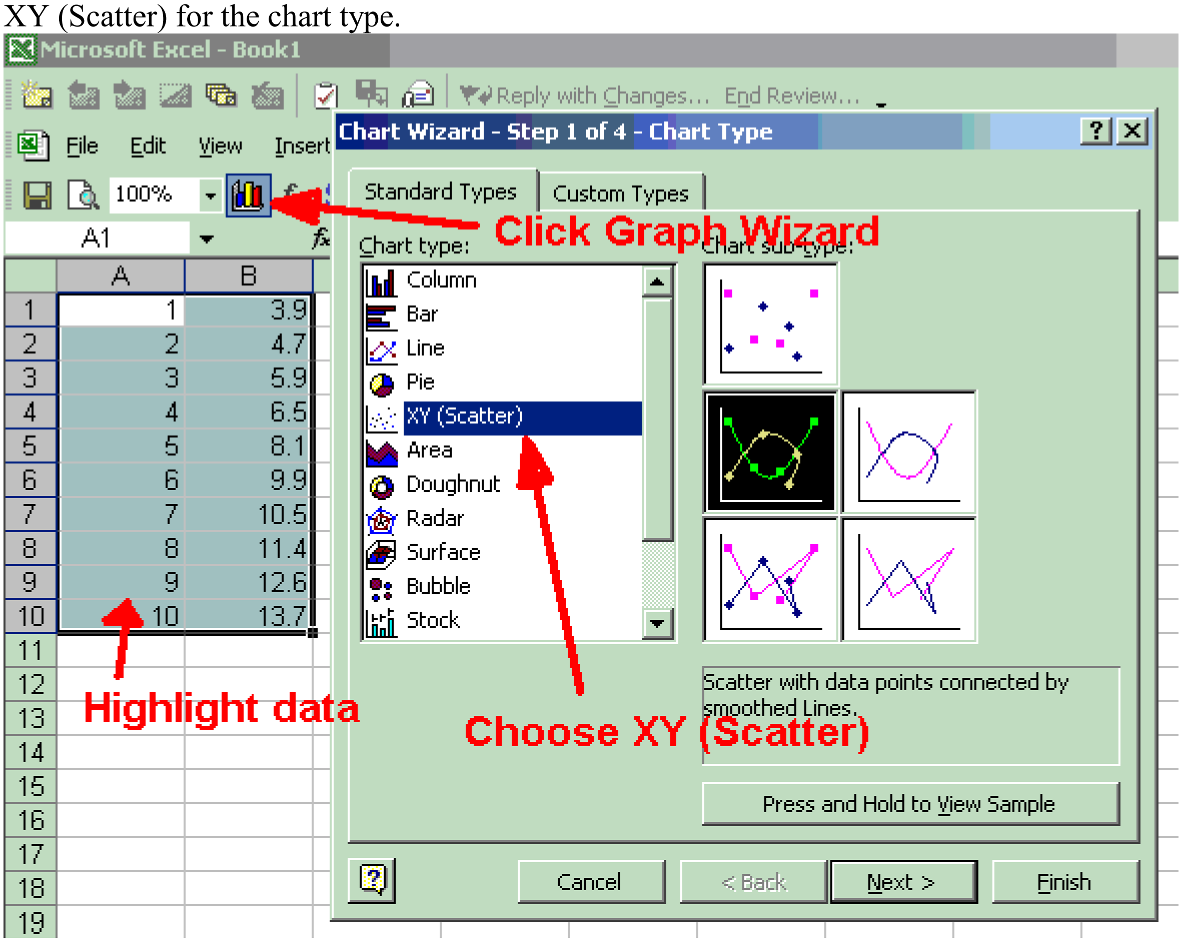


We will draw lots of graphs of the data we collect in lab this semester. Excel (or any other spreadsheet program) makes it very easy to graph and use that data. Some of the advantages to graphing in Excel rather than on paper by hand are the following:

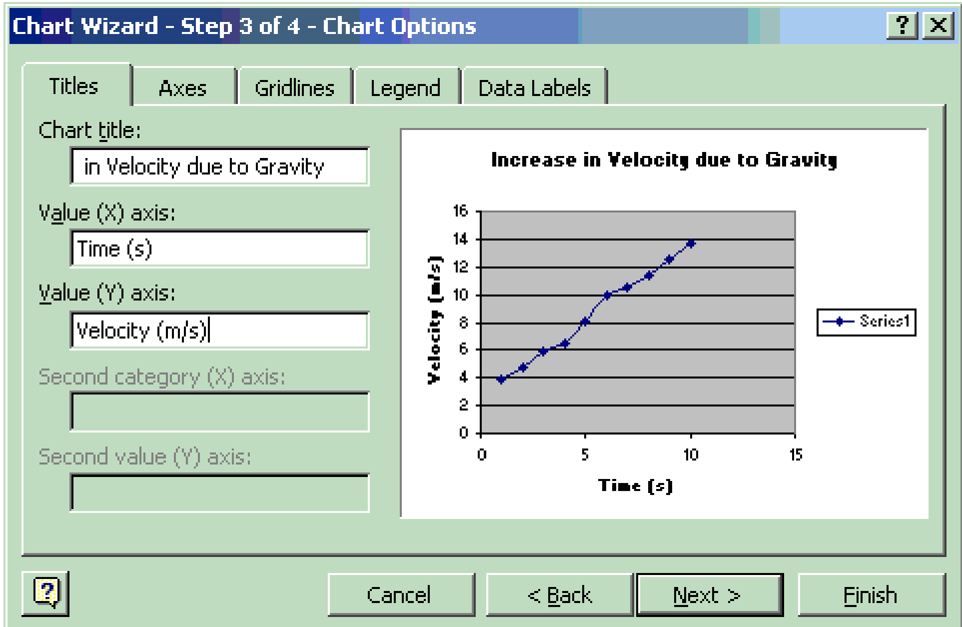
- easy and quick to do
- can print a nice looking graph with titles, units, labels
- can do linear regressions without knowing a ton of statistics
- can save, back-up, copy and email data to lab-partners or to me
- learn computer skills/valuable job skills

Step 1: Put the data into Excel: Place the data for the x-axis in column A (1,2,3...) and the data for the y-axis in column B (3.9, 4.7, ...)

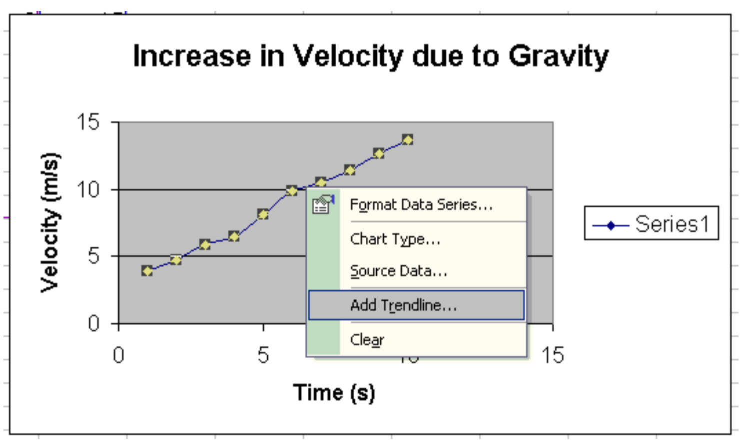
Step 2: Using the mouse, highlight the entire data block, click the Graph Wizard button, choose XY (Scatter) for the chart type.



Step 3: Click next. Click next again. Enter Chart title, X axis label, Y axis label. Click Finish

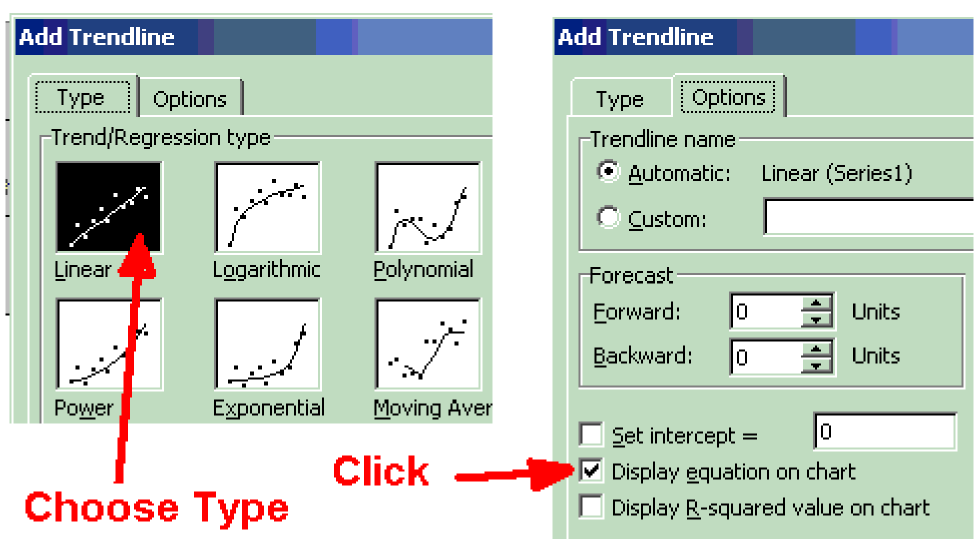


Step 4: To add a trendline, click the line connecting the data points, right click to get the window options, select Add Trendline



Step 5: Select the type of Trendline - generally linear in these labs. On the options tab, select the "Display equation on chart" option.

Step 6: To print, click on graph and click Print.

