Physics 112 and Physics 212 Lab Manual

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Preface

These are the laboratory experiments performed in Physics 112 and Physics 212 during the Fall of 1998. The only changes are a few corrections made after the fact.

This is first attempt at producing a BHSU physics lab manual. It is not meant to be a polished, finished manual to be used for years and years. It is just meant as a first stab at organizing the laboratories around the equipment we had at the time.

Beginning in the Fall of 1997, a process was started to base the laboratory on experiments using the Pasco computer interface system. A large number of experiments here use this system. Some of the terse instructions here can and should be supplemented with more detailed instructions found in the Pasco physics experiment manuals. Copies of these may be found in the physics instructor's office.

Older Vernier computer interfaces are also available. Instructions for these DOS-based interfaces appear in an appendix of this manual. It is hoped that additional acquisitions of Pasco-based systems will eventually supplant the DOS-based systems, making those instructions obsolete.

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Contents

Lab 1

Measurement of Length and Velocity

1.1 Length

In this part of the lab you will measure lengths using three devices: a ruler, Vernier caliper, and micrometer. You will also determine the percentage accuracy of your measurements by taking into account each instrument's precision. This precision is determined by the smallest measurement unit of the device.

1.1.1 Ruler measurements

1. Use a metric ruler to measure the length of the lines below. Give your measurements to the closest tenth of a centimeter (that is the smallest mark on a ruler).

2. Convert these measurements into millimeters and meters.

3. Calculate the error for each of these measurements using the equation:

$$\%\ \text{Error} = \frac{\text{Precsion}}{\text{Length}} \times 100\% \tag{1.1}$$

For example:

length = 5.7 cm, precision = 0.1 cm

$$\begin{aligned}\text{\% Error} &= \frac{0.1\text{ cm}}{5.7\text{ cm}} \times 100\% \\ &= 1.75\% \\ &= 2\% \quad \text{(best to round off to nearest number in this case)}\end{aligned} \tag{1.2}$$

4. Is the percentage error greatest for a large or small object?

1.1.2 Vernier Caliper

- Use the Vernier caliper to measure the length of the lines in Section 1.1.1 (instructions on how to use the Vernier caliper will be provided to each group during lab).
- Calculate the percentage error for these measurements. Note that precision of the caliper is different from that for the ruler (it measures distances to within 1/10th of a millimeter). Make sure that each person in your group measures at least one line and that each line is measured by at least two people.

1.1.3 Micrometer Caliper

In this part, you will use a micrometer to measure the thickness of twenty pieces of paper.

To use the micrometer, note the following. The micrometer handle turns through two revolutions to make the jaws open or close one millimeter (1 mm). In two revolutions, 100 numbers go by, thus the micrometer is accurate to within 0.01 mm. (Make sure the micrometer gives a value of 0.00 mm when nothing is between the jaws.)

- Use the micrometer caliper to measure the thickness of twenty sheets of paper.
- From the above measurement, calculate the thickness of a single sheet of paper.

1.2 Speed

In this laboratory we will use the formula relating average speed, distance, and the time interval,

$$\text{average speed} = \frac{\text{distance}}{\text{time interval}}. \tag{1.3}$$

In symbols, Eq. 1.3 reads

$$v_{\text{avg}} = \frac{l}{t}. \tag{1.4}$$

1.2.1 Walking speed on level ground

1. Use a meter stick to mark a four meter path. With a stopwatch, each person should measure the time it takes to leisurely walk this distance.

2. Using Eq. (1.3), determine your average walking speed in meters/second.

3. Americans are most accustomed to expressing speed in units of miles per hour. To change your speed from meters per second (show all your steps):

   (a) change to meters/hour by multiplying your meters/second speed by the number of seconds in an hour,

   (b) change to kilometers/hour by diving by the number of meters in a kilometer (1000), and

   (c) change to miles/hour by dividing by the number kilometers in a mile (1.6).

1.2.2 Time, distance, and speed

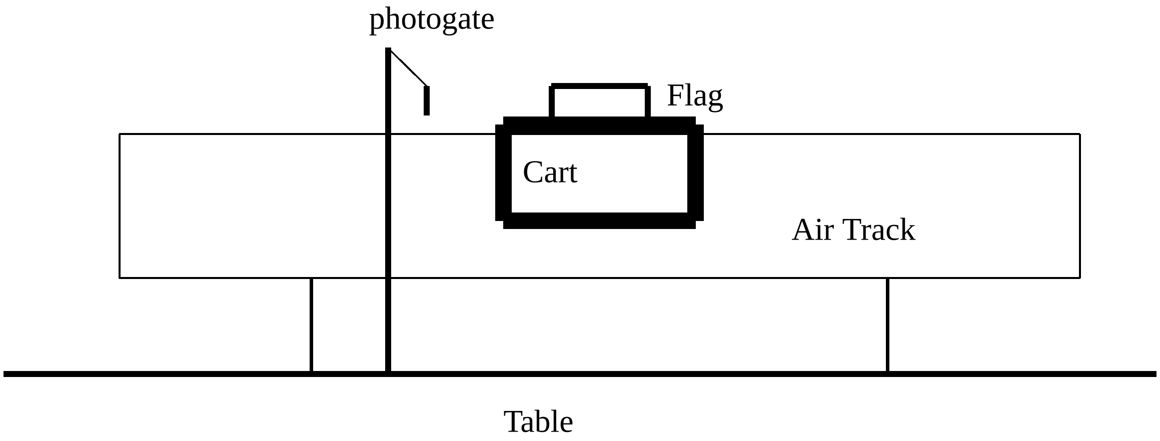
1. Now that you know your average walking speed in miles per hour, estimate the time it would take you to walk to Rapid City (about 45 miles).

2. It is approximately 3000 miles from Los Angeles to New York. How many hours would it take you to make this trip by walking? How many days if you walk 10 hours each day? Ask a group member or the instructor if you need help with this calculation.

1.2.3 Photogates and the Air Track Apparatus

The following diagram represents a cart on an air track. The force of friction between the cart and track is reduced by forcing air through holes on the air track which in turn lifts the cart slightly from the surface.

On top of the air cart is an opaque “flag.” When the cart moves on the air track it passes under a photogate assembly. The time interval during which the flag closes the gate (preventing light from passing from one side of the gate to the other) along with measurement of the size of the flag provides a means for obtaining the velocity of the cart.



1.2.4 Velocity Measurement

First, you will need to roll a computer cart close to an air track. We have two separate systems for measuring the time that a photogate is blocked. If you have a DOS-based computer, then you should refer to instructions in Appendix A. If you have a Windows-based computer, then you will be using the Scientific Workshop software which is described in Appendix B. Use those instructions to determine how to plug your photogates to the computer and to prepare the computer for data-taking.

1. To obtain the cart velocity, you will need to measure the width of the flag on top of the air cart. Use a ruler to obtain the width of the flag to the nearest mm (0.1 cm).

2. You are now ready to measure the velocity using the computer and photogates, but before proceeding with the computer measurements, prepare for taking a simultaneous stopwatch measurement.

   To get a stopwatch measurement, you will have one member of the group measure the time it takes the cart to go a certain distance (perhaps the distance between the two photogates) as it moves down the air track. Of course, this will be done at the same time photogate measurements are made so that you can make a direct comparison of these two methods.

3. Prepare the computer for data taking (using instructions in Appendix A and Appendix B) and then push the air cart through the photogates. After the air cart has passed through the photogates, then you should have a photogate-blocked-time for each photogate.

4. Determine the stopwatch value of the average speed using

$$\text{stopwatch velocity} = \frac{\text{distance}}{\text{stopwatch time}}. \tag{1.5}$$

5. The computer should show the amount of time that photogate 1 and photogate 2 were blocked. Use both of these measurements to obtain the speed as the cart moved down the track.

$$\text{velocity through photogate} = \frac{\text{flag size}}{\text{photogate time}}. \tag{1.6}$$

6. If the track is exactly level and friction is completely eliminated, then the cart speed should not have changed much as it passed between the two photogates. What is the difference between your photogate speeds?

7. How do the photogate speeds compare with the stopwatch speed? Which do you think are more accurate, the stopwatch measurements or the photogates? Why?

Lab 2

Acceleration

2.1 Tutorial on velocity and acceleration

2.1.1 Data in tabular format

The following two tables list the position versus time and speed versus time for two objects. Their motions are not the same so there is no correlation between the two tables.

time	position
0 sec	1.2 meters
1 sec	1.8 meters
2 sec	2.4 meters
3 sec	3.0 meters
4 sec	3.6 meters

time	speed
0 sec	2.3 m / sec
1 sec	2.8 m / sec
2 sec	3.3 m / sec
3 sec	3.8 m / sec
4 sec	4.3 m / sec

1. For each of these objects, state whether or not there is evidence for acceleration. Be sure to state your answers clearly and use the definition of acceleration in your answer.

