Selected General Physics I Activities

John Deisz
Department of Physics
University of Northern Iowa

January 3, 2003

Contents

Lab 1

Kinematics Simulations in One Dimension

1.1 Getting Started

The first step in this activity is to get acquainted with the simulation software "CPUS." To get the program started do the following.

- To start the program, select "Run CPU Simulators" on the desktop or from the Program Menu.
- Provide user and group names (whatever you want to use). This is useful for saving your final set up to make it easier to start on the next class period. The computers are numbered on the right side of the cart to ensure that you use the same computer.
- Choose `Full Screen` mode on the Internet Explorer menu bar.
- Select the Force and Motion Simulation link.

The screen consists of a grid with x and y axis. The axis could represent east-west and north-south or horizontal and vertical. However, we will look at motion only along one of the axis at a time during this activity.

In the lower right-hand corner of the graph is a black square with white dots. Double left-click on this. This provides a large set of options including

- the gravitational source (left column - leave as "none"),
- the labeling of force vectors (middle column - deselect all of these except for "show velocity"),

- object path representation (right column - select “show path”), and
- the simulation stop time (leave at 10 s).

Below and to the left of the graph is a collection of buttons for items that are used to setup a simulation.

- Placing and deleting objects. Click the sphere button and then drop objects at several place by left clicking on the grid. Next, click the **X**. When **X** is selected, you delete objects by clicking on them. Delete all but one object. The **X** is used to delete any element that is placed on the graph.
- Making graph windows. Select the graph button (the middle button in the top row). Left click in the main graph window to display the smaller graph. The program is picky about where these can be placed. You may have to try several locations before the small graph appears.
- Now you have two objects on the screen. To change the properties of any object, select the arrow button (the leftmost button in the top row). Double clicking on any object will give you a menu of options for the object. Test this by changing the color of the object you have placed on the graph.

  Next, double click on the small window graph. Set the graph to plot the “x value” of the object on the vertical axis and “time” on the horizontal axis, hit “OK” and then move the graph to a convenient location.
- Add a second graph that shows “v_x” vs. “time.”
- Run the simulation by hitting the “play” button from the set of buttons on the right side of the screen.
- **Q1** What did the object do during the simulation? In a sentence, describe the x vs. time and v_x vs. time graphs.
- Have your setup verified with the instructor before proceeding.

1.2 Motion with constant velocity

- To give your object an initial velocity, select the “V” button, left click and hold on the object, then drag in the preferred direction (horizontal) for the velocity, and then release. To precisely define the properties of the initial velocity, click on the arrow button and then double-click on the velocity vector you have just drawn. Give it a strength of 20 (standing for 20 m/s) and an angle of 0 degrees.

- There is only this initial velocity. There is no acceleration. With your group, make predictions for what the two graphs will look like (you don't need to write your predictions on your report). Run the simulation.
- **Q2** Describe the motion of the object. Make rough sketches of the horizontal position vs. t and v_x vs. t graphs.
- **Q3** What are the values of a_x and v_{ox} in this simulation? Use these values and one of the basic kinematic equations to determine the expected horizontal displacement, x, in 10 seconds. Show the work you needed to obtain this result. Does the result agree with the simulation?
- Hit the rewind button. Hit the select button and then change the velocity vector so that it points to the left.
- **Q4** Repeat all questions in **Q2** and **Q3**.
- If possible, verify your results so far with the instructor before proceeding. However, if the instructor is busy and you are confident in your progress thus far, then feel free to proceed.

1.3 Motion with constant acceleration

- Next, we will add constant acceleration to the object. Before doing so, reset the initial velocity vector so that it points in the positive horizontal direction. Next, select the "*a*" button. Left click and hold on the object and then drag in the preferred direction for the acceleration vector. Since we are studying one dimensional motion, the acceleration vector should point either to the left or to the right.
- After hitting the select button, modify the acceleration vector so it has a magnitude of three units. Set the direction of the acceleration vector so that the object *speeds up* when the simulation starts.
- **Q5** Which direction for the acceleration vector did you choose and why?
- **Q6** Run the simulation. Sketch the horizontal vs. time and v_x vs. time graphs that are obtained.
- **Q7** What are the values (with units) for v_{ox} and a_x for this simulation? Using kinematic equation 1, determine the expected value for v_x after 10 seconds. Using equation 2, determine the expect displacement, x, after 10 seconds. Include all your work in your write-ups. Do your results agree with the simulation?
- **Q8** Describe the spacing of the dots along the path of the object. What does the spacing describe?
- Change the direction of the acceleration and run the simulation.
- **Q9** In words, describe the motion of the object.

- **Q10** Generally speaking, what is the relationship between the acceleration and velocity when an object is gaining speed? What is this relationship when an object is losing speed?

- **Q11** Make sketches of the x vs. t and v_x vs. t plots that are displayed on the computer screen.

- **Q12** What are the values (with units) for v_{ox} and a_x for this simulation? Using kinematic equation 1, determine the expect value for v_x after 10 seconds. Use equation 2, determine the expect displacement, x, after 10 seconds. Include all your work in your write-ups. Do your results agree with the simulation?

1.4 Freely falling bodies

- Remove all existing objects from the grid. Next, double-click on the black square in the lower right corner of the main graph. In the dialog box select "Earth" as the gravitational source. De-select all the "show" options related to forces. Set the simulation time to 2.0 seconds and the refresh time to 20 milliseconds. Finally, hit "OK."

- Place an object at approximately x=-200, y=0.

- Change the small graph windows so that they display y vs. time and v_y vs. time. For the y vs. time graph additional changes must be made. Change the scale mode to "hand," the vertical begin value to "0", the vertical step value to 0.5 and the vertical step size to 10. Also, change the step precision to 2.

- Give the object an initial vertical velocity of 9.8 m/s and run the simulation.

- **Q12** Make a sketch of velocity vs. time.

- **Q13** From this sketch, would you say that acceleration in the vertical direction is constant. Why? Based on what you know from reading the textbook or from elsewhere, what is the value of a_y for this simulation (include the appropriate sign)?

- **Q14** What is the vertical velocity v_y at the maximum height for the object? Why must this be so?

- **Q15** List the values of v_{oy} and a_y. Also write the value of v_y at the peak. Use these values and kinematic equation 1 to mathematically determine the time it takes to reach the peak. Show your work. Does the result agree with time value obtained from the simulation?

- **Q16** Since you know v_{oy} and a_y as well as v_y at the peak and the time to reach the peak, you can use either kinematic equation 2 or equation 3 to determine the vertical displacement between the initial location and the peak. Show your work. Does the result agree with the simulation? Note: the simulation doesn't produce a very accurate position graph, so there may be some difference.