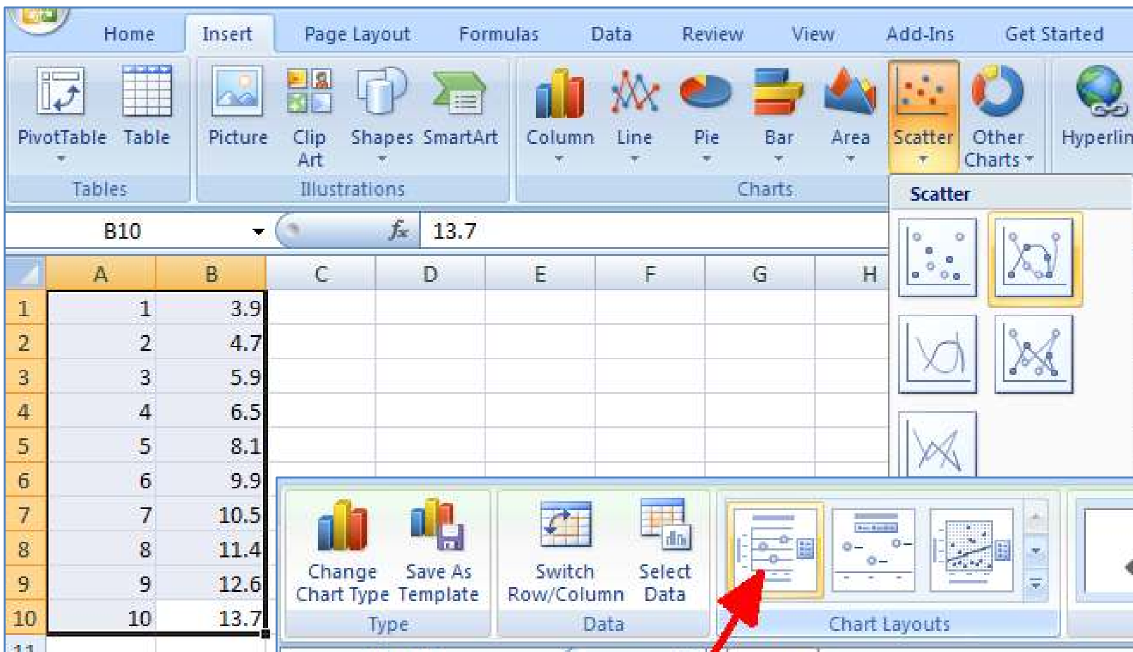


Excel 2007 Graphing

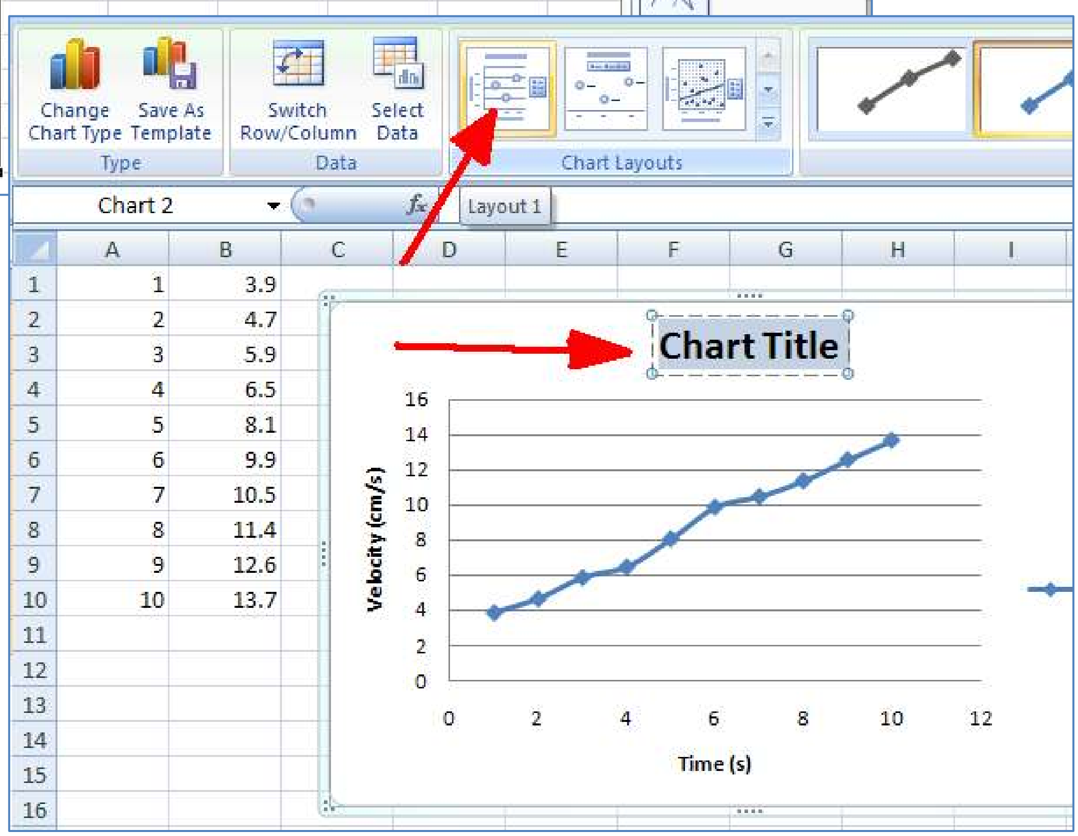
We will draw lots of graphs of the data we collect in lab this semester. Excel (or any other spreadsheet program) makes it very easy to graph and use that data. Some of the advantages to graphing in Excel rather than on paper by hand are the following:

- easy and quick to do
- can print a nice looking graph with titles, units, labels
- can do linear regressions without knowing a ton of statistics
- can save, back-up, copy and email data to lab-partners or to me
- learn computer skills/valuable job skills

Step 1: Put the data into Excel: Place the data for the x-axis in column A (1,2,3...) and the data for the y-axis in column B (3.9, 4.7, ...)

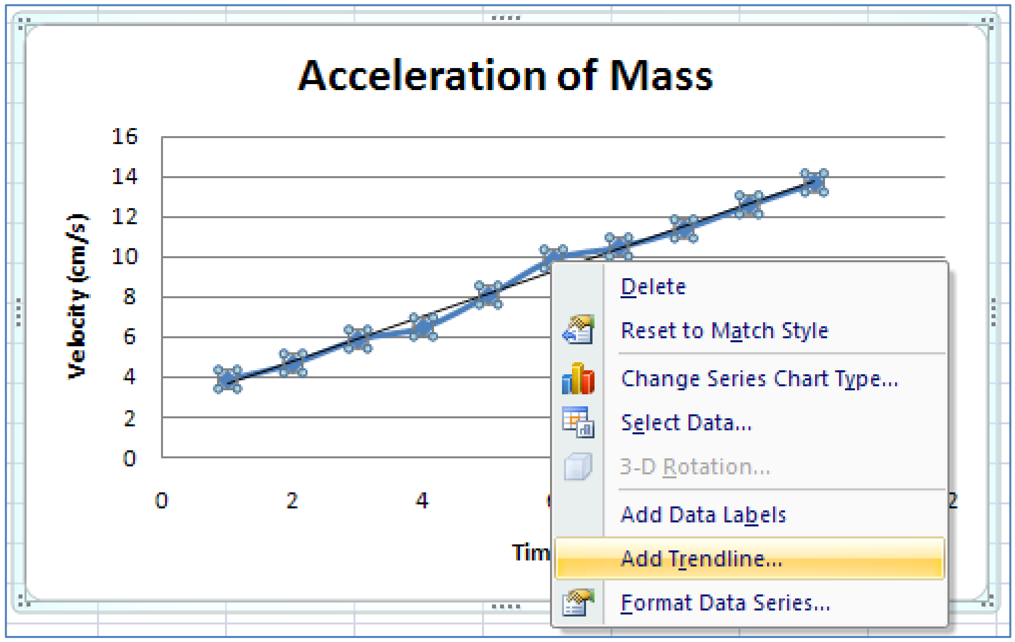


Step 2: Using the mouse, highlight the entire data block, click the Insert Tab, choose Scatter for the chart type and pick one of the Scatter types.



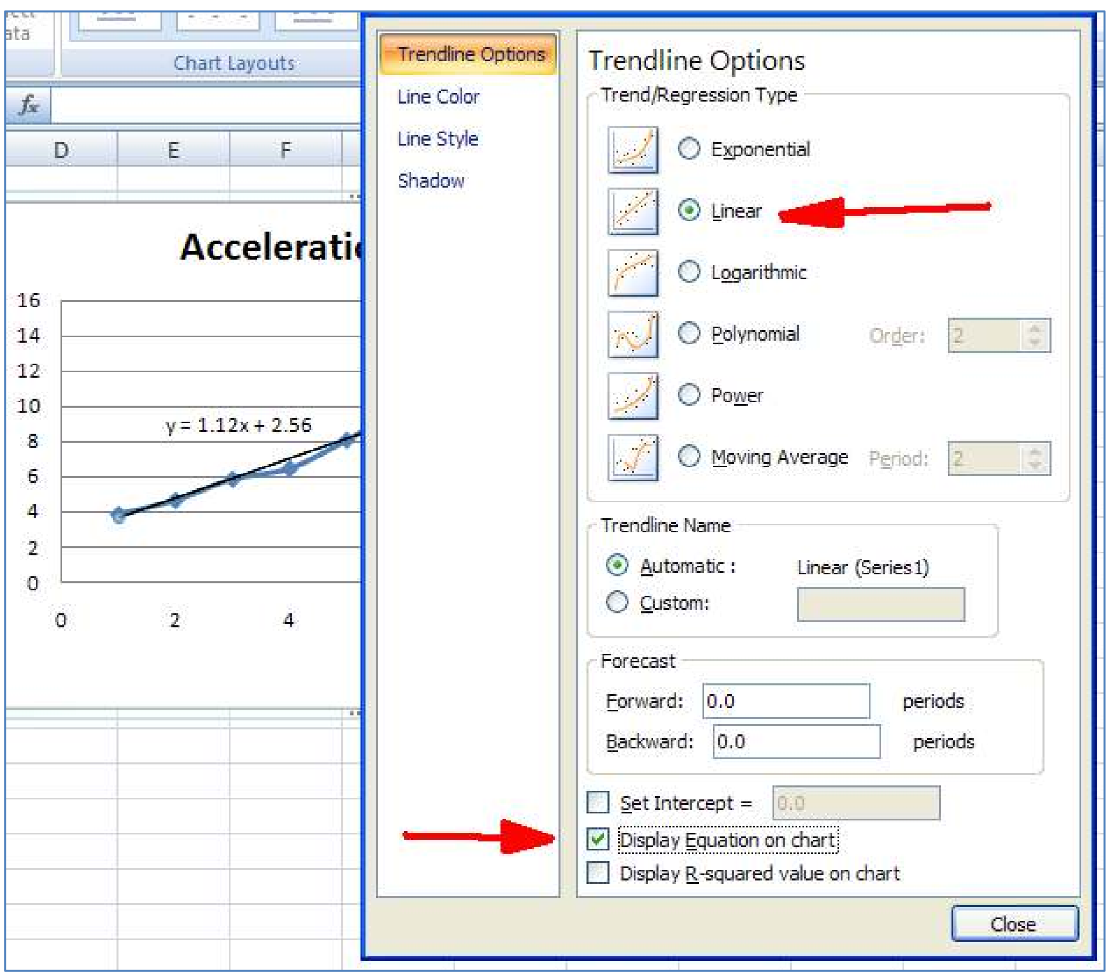
Step 3: Click the first Chart Layout to get titles. Enter Chart title, X axis label, Y axis label by clicking each label and editing.

Step 4: To add a trendline, click the line connecting the data points, right click to get the window options, select Add Trendline



Step 5: Select the type of Trendline - generally linear in these labs. Select the "Display equation on chart" option.

Step 6: To print, click on graph and click Print.



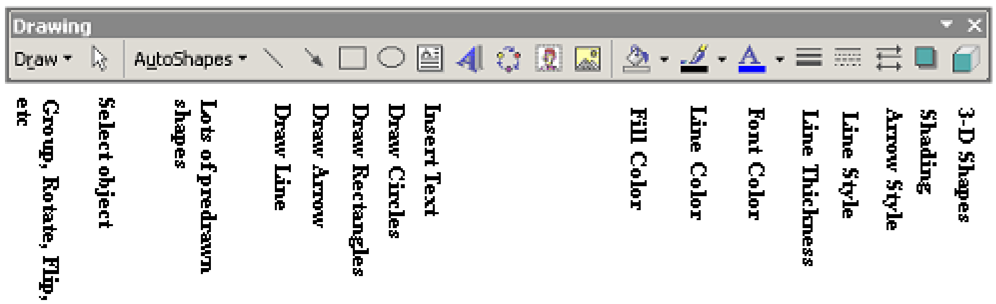
Producing Scientific/Graphical Documents with Word

There are many features included in Word (and all the other word-processing programs) to make it very easy to produce professional looking documents that include diagrams, mathematical equations, subscipts and superscripts. Hopefully this will get you started. If you have questions, come by.

Including diagrams – If you already have a diagram you would like to put in your document, click Insert:Picture:From File and go find your file.

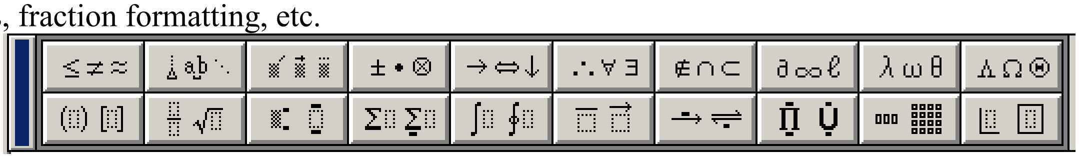
If you find a graphic on the web you want to use (assuming it's copyright free) then right-click the graphic, select copy, go to your Word document, put the cursor where you want it and right-click, select paste.

Producing diagrams – First activate the "Drawing" toolbar by clicking View:Toolbars:Drawing



To use any of the functions shown, simply click the icon, move the mouse to where you want the object to be, and click and drag. For example, all of the diagrams in this labbook were made with this toolbar.

Including Equations – To write formatted mathematical equations, use equation editor. It is included free with MS Word (but may not have been installed on your computer). Simply click Insert:Object, select Microsoft Equation. A new window/tool bar comes up with hundreds of math symbols, fraction formatting, etc.



Subscripts and superscripts – x^3 and $v_2'^2$ are easy to do with subscript and superscript functionality in Word. Select the text you want to put up or down and click Format:Font, choose subscript or superscript.