2.1.2 Continuous plot of position versus time

Analyze the following plot which describes the position of a car traveling on a straight path as a function of time. We call a velocity "positive" when the car is moving further away and "negative" when it is getting closer.

1. Divide the graph into regions where the velocity is positive, negative, or zero and clearly label these regions.

2. Divide the graph into regions where there is acceleration or the acceleration is zero. Where the acceleration is not-zero, state whether it is positive or negative.

You may find it helpful to make labels for the velocity on the top side of the curve and labels for acceleration on the bottom side of the curve.

2.2 Estimate of g, the acceleration due to gravity

A picket fence consists of a plastic piece with a regular series of stripes. When the picket fence passes through the photogate, the time that a stripe blocks the gate will allow the computer the estimate the velocity of the picket fence.

In this experiment, you will drop a picket fence through a photogate and examine a graph of the picket fence velocity versus time. You will use the results to obtain an estimate of the acceleration due to gravity.

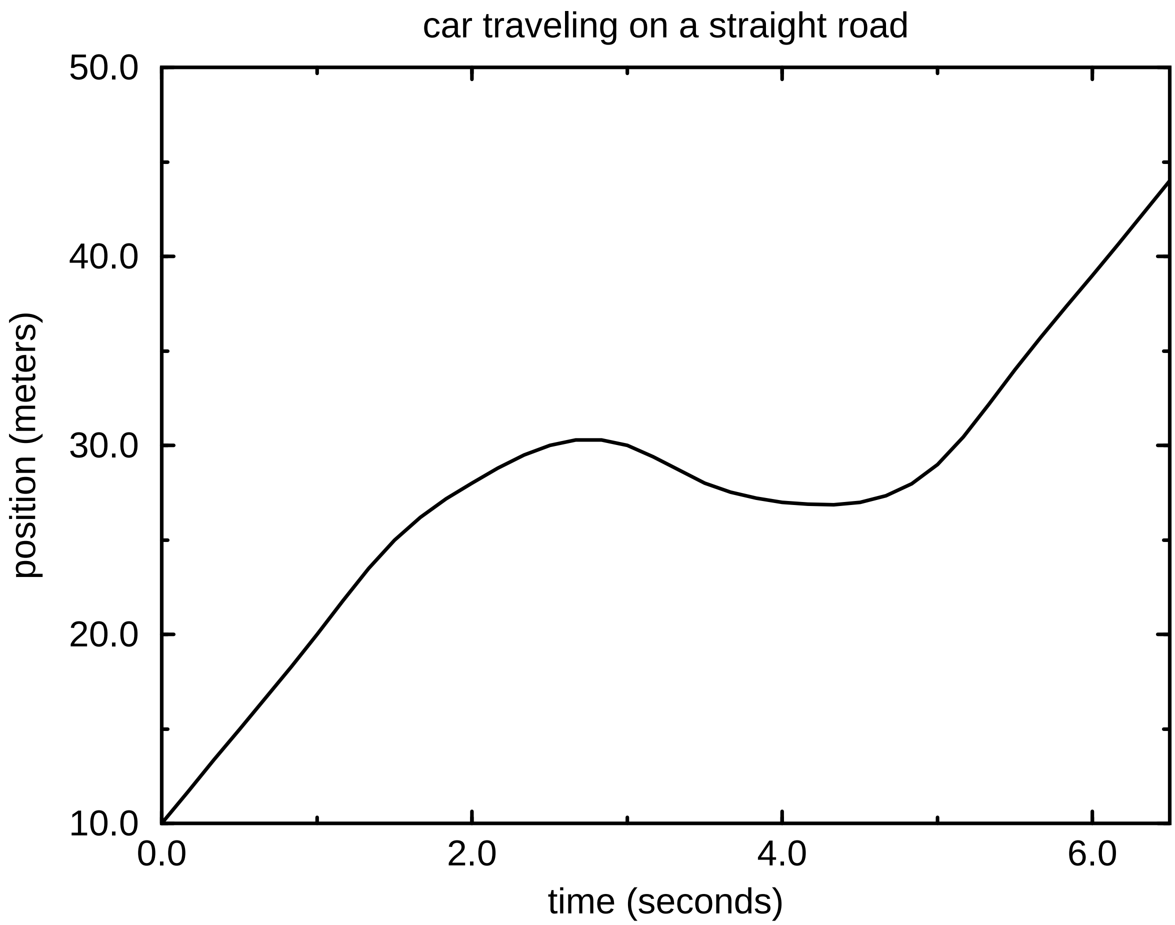
There are two types of set-ups. The procedure for using the DOS/Vernier setups is given in Appendix A.3. For instructions on how to use the Windows/Science Workshop set up refer to Appendix B.3. Perform the experiment as outlined in those instructions and answer the following questions.

1. You should have a graph of picket fence velocity versus time. Does it look like the picket fence gains velocity at a constant rate?

2. What is the estimate for "g," the acceleration due to gravity, that you obtain when the computer performs a regression fit to your velocity versus time data.

3. Is your experimental result for g close to the known result, 9.8 m/s^2?

4. Repeat this experiment and compare the result for g with what you obtained previously.



2.3 Displacement versus time for constant acceleration

In the following exercise you will use the formula for the displacement of an object when its acceleration is constant and the initial velocity is zero ($v_o = 0$);

$$\text{displacement} = \frac{1}{2}(\text{acceleration})(\text{time})^2, \tag{2.1}$$

which in symbols reads

$$s = \frac{1}{2}\, a\, t^2. \tag{2.2}$$

2.3.1 Estimating the height of tall objects with Eq. (2.2)

When air resistance is small enough to be neglected, gravity will force an object to have a constant acceleration of 9.8 m/sec^2. We are going to use this to estimate the height of objects by timing how long it takes a ball to fall from the top of an object to its base.

1. To get some feel for the accuracy of this method, measure a height of two meters using a meter stick. Drop a ball from this height and measure how long it takes for it to hit the ground. Using this time in Eq. (2.2), what value do you get for the distance the ball fell? How does this compare to the correct answer of 2 meters?

The next part is a little trickier, but uses the same idea. Now we are going to measure the height of objects which are too high to reach the top, but low enough so we can toss a ball to the top (possibilities includes street lamps, trees, and buildings).

What you will do now is have a group member toss a ball so that the maximum height it reaches is close to the height of the object you are measuring. Another group member (or two) will stand back a bit and measure the time it takes for the ball to go from the top of its path (where it has stopped going up or down for just an instant and is now at about the height of the object) until it reaches the ground again. Use this time in Eq. (2.2) to estimate the height of the object.

1. Estimate the height of four objects using this method. Be sure to list the object and show your work for how you obtained the height.
2. You should have obtained your height estimates in meters. Convert these measurements to feet using the conversion 1 meter = 3.3 feet.

2.3.2 Estimating acceleration

If an object starts at rest and has a displacement s in a time t, then it is also possible to obtain the average acceleration of the object using the equation

$$a = 2\,s/t^2. \tag{2.3}$$

You will use this to estimate the acceleration of carts on a tilted air track.

In this experiment, one group member will hold an air track at an angle and at least one other member will be in charge of measuring the time it takes the cart to go a certain distance.

1. Measure the time it takes the cart to travel a fixed distance on the air track for three different air track angles. Indicate which measurements correspond to the small, medium, and large angles (you don't need to try to measure these angles).

2. Use Eq. (2.3) to estimate the acceleration for each of these angles.
3. Compared to the acceleration of a freely falling object that you obtained in Section 2.2, is the acceleration on an inclined plane smaller, larger, or about the same? Why is this the case?

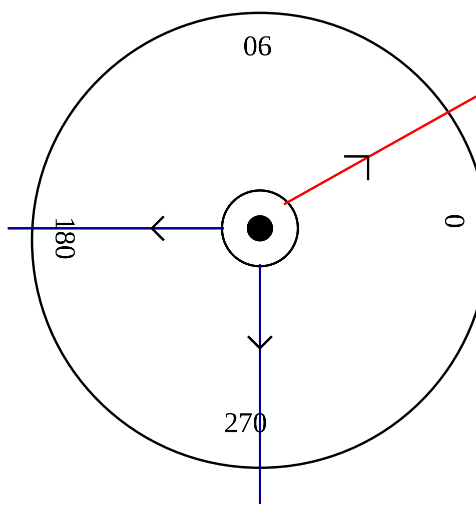
Lab 3

Forces in static equilibrium

3.1 Force table

3.1.1 Introduction

A force table consists of a circular disk with marks for angles from 0 to 360 degrees. In the center of the disk is a short rod around which is placed a ring. Strings are attached to the ring and the strings go over pulleys which are attached to the edge of the table. A top view looks something like this.



Force Table Set-up

Place one pulley at the 30 degree mark. Pull a string over this pulley and attach a 400 gram weight so that the mass hangs over the force table. The ring in the center will be pulled in the direction of this pulley because of the force of the string.