- **Q17** Make a table with three columns. The first column will be for v_{oy}, the second column is time to reach the peak, and the third is the peak height. Run these simulations using initial velocities of v_{oy} of 9.8, 19.6, 29.4, and 39.2 (in m/s). Note, that to reach the peak, you may need to extend the time of the simulation beyond two seconds. Further, you may need to change the scale for the vertical position graph. Do this by making the vertical step value from 0.5 to some larger number.

- **Q18** Based on the results in the table, what happens to the time it takes to reach the peak if the initial vertical velocity doubles? What is the reason for this?

- **Q19** When the initial vertical velocity doubles, does the maximum height also double? If not, what does the maximum height do (approximately)?

Lab 2

Kinematics in Two Dimensions and Projectile Motion

2.1 Getting Started

The first step in this activity is to get acquainted with the simulation software "CPUS." To get the program started do the following.

- To start the program, select "Run CPU Simulators" on the desktop or from the Program Menu.
- Provide user and group names (whatever you want to use). This is useful for saving your final set up to make it easier to start on the next class period. The computers are numbered on the right side of the cart to ensure that you use the same computer.
- Choose `Full Screen` mode on the Internet Explorer menu bar.
- Select the Force and Motion Simulation link.

The screen consists of a grid with x and y axis. The axis could represent east-west and north-south or horizontal and vertical.

In the lower right-hand corner of the graph is a black square with white dots. Double left-click on this. This provides a large set of options including

- the gravitational source (left column - leave as "none"),
- options for displaying vectors (middle column - unselect all of these except for "show velocity"),

- object path representation (right column - select “show path”), and
- the simulation stop time (leave at 10 s).

Below and to the left of the graph is a collection of buttons for items that are used to setup a simulation.

- Placing and deleting objects. Click the sphere button and then drop objects at several places by left clicking on the grid. Next, click the large **X**. When **X** is selected, you delete objects by clicking on them. Delete all but one object. The **X** is used to delete any element that is placed on the graph.
- Making graph windows. Select the graph button (the middle button in the top row). Left click in the main graph window to display the smaller graph. The program is picky about where these can be placed. You may have to try several locations before the small graph appears.
- Now you have two objects on the screen, a spherical object and a small graph window. To move an object or change its properties, select the arrow button (the leftmost button in the top row). Double clicking on any object will give you a menu of options for the object. Test this by changing the color of the spherical object.

  Next, double click on the small window graph. Set the graph to plot the “x value” of the object on the vertical axis and “time” on the horizontal axis, hit “OK” and then move the graph to a convenient location.
- Add a second graph that shows “v_x” vs. “time.”
- Run the simulation by hitting the “play” button from the set of buttons on the right side of the screen.
- **Q1** What did the object do during the simulation? In a sentence, describe the x vs. time and v_x vs. time graphs.

To make the simulation more interesting we need to explicitly provide the object with an initial velocity, an acceleration, or both. To give your object an initial velocity, select the “V” button. Next, **left click and hold** on the object which will receive the velocity, while holding drag the mouse pointer from the object toward the direction you wish the velocity to point - make this direction horizontal. Once you have the desired velocity direction and magnitude, release the mouse button.

To precisely define the properties of the initial velocity, left click on the arrow button and then double-click on the velocity vector you have just drawn. A small window will appear into which you can type numerical value for the size and direction of the initial velocity vector. Give it a size of 20 (standing for 20 m/s) and an angle of 0 degrees.

Finally, rerun the simulation to verify the object moves as expected.

An acceleration vector is given in the same way. In this case you click on the "a" button and then click, hold and drag on the object which is to receive an acceleration.

2.2 Simulation of constant velocity in two dimensions

- Delete all previously created objects. Next, create an object with an initial velocity vector of 40 m/s pointing at 30 degrees. Do not give the object any acceleration. Create graph windows to plot v_x vs. time and v_y vs. time.
- **Q1** Mathematically determine the expected value of v_{ox} and v_{oy} for this case, *i.e.* using the rules for components.
- Run the simulation.
- **Q2** How do v_x and v_y behave as a function of time? Why does this happen?
- Change the two graphs so they plot x vs. time and y vs. time. Before running the simulation, discuss with your group how you believe these graphs will appear when the simulation is run.
- **Q3** Click on the rewind button and repeat the simulation. From the graphs, estimate the x and y *displacements* that occur over 10 seconds. Use kinematics equation 2 to determine the expected values for x and y based on your known values of v_{ox}, v_{oy}, a_x, a_y, and time. Show your work. Do the results agree with the simulation?

2.3 Simulation of constant acceleration in two dimensions

- Delete all existing objects. Next, create a new object with an initial velocity vector of 20 m/s pointing at 0 degrees (horizontal). Add an acceleration of 5 units pointing at 90 degrees. Create graph windows to plot v_x vs. time and v_y vs. time.

- **Q4** What are the values for v_{ox}, v_{oy}, a_x and a_y?

- Run the simulation.

- **Q5** How are the behaviors of v_x and v_y different as a function of time?

- Change the two graphs so they plot x vs. time and y vs. time. Before running the simulation, discuss with your group how you believe these graphs will appear when the simulation is run.

- **Q6** Run the simulation. From the graphs, estimate the x and y *displacements* that occur over 10 seconds. Use kinematics equation 2 to determine the expected values for x and y based on your known values of v_{ox}, v_{oy}, a_x, a_y, and time. Show your work. Do the results agree with the simulation?

2.4 Simulation of projectile motion

- Delete any existing objects. Double-click on the star-field in the lower right corner of the main graph window. Add the earth's gravitational field to the simulation (this provides the downward 9.8 m/s^2 acceleration).

- Delete all existing objects and then create a new one. Place it on the horizontal axis on the left half of the graph.. Give the object an initial velocity of 45 m/s in the positive vertical direction. Make two graph windows, one that plots y vs. time and v_y vs. time for the other. Finally, run the simulation.

- **Q7** How long does it take for the object to reach its peak? How high does it go? Use one of your kinematic equations to "predict" the *maximum height* when the initial vertical velocity is 45 m/s and verify that your prediction agrees with the result from the simulation. Show all of your work.

- Change the velocity vector to point at a 20 degree angle with respect to the horizontal. Run the simulation.

- **Q8** How long does it take for the object to reach its peak? How high does it go? Are these values greater, smaller, or the same compared to when the velocity is vertical? Why is this the case?

- **Q9** Mathematically determine the components of the initial velocity vector, v_{ox} and v_{oy} (your v_{oy} should agree with the initial v_y value in the v_y vs. time plot). Use kinematic equation 1 for the vertical motion to predict the time to reach the peak. Verify that the result you obtain agrees with the simulation.

- **Q10** Sketch the behavior of v_x vs. time and v_y vs. time (as obtained from graphs of these on the computer)? In words, describe the behavior of v_x vs. time and v_y vs. time.

- **Q11** Generate plots of of x vs. time and y vs. time on the computer and make sketches in your report. In words, describe the behavior of the graphs.