Setting up shortcuts – If you are going to do a lot of this kind of editing it's easier to set up buttons to get there quicker. Click Tools:Customize. Any of the buttons and functions you see can be added to any toolbar, or you can build your own custom toolbar and throw all the old ones away. Here's a little toolbar I built that does symbols, pictures, superscripts, subscripts, bulleted lists and equations with the click of a button.

TI Calculator Graphing

If a thug walked up to you in a dark alley and said "Quick, plot a quadratic regression of these data points or you're toast, buddy." would you make it out alive? The following functionality is available on the TI-83, but sometimes it's hard to recall the way to get there. This is designed to serve as a ready reference. Print, cut and fold to wallet size. The life you save may be your own.

Lists/Regress:
Clear lists: [STAT] 4 L1[,] etc.
Edit lists: [STAT] 1
Plot lists: [2nd][Y=] (set options) [GRAPH]
Regress: [STAT][▸] (choose 4 - C)
Plot Reg: [VARS] 5 [▸][▸] 1 [GRAPH]

Tables:
Setup Fcns: [Y=]
Setup: [2nd][WINDOW]
Edit: [2nd][GRAPH]
Clear: ClrTable from Catalog
Evaluate Functions:
[VARS][▸]1 (pick fcn) [(]#[)]
Change Plot Props:
[WINDOW] or [ZOOM] or [2nd][ZOOM]

Competencies for Physics I

201- Algebra Physics I

Measurement
Motion in One and Two Dimensions
Force and Motion
Work and Energy
Linear Momentum
Torque and Rotational Motion
Periodic Motion and Waves

Module1. Measurement
- Demonstrate an understanding of basic units used in the International System.
- Specify results of addition, subtraction, multiplication and division to proper number of significant figures.
- Prepare graphs of functions.
- Demonstrate units conversion.
- Perform estimates and order of magnitude calculations.

221 - Calculus Physics I

Measurement
Motion in One and Two Dimensions
Force and Motion
Energy, Work and Power
Linear Momentum
Rotational Motion
Periodic Motion and Waves

Module1: Measurement and Motion
- Demonstrate an understanding of basic units used in the International System.
- Specify results of addition, subtraction, multiplication and division to proper number of significant figures.
- Interpret and graph functional relationships between displacement, velocity, acceleration, and time.
- Demonstrate units conversion.

Module 2. Motion in One and Two Dimensions

- Solve word problems relative to motion in one dimension using fundamental mathematical skills, including unit conversion.
- Define the following: distance, speed, displacement, initial velocity, average velocity,instantaneous velocity, acceleration.
- Demonstrate an understanding of and apply relationships involving displacement,velocity, acceleration and time.
- Be aware of modern concepts involving mass and velocity.
- Identify scalar and vector quantities related to motion.
- Demonstrate proficiency adding and subtracting vector quantities graphically and analytically.
- Demonstrate proficiency multiplying a vector quantity by a scalar quantity.
- Determine relative velocities in regions of one- and two-dimensions.
- Determine motion of projectiles in two-dimensional space.
- Obtain data in the laboratory and use techniques such as graphing, finding percent difference and finding percent error in order to verify relationships in one- and two-dimensional motion, and properly report results of laboratory work.

- Solve word problems relative to motion in one dimension using fundamental mathematical skills, including unit conversion.
- Define the following: displacement, average velocity, average speed, instantaneous velocity, acceleration.
- Demonstrate an understanding of and apply relationships involving displacement, velocity, acceleration and time.
- Be aware of modern concepts involving mass and velocity.
- Identify scalar and vector quantities.
- Demonstrate proficiency adding and subtracting vector quantities graphically and analytically.
- Demonstrate proficiency multiplying a vector quantity by a scalar quantity.
- Describe relative motions of objects in one and two dimensions.
- Describe motion of projectiles mathematically.
- Obtain data in the laboratory manually and with transducers and a graphing calculator interface to verify relationships in one- and two-dimensional motion, and properly report results of laboratory work.
- **Determine velocity and displacement of freely falling objects.**
- **Use unit vector notation to describe vectors and vector components.**
- **Multiply a vector by a scalar.**
- **Obtain the dot product of two vectors and the cross product of two vectors.**
- **Use position vectors in determining average and instantaneous velocity, and average and instantaneous acceleration.**

Module 3. Force and Motion

- Demonstrate an understanding of Newton’s Laws of Motion and apply these laws to problems relating force and motion in one and two dimensions.
- Describe inertial and non-inertial frames of reference.
- Prepare and use force diagrams in the solution of problems involving force and motion.
- Demonstrate an understanding of static and kinetic friction, and the effect of friction on motion of an object.
- Demonstrate an understanding of and utilize the concept of static equilibrium.

Module 2: Force and Motion

- Demonstrate an understanding of Newton’s Laws of Motion and apply these laws to problems relating force and motion in one and two dimensions.
- Describe inertial and non-inertial frames of reference.
- Prepare and use force diagrams in the solution of problems involving force and motion.
- Demonstrate an understanding of static and kinetic friction, and the effect of friction on motion of an object.
- Demonstrate an understanding of and utilize the concept of static equilibrium.

- Define the following: angular displacement, angular velocity, angular acceleration, centripetal acceleration, centripetal force. - Demonstrate an understanding of and apply relationships involving angular and linear displacement, angular and linear velocity, angular and linear acceleration, centripetal force and centripetal acceleration.	
- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.	- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.
Module 4. Mechanical Work, Energy and Power	**Module 3: Energy, Work and Power**
- Define the following: work done by a constant and a varying force, gravitational potential energy, kinetic energy, power.	- Define the following: kinetic energy, work done by a constant and a varying force, power, elastic and gravitational potential energy, conservative and no-conservative force, neutral equilibrium, stable and unstable equilibrium.
- Demonstrate an understanding of and apply relationships involving work, energy and power.	- Demonstrate an understanding of and apply relationships involving kinetic energy and work.
- Demonstrate an understanding of and apply the Law of Conservation of Energy.	- Demonstrate an understanding of and apply the Law of Conservation of Energy.
- Describe conservative and non-conservative forces. - Describe sources of renewable and non-renewable energy, and state advantages and problems associated with each source of energy.	
- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.	- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work. **- Determine work done by a spring force.** **- Determine work done by a general variable force.** **- Obtain average and instantaneous power and know units for describing power.** **- Demonstrate an understanding of and apply relationships involving potential energy and work.** **- Use the concept of path independence in the solution of problems involving work.** **- Determine gravitational and elastic potential energy of a system.** **- Interpret potential energy curves for a system, and locate equilibrium points and turning points for a system.**
Module 5. Linear Momentum	**Module 4: Linear Momentum**
- Define the following: linear momentum, impulse, elastic collision, inelastic collision.	- Define the following: center of mass, linear momentum, impulse, elastic collision, inelastic collision.

- Demonstrate an understanding of and apply the Law of Conservation of Momentum.	- Demonstrate an understanding of and apply the Law of Conservation of Linear Momentum for elastic and inelastic collisions in one dimension.
- Demonstrate an understanding of and apply relationships involving linear momentum, kinetic energy and impulse.	- Demonstrate an understanding of and apply relationships involving impulse and linear momentum to a system of particles.
- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.	- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.
Module 6. Torque and Rotational Motion	**Module 5: Rotational Motion**
- Define torque, moment of inertia, rotational equilibrium, angular momentum, and rotational kinetic energy.	- Define angular displacement, angular velocity, angular acceleration, centripetal acceleration, centripetal force, torque, moment of inertia, rotational equilibrium, angular momentum, rotational kinetic energy.
- Prepare and use force diagrams in the solution of problems in static equilibrium.	- Prepare and use force diagrams in the solution of problems in static equilibrium.
- Prepare and use force diagrams in the solution of problems involving torque and acceleration.	- Demonstrate an understanding of and apply relationships involving torque, rotational motion, angular momentum and rotational kinetic energy .
- Demonstrate an understanding of and apply relationships involving torque, rotational motion, angular momentum and rotational kinetic energy.	- Demonstrate an understanding of and apply relationships involving angular and linear displacement, angular and linear velocity, angular and linear acceleration, centripetal force and centripetal acceleration.
- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.	- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.
	- Apply the parallel-axis theorem to determine moment of inertia of a body.
	- Demonstrate an understanding of and apply the Law of Conservation of Angular Momentum to problems involving systems of particles.
Module 7. Periodic Motion	**Module 6: Periodic Motion**
- Demonstrate an understanding of and apply Hooke's Law	- Demonstrate an understanding of and apply Hooke's Law
- Define simple harmonic motion and list practical applications of this concept.	- Describe simple harmonic motion and list practical applications of this concept.
- Determine amplitude, peak-to-peak displacement, period and frequency of a harmonic oscillator.	- Determine frequency, amplitude, peak-to-peak displacement, and period of a harmonic oscillator.
- Determine displacement, velocity, acceleration, potential energy and kinetic energy of a harmonic oscillator, and graph these quantities as functions of angular displacement and time.	- Determine displacement, velocity, acceleration, potential energy and kinetic energy of a harmonic oscillator, and graph these quantities as functions of angular displacement and time.
- Relate simple harmonic motion to uniform circular motion.	- Relate simple harmonic motion to uniform circular motion.
- Describe a simple pendulum.	- Describe a simple and a physical pendulum.
- Describe harmonic waves.	
- Define wavelength, wave speed, and phase.	- Define wavelength, angular wave number, wave speed, and phase.

- Demonstrate an understanding of and apply relationships involving wave speed, wavelength and frequency.	- Demonstrate an understanding of and apply relationships involving amplitude, wave displacement, wavelength, time, and period.
- Demonstrate an understanding of and apply relationships involving amplitude, wave displacement, wavelength, time, and period.	- Demonstrate an understanding of and apply relationships involving wave speed, wavelength and frequency.
- Describe transfer and longitudinal waves.	- Describe transfer and longitudinal waves.
- Demonstrate an understanding of and apply relationships involving intensity and intensity level.	
- Describe the Doppler effect, and determine observed frequency from a moving source.	
- Describe the formation of a shock wave.	
- Describe reflections of a wave pulse.	- Describe reflections of a wave pulse.
- Demonstrate an understanding of and apply the principle of superposition to determine constructive interference, destructive interference, fundamental and harmonic frequencies for strings and air columns.	- Demonstrate an understanding of and apply the principle of superposition to determine constructive interference, destructive interference, fundamental and harmonic frequencies for strings and air columns.
- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.	- Obtain data in the laboratory in order to verify concepts introduced in this module, and properly report results of laboratory work.
	- Describe three basic types of waves.
	- Define the Principle of Superposition for Waves

Tables of Physical Data

Frequently used constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
speed of light in vacuum	c, c_0	299 792 458	m s^{-1}	(exact)
magnetic constant	μ_0	$4\pi \times 10^{-7}$	N A^{-2}	
		$= 12.566\,370\,614... \times 10^{-7}$	N A^{-2}	(exact)
electric constant $1/\mu_0 c^2$	ϵ_0	$8.854\,187\,817... \times 10^{-12}$	F m^{-1}	(exact)
Newtonian constant of gravitation	G	$6.6742(10) \times 10^{-11}$	$m^3\,kg^{-1}\,s^{-2}$	1.5×10^{-4}
Planck constant	h	$6.626\,0693(11) \times 10^{-34}$	J s	1.7×10^{-7}
$h/2\pi$	$\hbar$	$1.054\,571\,68(18) \times 10^{-34}$	J s	1.7×10^{-7}
elementary charge	e	$1.602\,176\,53(14) \times 10^{-19}$	C	8.5×10^{-8}
magnetic flux quantum $h/2e$	Φ_0	$2.067\,833\,72(18) \times 10^{-15}$	Wb	8.5×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\,091\,733(26) \times 10^{-5}$	S	3.3×10^{-9}
electron mass	m_e	$9.109\,3826(16) \times 10^{-31}$	kg	1.7×10^{-7}
proton mass	m_p	$1.672\,621\,71(29) \times 10^{-27}$	kg	1.7×10^{-7}
proton-electron mass ratio	m_p/m_e	1836.152 672 61(85)		4.6×10^{-10}
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,568(24) \times 10^{-3}$		3.3×10^{-9}
inverse fine-structure constant	α^{-1}	137.035 999 11(46)		3.3×10^{-9}
Rydberg constant $\alpha^2 m_e c/2h$	R_∞	10 973 731.568 525(73)	m^{-1}	6.6×10^{-12}
Avogadro constant	N_A, L	$6.022\,1415(10) \times 10^{23}$	mol^{-1}	1.7×10^{-7}
Faraday constant $N_A e$	F	96 485.3383(83)	C mol^{-1}	8.6×10^{-8}
molar gas constant	R	8.314 472(15)	J mol^{-1} K^{-1}	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6505(24) \times 10^{-23}$	J K^{-1}	1.8×10^{-6}
Stefan-Boltzmann constant $(\pi^2/60)k^4/\hbar^3 c^2$	σ	$5.670\,400(40) \times 10^{-8}$	W m^{-2} K^{-4}	7.0×10^{-6}
Non-SI units accepted for use with the SI				
electron volt: (e/C) J	eV	$1.602\,176\,53(14) \times 10^{-19}$	J	8.5×10^{-8}
(unified) atomic mass unit $1\,u = m_u = \frac{1}{12}m(^{12}C) = 10^{-3}$ kg mol^{-1}/N_A	u	$1.660\,538\,86(28) \times 10^{-27}$	kg	1.7×10^{-7}