Place two other pulleys at the 180 and 270 degree marks. Attach weight holders to strings going over these pulleys. Now add weights to the ends of strings going over these pulleys until the forces on the ring cancel. Continually try moving the ring to the center to see when the forces balance.

Assuming that the first string pulls on the ring with a force whose size is proportional to 400 grams, then the x-component of that force (the component in the 0 degree direction) is equal to the force that balanced it – the weight attached to the string in the 180 degree direction. Likewise the y-component of the force from the 400 gram weight is balanced by force of the weights attached to the string in the 270 degree direction.

Frictional forces in the pulleys will cause some inaccuracy in the following analysis. However, perfectly balancing the forces on the ring would be impossible without help from this friction.

3.2 Analysis

3.2.1 30 degrees

1. Use the parallelogram rule to resolve graphically the force of the 400 gram weights at 30 degrees into components. A good place to start is to represent the weight of 400 grams by a 4 cm line at thirty degrees (a protractor is provided to help you make this picture). Show your diagram and measurements on your lab report.

2. How does your estimate of the components compare with the values you got from the force table?

3. Now obtain the x and y components for the force from the 400 gram weight using trigonometry. How does this compare to your graphical and experimental results?

4. Now we will try to get some sense of the experimental accuracy for the force table. You will find that adding small amounts of weight to the 180 and 270 degree hangers will not change the balance of the ring. Using smaller weights find what range of weights will work on the 180 (x-components) and 270 (y-component) hangers.

   Your results will have the following form:

   m_x = [250 g, 290 g]
   m_y = [270 g, 310 g]

   Instead of writing this as a range, take the midpoint as your best value and express your results like

m_x = 270 g ± 20 g
m_y = 290 g ± 20 g

where the 20 g indicates how far on either side of the midpoint balance can be achieved.

5. Do the results you obtain using trigonometry fall in these ranges?

3.2.2 45 degrees

Repeat the force table measurements for the 400 gram mass hanging from a 45 degree angle. Compare this measurement of components to what you get using the parallelogram rule and using trigonometric formulas. Once again find the range of x and y components which give balance on the force table.

3.2.3 80 degrees

Repeat all of the above for the 400 gram mass hanging from an 80 degree angle.

3.3 Tensile strength

This is a simple experiment to estimate the tensile strength (strength limit) of a strand of thread. The strength limit is often a result of imperfections in the material. As these imperfections can vary, you will probably see differences in the tensile strength for different strands. Repeat each of the following measurements three times to see whether or not these variations are large enough to be observed easily.

1. Measure the tensile strength of a single strand of thread. To do this, tie a weight hanger to the end of a strand of thread. Slowly add weight to the hanger. Precision of about 50 grams is sufficient for this experiment, so you don't need to use weights any smaller 50 grams. Find the mass that causes the thread to break. The tensile strength of the thread is the force of the mass (in Newtons) that caused the thread to break. List the forces for your three measurements (remember to include the weight of the hanger).

2. Make a loop out of thread. Hang the weight hanger from the loop and then carefully add weights until the thread breaks. Did this arrangement support more or less weight than a single thread? Why is this the case?

3. Estimate how many strands of thread are needed to suspend a mass of 100 kgs.

3.4 Buoyant force

In this section, you will test Archimedes' model for the Buoyant force: the upward force of a fluid on an immersed object is equal to the weight of the fluid displaced by the object.

3.4.1 Volumes

You will test this model for two objects, both of which must be sufficiently dense to sink in water. For each object, do the following.

1. Determine the volume of the object. To do this, drop the object into a beaker of water. Observe how much the total volume changes. The volume change is equal to the volume of the object.

2. For each object, determine the weight of an equivalent volume of water. To do this, note that the weight of water (near Earth's surface) is given by

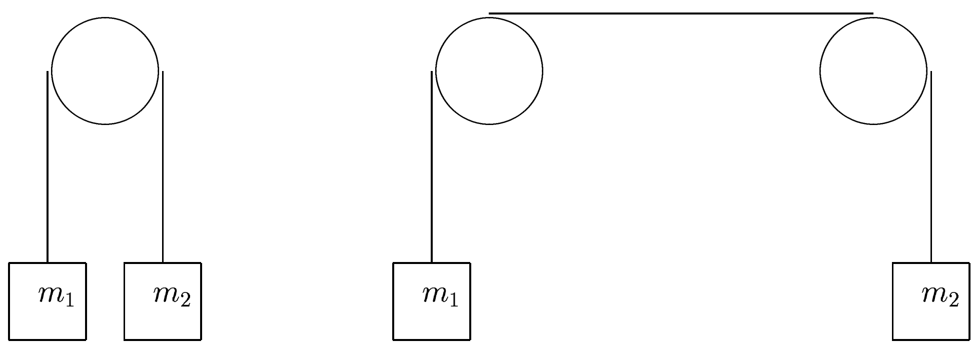
$$(\text{water weight}) = (\text{volume})\,\frac{0.0098\text{ Newtons}}{\text{milliliter of water}} \tag{3.1}$$

Lab 4

Newton's 2nd law

4.1 Atwood's Machine

Atwood's machine consists of a single or double pulley with two weights suspended from a common string.



The analysis of this machine, based on Newton's 2nd law, is the same whether one or two pulley wheels are used. The 2nd law equations for the vertical motions of m_1 and m_2 are

$$m_1 a_1^y = T - m_1 g \tag{4.1}$$
$$m_2 a_2^y = T - m_2 g. \tag{4.2}$$

Algebra can be used to eliminate the force of the string, T, from these equations. This yields

$$m_1 a_1^y + m_1 g = m_2 a_2^y + m_2 g. \tag{4.3}$$

Equation (4.3) can be simplified further by recognizing that $a_2^y = -a_1^y$; the acceleration of the two masses must have the same magnitude, but are in opposite directions. Using this in Eq. 4.3, we can make a prediction for the acceleration of the masses on Atwood's machine:

$$a_1^y = \frac{m_2 - m_1}{m_2 + m_1}\, g. \tag{4.4}$$

where g is the acceleration due to gravity, 9.8 m/sec^2.

1. Start with $m_1 = m_2 = 100$ grams. These should balance and no acceleration should occur ($a_1^y = 0$).

   Make sure your strings are long enough so that when one weight hits the table, the other weight is still a few inches below the pulley wheel.

2. Prepare your computer to observe and record the motion of the pulley wheels. For the DOS-based systems, refer to Appendix A.4. For the windows based system, refer to Appendix B.4

3. Attach 10 extra grams to one side of the Atwood's machine. Now you should have 100 grams one side and 110 grams on the other. Since the weights no longer balance, once they are released motion will occur which you should record on your computers.

   Warning! Weights may fly around a bit after they smack the table!

4. Eliminate data which corresponds to the time before the weights were released and the time after the heavy set of weights strikes the table.

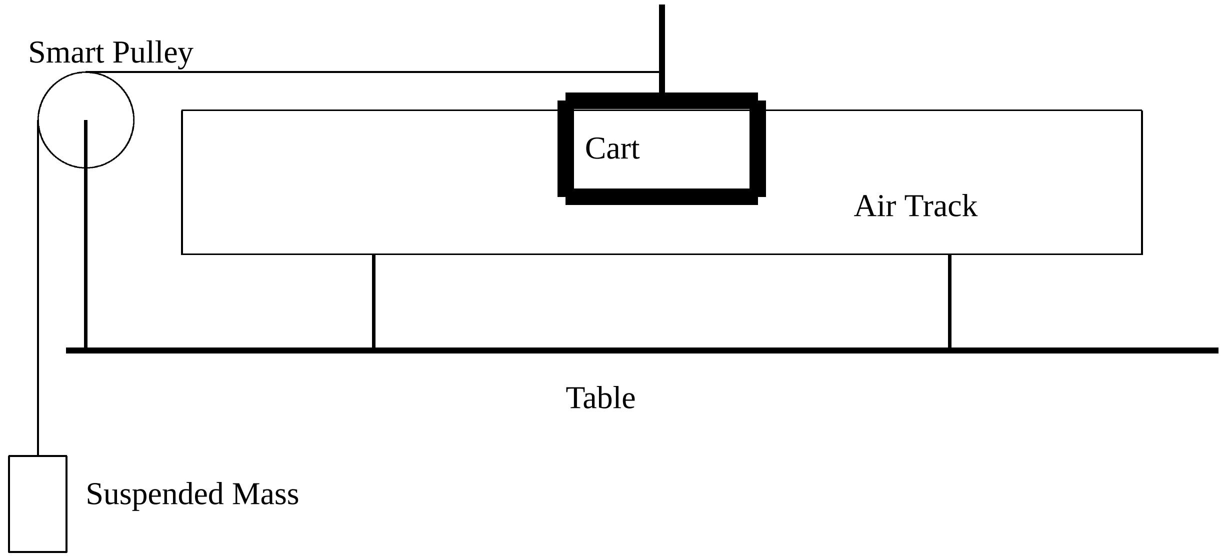
5. Plot the velocity versus time for the motion. Since acceleration should be constant, this data should approximately lie on a straight line. Perform a straight line fit to the data. The slope of this line (which is evaluated by the computer) is your result for the acceleration. List your result here.