- Place two objects side-by-side approximately 50 meters above the horizontal axis. Give one object an initial velocity of 40 m/s in the horizontal direction. The other object will have no initial velocity (as if it is being dropped).

  Before running the simulation, predict which of the two objects will hit the "ground" first. After making your prediction, create graph windows to show the vertical velocity for each object. Finally, run the simulation.

- **Q12** Which of the objects hits the ground first? Use the results from the vertical velocity graphs to explain more precisely the difference/similarity in the vertical motions for these objects.

- **Q13** Place an object at y = 150 m, x=0. Place a second object at x=-150 m, y=0. The second object is given an initial velocity of 80 m/s at a 45 degree angle. If there were no gravity the objects would collide at the position of the first object. How close do these objects approach when gravity is taken into account. Run the simulation and report your result.

2.5 Motion of a projectile

Initial vertical velocity and maximum height

A projectile fired directly upward will reach a maximum height, y_{max}, before falling back to the ground. The value of y_{max} depends on the initial speed, v_o. The larger v_o is, the greater y_{max} will be.

- Aim your projectile launcher straight upward. Insert the yellow projectile and use the plunger so that the launcher produces the maximum firing range. Launch the ball upward and record *as best as you are able* the maximum height attained by the ball, y_{max} (note, the value of y is measured with respect to the position from which the ball is launched as indicated on the projectile launcher).

  Repeat the height measurement three times and average these for your final value.

- **Q14** Use one of your equations of motion to obtain v_o, the initial velocity, from the value of y_{max} that you have measured (hint: what is the velocity at $y = y_{max}$?).

Predicting x_{total} vs θ

Now that you know the velocity at which the projectile leaves the launcher, you can make predictions for the projectile's motion when it is launched at a variety of angles.

- **40 degrees**

Answer the following questions **before** firing a projectile at 40 degrees with respect to the horizontal.

- **Q15** At this angle, how large are $v_{o,x}$ and $v_{o,y}$ (assuming the magnitude of the velocity is the same as for the upward projectile)?

- **Q16** Assuming the projectile lands at the same height as it is fired, how much time will it remain in the air? **Hint:** Determine how much time it takes to reach the top of its trajectory (where $v_y = 0$) and double that time value.

- **Q17** The horizontal displacement in a time, t, for a projectile is just $x = v_{o,x}t$. Use this to predict how far your projectile will travel horizontally.

- Test your prediction by firing your projectile at 40 degrees and recording the horizontal displacement between the firing position and where the projectile lands. **Note:** Since we assume the firing and landing heights are the same, you will need to use books, notebooks, etc. to create a landing platform that is at the same height as the launch position.

- **Q18** Are your predicted and measured values close?

* **Q19** Repeat the calculations for a a firing angle of 55 degrees. Compare the calculated and measured distances.

* **Q20** Repeat the calculations for a a firing angle of 70 degrees. Compare the calculated and

measured distances.

Lab 3

Introduction to Forces

3.1 Force is a vector quantity

Equipment: three spring scales (they must be *all* yellow 50 N max scales or *all* brown 10 N max scales), a protractor, and a calibration weight (1 kg for the 50 N spring scales 200 g or 500 g for the 10 N spring scales).

- Choose and mark a center point on a blank sheet of paper. Use a protractor to accurately draw lines at 0, 90, 180, 225, 240 and 270 degrees that start at the center point.

- Next calibrate your spring scales. To do this hang the calibration mass from the scale and adjust the top screw on the spring scale until it produces the correct reading.

- Hook two spring scales to a small, light ring (such as an empty key ring). Pull one spring scale along the 0 degree direction and the other at 180 degrees. Pull so that the scales do not touch the table surface. While holding the scales steady and in place over the center point, obtain force readings (Newtons) for each scale.

- **Q1** The force readings you obtain represent the two forces applied to the ring by the spring scales. Draw a diagram to represent the force vectors that are applied to the ring. What is the net force acting on the ring?

- Connect a third spring scale to the ring. Make sure the hooks from all spring scales are placed on the ring in exactly the same manner (*i.e.* all are hooked over the top). Pull one scale with a force of about 10 N (10 N scale) or 30 N (50 N) scale at an angle of 225 degrees. The other scales should be pulled in the 0 and 90 degree directions such that the ring remains over the center point. When all forces are applied and the ring is steady over the center point, then obtain force readings (in Newtons) from all scales.

- **Q2** Since the ring is remaining in place over the center point, what must be the net force acting on the ring?
- **Q3** Make a vector diagram showing the forces acting on the ring.
- **Q4** Using the trigonometric formulas, determine the x and y components of the force at 225 degrees. How do these components compare to the forces applied at 0 and 90 degrees?
- **Q5** Change the direction of the force from 225 degrees to 240 degrees. As before, apply forces at 0 and 90 degrees such that the ring remains in place over the center point. Obtain force readings and repeat questions **Q3** and **Q4**.

3.2 Relationship between force and acceleration: simulations

We will use the CPU software to simulate the relationship between force and acceleration. Set up the program so that there are no gravitational forces and the object leaves a trail as it moves through the grid. By default, objects have a mass of 5 kg.

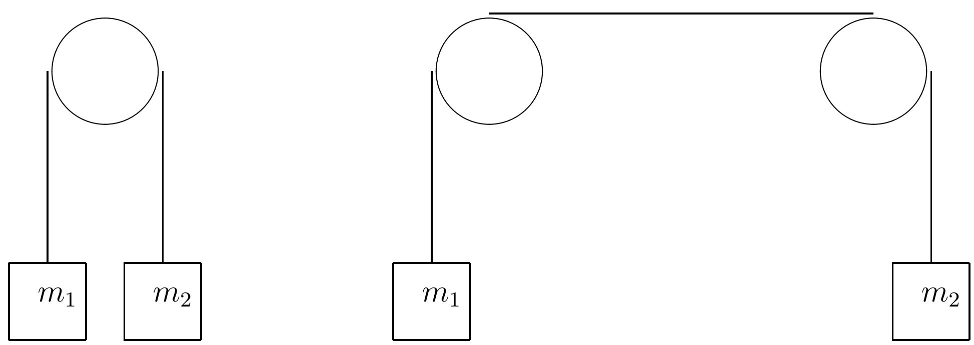
- **Q6** Create an object. Assume that its initial velocity is zero and there are no forces acting on the object. Predict the motion of the object as a function of time. Perform the simulation and report the results.
- **Q7** Give the object a 10 N force to the right. Predict the motion of the object, run the simulation and then report the results.
- **Q8** Make a small graph window that plots a_x versus time. You should see that a_x is constant as a function of time. What is the constant value of a_x? Show that the value is consistent with Newton's second law.
- **Q9** Add an initial velocity of 10 m/s to the right. Does this change the a_x versus time graph? Now change the initial velocity to be 10 m/s to the left. Does the acceleration behave at all differently? Is the acceleration related at all to the direction of the initial velocity? What determines the acceleration?
- **Q9** Remove the initial velocity vector, but keep the 10 N force to the right. Now add a second 10 N force (you can place multiple forces on objects), but make its direction 180 degrees. What happens when you run the simulation? Why does this happen?
- **Q10** Remove the two forces and place three new ones at 0, 90, and 240 degrees. Use the same sizes for these forces as you obtained in the first section of this activity. What do you expect to happen when the simulation is run? Run the simulation and report your results.