Greek Alphabet					
Α	α	alpha	Ν	ν	nu
Β	β	beta	Ξ	ξ	xi
Γ	γ	gamma	Ο	ο	omicron
Δ	δ	delta	Π	π	pi
Ε	ε	epsilon	Ρ	ρ	rho
Ζ	ξ ζ	zeta	Σ	σ	sigma
Η	η	eta	Τ	τ	tau
Θ	θ	theta	Υ	υ	upsilon
Ι	ι	iota	Φ	φ ϕ	phi
Κ	κ ϰ	kappa	Χ	χ	chi
Λ	λ	lambda	Ψ	ψ	psi
Μ	μ	mu	Ω	ω	omega

Planetary Data					
Object	**Radius**	**Mass**	**Orbital Radius**	**Orbital Period**	**Gravity**
Sun	6.96 E8 m	1.99 E30 kg	-	-	
Mercury	2450 km	3.28 E23 kg	0.387 AU	0.241 Years	.38g
Venus	6050 km	4.90 E24 kg	0.723 AU	0.615 Years	.90g
Earth	6380 km	5.98 E24 kg	1 AU (1.5E11 m)	1 Year	g
Moon (to Earth)	1740 km	7.35 E22 kg	3.84 E8 m	29 days	.167g
Mars	3400 km	6.58 E23 kg	1.524 AU	1.881 Years	.38g
Jupiter	71500 km	1.90 E25 kg	5.203 AU	11.862 Years	2.6g
Saturn	60000 km	5.68 E26 kg	9.516 AU	29.458 Years	1.2g
Uranus	25500 km	8.97 E25 kg	19.166 AU	84.013 Years	1.1g
Neptune	25000 km	1.02 E26 kg	30.012 AU	164.793 Years	1.2g
Pluto	1200 km	1.79 E23 kg	39.557 AU	248.530 Years	.43g

Elastic Properties of Selected Engineering Materials				
Material	**Density (kg/m^3)**	**Young's Modulus 10^9 N/m^2**	**Ultimate Strength S_u 10^6 N/m^2**	**Yield Strength S_y 10^6 N/m^2**
Steel	7860	200	400	250
Aluminum	2710	70	110	95
Glass	2190	65	50 (compress)	...
Concrete	2320	30	40 (compress)	...
Wood	525	13	50 (compress)	...
Bone	1900	9	170 (compress)	...
Polystyrene	1050	3	48	...

Coefficients of Friction			
Material 1	**Material 2**	**Conditions**	**μ**
Glass	Glass	Clean	0.9 - 1.0
Wood	Wood	Clean & dry	0.25 - 0.5
Wood	Wood	Wet	0.2
Steel	Steel	Clean	0.58
Steel	Steel	Oiled	0.2
Rubber	Solids	Dry	1-4
Teflon	Steel	Clean	0.04
Waxed Hickory	Dry Snow		0.03 - 0.06
Brass	Ice		0.02 - 0.08

Speed of Sound in Various Bulk Media					
Gases		**Liquids at 25°C**		**Solids**	
Material	**v (m/s)**	**Material**	**v (m/s)**	**Material**	**v (m/s)**
Hydrogen (0°C)	1286	Glycerol	1904	Diamond	12000
Helium (0°C)	972	Sea water	1533	Pyrex glass	5640
Air (20°C)	343	Water	1493	Iron	5130
Air (0°C)	331	Mercury	1450	Aluminum	5100
		Kerosene	1324	Brass	4700
		Methyl alcohol	1143	Copper	3560
				Gold	3240
				Lucite	2680
				Lead	1322
				Rubber	1600

Material Density (g/cm^3)					
Liquids		**Solids**		**Gasses**	
Water at 4 C	1.0000	Aluminum	2.7	Air	0.001293
Water at 20 C	0.998	Copper	8.3-9.0	Carbon dioxide	.001977
Gasoline	0.70	Gold	19.3	Carbon monoxide	0.00125
Mercury	13.6	Iron	7.8	Hydrogen	0.00009
Milk	1.03	Platinum	21.4	Helium	0.000178
		Uranium	18.7		
		Ice at 0 C	0.92		

Datasheets for Lab

Datasheet for Lab 1: Measurement and Graphing

1. Significant Figures

A. How many significant figures are in each of the following values?

5.0	0.0025	3.00×10^6	400.2	0.400	2.62×10^{-2}	0.008

B. Perform the computation indicated and round your answer to the correct number of significant figures:

$\frac{(34280)\ (265)}{(5347)\ (12)}$ $\frac{65.431}{3.1416}$ $\frac{26}{5280}$ $\frac{2.3 \times 10^4}{2.000}$ $\frac{3425}{2.0000}$ $(5 \times 10^5)\ (3 \times 10^2)$

__________ ________ _______ _________ ________ ____________

2. Scientific Notation

A. Express the following values in scientific notation and normal form:

Normal form	**Scientific Notation**
300,000	
468,900,000	
-0.0004	
0.000000561	
-695	
	-7×10^{-3}
	8.6×10^3
	5.28×10^4

B. Calculations

Expression	**Value**
$(-2.4 \times 10^2)^3$	
$(1.4 \times 10^{-3})^2$	
$(5.58 \times 10^3) + (4.001 \times 10^3)$	
$(5.58 \times 10^5) - (4.001 \times 10^4)$	
$(5.58 \times 10^3) \cdot (4.001 \times 10^3)$	
$(5.58 \times 10^5) \,/\, (4.001 \times 10^4)$	

4. A. Value of Pi, First Method

	Trial 1	Trial 2	Trial 3	Average
Outer Diameter				
Circumference				

Calculated value of pi _______________

Actual value of pi _______________

% Error $\left(\frac{\text{actual} - \text{calculated}}{\text{actual}} \times 100\%\right)$ _______________

4.B. Value of Pi, Second Method

	Trial 1	Trial 2	Trial 3	Average
Circumference				

Calculated value of pi _______________

% Error $\left(\frac{\text{actual} - \text{calculated}}{\text{actual}} \times 100\%\right)$ _______________

5.A. Interior Volume of a Cylinder, First Method

	Trial 1	Trial 2	Trial 3	Average
Inner Diameter				

Internal height of cylinder ________________

Calculated interior volume of cylinder _________________

5.B. Interior Volume of Cylinder, Second Method

Volume of water to fill vial _____________________

% difference $\left(\frac{\text{first value} - \text{second value}}{\text{average value}} \times 100\%\right)$ in volumes _______________________

Datasheet for Lab 2: Acceleration due to Gravity

Spark #	Distance y_n (cm)	Elapsed Time (s)	Δy $y_{n+1} - y_{n-1}$ (cm)	Δt (s)	Velocity Δy/ Δt(cm/s)
0	0	0	-	-	-
1		1/60		0.03333	
2		2/60		0.03333	
3		3/60		0.03333	
4		4/60		0.03333	
5		5/60		0.03333	
6		6/60		0.03333	
7		7/60		0.03333	
8		8/60		0.03333	
9		9/60		0.03333	
10		10/60		0.03333	
11		11/60		0.03333	
12		12/60		0.03333	
13		13/60		0.03333	
14		14/60		0.03333	
15		15/60		0.03333	
16		16/60		0.03333	
17		17/60		0.03333	
18		18/60		0.03333	
19		19/60		0.03333	
20		20/60		0.03333	
21		21/60		0.03333	
22		22/60		0.03333	
23		23/60		0.03333	
24		24/60		0.03333	
25		25/60		0.03333	
26		26/60	-	-	-

Datasheet for Lab 3: Velocity and Acceleration

Enter the values from the Data and Calculations sheet to confirm $s = v_o t + 0.5\ a\ t^2$. This is the first equation listed under Objective. Then, calculate and list percent error in the observations.

Measured Displacement **s** **(line 3)**	**Predicted Value for Displacement** $v_o t + 0.5\ a\ t^2$ **(line 11 + 12)**	**Percent Error**
	Average Percent Error	

Enter the values from the Data and Calculations sheet to confirm $v^2 = v_o^2 + 2\ a\ s$. This is the second equation listed under Objective. Then, calculate and list percent difference error in the observations.

Calc. Final Velocity **Squared** v^2 **(line 13)**	**Predicted Final Velocity Squared** $v_o^2 + 2\ a\ s$ **(line 14 + 15)**	**Percent Difference**
	Average Percent Difference	

DATA and CALCULATIONS (Finish each column before moving on)

1. Initial position of glider on track (used for locating master photogate)	0.200 m	0.200 m	0.200 m	0.200 m	0.200 m
2. Final position of glider on track (used for locating remote photogate)	0.700 m	0.900 m	1.100 m	1.300 m	1.500 m
3. Displacement , s (line 2 - line 1)	0.500 m	0.700 m	0.900 m	1.100 m	1.300 m
4. Time to pass between photogates, t **(pulse mode)**	s	s	s	s	s
5. Time to pass under master photogate, Δt_1 **(gate mode)**	s	s	s	s	s
6. Time to pass under both photogates $\Delta t_1 + \Delta t_2$ **(gate mode)**	s	s	s	s	s
7. CALC. Time to pass under remote photogate Δt_2	s	s	s	s	s
8. CALC. initial velocity, v_o = flagwidth / Δt_1	m/s	m/s	m/s	m/s	m/s
9. CALC. final velocity, v = flagwidth / Δt_2	m/s	m/s	m/s	m/s	m/s
10. CALC. acceleration from Equation 1 (line 9. - line 8.) / line 4	m/s^2	m/s^2	m/s^2	m/s^2	m/s^2
11. CALC. v_o t (line 8. * line 4.)	m	m	m	m	m
12. CALC. 0.5 a t^2 (0.5 * line 10. * line 4. * line 4.)	m	m	m	m	m
13. CALC. v^2 (line 9. * line 9)	m^2/s^2	m^2 / s^2	m^2/s^2	m^2/s^2	m^2/s^2
14. CALC. v_o^2 (line 8. * line 8)	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2
15. CALC. 2 a (x - x_o) (2 * line 10. * line 3.)	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2	m^2/s^2

Datasheet for Lab 4: Resolution of Forces

Add these vectors in the three ways described. In your conclusion, include a table showing the results for all methods.

Test 1: $\vec{A} = 360\angle 90^O$ $\vec{B} = 180\angle 180^O$

Test 2: $\vec{A} = 180\angle 162^O$ $\vec{B} = 200\angle 250^O$ $\vec{C} = 205\angle 10^O$

Test 3: $\vec{A} = 200\angle 80^O$ $\vec{B} = 250\angle 120^O$ $\vec{C} = 300\angle 210^O$

Test 4: $\vec{A} = 150\angle 90^O$ $\vec{B} = 300\angle 30^O$ $\vec{C} = 400\angle 250^O$

	Graphical Method	Algebraic Method	Force Table
Test 1			
Test 2			
Test 3			
Test 4			

Note: Since the first two methods give the resultant and the force table method gives the equilibrant, the results from the force table should be 180^O off from the other two methods.