6. Compare the result you obtain for the acceleration to the prediction made by Eq. (4.4). What is the percentage difference between the two values?

7. Repeat this experiment two additional times using the following pairs of masses: (100 grams, 120 grams) and (100 grams, 130 grams). In each case, compare the value of the acceleration you obtain from the experiment to the prediction made by Eq. (4.4).

4.2 Newton's 2nd Law on the air track

This diagram represents a "cart" on a nearly frictionless air track. Reduction of friction is achieved by forcing air through holes on the air track which in turn lifts the cart slightly from the surface.



A string attached to the cart goes over a pulley. At the end of this string is a suspended mass. With the cart held in place, the string is taught. When the cart is released the mass falls to the ground and the air cart is yanked towards the pulley. A photogate (not shown) is used to monitor the spinning of the pulley spokes.

4.2.1 Theory

Newton's second law gives the acceleration of the suspended mass as

$$m_{susp}\, a_{susp} = F^{net}_{susp}. \tag{4.5}$$

Only two forces act on the suspended mass: the force of gravity (which points down) and the string (which pulls up). We re-write Eq. (4.5) as

$$m_{susp}\, a_{susp} = m_{susp}\, g - T_{susp} \tag{4.6}$$

where T_{susp} is the force of the string on the suspended mass and g is the acceleration due to gravity, $g = 9.8$m/s^2 (we call the down direction positive in this case).

Assuming the air track is level (check this before proceeding!), the only horizontal force of substantial size acting on the cart is the force of the string. So for the cart, Newton's second law gives

$$m_{cart}\, a_{cart} = T_{cart}. \tag{4.7}$$

Two observations make it possible to solve these equations and predict the acceleration of the suspended mass and cart. First, as long as the string doesn't stretch, the cart and mass move the same distance in any given time interval. So $a_{cart} = a_{susp}$. The second observation is not so obvious, but if the friction in the pulley, the mass of the string, and the rotational inertia of the pulley are all small, then the string pulls on the mass and cart with the same force: $T_{cart} = T_{mass}$.

Newton's second law simplifies to

$$\text{cart:}\quad m_{cart}\, a = T \tag{4.8}$$

$$\text{susp:}\quad m_{susp}\, a = m_{susp}\, g - T \tag{4.9}$$

This gives an acceleration of

$$a = \frac{m_{susp}}{m_{susp} + m_{cart}}\, g. \tag{4.10}$$

4.2.2 Experiment

1. Using about 5 grams for the suspended mass, analyze the motion of the cart after it is released. You will use the pulley wheel to monitor this motion, as is described in Appendix A.4 and Appendix B.4.

2. After you release the cart the suspended mass. cart and pulley wheel begin to move. After the cart reaches the end of the air track stop data stop the data recording.

3. Plot the motion and obtain the regression fit for the acceleration. Remember to eliminate all data which occurs after the motion of the cart has been obstructed.

4. Obtain the acceleration for suspended masses of 5, 10, and 15 grams. List the acceleration obtained along with each mass.

5. Compare your acceleration results to the theoretical predictions made by Eq. (4.10). Give the percentage difference for each case.

Lab 5

Friction

5.1 Coefficient of Friction I

For this experiment you will measure the coefficient of friction between a wood block and a wood surface. You will be provided large wooden blocks and friction tables (whose pitch can be adjusted) to which pulleys are attached.

You will slide a block across the surface several times under different conditions. However, You need to ensure you are using the same contact surface, *i.e.* the block is always placed at the same position on the surface. Also, to be consistent, Make sure that the same side of the wood block is always in contact with the surface. These steps are necessary to ensure that a consistent contact surface is used for all the trials.

1. Obtain the mass of the block using the large balance by the air tracks.

2. Make the friction table horizontal (0^o). Place the block on the surface and pull the string attached to the block over the pulley. Attach a weight hanger to the other end of the string and start adding weights until the hanging mass forces the block to move. The weight that forces the block to move is approximately equal to the maximum static friction between the block and the friction table.

3. The maximum static friction is approximately given by

$$F_{\text{static}}^{\text{max}} = \mu_{\text{static}} F_{\text{normal}} \tag{5.1}$$

   where F_{normal} is the normal force between block and table. When the table is horizontal, F_{normal} is the same as the block's weight. Having determined the block's mass and having obtained $F_{\text{static}}^{\text{max}}$, you should be able to estimate μ_{static}.

4. Repeat this experiment for the case when the normal force is approximately doubled (achieved by placing extra mass on top of the block). This should increase $F_{\text{static}}^{\text{max}}$ as well. After making your measurements, obtain μ_{static} with this new set of normal and maximum frictional forces. Is μ_{static} about the same as your previous estimate? Does the assumption that μ_{static} is constant appear justified in this case?

5. The critical angle, θ_c, for when an object will slide down a non-horizontal surface is given by

$$\theta_c = \tan^{-1} \mu_{\text{static}}. \tag{5.2}$$

Use your result for μ_{static} to predict what θ_c will be. Compare this to θ_c obtained by varying the angle of the friction table.

5.2 Coefficient of Friction, II

Obtain the coefficient of static friction, μ_s, between a wood block and a desk.

1. Attach a pulley wheel to the edge of the lab desk.

2. Run a string from the wood block and over the pulley wheel. Attach a weight hanger to the other edge of the string.

3. Find the string tension (equal to the weight of the hanging mass) required to budge the block. This is called $F_{\text{static}}^{\text{max}}$.

4. Determine the coefficient of friction,

$$\mu_s = \frac{F_{\text{static}}^{\text{max}}}{F_{\text{normal}}} \tag{5.3}$$

5. Repeat this experiment while placing the block at four different starting positions on the table (the positions must be chosen so that the string still goes straight over the pulley).

6. Your results can be summarized by a table that looks like the following:

position	F_{max}	μ_s
A		
B		
C		
D		

7. Repeat this experiment after placing 500 grams of mass on the wood block (remember to keep the same side of the block in contact with the table). Remember that this changes the normal force between the block and the table. Make a table just as above.

8. Does the range of μ_s values depend strongly on the normal force between the block and table? What about F_{max}?

Lab 6

Work and Energy Conservation

6.1 Pendulum

A pendulum consists of a massive “bob” connected by a string to a support. When the pendulum swings, energy is constantly changing from potential energy (which is highest when the bob is at its highest point) to kinetic energy (which is highest when the bob passes through the lowest point of its motion).

In this experiment you will try to verify that the change in potential energy in going from the highest to lowest point goes into changing the kinetic energy by (nearly) the same amount.

1. Make a pendulum by connecting a mass to a string that hangs from a support. Make sure that it is able to swing freely and that the amplitude of oscillation isn’t damped-out quickly.

2. Set-up the Pasco motion detector so that it is able to record the velocity of the bob as it passes through its lowest point. For this to work, the bob must be going directly toward the detector as it passes through the lowest point.

3. Using a meter stick, have the bob start at three different heights. For each height, record the bob’s speed as it passes through the minimum.

   Sharp spikes will occasionally appear in the velocity curves when the pendulum bob goes out of the “view” of the motion detector. Make sure you only use the smooth part of the velocity curve when obtaining your measurements.

4. Make a table showing the change in potential energy versus increase in kinetic energy that looks like the following: (this is just a sample, don’t expect your results to look exactly like this)

h (top) h (bottom)	PE(top) = m g h PE(bottom) = m g h	v (top) v (bottom)	KE(top) = $1/2$ m v^2 KE(bottom) = $1/2$ m v^2	PE + KE PE + KE
1.10 m 0.93 m	0.21 J 0.18 J	0 0.53 m/s	0 0.035 J	0.21 J 0.215 J
1.20 m 0.93 m	0.24 J 0.18 J	0 0.77 m/s	0 0.055 J	0.24 J 0.235 J

5. For each initial height of the bob, is the total energy about the same at the high and low points of its motion?

6.2 Inclined Plane

An (small) air track will be used to minimize friction. You will not need to hook up a computer to complete this exercise.

When the air track is at an angle, a cart will slide backwards because of gravity. As the cart is tilted further, the force of gravity is more and more effective in pulling on the cart.

1. With a smart-pulley attached to the high end of an inclined air track, run a string from an air cart to a weight holder that hangs from the other side of the pulley.

2. Add or remove weights to the holder until the forces are as balanced as well as is practically possible. (mass)(gravity) for the suspended weight is the minimum force needed to pull the cart up the incline.

3. Measure how much the height of the cart changes when you pull the weight down 30 cm (it should be easy to move the weight since the forces are nearly balanced).