Lab 4

Newton's Second 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 important idea is that each mass is acted on by the same forces: (1) the force of gravity, F_G, pulling downward and (2) the force of the string, T, pulling upward. It is acceptable to assume that the string applies the same size force T on each mass. The force of gravity depends on the size of each mass.

- **Q1** Assume that $m_1 > m_2$. What do you expect will happen when they are released from rest? Don't perform the experiment, just make a prediction.
- **Q2** Based on your prediction in **Q1**, how does the size of $F_{G\to 1}$ (the downward force of gravity acting on object one) compare to T (the upward force from the string)? Explain why you think this is so.

- **Q3** Based on your prediction in **Q1**, how does the size of $F_{G\to 2}$ (the downward force of gravity acting on object two) compare to T (the upward force from the string)? Explain why you think this is so.

  Finally, rank in order, from largest to smallest, the three forces that appear in this problem: T, $F_{G\to 1}$, and $F_{G\to 2}$.

Newton's 2nd law states that the vertical acceleration of an object times its mass is equal to the sum of the vertical components of all forces acting on the object. Thus, for object one we have

$$\begin{aligned} m_1 a_{1,y} &= F_{net\to 1,y} && (4.1) \\ &= T - F_{G\to 1} && (4.2) \end{aligned}$$

while for object two this gives us

$$\begin{aligned} m_2 a_{2,y} &= F_{net\to 2,y} && (4.3) \\ &= T - F_{G\to 2}. && (4.4) \end{aligned}$$

We can use these two equations to predict the acceleration of the masses. Your group should try to work through the steps as outlined below, but should of course ask for help if needed.

- **Q4** Showing all your steps in the report, solve both Eq. (4.2) and Eq. (4.4) for T. Since you have two quantities that are separately equal to T, you can set them equal to each other. You should get

$$m_1 a_{1,y} + F_{G\to 1} = m_2 a_{2,y} + F_{G\to 2}. \quad (4.5)$$

- **Q5** You now have a single equation to work with, but two unknowns, $a_{1,y}$ and $a_{2,y}$. However, for Atwood's machine $a_{1,y}$ and $a_{2,y}$ are directly related. What is the relationship?

- **Q6** Using the relationship between $a_{1,y}$ and $a_{2,y}$, it is possible to solve Equation (4.5) in terms of $a_{1,y}$ only. You should get

$$a_{1,y} = \frac{F_{G\to 2} - F_{G\to 1}}{m_2 + m_1}. \quad (4.6)$$

  Show the steps needed to arrive at this result.

- **Q7** Finally, by using $F_G = mg$, obtain the final form for $a_{1,y}$:

$$a_{1,y} = \frac{m_2 - m_1}{m_2 + m_1}\, g. \quad (4.7)$$

Next, you will perform the experiment and compare the observed acceleration to the prediction made by Eq. (4.7).

- Set up an Atwood machine that corresponds to the drawing. Mass two should be either 50 or 100 grams and mass one should be approximately 5% larger. The string should be sufficiently long so that mass one is able to drop a distance of 1.75 meter before hitting the floor.

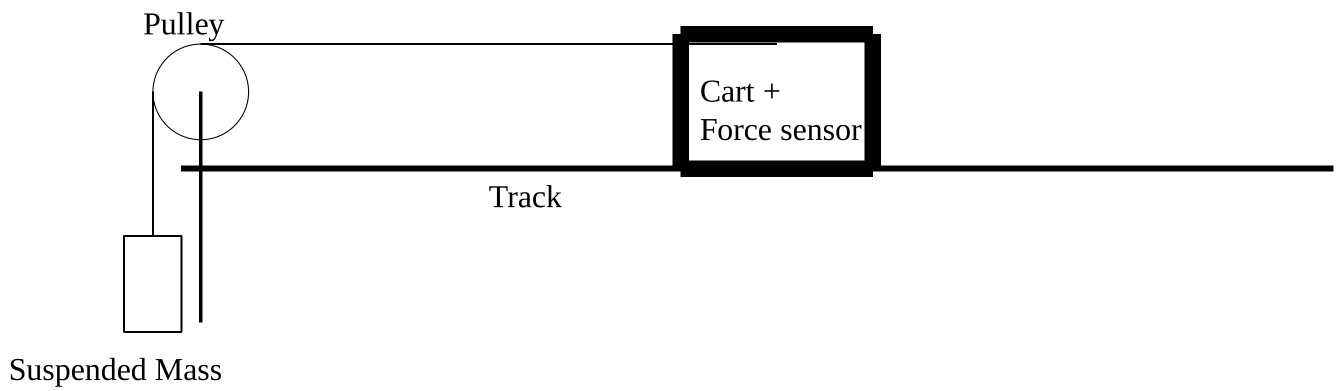
- Hold the masses steady so that mass one is one meter above the floor. Use a stopwatch to determine the time it takes mass one to reach the floor when the masses are released.

- **Q8** Since you know the time, vertical displacement, and initial vertical velocity, kinematic equation number two can be used to determine the acceleration of mass one. Obtain this value.

- **Q9** Find the percentage difference between the acceleration you obtain and the theoretical value given by Eq. (4.7).

4.2 Newton's 2nd Law on the dynamics track

A motion cart with a force sensor attached is placed on a dynamics track. A string is attached to the hook of the force sensor and the string runs over a pulley wheel. A mass of approximately 50 grams is attached to the other end of the string. A motion sensor is placed behind the cart.



We will try to observe both the force applied to the cart+force sensor combination as well as the acceleration that results. Setup instructions follow.

- Before starting the Logger Pro program, plug the force and motion sensors into the Lab Pro interface. Make sure the range setting on the force sensor is set at 10 N.
- Start the Logger Pro program. It should recognize that a motion sensor is attached. However, you will need to configure the software obtain force measurements. To do this, click on the oval green Lab Pro icon in the tool bar. Highlight the icon for the port into which the force probe is attached. Go through the list of sensors for that port and choose the Pasco 10 N force probe. After selecting "OK" you should find that it is possible to obtain force vs. time plots.
- To verify that your force probe is working, start data collection and pull back and forth on the force sensor hook. The pushes and pulls should appear on the force vs. time graph.
- Now with the cart and force sensor flat and no forces applied to the force sensor, collect force vs. time data again. Although the force should be zero, you will most likely obtain a non-zero reading. After data collection has stopped and when there are no forces applied to the sensor, hit the "tare" button on the side of sensor and then, under the experiment menu, select the item that allows you to "zero" the force sensor. After going through these steps, you should obtain a zero reading when the force is remeasured with no forces applied to the sensor. Verify that this is the case.