Datasheet for Lab 5: Projectile Motion

Data for Procedure 1

Vertical height, h __________ m

Diameter of projectile __________ cm

Time to reach floor from h __________ s

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Range						

Calculated velocity based on range and height ________m/s ________miles/h _________ft/s
(Show calculations and units conversion in your calculations section.)

Data for Procedure 2

Vertical height, h __________ m

Time, t, to reach floor from h __________ s

Predicted horizontal distance traveled in t seconds ____________ m

Actual horizontal distance traveled in t seconds ____________ m

% error _____________ %

Data for Procedure 3

Vertical height, h __________ m

Angle, θ ____________ ^{o}

Time, t, to reach floor from h __________ s

Predicted horizontal distance traveled in t seconds ____________ m (Show calculations)

Actual horizontal distance traveled in t seconds ____________ m

% error _____________ %

Datasheet for Lab 6: Friction

We will try to measure μ using three different methods. Show your methods of calculation and at least one example of each method on a separate page. The three methods are:

- Raising the inclined plane to find the angle necessary for the object to just begin moving **without** tapping or vibration. Record the angle necessary to move the object.
- Raising the inclined plane to find the angle necessary for the object to just begin moving **with** tapping or vibration. Record the angle necessary to move the object
- Using a pulley and weights to drag the object uphill without tapping or vibration. Set angle to 25^0. Record the mass necessary to move the object.

			Without Tapping (degrees of inclination)				With Tapping (degrees of inclination)				Pulley & Weight (grams to move object)			
Stationary Material	**Sliding Material**	**Mass**	**Trial 1**	**Trial 2**	**Av**	**μ**	**Trial 1**	**Trial 2**	**Av**	**μ**	**Trial 1**	**Trial 2**	**Av**	**μ**
Painted Steel														

Analysis - Answer in complete, grammatically correct sentences.

1. Would you expect the force of friction to be greater when the materials are vibrating or when they are not vibrating? Explain.

2. Which method would most likely present values of kinetic coefficients of friction, that is, values of μ for objects that are moving with respect to each other? Why?

3. Suggest an experimental procedure to determine the amount of friction that occurs between a moving solid and a liquid. (The procedure should be specific; include a sketch if needed.)

4. Suggest an experimental procedure to determine the amount of friction that occurs between a moving liquid and a gas. (The procedure should be specific; include a sketch if needed.)

5. In the lab we derived that mass has no effect on μ. Do your results support that idea?

Data Sheet for Lab 7: Uniform Circular Motion

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
Spring setting				
Radius of rotation, r				
Number of revolutions, n				
Time for revolutions, t				
Calc. Speed $v = 2 \pi r n / t$				
mass of rotating object, m				
Calc. centripetal force $F_c = m v^2/r$				
hanging mass, M				
Calc. force on spring, $F_{spring} = M g$				
% Error between F_{spring} and F_c				

Data Sheet for Lab 8: Work and Energy

	Test 1	Test 2	Test 3	Test 4	Test 5
Work					
Force	N	N	N	N	N
Distance	m	m	m	m	m
Calc Work	J	J	J	J	J
Potential Energy					
Height	m	m	m	m	m
Mass	Kg	Kg	Kg	Kg	Kg
Calc PE	J	J	J	J	J
Kinetic Energy					
Time	S	S	S	S	S
Calc velocity	m/s	m/s	m/s	m/s	m/s
Calc KE	J	J	J	J	J

Data Sheet for Lab 9: Conservation of Momentum

Inelastic Collisions, Cart 2 stationary	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Units**
Photogate A Time						s
Photogate B Time						s
Mass of Cart 1, m_1						Kg
Initial Velocity of Cart 1, v_1 = flagwidth/time						m/s
Cart 1 initial momentum, $\mathbf{P_1} = m_1 v_1$						Kg m/s
Mass of Cart 2, m_2						Kg
Initial Velocity of Cart 2, v_2	0	0	0	0	0	m/s
Cart 2 initial momentum, $\mathbf{P_2} = m_2 v_2$						Kg m/s
Mass of Cart 1 and Cart 2, $m_1 + m_2$						Kg
Final Velocity of Cart 1 and 2, v'						m/s
Calculated v' from formula						m/s
Cart 1 and 2 final momentum, $\mathbf{P'} = (m_1 + m_2)\, v'$						Kg m/s
Difference in momentum $\mathbf{P_1 + P_2 - P'}$						Kg m/s

Inelastic Collisions	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Units
Photogate A Time						s
Photogate A Memory Time						s
Photogate B Time						s
Photogate B Memory Time						s
Mass of Cart 1, m_1						Kg
Initial Velocity of Cart 1, v_1						m/s
Cart A initial momentum, $\mathbf{P_1} = m_1 v_1$						Kg m/s
Mass of Cart 2, m_2						Kg
Initial Velocity of Cart 2, v_2						m/s
Cart 2 initial momentum, $\mathbf{P_2} = m_2 v_2$						Kg m/s
Mass of Cart 1 and Cart 2, $m_2 + m_2$						Kg
Final Velocity of Cart 1 and 2, v'						m/s
Calculated v' from formula						m/s
Cart 1 and 2 final momentum, $\mathbf{P}' = (m_1 + m_2)v'$						Kg m/s
Difference in momentum $\mathbf{P_1 + P_2 - P'}$						Kg m/s

Elastic Collisions, Cart 2 stationary	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Units**
Photogate A Time						s
Photogate A Memory Time						s
Photogate B Time						s
Photogate B Memory Time						s
Mass of Cart 1, m_1						Kg
Initial Velocity of Cart 1, v_1						m/s
Cart A initial momentum, $\mathbf{P_1} = m_1 v_1$						Kg m/s
Mass of Cart 2, m_2						Kg
Initial Velocity of Cart 2, v_2	0	0	0	0	0	m/s
Cart B initial momentum, $\mathbf{P_2} = m_2 v_2$						Kg m/s
Final Velocity of Cart 1 , v_1'						m/s
Calculated v_1' `from formula`						m/s
Final momentum of cart 1, $\mathbf{P_1}'$						Kg m/s
Final Velocity of Cart 2, v_2'						m/s
Calculated v_2' `from formula`						m/s
Final momentum of cart 2, $\mathbf{P_2}'$						Kg m/s
Difference in momentum $\mathbf{P_1 + P_2 - P_1' - P_2'}$						Kg m/s

Data Sheet for Lab 10: Torque

<u>Procedure 1</u> - Center of Gravity of a Meter Stick

Balance point of meter stick ____________ (This is center of mass of the meter stick.)

<u>Procedure 2</u> – Balancing two Masses with the Balance at the Center of Mass
Draw a diagram and show calculations to determine equilibrium position of 250-gram Mass

Predicted Position of 250-gram Mass for Equilibrium ____________

Actual Position of 250-gram Mass for Equilibrium ____________ % Error ____________

<u>Experiment 3</u> - Find the Mass of the Meter Stick

Balance point of the meter stick with 150-gram mass _____________
Draw a diagram and show calculations to determine the mass of the meter stick

Predicted mass of the meter stick, __________________

Actual mass of the meter stick, from balance __________________ % Error ____________

Experiment 4. Forces on a System
Draw a diagram and show calculations to determine scale readings

Predicted reading of spring scale at 15 cm mark _________________

Actual reading of spring scale at 15 cm mark _________________ % Error ____________

Predicted reading of spring scale at 95 cm mark _________________

Reading of spring scale at 95 cm mark _________________ % Error ____________

Experiment 5 - Load Suspended from a Boom
Draw a diagram and show calculations to determine reading of spring scale

Predicted reading of spring scale _________________

Actual reading of spring scale __________________ % Error ____________

Data Sheet for Lab 12: Simple Harmonic Motion

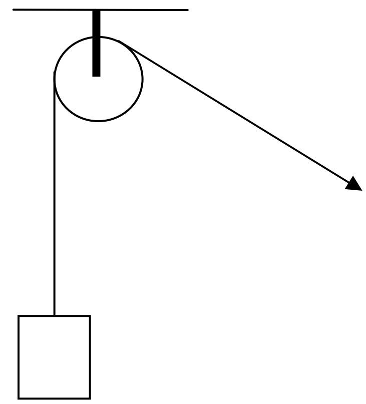
Mass on Spring	Calc. Force	Height above table	Calc. Static Displacement	Total time for cycles	# of cycles	Calc Period	Period Squared
kg	N	m	m	s	#	s	s^2
0							
.050							
.070							
.090							
.110							
.130							
.150							
.170							
.190							
.210							
.230							
.250							
.270							
.290							
.310							
.330							
.350							
.370							

Data Sheet for Lab 13: Pulleys

<u>Procedure 1</u> - Single Fixed Pulley

- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.
- Try pulling the sting at different angles, does it make a difference?

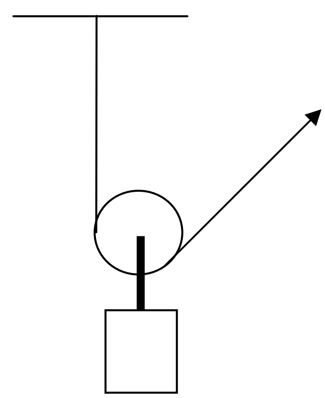
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 2</u> - Single Moveable Pulley

- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.
- Try pulling the sting at different angles, does it make a difference?

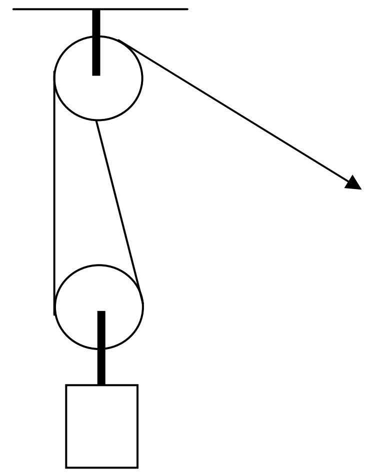
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 3</u> – One Fixed and One Moveable Pulley

- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

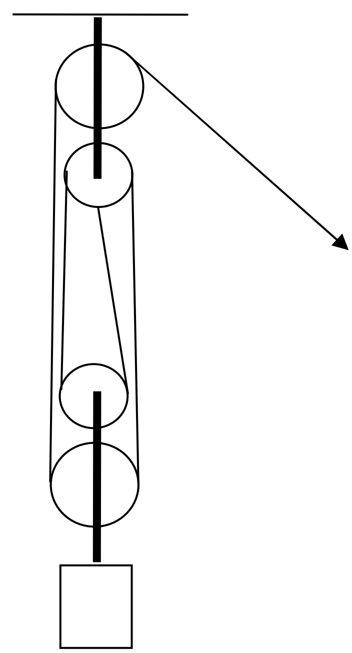
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 4</u> – Two Double Pulleys

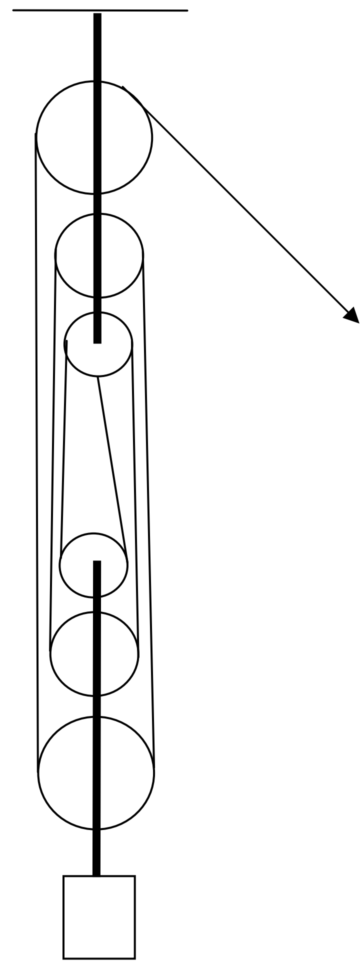
- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



<u>Procedure 5</u> – Two Triple Pulleys

- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

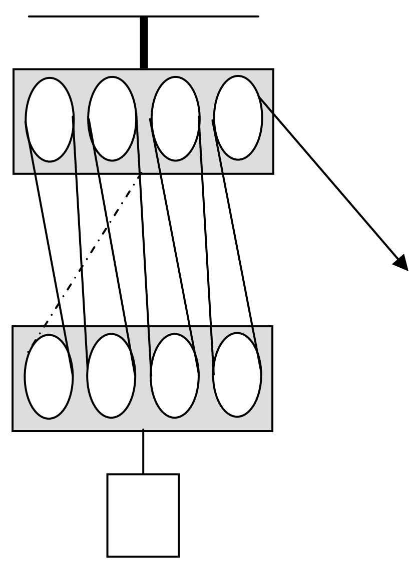


M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%

<u>Procedure 6</u> – Two Quadruple Pulleys

- Draw a force diagram of the bottom pulley and, using Newton's second law, calculate the expected applied Force. Compare this with the measured F_{in}.