   The work done by the weight on the cart is approximately

   $$\text{work done} = (\text{mass})(\text{gravity})(0.3\text{ m}). \tag{6.1}$$

   The change in potential energy of the cart is

   $$\Delta\,\text{PE} = (\text{mass}_{\text{cart}})(\text{gravity})(\text{change in height of cart}). \tag{6.2}$$

   How does the work done by the weight compare to the change in potential energy of the cart?

4. Repeat this experiment using a steeper angle for the air track.

6.3 Pulley

Just like the inclined plane, the pulley enables you to lift a heavy weight with a smaller force. The trade-off is that you must apply the force for a large distance to change the height of the heavy object by a small amount.

1. To string up a pulley, you begin by hanging one set of pulley wheels from a high bar. The large mass will hang from the other set of pulley wheels. For help on how to run a string through the pulley wheels, look at the cartoon diagram of page 108 in *Conceptual Physics*.

2. With a 500 gram mass hanging from the bottom pulley, see how much force must be applied to the support string to balance the weight of the 500 gram mass and the pulley wheel that it hangs from.

   One way to do this is to place a weight hanger on the support string and add and subtract weights until the forces are balanced. The balancing force is equal to (mass)(gravity) where mass is the mass of the weights on the support string.

3. Measure how much the 500 gram weight goes up when you pull the support string 20 cm. Since the forces are nearly balanced, you should not need to provide much force to raise the weight.

   The work done by the balancing force is equal to (mass)(gravity)(0.20 meters). The change in potential energy of the 500 gram weight plus the pulley wheel it hangs from is $(0.500\ \text{kg} + \text{mass}_{\text{pulley wheel}})(\text{gravity})(\text{change in height})$.

   How do these numbers compare?

6.4 Potential Energy of a Spring

The work done on an object is equal to (Force)(distance) when the force is constant. With a spring, it takes more and more force to stretch it further and further. To get the spring's potential energy we need to to break the stretching process into pieces and use the usual formula for work over a small distance where (hopefully) the force does not change too much.

1. You will stretch the spring in 8 steps with each step equal to 5 cm.

2. Use an electronic force meter to verify that the force necessary to hold the spring in place increases as the string is stretched.

3. As you stretch your spring, try to eliminate frictional forces that might help hold the spring in place and ruin your force measurements.

4. Make a table of force versus stretching of the spring. It should look something like the following. The extra columns will be explained below.

stretch	force	average force between points	work from last point to here	total work
0	**0 N**		0	0
		0.55 N		
0.05 m	**1.1 N**		0.0275 J	0.0275 J
		1.65 N		
0.1 m	**2.2 N**		.0825 J	0.11 J
		2.8 N		
0.15 m	**3.4 N**		0.14 J	0.25 J

The numbers in bold face are the ones you actually measure the rest you will figure out on your calculator.

5. Since the force between points is changing make a column with the average force which we assume to be one-half of the sum of the beginning and ending forces.

6. Compute the work done between points. This is equal to the average force between points times the distance between points (0.05 m in this example).

7. Make another column which adds up all the work done in stretching the spring up to that point. This number is equal to the potential energy of the spring when it is stretched this far.

8. Make a simple plot of the potential energy of the string versus how far it has been stretched.

Lab 7

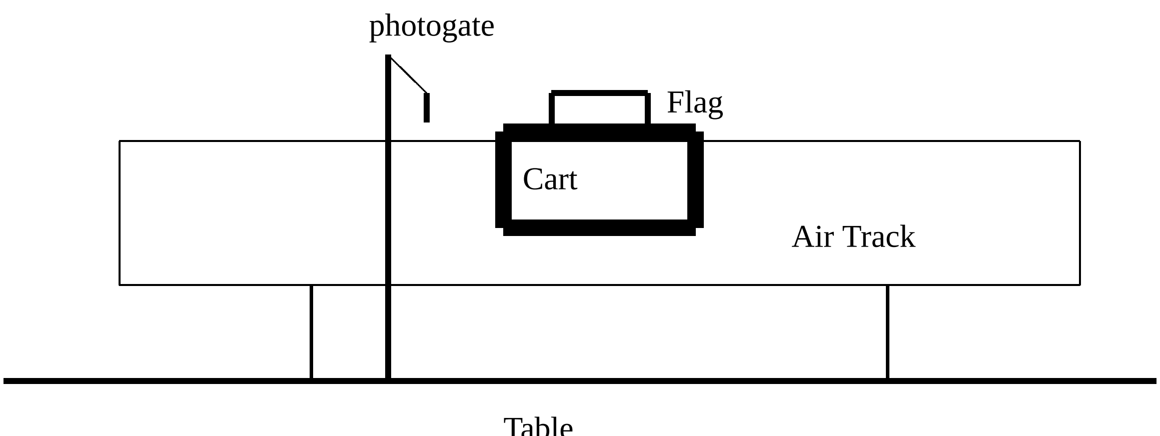
Conservation of momentum

7.1 Photogates and the Air Track Apparatus

The following diagram represents a cart on an air track. The force of friction between the cart and track is reduced by forcing air through holes on the air track which in turn lifts the cart slightly from the surface.

On top of the air cart is an opaque "flag." When the cart moves on the air track it passes under a Pasco photogate assembly. Pasco software on a computer evaluates the time interval during which the flag closes the gate (preventing light from passing from one side of the gate to the other).

This time interval along with the flag size is used to obtain the velocity of the cart.



7.2 Velocity Measurement

Author's note: *The following instructions are for the DOS/Vernier setups. Instructions for the Windows/Pasco setup were not ready at the time of printing. These will be provided at lab time.*

First, you will need to roll a computer cart close to an air track. Place two photogates along the air track and plug them into the input adapter coming from the computer. Turn the power on for the computer and monitor. When a menu appears on the computer, choose the `<precision timer>` menu item. After you enter the precision timer program, choose menu item `<C>` for the Collision Timer.

Once you enter Collision Timer mode and press `<enter>` again, then both photogates are ready to take data. Push an air cart so that it passes through both photogates. Hit `<enter>` once you are finished taking data. Each photogate should show one data point. A data point describes the duration of time (in seconds) that the photogate was blocked by the flag on top of the cart.

Once you have ensured that the photogates are operational, try to make the track as level as possible to eliminate acceleration due to gravity in the following measurements. To see if the track is uneven, place a cart in the center of the track. If the cart drifts, the track is uneven and should be adjusted.

1. To obtain the cart velocity, you will need to measure the width of the flag on top of the air cart. Use a ruler to obtain the width of the flag to the nearest mm (0.1 cm).

2. Prepare the computer for taking data and then push the cart through the photogates. Once the cart is through both gates hit `<enter>` so that the computer stops taking data. You are now ready to obtain velocity values.

3. The computer should show the amount of time that photogate 1 and photogate 2 were blocked. Use both of these measurements to obtain the velocity as the cart moved down the track.

$$\text{velocity through photogate} = \frac{\text{flag size}}{\text{photogate time}}. \tag{7.1}$$

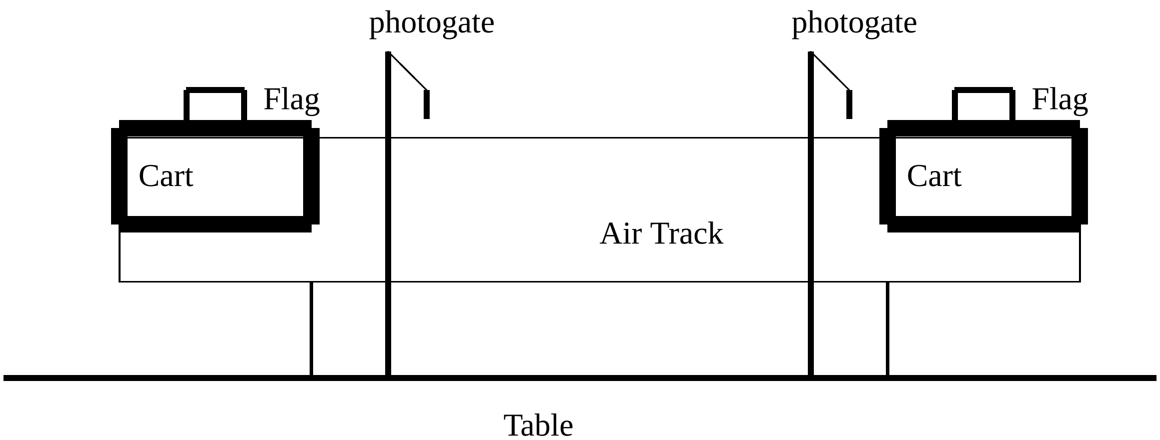
4. If the track is exactly level and friction is completely eliminated, then the cart velocity should be the same through both photogates. What is the difference between your photogate velocities?

5. Repeat this experiment with the cart moving in the opposite direction on the track. To distinguish the velocity in this case from motion in the other direction, *list the velocity values for this case as negative.* Compare initial and final photogate velocities as you did before.