Note: Prior to every force measurement you make, you should repeat these steps as the force sensor gradually loses track of the proper zero reading.

Before proceeding, please consider the following questions.

- **Q10** Using the relationship between mass and the force of gravity, determine F_G for the mass you plan to suspend. Since you know the suspended mass will fall to the ground, what does this tell you about the size of the string's force, T, acting on the suspended mass?

- Proceed with the experiment. Show separate plots of velocity vs. time, acceleration vs. time and force vs. time on your computer screen. You should find that as the cart is pulled by the string, the acceleration and force are approximately constant (make sure the force probe is properly "zeroed" before this experiment).

- **Q11** What are the force and acceleration values you obtain? According to Newton's second law, what should the ratio F/a be equal to assuming that the force of the string is the only horizontal force acting on the cart+force sensor? Compare F/a to the combined mass of the cart and force sensor as obtained from a balance.

  Note: You may find that the results in **Q11** show substantial disagreement. Unfortunately, the force sensors are not accurate for measuring smaller forces. Plus, we have ignored frictional forces in this analysis.

- **Q12** Just like for Atwood's machine, it is possible to predict the acceleration by using Newton's laws. We don't go through the steps here, but the result is

$$a = \frac{m_{susp}}{m_{susp} + m_{cart}}\, g. \qquad (4.8)$$

  Find the percentage difference between the measured acceleration and the theoretical result obtained from Eq. (4.8). Once again, the theory ignores frictional forces, so some inconsistency is expected.

4.3 Exercises

As a group, solve the following exercises. Verify your results with the instructor before leaving the laboratory.

- **Q13** Exercise 115, page 128 in your textbook.

- **Q14** Exercise 116, page 129 in your textbook.

Lab 5

Tension and more free-body diagrams

5.1 An equilibrium problem with tension

A mass can be supported using a single upward force. Typically, this force is provided through tension. Here we investigate the slightly more complicated case where a mass is supported using two tension forces, both of which contain vertical and horizontal components.

1. Attach two vertical support rods to your laboratory table with a separation of approximately one meter. Add a horizontal rod that goes from the top of one vertical support to the other.

2. Tie two pieces of string to the horizontal rod. The hanging part of the string should have a length of about 1.5 feet. Suspend a 10 N spring scale from the end of each spring. The hooks of the scales should be at approximately the same level (though it doesn't need to be exact). The hooks should have on the order of one foot of clearance from the lab table.

3. Suspend either a 500 gram mass or a 1000 gram mass from one of the spring scales. Draw a freebody diagram for the mass.

4. How large should be the tension force applied by the spring scale? How do you know that this is the case? Explain.

5. You may find that the spring scale does not give the proper reading. If not, calibrate the spring scale so that it produces the proper value. Repeat the calibration for the second spring scale.

6. Now support the mass using both spring scales. Adjust the the location of the strings on the horizontal support so that the strings and spring scales are not vertical. Also, try to arrange the strings so that each makes a different angle with respect to vertical.

7. Draw a free-body diagram for the mass. Include the sizes for all forces in the diagram (tension forces are obtained from the spring scale readings).

   You must also determine the angles of the tension forces. To do this, estimate the angle the string makes with the horizontal support by using a protractor. This angle (along with a simple drawing) can be used to determine the angle for each tension force vector.

8. Determine the x-component for each of the force vectors appearing in the freebody diagram. Use these components to determine $F_{net,x}$ for the mass.

9. What is the expected value for $F_{net,x}$? Why? Does your result agree with this (or very nearly so)? Note that the precision of the experiment is approximately 0.2 N.

10. Determine the y-component for each force vector. Use these components to determine $F_{net,y}$ for the mass.

11. What is the expected value for $F_{net,y}$? Why? Does your result agree with this (or very nearly so)?

5.2 Free-body diagrams

Under the program menu, select the Freebody program. Even if you haven't used the program before, skip the instructions and go directly to the exercises.

1. Work through exercise 1 until the program indicates you have successfully completed the exercise. In your activity reports, include (1) a simple sketch for the problem, (2) the final free-body diagram that you produce (with vectors roughly to scale), and (3) numerical values for F_x and F_y for each the individual force vectors as well as for the net force.

2. Exercise 2 on the Freebody program.

3. Exericse 3.

4. Exercise 6.

5. Exercise 7.

6. Exercise 8.

7. Exercise 9.

8. Exercise 10.

9. If you have any time remaining, then work through the exercises that we have skipped (4,5). However, you do not need to turn in work for these exercises.

Lab 6

Free-body diagrams and friction

6.1 Free-body diagrams

Under the program menu, select the Freebody program. Even if you haven't used the program before, skip the instructions and go directly to the exercises.

- **Q1** Work through exercise 1 until the program indicates you have successfully completed the exercise. In your activity reports, include (1) a simple sketch of the situation represented, (2) the free-body diagram that you produce, and (3) everything that appears under description of forces (sentences and value for forces) after the exercise is completed.

- **Q2** Jump to exercise 3. Complete the exercise and include (1), (2), and (3) in your report as described above.

6.2 Coefficient of friction

In this activity, you will investigate the force of friction between an object and your laboratory table. Objects that you may consider using are wood blocks, bricks, or any other item that has a reasonably flat surface and a mass of at least 250 grams.

Unless there is some type of hook on the object, tie a piece of string around the object. This will be used for pulling horizontally on the object.

Attach a force sensor to the Lab Pro interface. Start the Logger Pro program on the computer. Click on the green lab pro icon and perform the configuration needed to use a Pasco 10 N force probe. However, if you find that the forces in the experiment go above 10 N, then change the settings on the force probe and in the software to use the 50 N range instead of the 10 N range.

- Obtain the mass of your object and list its value.
- **Q3** Imagine that you are pulling on the object, but it remains at rest. Draw a free-body diagram for the object that represents all forces acting on it, vertical and horizontal. Clearly label the forces.

  Although the size of the horizontal forces are unknown, you should be able to determine the magnitude of the vertical forces. Include these magnitudes in your free body diagram.
- **Q4** Now imagine that you are dragging the object across the table, but at constant velocity. Once again, draw a free-body diagram for the object that represents all forces acting on the object, vertical and horizontal. Clearly label the forces. Include the magnitudes of the vertical forces.
- Obtain a force versus time plot for when you (1) very gradually increase the pull on the object until it starts to move and (2) once it begins to move continue to drag the object at a slow and constant speed.