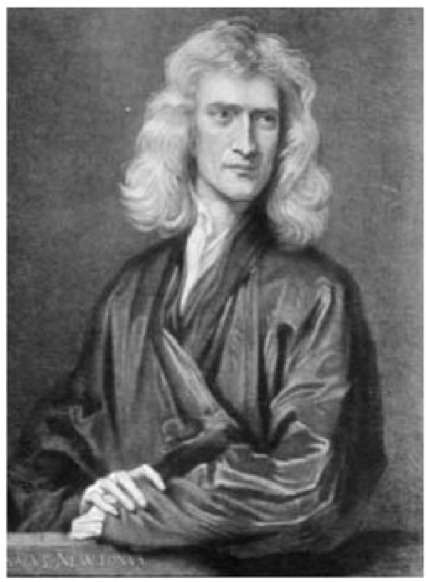
M_{Load}	kg
F_{out}: Load	N
F_{in}: Applied Force	N
S_{out}: Dist. load moves	cm
S_{in}: Dist pull string	cm
Calc. AMA	
Calc. IMA	
Calc efficiency	%
Calc F_{in}	N
% Error	%



Make a table listing pulley system, ideal mechanical advantage, actual mechanical advantage and efficiency.

	IMA	AMA	% Efficiency
Procedure 1:			
Procedure 2:			
Procedure 3:			
Procedure 4:			
Procedure 5:			
Procedure 6:			

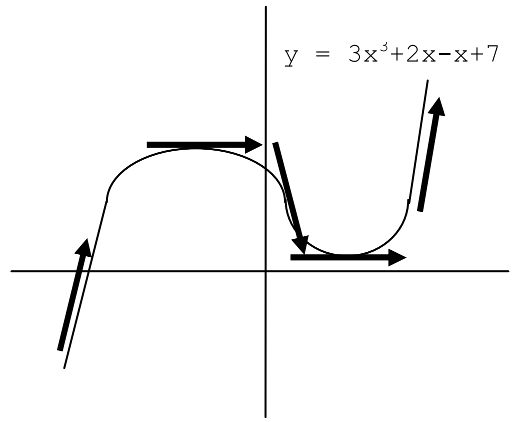
Physics 221
Calculus Physics Notes



Calculus Review

Basic knowledge of Calculus opens doors to a lot of problems in Physics and makes them much easier to solve. There are two things in Calculus that we need to know how to do; how to take derivatives and how to integrate. While you should find a good Calculus text for a full explanation, here are a couple of reminders.

The derivative express how a function is changing as we examine a small piece of it. Looking at the function to the right we can find places where it slopes down or slopes up or levels off flat. The arrows represent tangent lines, lines that only touch the curve at one point. If we want to know how something is changing, we look at the slope of the tangent line.



To find this slope we take the derivative. The derivative of a power of x is easy to find since

$$\frac{d}{dx}\left(Ax^n\right) = Anx^{n-1}$$

For a polynomial, simply take the derivative of each term as shown in the following example

$$\frac{d}{dx}\left(3x^3 + 2x^2 - x + 7\right)$$
$$= \frac{d}{dx}\left(3x^3 + 2x^2 - 1x^1 + 7x^0\right)$$
$$= 3 \cdot 3x^{3-1} + 2 \cdot 2x^{2-1} - 1 \cdot 1x^{1-1} + 7 \cdot 0x^{0-1}$$
$$= 9x^2 + 4x - 1x^0 + 0$$
$$= 9x^2 + 4x - 1$$

Now at any value of x we can find the slope of this function and see it on the graph above. If x = -3 in the example, then plug -3 in for x into the derivative $9(-3)^2+4(-3)-1 = 68$. Since the answer is positive and represents the slope, we know the curve heads up at x = -3. At x = -1, $9(-1)^2+4(-1)-1 = 4$ so the curve is still headed up, but not nearly so steeply. At x = 0, $9(0)^2+4(0)-1 = -1$, the slope is now negative and the curve heads down. Somewhere in between x = -1 and x = 0 the slope went to zero, which would be represented on the graph by a flat horizontal tangent line.

The easy way to find the point where the slope is zero is to set the derivative of the function equal to zero and solve for x. We solve $9x^2+4x-1 = 0$ by using the quadratic formula with a = 9, b = 4, c = -1

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-4 \pm \sqrt{4^2 - 4(9)(-1)}}{2(9)} \approx 0.178 \ or \ -0.623 \ .$$

These are the x values of the points where the slope = 0. At x = - 0.623 we see have a local maximum and at x = 0.178 we have a local minimum.

$$\frac{d}{dx}\left(uv\right) = u\frac{dv}{dx} + v\frac{du}{dx}$$
$$\frac{d}{dx}\left(\frac{u}{v}\right) = \frac{v\frac{du}{dx} - u\frac{dv}{dx}}{v^2}$$
$$\frac{d}{dx}\left(e^x\right) = e^x \qquad \frac{d}{dx}\left(e^u\right) = e^u\frac{du}{dx}$$
$$\frac{d}{dx}\left(\ln x\right) = \frac{1}{x} \qquad \frac{d}{dx}\left(\ln u\right) = \frac{1}{u}\frac{du}{dx}$$
$$\frac{d}{dx}\left(\sin x\right) = \cos x \qquad \frac{d}{dx}\left(\sin u\right) = \cos u\frac{du}{dx}$$
$$\frac{d}{dx}\left(\cos x\right) = -\sin x \qquad \frac{d}{dx}\left(\cos u\right) = -\sin u\frac{du}{dx}$$
$$\frac{d}{dx}\left(\tan x\right) = \sec^2 x \qquad \frac{d}{dx}\left(\tan u\right) = \sec^2 u\frac{du}{dx}$$

Other functions are trickier, but can usually be looked up in a table like the few shown here. The variables u and v represent functions of x.
Before we saw that for polynomials

$$\frac{d}{dx}\left(3x^3 + 2x^2 - x + 7\right) = 9x^2 + 4x - 1$$

Here we had to multiply the coefficient by the exponent and lower the exponent by one. To get back to the original function we would have to do the opposite; raise the exponent by one and divide by the new exponent.

The integral is sometimes called the anti-derivative because it "undoes" the derivative. For our example we would use the following notation

$\int (9x^2 + 4x - 1)dx$ which is read "taking the integral of $9x^2+4x-1$ with respect to x." The dx notation simply tells us which variable to integrate. Here is the integration

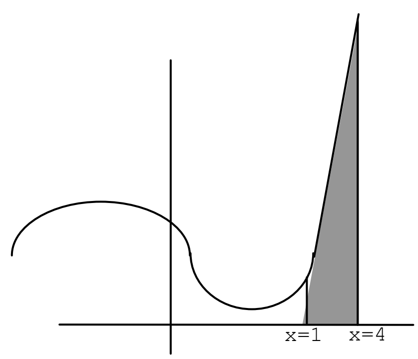
$$\int (9x^2 + 4x - 1)dx$$
$$= \frac{9x^{2+1}}{2+1} + \frac{4x^{1+1}}{1+1} - \frac{1x^{0+1}}{0+1}$$
$$= \frac{9x^3}{3} + \frac{4x^2}{2} - \frac{x^1}{1}$$
$$= 3x^3 + 2x^2 - x$$

Which is very close to the original $3x^3+2x^2-x+7$. However, we lost the constant term "+7" at the end, so whenever we integrate we can do one of two things; add a constant or use limits of integration.

Adding a constant is easy, $\int (9x^2 + 4x - 1)dx = 3x^3 + 2x^2 - x + C$. We don't know what C is, but it represents that we recognize that there could have been something there before we took the derivative. Sometimes the problem gives enough information to find C.

If the problem specifies a range of x values for the problem then we use these as limits of integration. If we are interested in the region between x=1 and x=4 for $9x^2+4x-1$, then the integration is completed when we substitute these x values in. The integral is the (result with the upper limit) – (the result with the lower limit) as shown

$$\int_{x=1}^{x=4} (9x^2 + 4x - 1)dx$$
$$= 3x^3 + 2x^2 - x\Big|_{x=1}^{x=4}$$
$$= \left[3(4)^3 + 2(4)^2 - (4)\right] - \left[3(1)^3 + 2(1)^2 - (1)\right]$$
$$= [220] - [4]$$
$$= 216$$



This number is the area under the curve and between x = 1 and x=4. In the graph at the right, this area is shaded. There are many applications for finding the area under a curve in Physics and Engineering and Economics and many other fields.

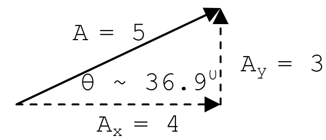
Again if the function you wish to integrate is not a polynomial, there are tables to assist in finding the integrals. Here are a couple, but there are easily 500 or more in complete tables.

$$\int uv\,dx = uv - \int v\,du$$
$$\int e^{ax}dx = \frac{1}{a}e^{ax} \qquad \int xe^{ax}dx = \frac{e^{ax}}{a^2}(ax-1) \qquad \int \ln ax\,dx = (x \ln ax) - x$$
$$\int \sin ax\,dx = -\frac{1}{a}\cos ax \qquad \int \cos ax\,dx = \frac{1}{a}\sin ax \qquad \int \tan ax\,dx = -\frac{1}{a}\ln(\cos ax)$$

Test 1 - Measurement Topics

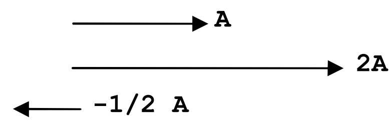
The extra topics included in Test 1 include knowing rectangular and polar notations for vectors and a couple of extra operations with vectors. Bold print denotes a vector.

- **Use unit vector notation to describe vectors and vector components.**



Vectors can be expressed using rectangular coordinates or polar coordinates. For a given vector, rectangular coordinates specify the x and y components, whereas polar coordinates give the magnitude and direction. In the example at the right, we can either write $\mathbf{A} = 4\mathbf{i} + 3\mathbf{j}$ or $\mathbf{A} = 5\angle 36.9^0$ where the first uses a rectangular coordinate system and the second is in polar coordinates. **i** and **j** are called unit vectors; they are 1 unit in length and point in the x and y direction respectively.

- **Multiply a vector by a scalar.**



Multiplication by a scalar involves changing the magnitude of a vector. It can also reverse the direction of the vector. Simply multiply the vector by a number (also known as a scalar)

For some vector R multiplied by the scalar 2, in rectangular and polar coordinates

$\mathbf{R} = 4\mathbf{i} + 3\mathbf{j}$	$\mathbf{R} = 5 < 36.9^0$
$2\,\mathbf{R} = 2(4\mathbf{i} + 3\mathbf{j})$	$2\mathbf{R} = 2\cdot 5 < 36.9^0$
$2\,\mathbf{R} = 8\mathbf{i} + 6\mathbf{j}$	$2\mathbf{R} = 10 < 36.9^0$

Here is an example using a negative scalar. When using polar coordinates, simply add or subtract 180^0 to the angle to reverse the direction.