7.3 Collision Experiment Set-up

The following diagram represents two carts on an air track. On top of each air cart is a flag. When the carts move on the air track they pass under a Pasco photogate assembly. The Pasco software evaluates the time intervals during which the flags close the gates (preventing light from passing from one side of the gate to the other).

Next, the carts collide between the photogates. Either both carts will recoil back through their initial photogates or both will continue in the same direction and pass through the same photogate. In either case, you will be able to get the time readings necessary for determining the final velocity for each cart.



7.4 Elastic Collision

Make sure there is a flexible spring on the colliding side of each cart so that they easily bounce from each other. Also, *ensure that your air track is as level as possible.* To do this, place a single cart at the middle of the air track. If it moves, then the track isn't level and should be adjusted. Most of the error in this experiment will be due to having an uneven track.

1. Obtain the mass of each cart.
2. After putting the two photogates in collision mode, send the carts through the photogates so they collide in the center and recoil back through the photogate.

   List the time interval for each flag to pass through its first photogate. Obtain the velocity of each cart by using Eq. (7.1). Make sure the velocity is listed as negative if the cart is moving to the left.
3. List the total momentum of the carts before the collision using

$$\text{total momentum} = (\text{mass}_1)(\text{velocity}_1) + (\text{mass}_2)(\text{velocity}_2). \tag{7.2}$$

4. List the time interval for each flag to pass through its photogate after the collision. Once again, use Eq. (7.1) to obtain the velocity of each cart.
5. Determine the total momentum for the two carts after the collision. Show how you obtained your result. Is it close to the total momentum before the collision? Remember that this analysis requires you to distinguish between positive and negative velocities.
6. Determine the momentum change for each cart. How do these compare?
7. Compare the total kinetic energy before the collision to the total kinetic energy after the collision.

7.5 Inelastic Collision

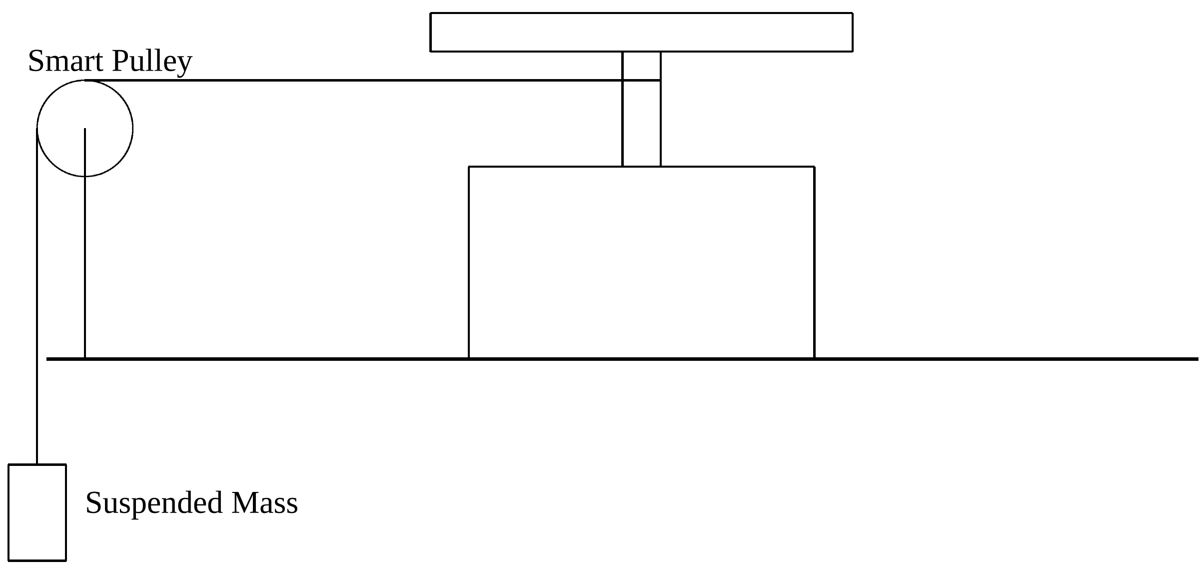
Put putty between the two carts so that they stick together when they collide. As before, have the carts collide between the two photogates.

1. List the time interval for each flag to pass through its first photogate. Obtain the velocity of each cart by using Eq. (7.1).
2. Determine the total momentum of the carts before the collision.
3. List the time interval for a flag to pass through a photogate after the collision. (Since the carts are moving together, you only need to obtain the velocity for one cart.) Use Eq. (7.1) to obtain the velocity of the carts.
4. Determine the total momentum for the two carts after the collision. Show how you obtained your number. Is it close to the total momentum before the collision?
5. Determine the momentum change for each cart. How do these compare?
6. Compare the total kinetic energy before the collision to the total kinetic energy after the collision.

Lab 8

Moment of Inertia and Torque

8.1 Moment of Inertia Apparatus



The moment of inertia apparatus consists of a rotating support apparatus mounted on an adjustable base. On a cylinder connecting the support to the base is a peg for attaching a string. After attaching a string to the peg, the string is wrapped around the cylinder several times and then the string goes from the cylinder and over the top of the pulley. Weights are attached on the other side of the pulley.

The weight will create tension in the string. This in turn applies a torque to the rotating support. The rotating support spins as the weight drops.

Various objects can be placed on the support which results in an increase in the rotational inertia.

8.1.1 Theory

Applied to the hanging mass, Newton's 2nd law gives

$$m_h\, a = m_h g - T \tag{8.1}$$

where T is the force of the string on the suspended mass and g is the acceleration due to gravity (we call the down direction positive in this case). For the rotating support we have

$$\begin{aligned} I\alpha &= \tau_{net} && (8.2) \\ &= T\, r - \tau_F && (8.3) \end{aligned}$$

where r is the radius of the cylinder around which the string is wrapped. We also include a τ_F to model friction opposing the torque the string applies to the support.

We can use the relation $\alpha\, r = a$ (the string unwraps at the same rate as the weight falls) and eliminate T from this coupled pair of equations. We get

$$\tau_F = m_h(g - a)r - Ia/r. \tag{8.4}$$

To get an approximate value for τ_F appropriate for when the object is rotating, find the mass, m_o, which just barely makes the support spin. Since a is about zero in Eq. (8.4), we get the approximate value $\tau_F = m_o\, g\, r$.

Once a value for τ_F is estimated, I can be obtained. To do this, increase the hanging mass and measure the resulting acceleration, a, using the Pasco photogate timers and the special pulleys. I is then given by

$$I = \frac{m_h(g - a)r^2}{a} - \frac{m_o g r^2}{a}. \tag{8.5}$$

.

8.1.2 Moment of Inertia of the Supporting Apparatus

Before adding disks and rings, we need to obtain the moment of inertia for the bare support.

1. Using a Vernier Calliper, measure the radius r of the cylinder on which the string is wrapped.
2. Find m_o, the mass needed to start the support rotating.

3. Using a larger hanging mass, m_h, determine the resulting acceleration, a.

   The best way to obtain a is by using a smart pulley attachment to Science Workshop. Make a graph of velocity versus time. Use Science Workshop to obtain the slope of the velocity versus time curve *for when the hanging mass is accelerating downward*. This slope provides the a value that is used in Eq. (8.5).

4. Repeat the acceleration measurement using a larger hanging mass, m_h. Both a and m_h should then be larger, Find $I_{support}$ again using Eq. (8.5). How close are your two results for $I_{support}$?

8.1.3 Moment of inertia of a ring

1. Place the solid ring in the support.

2. Find the new (and larger) m_o needed to make the apparatus spin.

3. After increasing the hanging mass appreciably, measure a.

4. Obtain the total moment of inertia, I_{total}, using Eq. (8.5). To get the moment of inertia of the ring, you need to subtract the moment of inertia for the support: $I_{ring} = I_{total} - I_{support}$.

5. Compare the value you obtain to the theoretical value: $I_{ring} = m_{\text{ring}}(R_1^2 + R_2^2)/2$, where R_1 and R_2 are the inner and outer radii of the ring.

8.1.4 Moment of Inertia for a Disk

1. Repeat the previous steps to find I_{disk}.

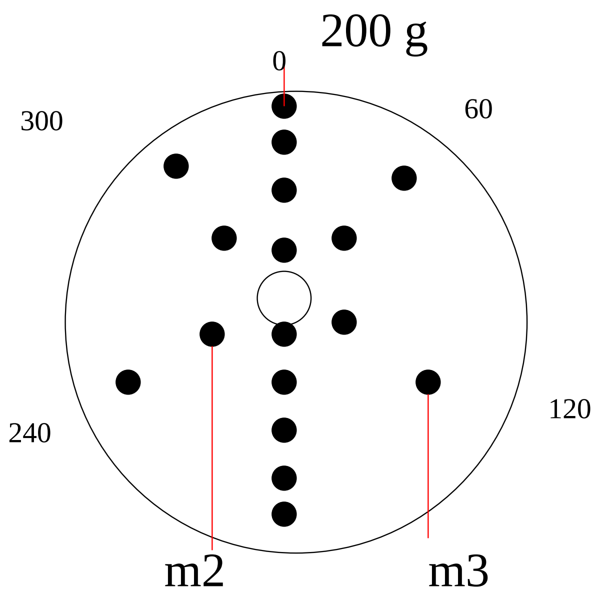
2. Compare this to the theoretical value, $I_{disk} = m_{\text{disk}}R^2/2$ where R is the disk's radius.