  Note: First, you must zero your force probe by (1) removing all forces from the sensor and making it lie flat, (2) hitting the tar button on the sensor, and (3) zeroing the force sensor under the experiment menu in Logger Pro.

  Your force vs. time plot should start with a force near zero, slowly rise as the pull increases, and then drop off to an approximately steady value as the object begins to move at constant speed. Make a print out of the graph for each member of the group.
- **Q5** Mark the point on your graph that represents $f_{s,max}$, the maximum static frictional force between your object and the table. Also indicate which section of your curve describes f_k, the constant kinetic frictional force between your object and the table.

  List your values for $f_{s,max}$ and f_k.
- If you double the force between the table and your object, then do you expect $f_{s,max}$ to change or stay the same? What about for f_k?
- **Q6** Add masses to the top of your object so that the force between the table and the object approximately doubles. Repeat the measurements made above, but you don't need to make a printout. List the values for F_N, $f_{s,max}$ and f_k for this case.
- **Q7** Add even more mass and repeat. List the values for F_N, $f_{s,max}$ and f_k that you obtain.
- **Q8** In general, as the normal force, F_N, increases, what happens to $f_{s,max}$ and f_k.
- Use your data to fill in the following table:

F_N	$f_{s,max}$	$\mu_s = f_{s,max}/F_N$	f_k	$\mu_k = f_k/F_N$

- **Q9** According to our simple model for friction and assuming that the table's surface has a consistent texture, the ratio of $f_{s,max}$ to F_N should be constant. We call this constant ration μ_s. Do your results confirm that this is the case?

- **Q10** According to our simple model for friction, the ratio of f_k to F_N should be constant. We call this constant ration μ_k. Do your results confirm that this is the case?

- **Q11** Based on your results, predict how large a force would be needed to *budge your object* if a 10 kg mass where placed on top of it. Include a free-body diagram and show the mathematical steps used to obtain your result.

- **Q12** Based on your results, predict how large a force would be needed to *slide your object* at constant velocity if a 10 kg mass where placed on top of it. Include a free-body diagram and show the mathematical steps used to obtain your result.

Lab 7

Uniform Circular Motion

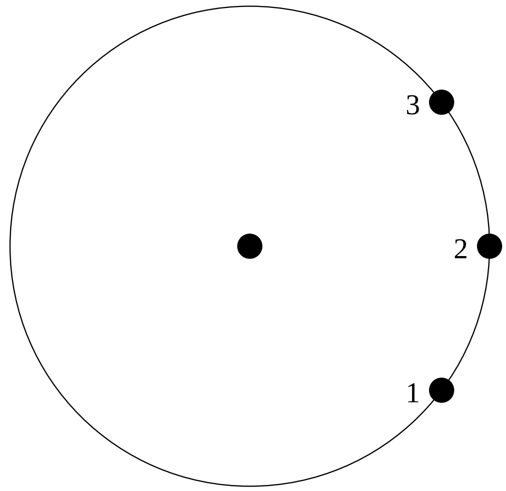
7.1 Acceleration in uniform circular motion

Uniform circular motion refers to the special case where circular motion takes place at constant speed.

Q1: Given that the speed is constant, is it possible to have acceleration in this case? Explain.

Determining the direction of the acceleration

An object moves at constant speed on a circle which we represent with the circle that appears below:



The object moves in the counterclockwise direction and passes through points 1, 2, and 3 in succession.

We wish to determine the direction of the *instanteneous* acceleration when the object is at point 2. It is reasonable to expect that the direction of the *instantenous* acceleration at point 2 is the same as the *average* acceleration between points 1 and 3. Thus, in what follows we determine the direction of this average acceleration and assume this corresponds to the direction of the acceleration at point 2.

By definition, average acceleration is given by

$$\mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t} \tag{7.1}$$

Thus, we need to find the $\Delta\mathbf{v}$ between points 1 and 3. The direction of $\Delta\mathbf{v}$ is the same as the direction of $\mathbf{a}$.

The first step in finding $\Delta\mathbf{v}$ is to draw velocity vectors, $\mathbf{v}_1$ and $\mathbf{v}_3$. These should be drawn with the tail of these vectors starting at points 1 and 3 respectively. Make each vector 3.0 cm long. Draw the direction of each vector as carefully as possible.

Redraw $\mathbf{v}_1$ and $\mathbf{v}_3$ to the right of the circle with their tails together (they should make a "v"). Make this drawing as accurately as possible (directions, size).

$\mathbf{v}_1$ is the initial velocity and $\mathbf{v}_3$ is the final velocity. So, $\Delta\mathbf{v}$ is the vector that must be added to $\mathbf{v}_1$ to obtain $\mathbf{v}_3$. Draw $\Delta\mathbf{v}$ on your drawing the appears to the right of the circle.

Q2: What is the direction of $\Delta\mathbf{v}$ between points 1 and 3? What is the direction of the average acceleration between points 1 and 3?

Q3: Draw an arrow at point 2 that represents the acceleration at that point. In which direction does it point? How does the direction of the acceleration compare to the direction of the velocity at point 2?

7.2 Investigating the magnitude of the acceleration

The textbook formula for the size of the center-directed acceleration vector is $a_c = v^2/r$. The following questions aim to address why the acceleration has this special dependence on speed (v) and radius (r).

Consider what happens when the speed doubles, but the radius remains the same. For this case **Q4:** (a) What happens to the magnitudes of $\mathbf{v}_1$ and $\mathbf{v}_3$? (b) What must happen to the magnitude of $\Delta\mathbf{v}$ and why?

Q5: (a) What, if anything happens to the distance the body has to travel in going from point 1 to point 3? (b) What happens to the time, Δt, that it takes to move this distance and why?

Q6: Based on your answers to the previous two questions and using the definition of acceleration (Eq. 7.1), what must happen to the size of the acceleration on account of doubling the speed? Is this consistent with the textbook formula for the size of the acceleration?

Next we keep the speed fixed, but now consider what happens when the radius of the circle is doubled. Points 1, 2, and 3 are assumed to appear at the same angular positions on the enlarged circle as on the original circle.

Q7: (a) What, if anything, happens to the vectors $\mathbf{v}_1$ to obtain $\mathbf{v}_3$ in going from the small to the large circle? (b) What, if anything, happens to $\Delta \mathbf{v}$?

Q8: (a) What, if anything happens to the distance the body has to travel in going from point 1 to point 3? (b) What happens to the time, Δt, that it takes to move this distance and why?

Q9: Based on your answers to the previous two questions and using the definition of acceleration (Eq. 7.1), what must happen to the size of the acceleration on account of doubling the radius? Is this consistent with the textbook formula for the size of the acceleration?

7.3 Uniform circular motion on the rotating platform

By analyzing the motion of the object, one can obtain its acceleration. This is true whether the object moves in a straight line or in a circle. For motion in one-dimension, one notes how the velocity has changed (for example, from +2 m/s to +5 m/s) and divides this change by the elapsed time. In uniform circular motion, one observes the speed and the size of the circle. This information is enough to determine the acceleration having to do with changing direction, $a_c = v^2/r$.