$\mathbf{R} = 4\mathbf{i} + 3\mathbf{j}$	$\mathbf{R} = 5 < 36.9^0$
$-1.7\,\mathbf{R} = -1.7\,(4\mathbf{i} + 3\mathbf{j})$	$-1.7\,\mathbf{R} = 1.7(5) < (36.9^0+180^0)$
$-1.7\,\mathbf{R} = -6.8\mathbf{i} - 5.1\mathbf{j}$	$-1.7\,\mathbf{R} = 8.5 < 216.9^0$

- **Obtain the dot product of two vectors**

The dot product is defined

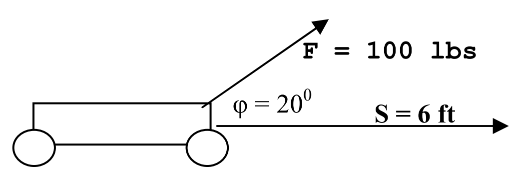
Polar Coordinates: $\mathbf{A}\cdot\mathbf{B} = AB\cos\varphi$ where φ is the angle between **A** and **B** **or**

Rectangular Coordinates: $\mathbf{A}\cdot\mathbf{B} = a_1b_1 + a_2b_2 + \ldots$

Example: If $\mathbf{A} = 10 < 23^0$ and $\mathbf{B} = 7 < 82^0$ then $\mathbf{A}\cdot\mathbf{B} = 10\cdot 7\cos 59^0 = 70\,(0.5150) = 36.05$

If $\mathbf{A} = 3\mathbf{i} + 5\mathbf{j}$ and $\mathbf{B} = 6\mathbf{i} + 12\mathbf{j}$ then $\mathbf{A}\cdot\mathbf{B} = 3\cdot 6 + 5\cdot 12 = 78$

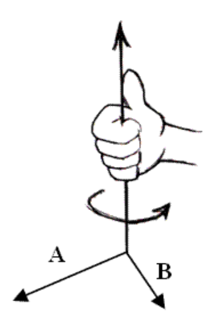
Note that the dot product results in a scalar number. For this reason, the dot product is also sometimes called the scalar product.



The picture of the wagon shows an application of the dot product. A force **F** pulls up and to the right to move the wagon to the right. The upward force does nothing to move the wagon forward. To calculate the work performed,

$W = \mathbf{F}\cdot\mathbf{s} = Fs\cos\varphi = 100\cdot 6\cos 20^0 = 564$ J

- **Obtain the cross product of two vectors.**



Whereas the dot product results in a scalar, the cross product "multiplies" two vectors and results in a third vector. The magnitude of the cross product is given by

$|\mathbf{A}\mathrm{x}\mathbf{B}| = AB\sin\varphi$ where φ is the angle between **A** and **B**

and the direction is given by the "right hand rule". To use the right hand rule, place the

fingers of your right hand in the direction of the first vector, curl them in the direction of the second vector, your thumb will be pointing in the direction of the resulting vector.
Example: If **A** = $10 < 23^0$ and **B** = $7 < 82^0$ where A and B are both on the x-y plane, then
|**AxB**| = 10•7 sin 59^0 = 70 (0.8572) = 60.00 and the direction is in the positive z direction.

Since the cross product results in another vector, sometimes it is called the vector product.

- **Practice Problems**

A = 5**i** - 3**j** **B** = 4**i** + 2**j** **C** = $15 < 243^0$ **D** = $12 < 73^0$

1) Express **A** in polar notation.
2) Express **D** in rectangular notation.
3) Find 2**B**
4) Find 5**A – 2B**
5) Find **A·B**
6) Find **C·D**
7) Does **A·B = B·A?** Show your reasoning.
8) Find **AxB**
9) Find **CxD**
10) Does **AxB = BxA?** Show your reasoning.

Test 2 – Motion Topics

- **Determine velocity and displacement of freely falling objects.**

We do this in the text book with the three formulas $v = v_0 + at$, $s = v_0t + ½ at^2$ and $v^2 = v_0^2 + 2as$. Here, we will do some extra problems for practice that are a step above those found in the text book.

- **Use position vectors in determining average and instantaneous velocity, and average and instantaneous acceleration.**

The definitions in the text book can now be extended to use calculus,

$$v = \frac{\Delta s}{\Delta t} \quad so \;\; v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

$$a = \frac{\Delta v}{\Delta t} \quad so \;\; a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

Now, if given an expression for the position of an object, we can find the velocity and acceleration of the object. For example, if $s = 3t^2 – 4t + 43$, then

$$v = \frac{ds}{dt} = \frac{d}{dt}(3t^2 - 4t + 43) = 6t - 4$$

$$a = \frac{dv}{dt} = \frac{d}{dt}(6t - 4) = 6$$

If we wanted to know the speed and acceleration of this object after t = 17 s

$$v = 6(17) - 4 = 98$$

$$a = 6$$

We can also work the other way and solve these differential equations. If we know the acceleration of an object, we can find the velocity and position of the object as shown.

Since $a = \frac{dv}{dt}$

$a\,dt = dv$

$\int a\,dt = \int dv$

$at + c = v$

which is the familiar $v = v_0 + at$.

Then, since $v = \frac{ds}{dt}$

$v\,dt = ds$

$\int v\,dt = \int ds$

$\int (v_0 + at)\,dt = \int ds$

$v_0 t + \frac{1}{2}at^2 + c = s$

which is the familiar $s = s_0 + v_0 t + \frac{1}{2}at^2$

Another example: Find the velocity and position of a rocket after 12 seconds if acceleration is given by $a = 3t^2$ and we know that v = 200 ft at t = 4 s and s = 40 at t= 0 s.

$v = \int a\,dt = \int 3t^2\,dt = t^3 + C_1$

$\text{Since}\; v = t^3 + C_1 \;\text{and}\; v = 200 \;\text{when}\; t = 4$

$200 = 4^3 + C_1 \;\text{so}\; C_1 = 136$

$\text{Thus}\; v = t^3 + 136$

$s = \int v\,dt = \int (t^3 + 136)\,dt = \frac{1}{4}t^4 + 136t + C_2$

$\text{Since}\; s = \frac{1}{4}t^4 + 136t + C_2 \;\text{and}\; s = 40 \;\text{when}\; t = 0$

$40 = \frac{1}{4}(0)^4 + 136(0) + C_2 \;\text{so}\; C_2 = 40$

$\text{Thus}\; s = \frac{1}{4}t^4 + 136t + 40$

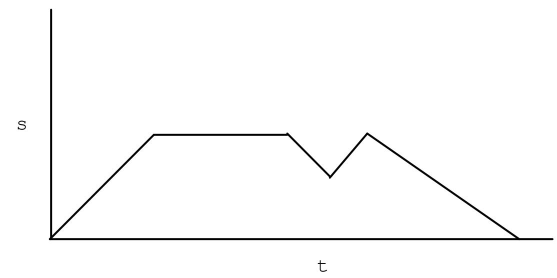
$\text{At}\; t = 12s,$

$v = (12)^3 + 136 = 1864\; ft/s$

$s = \frac{1}{4}(12)^4 + 136(12) + 40 = 6856\; ft$

In summary, $v = \frac{ds}{dt} \qquad a = \frac{dv}{dt} \qquad v = \int a\,dt \qquad s = \int v\,dt$

- **Practice Problems**
    1) Find the velocity and acceleration of a rocket 20 seconds after launch if it's position is given by $y = 3t^2 + 42t + 30$.
    2) Find the velocity and acceleration of a rocket car is traveling after 30s if it can accelerate at $a = 2 + 4t$ m/s^2, and is traveling at 16 m/s at t=1 s and is at s = 0 at t = 0.
    3) A speeder passes a cop in a speed trap. The cop is initially at rest but begins to accelerate at 2 m/s^2 at the instant the speeder passes. The speeder is unaware of the cop and continues at constant velocity until the cop catches up after 600 m. Find the velocity of the speeder.
    4) Little Johnny rides his bike from his house to the store. He looks at the comic books for a while and starts to ride home again, but then remembers his momma asked him to get some baking soda. He returns to the store, gets the soda and rides back home. A graph of his displacement from home in time would look like that below. Draw the graph for his velocity.

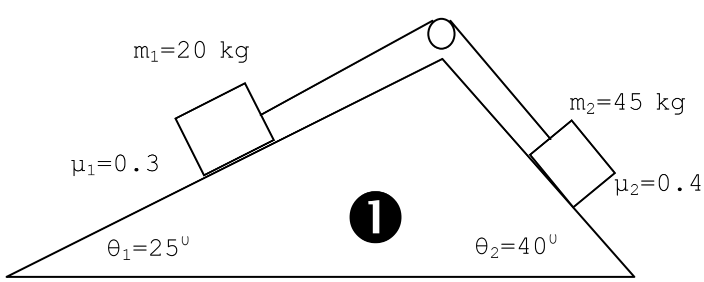


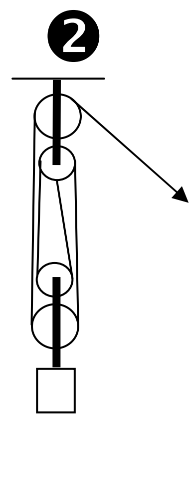
    5) In 1971 DB Cooper hijacked a 727 airplane, got $200,000 from the airline company and parachuted from the back of the airliner at 10,000 ft into the stormy darkness of Thanksgiving eve night. He was never found or caught. Find estimates for the minimum horizontal drift distance (if his parachute didn't open) and the maximum horizontal drift distance (if his parachute did open). The plane was moving at 170 knots. Look up and use terminal velocity for a falling body and for a parachutist in both estimates.

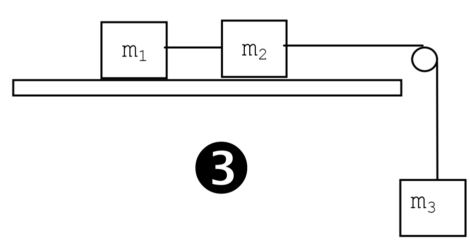
Test 3 - Force and Motion Topics

No new topics this time, just some problems to work.

- **Practice Problems**
    1) Two masses are suspended by a string over a pulley as shown❶. Find the acceleration and tension in the string. Assume m_1 moves uphill.
    2) A pulley system like the one shown❷ lifts 200 kg. Find the applied force (how hard you have to pull on the rope). Hint: think about the forces on the bottom pulley block.
    3) Three blocks are moving together as shown❸. Find the hanging mass needed to accelerate the system at 1.2 m/s^2. m_1 = 6 kg, m_2 = 10 kg, μ = .9
    4) If μ = .7, m_1 = 8 kg, m_2 = 12 kg and m_3 = 22 kg as shown ❸, find the acceleration, the tension between m_1 and m_2 and the tension between m_2 and m_3.







Test 4 - Energy, Work and Power Topics

- **Determine work done by a general variable force.**
  In the book, we calculate work with the formula W = Fs. This works great with a constant force. When the force is changing we have to add up the individual pieces of force times distance, and if the force is a continuous function then integration is our best bet. Thus,

  $$W = \int_{x_1}^{x_2} F\,dx$$

- **Determine work done by a spring force.**
  The best example of a variable force doing work is a spring. The spring force is given by F = -kx, that is, a bigger displacement causes a bigger restoring force. Since the force is not constant, we can't use W = Fx. The proper calculation of work requires the following, which is what the text book shows for work or energy of a spring:

  $$W = \int F\,dx$$

  $$W = \int (kx)dx$$.

  $$W = \frac{1}{2}kx^2$$

- **Obtain average and instantaneous power and know units for describing power.**
  We have seen that average power is given by P = W/t. As we look at a smaller and smaller slice of time, the instantaneous power is given by

  $$P = \frac{W}{t} \quad so \;\; P_{inst} = \lim_{\Delta t \to 0}\frac{\Delta W}{\Delta t} = \frac{dW}{dt}$$

  For example, to find the instantaneous power after 13s, if $W = 3t^2 + 2$

  $$then \;\; P_{inst} = \frac{d}{dt}\left(3t^2 + 2\right) = 6t = 6(13s) = 78W$$

- **Demonstrate an understanding of and apply relationships involving potential energy and work.**
  We do this in the text book.