8.2 The Moment Apparatus for the Force Table

The force table can be modified to examine the balance of torque as well as force. First a flat, greased disk is placed over the centering pin on the force table. Next, three ball bearings are placed on the disk at evenly spaced locations on the greased side of the disk.

A second disk with holes for inserting pins is placed over the centering pin and onto the bearings. At this point you should make sure your force table is level. The top disk should stay in position after it is centered over the force table. Leveling screws are found on the bottom of the stand.

Attach strings to pins at the locations shown below. Run these strings over pulleys attached to the edge of the force table. Although the pin locations are at 120^o angles with respect to each other, all strings should be parallel (straight up and down in the figure).



8.2.1 Balance of Torques

Once your set-up looks like the diagram (and the pulleys are mounted), begin attaching weights to the pulley strings. You will want to use the weight hangers so you can add and remove weights for $m2$ and $m3$. The top weight is fixed at 200 grams. Begin by using about 100 grams each for $m2$ and $m3$.

1. Add or remove weights for $m2$ and $m3$ until the the top disk no longer rotates and remains centered over the centering pin. When this balance is reached, make sure that the pulleys are positioned so that they don't add friction to the string. Have me look at the set-up when you think you have balanced the forces and torques.

   What are the values of $m2$ and $m3$ when balance is achieved?

2. Do the weights on the pulley strings add to give a net force of zero on the disk? Remember that force is a vector and the directions of the strings are important.

3. Does the sum of the torques from all three weights add to zero? Recall that the torque from each force is equal to (force)(moment arm).

Lab 9

Harmonic Motion

9.1 Evaluation of the force constant, *k*

Use the following procedure to measure the force constant for two dissimilar springs.

1. Suspend a spring from a hanger and measure its length, l_o, in the absence of a dangling mass.
2. As you add a mass to the spring, the mass's force, $F_{M,s} = M\,g$, stretches the spring to a length $l_{eq}(M)$ that increases as M increases. Generate a table that looks something like the following:

M (kg)	Mg (Newtons)	$l_{eq}(M)$ (meters)	$l_{eq}(M) - l_o$ (meters)
0.00	0	0.15	0.00
0.10	0.98	0.17	0.02
0.20	1.96	0.19	0.04
.	.	.	.
.	.	.	.
0.5	4.9	0.25	0.10

3. For a reasonable amount of stretching, springs obey the equation

$$F = k(l_{eq} - l_o) \tag{9.1}$$

where F is the force stretching the spring. Thus, a plot of F versus $l_{eq} - l_o$ should be a straight line with the slope equal to k. In the following, you will produce a computer plot of your data and use this to obtain an estimate of k for the spring.

   (a) Use either the slow terminal in the lab (labeled "weyl") or the terminals labeled "abel" and "galileo" in the Math computer room next door to log into the computer in my office named “sakharov.” weyl is ready for immediate logins. However, you first have to double click on “sakharov” from the XDMCP menu on abel and galileo.

You can log in under one of the accounts setup for Physics 211: phy211a, phy211b, or phy211c. Your group will be assigned an account and password for this lab session.

(b) Once you have logged on, left-click on the penguin on the top of the screen. This produces a menu. On this menu, click “applications” and under the sub-menu click on “kedit.”

(c) Simply type in your $l_{eq} - l_o$, F, data in column format:

0.0	0.0
0.02	0.98
.	.

(d) Once you are finished typing your data, go to the “file” menu in the kedit window and then click on “save.” The program will ask you to name the file. After you name the file, the editor program will exit.

(e) Once again under “applications” click on “xmgr.”

(f) This will bring up a plotting program. Under the “file” menu on this program, click on “read sets.” A window is created which allows you to scroll through your account’s list of files. One of these files should be the data file you just created. Double click on this to bring the data into the program, then remove this window using the button in the upper left corner of the window.

(g) Hit the “AS” button to scale the plot. You should see a line representing your data if everything worked right.

(h) Next you will obtain a regression fit to your data. Under the “data” menu on xmgr, select “transformations.” Under the new sub-menu select “regression.” After you have told the computer on which data set to perform a regression fit, a fit will be performed.

(i) A new window appears. The value of the slope for the fit appears in this window. Write down the value of this slope as this is your result for k.

(j) If this all worked, congratulations! Hit, the print button and a plot should appear on the printer in the Math computer room.

(k) Once you are finished with your plot, log off of the computer. To do this, left-click on the penguin, go to “close” on the menu, and underneath the sub-menu click “exit window manager.”

9.2 Oscillation frequency

1. Suspend a mass of average size from one of your springs and set the mass in oscillation. Measure the amount of time it takes the mass to make about five full oscillations. From this estimate the period, T, and frequency, f, for this mass-spring combination.

2. Compare your experimental result to the theoretical result:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}. \tag{9.2}$$

3. Repeat this measurement and comparison with your other spring.

Lab 10

Standing waves and resonance

10.1 Introduction

Tuning forks generate sound waves with a dominant frequency, f. We have three tuning forks, each labeled by its dominant frequency in units of Hertz (oscillations/sec). Like all linear waves, sound waves satisfy the wave equation:

$$f\,\lambda = v. \tag{10.1}$$

So, if you measure the wave length, λ, for the sound waves coming from a tuning fork, then you can use this along with the known value of f in Eq. (10.1) to obtain the sound velocity, v. In principle, the v value for each tuning fork should be the same; sound velocity is independent of frequency. To within experimental accuracy, we will verify that this is the case.

We will use a property call resonance to determine λ for each tuning fork. Resonance will be described in more detail during lecture later this week, but we will provide a brief explanation of how it works here.

If a tuning fork is place above an open column, then sound waves will be sent down the column, before being reflected at the base of the column. These sound waves are then reflected back up towards the tuning fork.

Now for a set of special column lengths,

$$L = \lambda/4 + c,\ 3\lambda/4 + c,\ 5\lambda/4 + c,\ \cdots, \tag{10.2}$$

the reflected sound waves are exactly in phase with the sound waves coming down into the column. Here, c is an end correction factor, a constant that depends on the geometry of the open end (top) end of the tube. Since the amplitudes of sound waves add, the net sound wave amplitude in the tube is enhanced in this case. This is called resonance and manifests itself in a substantial increase in the vibrational amplitude of the air in the tube which can be distinctly heard, even when the fork itself is too quiet to be heard. When L isn't one of these special values, then the phases between reflected and incident waves are essentially random leading to cancellation of the sound wave amplitude in the tube.

Thus, finding the column lengths where resonance is observed can be used to determine λ and, thus, the sound velocity, v.

10.2 Determination of resonance

A plastic tube with level markings is connected to a water reservoir that can be used to adjust the water level in the tube. The distance between the top of the column and the water level is equal to (to a good approximation) L, the air column length.

A tuning fork is held over the open end of the tube. When this is set into vibrations, L is adjusted by slowly varying the height of the water reservoir.

1. Start with the smallest L value possible (water is high in the tube). After the tuning fork is set in vibration, adjust L until resonance of the air column occurs.
2. For each of the three tuning forks, find all the L values that produce resonance. (There should be about one to three resonant L values for the three forks you will use.) You may need to add/remove water from the reservoir to vary the water level in the tube from top to bottom. Mark resonance positions with rubber bands that have been placed on the tube.
3. The distance between resonance water levels is $\lambda/2$ for a particular tuning fork. Use this to determine the λ. If there are three or more resonant water levels, use the average separation between resonant levels to obtain your best estimate of $\lambda/2$. However, for lower frequency tuning forks, you may find only two resonant levels.
4. Obtain the sound velocity, v that you obtain using the f and λ values for each fork.
5. You should have three estimates for v, one from each fork. Give the percentage difference between the smallest and largest values of v that you have obtained.