Four measurements were made of masses moving a circle on a rotating platform. In each case, the radius of the circle is given as well as the period, T, for the motion. For each case, determine the corresponding acceleration.

r (m)	T (s)	a_{obs} (m/s^2)
0.120	1.00	
0.120	1.42	
0.225	1.84	
0.225	1.32	

For each case, we have also measured the tension force needed to keep the mass moving in the circle. The experiemnt is set up so that the tension force is the *net* force acting on the mass as it rotates.

According to Newton's 2nd law, the acceleration of the mass should be equal to F_{net}/m. Compute the expected acceleration based on the measured and force values below. Compare these results to the accelerations obtained by observing the mass's motion.

F_{net} (N)	m (kg)	a_{exp}	% diff between a_{exp} and a_{obs}
0.51 N	0.107		
0.51 N	0.209		
0.54 N	0.209		
0.54 N	0.107		

Lab 8

Momentum Conservation

8.1 Elastic collisions

Roughly speaking, an elastic collision is one in which the objects "collide softly" and subsequently move separately from the collision point. More precisely, an elastic collision is one in which the internal energy of the colliding objects is unchanged by the collision so that the *total* final and initial kinetic energy must be the same. To investigate the properties of these collisions, we will softly collide two dynamics carts on a level dynamics track. To simplify the subsequent analysis, one of the two carts will be initially at rest. To produce the soft collision, the carts should be oriented so that their magnetic sides (typically marked with red tape) approach each other at the collision.

Two motion sensors will be needed, one at each end of the track. Once these sensors are oriented, start the Logger Pro program. Distance and velocity graphs appear with each of these graphs containing two labels, one for each motion sensor.

The next step is to test the setup to ensure that cart velocities are detected for both *immediately before* and *immediately after* the collision. To perform this test, place the stationary cart near the middle of the track. Start the other cart near (but at least 40 cm from) one of the sensors. Initiate data collection and the push the cart near the sensor towards the stationary cart in the middle of the track. You want to use enough initial velocity so that friction doesn't play too large of a role, but don't make the velocity unnecessarily large so that equipment is damaged.

There may be small irregularities in the measurements because of interference between the two sensors. However, the error resulting from these are likely to be smaller than other experimental errors. Once you are confident you are able to measure velocities before and after the collision you are ready to proceed.

There is one last part of the setup that must be performed. The two sensors disagree about the positive and negative directions of velocity. Since momentum is a vector quantity, it is important that we are consistent about directions. To rectify this, go to the green Lab Pro icon. Click on one of the two motion sensor icons. Select the "details" tab and then in the dialog box select the "unlock" button and then change "sign" from 1 to -1. This causes positive and negative directions to be reversed for that detector. After doing this, verify the operation has worked by performing another collision on the track.

8.1.1 $m_1 = m_2 = 1$ kg

- Set up both carts to have a mass of 1 kg. The cart mass is normally 0.5 kg and an extra bar weight provides the other 0.5 kg. Place one cart at rest near the the center of the track. After data collection is initiated on both computers by clicking on the `collect` button in Logger Pro, roll the cart on the end of the track towards the stationary cart in the middle.
- Select `Analyze` → `Examine` to obtain precise velocity values corresponding to just before the start and just after the end of the collision. List and analyze your results in the spaces below:
  - $v_{1,o}$ (velocity before collision of cart 1) =
  - $v_{2,o}$ (velocity before collision of cart 2) = 0
  - $p_{1,o}$ (momentum before collision of cart 1) =
  - $p_{2,o}$ (momentum before collision of cart 2) = 0

  - $p_{total,o} = p_{1,o} + p_{2,o}$ (total momentum before collision) =

  - $v_{1,f}$ (velocity after collision of cart 1) =
  - $v_{2,f}$ (velocity after collision of cart 2) =
  - $p_{1,f}$ (momentum after collision of cart 1) =
  - $p_{2,f}$ (momentum after collision of cart 2) =

  - $p_{total,f} = p_{1,f} + p_{2,f}$ (total momentum after collision) =
- **Q4** Determine the momentum change for cart 1 (Δp_1) and cart 2 (Δp_2). How do these compare?
- The total kinetic energy of the carts is given by KE $= (1/2)m_1v_1^2 + (1/2)m_2v_2^2$. Determine KE (a) before and (b) after the collision.
- **Q5** The precise definition of a perfectly elastic collision is one where KE is conserved. What fraction of KE is lost in this collision? Note: If KE is gained, it almost is certainly due to the track not being level.

8.1.2 $m_2 = 2m_1$

- This time, let the cart that is initially at rest have a mass of 1 kg and the cart at the end of the track have a mass of 0.5 kg.
- Repeat all measurements and questions from the experiment for $m_1 = m_2$.

8.2 Inelastic collisions

An inelastic collision is one where the total KE changes. A collision where two objects collide and stick will be seen to be highly inelastic. The inelastic collision you will study will have a cart initially at rest in the in the center. A second cart will collide with this cart. Velcro strips will cause the carts to stick together and move as a single unit.

For this experiment, you will need only one computer and motion sensor. If you are already in Logger Pro, exit the program. Unplug the second motion sensor and restart the program with only one motion sensor plugged in to the Lab Pro interface. Since we are not concerned with acceleration, set the graphics window to show only distance and velocity.

Once again, practice producing collisions between a moving cart and stationary cart. Verify that you are able to obtain good readings for the velocity before and after the collision. Once you are able to do so, proceed with the measurements and analysis that appear below.

8.2.1 $m_1 = m_2 = 1$ kg

- Let both carts have equal masses of 1 kg (achieved by placing a weight inside each cart). Place one cart near the middle and the other cart near the end of the track closest to the motion detector. After data taking is initiated on the computer by clicking on the `collect` button in Logger Pro, roll the cart on the end of the track towards the stationary cart.
- Display velocity vs. time. It should be easy to see what points correspond to just before and after the collision. To obtain precise values for these velocities, select `analyze` → `examine`.
  - $v_{1,o}$ (velocity before collision of cart 1) =
  - $v_{2,o}$ (velocity before collision of cart 2) = 0
  - $p_{1,o}$ (momentum before collision of cart 1) =
  - $p_{2,o}$ (momentum before collision of cart 2) = 0

  - $p_{total,o} = p_{1,o} + p_{2,o}$ (total momentum before collision) =

- $v_{1,f}$ (velocity after collision of cart 1) =
- $v_{2,f}$ (velocity after collision of cart 2) =
- $p_{1,f}$ (momentum after collision of cart 1) =
- $p_{2,f}$ (momentum after collision of cart 2) =

- $p_{total,f} = p_{1,f} + p_{2,f}$ (total momentum after collision) =

- **Q6** Determine the momentum change for cart 1 (Δp_1) and cart 2 (Δp_2). How do these compare?