- **Use the concept of path independence in the solution of problems involving work.**
  Work is calculated by multiplying the applied force by the net displacement, W = Fs. If I use a force of 30 N to move an object .1 m then the work is calculated to be (30 N)(.1 m) = 3 J. If I use 30 N to move the object all over the room, down the hall, upstairs and then bring it back to set it down .1 m from its original position then displacement is still .1 m and work is still 3 J. This is the idea of path independence. The calculation of work only considers the beginning and final position of the object, not the path it took to get there.

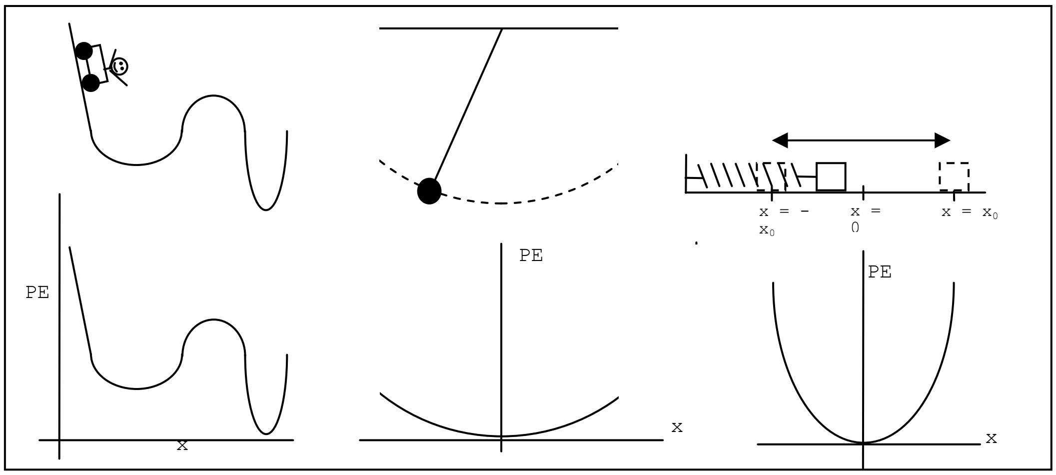
  If the object ends up in its initial position, displacement = 0 and work = 0, meaning there was no net change – nothing happened. Another way to think of this seeming paradox of doing so much "work" to accomplish nothing is to count the work on the way there as positive work since the displacement would be a positive number. On the way back, we move the opposite (or negative) direction so that would be negative work.

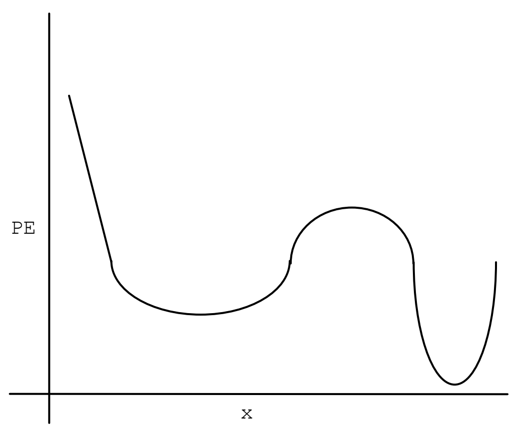
- **Determine gravitational and elastic potential energy of a system.**
  Since work and energy are often different aspects of the same thing, the gravitational and potential energy are determined as follows:

$$PE_{gravity} = \int F_{gravity}dy = \int_{y=0}^{h}(mg)dy = mgy\Big|_{y=0}^{h} = mgh$$

$$PE_{elastic} = \int F_{elastic}dx = \int(kx)dx = \frac{1}{2}kx^2$$

- **Interpret potential energy curves for a system, and locate equilibrium points and turning points for a system.** Some potential energy curves (or graphs) are shown below. In the first example, a roller coaster loses PE (and develops KE) as it drops and PE increases when it goes uphill (at the expense of KE). The pendulum is constantly losing and gaining PE as it swings back and forth. Similarly, an object attached to a spring is continually trading spring PE for KE and back again.





- **Practice Problems**
  1) In a tractor pull, tractors pull a sled with a moving weight that transfers weight from the wheels to a skidpan, making it harder to pull. If the force needed to pull the sled increases with distance as F = 170x + 9000 lbs, find the work to pull the sled for the full 300 ft run.
  2) Find the speed of a 60 g dart shot from a dartgun with a spring constant of 500 N/m after being compressed .2 m.
  3) A compound bow will shoot a 118 g arrow at 55 m/s, a) how high would the arrow go if pointed straight up (don't try this!) b) If the string does work on the arrow for 40 cm, find the average force of the bow.
  4) A 16 g bullet moving at 366 m/s strikes a board and exits the other side at 120 m/s. Find the heat generated in the board if all of the lost energy of the bullet goes into heat.

Test 5 - Linear Momentum Topics

No new topics this time, just some problems to work.

- **Practice Problems**
  1. **1)** A 7 g bullet moving 500 m/s hits a 3 kg block of wood which is at rest, passes through it and comes out the other side moving 430 m/s. How fast is the block moving when the bullet emerges?
  2. **2)** A 150 kg astronaut is stuck motionless in space when his rocketpack malfunctions. His tool belt has a five kg drill motor, a four kg camera and a two kg hammer. If he can throw the objects at 6 m/s, find the speed he will move in the opposite direction if he throws **a)** the drill, **b)** the camera and **c)** the hammer.
  3. **3)** A 180 lb diver jumps into a pool of water from a height of 12 ft. If it takes half a second for him to come to a stop, what average force does the water put on him?

Test 6 - Rotational Motion Topics

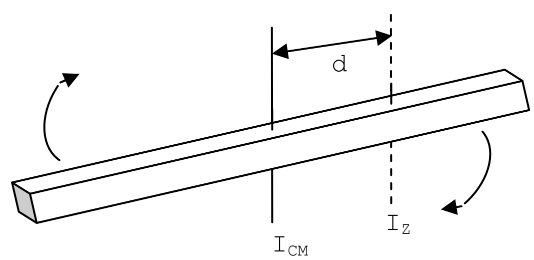
- **Apply the parallel-axis theorem to determine moment of inertia of a body.**

The text gives a number of formulas to use for some simple shapes when calculating the moment of inertia of everyday objects, each with an axis of rotation. To help match more real world cases that may not be as straightforward as the given cases, you can shift the location of the axis of rotation parallel to itself using the parallel axis theorem

$$I_Z = I_{CM} + Md^2$$

For example, a stick rotated about the center has a moment of inertia of $I = ML^2/12$. Shifting the axis of rotation from the solid line through the center of the stick to the dotted line a distance d away is as simple as the following:

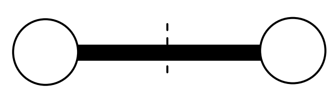
$$I_Z = I_{CM} + Md^2$$
$$= \frac{ML^2}{12} + Md^2$$



- **Demonstrate an understanding of and apply the Law of Conservation of Angular Momentum to problems involving systems of particles.**

See the other book.

- **Practice Problems**
  1. **1)** Find the moment of inertia of a 5 kg sphere with a radius of 10 cm, rotated about the edge.
  2. **2)** Two 3 kg solid balls with a radius of 7 cm are connected by a 4 kg rod that is 2 m long. Find the torque necessary to accelerate the assembly at 5 rad/s^2 about the dotted line axis.



  3. **3)** A 60 kg girl is spinning on the edge of a 400 kg playground merry-go round with a radius of 2m at an angular velocity of 8 rad/s. She then moves to the middle of the merry-go-round. Find the new angular velocity.

Test 7 - Periodic Motion Topics

- **Describe three basic types of waves.**

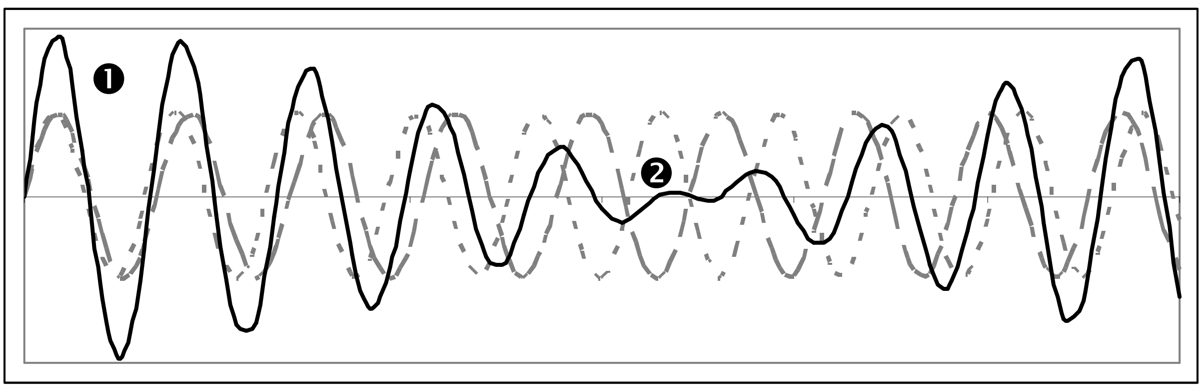
  In **transverse waves** particles are vibrated up and down as the wave moves horizontally. Light and other forms of electro-magnetic radiation are examples of transverse waves.

  In **longitudinal waves** particles are pushed forward and back in the same direction as the wave motion. Sound waves push air particles (and ear drums) forward and back in low and high pressure cycles.

  Mixed waves have both types of motion above. An object in the water will bob up and down and move forward and back at the same time. The resulting particle motion is circular or elliptical.

- **Define the Principle of Superposition for Waves**

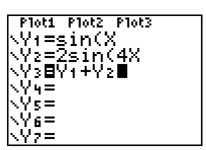
  When two or more waves occupy the same space, the wave forms add either constructively or destructively. Constructive interference, as it is called, occurs when two waves add to something bigger than either of the individual waves like shown below at ❶. The two dotted gray waves are passing through the same space and their sum, represented by the black line has a greater amplitude than either of the original waves. Destructive interference is shown at ❷, where the two waves cancel each other out.

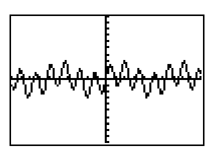


- **Practice Problems**

  1) Derive the formulas $v = 2\pi f A\cos(2\pi ft)$ and $a = -4\pi^2 f^2 A\sin(2\pi ft)$ from $s = A\sin(2\pi ft)$.

  2) Use a graphing calculator to set up the following two sin functions and the sum of the two and graph just the sum. Find the max and min values of the sum function between x = 6 and x = 9.





Hints: a) set calc to Radian mode,

b) arrow back to the equal sign in "Y_1" and "Y_2" and hit "Enter" to clear the block so that the first two lines don't graph

c) for the third line, hit the "VARS" button, then right arrow, then Function, and then choose Y_1 or Y_2

Summary of 221 Stuff

- Use unit vector notation to describe vectors and vector components.
  A = 4**i** + 3**j** or **A** = 5<36.9^0

- Multiply a vector by a scalar.
  R = 4**i** + 3**j** **so** 2**R** = 2(4**i** + 3**j**) = 8**i** + 6**j**
  R = 5 < 36.9^0 **so** 2**R** = 2·5 < 36.9^0 = 10 < 36.9^0

- Obtain the dot product of two vectors.
  A·B = AB cos φ where φ is the angle between **A** and **B**

- Obtain the cross product of two vectors.
  |**AxB**| = AB sin φ where φ is the angle between **A** and **B,** direction is given by the "right hand rule".

- Use position vectors in determining average and instantaneous velocity, and average and instantaneous acceleration.
  $$v = \frac{ds}{dt} \qquad a = \frac{dv}{dt} \qquad v = \int a\, dt \qquad s = \int v\, dt$$

- Determine work done by a general variable force.
  $$W = \int_{x_1}^{x_2} F\, dx$$

- Apply the parallel-axis theorem to determine moment of inertia of a body.
  $$I_Z = I_{CM} + Md^2$$