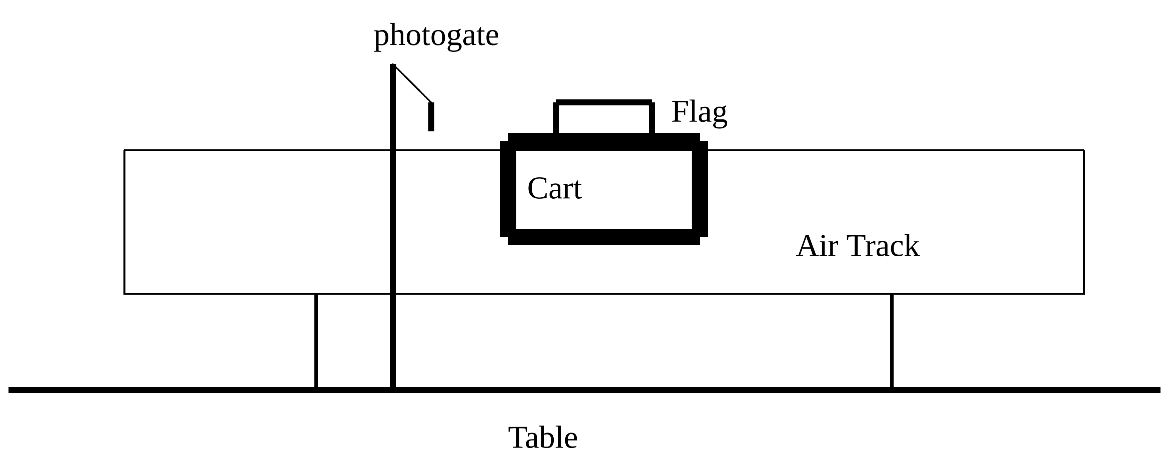
Appendix A

Precision timing: DOS/Vernier

A.1 Photogates and the Air Track Apparatus

The following diagram represents a cart on an air track. On top of the air cart is an opaque “flag.” When the cart moves on the air track it passes under a Pasco photogate assembly. Pasco software on a computer evaluates the time interval during which the flag closes the gate (preventing light from passing from one side of the gate to the other).

This all the photogates do, the measure the time that light is blocked. However, using this time interval along with measurement of the size of the flag provides a means for obtaining the velocity of the cart.



A.2 Velocity Measurement

Place two photogates along the air track and plug them into the input adapter coming from the computer. Turn the power on for the computer and monitor. When a DOS menu appears on the computer, choose the `<precision timer>` menu item. After you enter the precision timer program, choose menu item `<C>` for the Collision Timer.

Once you enter Collision Timer mode and press `<enter>` again, then both photogates are ready to take data. Push an air cart so that it passes through both photogates. Hit `<enter>` once you are finished taking data. Each photogate should show one data point. A data point describes the duration of time (in seconds) that the photogate was blocked by the flag on top of the cart.

Once you have ensured that the photogates are operational, try to make the track as level as possible to eliminate acceleration due to gravity in the following measurements.

- To obtain the cart velocity, you will need to measure the width of the flag on top of the air cart. Use a ruler to obtain the width of the flag to the nearest mm (0.1 cm). List your value in centimeters here.
- Prepare the computer for taking data and then push the cart through the photogates. Once the cart is through both gates hit `<enter>` so that the computer stops taking data. You are now ready to obtain velocity values.

$$\text{speed through photogate} = \frac{\text{flag size}}{\text{photogate blocking time}}. \tag{A.1}$$

A.3 Picket fence

- Plug a photogate into the gray computer plug with a black band.
- Start the Vernier precision timing software by selecting `<precision timer>` from the menu that appears when the computer starts up.
- Choose `<M>` to start the motion timer. The computer is ready to record and will start recording when the photogate is blocked.
- Drop the picket fence through the photogate.
- Hit `<return>` to stop recording.
- Now you need to analyze the data. Start by entering `<G>` to get the graph menu.
- Choose a velocity versus time graph from the graph menu.

- Select `<C>` to set the device to be a picket fence.
- Next is the graph style menu. This is a little more complicated. You can scroll through the items and turn them on and off by pressing the space bar. Turn on “point protectors,” “regression line,” and “statistics.” When you are finished, hit `<return>`.
- Choose “automatic scaling, variable origin” for both axes.
- The graph will appear with the regression fit. The slope (“M”) is the best estimate for the acceleration of the picket fence.

A.4 Pulley wheel motion timing

- Start by setting the precision timer software to use the motion timer.
- The motion timer starts taking data immediately. This is okay since you will have the opportunity to delete data points which have nothing to do with this experiment.
- After you release the cart the suspended mass and cart will move as will the pulley wheel. After the cart reaches the end of the air track stop data taking by hitting `<return>` on your computer. There is no rush in hitting `<return>` at precisely the right moment. You can manually delete points which occur after collision. They will be easy to find as you progress through the data analysis portion of the experiment.
- When you hit return, a list of times corresponding to successive turns of the spokes will be listed. Scanning through this list you should be able to pick out ones that should be deleted. Make a list of points to delete before pressing `<enter>`.
- You will be presented with several options. The three you are most likely to use are `<X>` (to start timing all over again), `<D>` (to delete data points before analyzing data), and `<G>` (to go ahead and graph data). Delete data points as you see necessary. Then go ahead to the graph menu.
- There are graph menu items for plotting the distance, velocity, and acceleration for the motion you have just observed. Start off by looking at velocity. However, you may wish to look at the other options later after you are comfortable with the program.
- To get velocity you not only need time, but also distance. Somehow the program needs to know how much things moved during the time intervals it has recorded. If you are as foolish as your instructor, you will assume that you are using a pulley with ten spokes. Count ’em; there are just eight. So here you need to use the `<D>` for “other.” This will give you the opportunity to put in the correct distance: 0.0175 meters.
- Next you will be provided several graph options. Of these, you will want to plot the points, perform statistics, and do a regression (options are activated/deactivated by pressing the

space bar when the option is highlighted). The regression will do a straight line fit to the velocity curve. The slope of this curve is the experimental value for the acceleration, *the number that you want from all these steps.*

- When you examine the velocity graph, you may find that several data points at the end don't lie on the straight line fit as they corresponded to data taken after the cart collided with the end. If this is the case, go back to the data analysis menu and delete these points and then go back and replot to get an improved fit for the slope of the velocity curve.

Appendix B

Precision timing: Science Workshop

These are a summary of instructions for using the Science Workshop computer interface for making a variety of measurements. The instructions are not complete and you may need help from the instructor the first few times you use the system.

B.1 Starting Science Workshop

Science Workshop is installed only on Windows based computers. The first step in using Science Workshop is to simply locate the Science Workshop icon on the Windows program screen. Double-clicking on the icon starts the Science Workshop program.

B.2 Photogate timing of air cart velocities

- Refer to the diagram in Appendix A to see how a photogate timer is placed on an air track.
- Plug the photogates into the digital channel receptacles on the Pasco 700 interface.
- Let the computer know that you are plugging a photogates into the digital plug-ins on the Pasco 700 interface. This is accomplished by dragging a "plug" icon onto the channels being used . After you drag the icon, then you will be asked to select the type of instrument being used.
- Setup the program to make a table recording the amount of time each photogate is blocked.
- Hit the "REC" button to initiate data recording.

- Send an air cart through both photogates. Each table will show the amount of time the photogate was blocked when the air cart passed through.
- The speed of the air cart through each photogate is given by

$$\text{speed} = \frac{\text{flag size}}{\text{photogate blocked time}}. \tag{B.1}$$

B.3 Photogate timing of picket fence velocity

- Start the *Science Workshop* software on the computer.
- Let the computer know that you are plugging a photogate into one of the digital plug-ins on the Pasco 700 interface and that the photogate will be used with a picket fence.
- Setup the program to make both a graph of velocity versus time. Do this by dragging a graph icon onto the plug you are using for the photogate.
- Tell the computer to start recording. It only will start measuring data when the photogate is blocked.
- Hang the picket fence just above the photogate and then drop it through.
- Hit the stop button on the computer to stop recording.
- In the velocity graph window, isolate (box it in using the mouse control of the computer) the part of the data where the picket fence is passing through the gate.
- Use the statistic menu (Σ button) to perform a regression analysis of the velocity versus time data. This will produce a straight line fit to your data. The slope of the fit is your best estimate for the acceleration of the picket fence as it dropped through the photogate.

B.4 Pulley wheel timing

- Select the science software package from the windows menu.
- In the Science workshop display, drag an analog plug into the plug-in that the smart pulley to which the smart pulley is attached. You will be asked what type of probe you are using and you should choose the 10-spoke smart pulley.
- Drag a graph icon on top of the plug-in you are using. You will be asked what should be plotted. Choose velocity versus time.

- Data recording commences after you click on the “REC” button and the pulley wheel begins to turn.
- Stop recording by hitting the “STOP” button.
- You should now have a velocity versus time graph. Choose the Σ button to analyze the graph data.
- Select the regression fit to perform a straight line fit (corresponding to constant acceleration) to the data.
- The fit may not be good because some of the points will correspond to when motion has been altered by an obstruction. Use the mouse to box the part of the graph data which represents unobstructed motion.
- A new regression fit should appear which should match the data well in the boxed region. The software also evaluates the slope of the regression fit. This slope is your result for the acceleration.