- The total kinetic energy of the carts is given by KE $= (1/2)m_1v_1^2 + (1/2)m_2v_2^2$. Determine KE (a) before and (b) after the collision.

- **Q7** Is the total KE conserved in the collision you observed? What fraction of the total KE is lost in the collision?

8.2.2 $m_2 = 2m_1$

- This time, let the cart that is initially at rest in the middle of the track have a mass of 1 kg and the cart at the end of the track have a mass of 0.5 kg.

- Repeat all measurements and questions from the experiment for $m_1 = m_2$.

Lab 9

Work and Kinetic Energy

A force probe is attached to a motion cart. A hanging weight of 50 grams is used to provide tension to a string which pulls on the force probe and moves the cart.

In this activity, we monitor both the force on the cart and the cart's motion. We use the results to illustrate the work-energy theorem.

9.1 Cart without friction

- The force probe must be calibrated before it is used. In this experiment, the forces will be relatively small, so set the force probe to measure in the 10 Newton range.

  Start LoggerPro and configure the Logger Pro interface to use both a force and motion detector. After this, go to the "experiment" menu and then "calibrate." You are asked which probe to callibrate. Choose the force probe.

  Your first callibration point will be with the probe held vertically with no mass attached. Once the probe is in this position hit the "tare" button on the probe. Then put "O" in for the callibration. For the second callibration point will be done using a known suspended weight. A 500 gram mass (4.9 Newtons) will work well. Take the reading and proceed.

- You will need to obtain the mass of the cart/force detector combination. Write down your value below:

$$\text{mass} = \underline{\hspace{3cm}\text{kg}} \tag{9.1}$$

- Cut approximately 3 meters of string and use this to complete the pulley assembly. One end of the string will be attached to the hooked and of the force probe. The string then goes over the pulleys and is attached to a suspended mass (use 50 grams). Adjust the bottom pulley height so that the string attached to the cart is horizontal.

- Before proceeding, make sure the friction pad on the motion cart is not touching the track's surface.

- **With the cart level on the track and with no tension force applied, hit the "tare" button on the side of the force probe. After this, go to the experiment menu and zero the force probe.** Verify that a force reading gives a result very close to zero Newtons.

- Bring the cart to the end of the track away from the pulleys, start recording data, and then release the cart. Stop the cart before it hits the opposite end of the track.

- Make sure you have a good velocity vs. time plot. The velocity should start at zero and it should be clear at what point the cart was no longer moving freely. If the cart's velocity doesn't start at zero, then it was probably too close to the motion detector initially.

  Once you are sure you have reliable graphs, proceed to the questions below.

- **Q1** From your data, determine (a) the final kinetic energy for the cart, (b) the initial kinetic energy, and (c) the change in kinetic energy.

  - $v_o =$ ______________ m/s   KE$_o =$ ______________ J
  - $v_f =$ ______________ m/s   KE$_f =$ ______________ J
  - Δ KE $=$ ______________ J

- **Q2** While the cart is pulled, the value of the tension force should be approximately constant. Give the value for the average tension force below:

$$F_T = \underline{\hspace{3cm}}\text{N} \tag{9.2}$$

- **Q3** When force and displacement are in the same direction, what is the rule for calculating the work done by that force? From your data, determine the appropriate value for the displacement and then determine the work done by the tension force on the cart.

$$W_T = \underline{\hspace{3cm}}\text{J} \tag{9.3}$$

- **Q4** If the tension force is the only force that is doing work on the cart, then the work done by the tension force should equal the change in the cart's kinetic energy. Is this (approximately) true in your case?

9.2 Cart with friction

Remove the tape from the friction pad so that the pad drags on the motion track.

- Repeat the motion experiment as above. Remember to "tare" and zero the force probe before attaching the string to the probe. If there is a large amount of friction, you may need to add extra mass to the weight hanger in order to get the cart to accelerate.
- **Q5** Determine the change in KE and list the value below.

$$\Delta\,\mathrm{KE} = \underline{\hspace{3cm}}\,\mathrm{J} \tag{9.4}$$

- **Q7** From your data, determine the average tension force applied and the displacement over which the force is applied. Calculate the work done by this force.

$$W_T = \underline{\hspace{3cm}}\,\mathrm{J} \tag{9.5}$$

- **Q8** In this experiment, two forces are doing work on the cart, tension and friction, so that

$$W_{net} = W_T + W_f \tag{9.6}$$

According to the work-energy theorem, $W_{net} = \Delta\,\mathrm{KE}$. Use this to determine W_f.

$$W_f = \underline{\hspace{3cm}}\,\mathrm{J} \tag{9.7}$$

- Is the value of W_f positive or negative? Why is this expected?

Lab 10

Conservation of Mechanical Energy

10.1 Introduction and Setup

In an earlier activity, we monitored the motion of a dynamics cart as it moved up and down a dynamics track in terms of displacement, velocity, and acceleration. In this activity, we will be concerned with the description of the motion of a cart in terms of kinetic, potential, and total mechanical energy, the latter of which we will refer simply to as the total energy.

To begin, elevate a dynamics track at one end to a height that is approximately equal to two flat physics textbooks. A motion sensor is placed at the bottom of the track. Ensure the cart you will use has a working friction pad as we will be performing trials both without and with friction.

Additional setup instructions are as follows:

- For these trials, we need to have high quality position vs. time graphs. Before proceeding, ensure that you are able to produce good (smooth) position vs. time graphs when the cart goes up and down the track.
- Obtain the mass (m) of your cart, the length of the dynamics track (L), and the height (H) the track rises over its entire length. Write your values in your report.
- By default Logger Pro displays position, velocity, and acceleration curves when you start the program with a motion sensor attached to the Lab Pro interface. To display other quantities, we need to configure the Logger Pro software. To do so, perform the following steps:
  - Kinetic Energy, KE

    Starting from the toolbar menu, select `Data` → `New Column` → `Formula`. In the dialog box for this selection, type `KE` For the long and short names type and `J` for the units. Select the `definition` tab and in the equation box type

`0.5*M*(‘‘Velocity")*(‘‘Velocity’’)`

In the above, do not type the letter M; for M substitute the mass (in kg) of the cart.

- Potential Energy, PE

  Starting from the toolbar menu, select `Data` → `New Column` → `Formula`. In the dialog box for this selection, type `PE` For the long and short names type and `J` for the units. Select the `definition` tab and in the equation box type

  `M*9.8*‘‘Distance’’*H/L`

  Again, in the equation you type, substitute the measured values for M, H and L.

- Total Energy, ME

  Starting from the toolbar menu, select `Data` → `New Column` → `Formula`. In the dialog box for this selection, type `ME` For the long and short names type and `J` for the units. Click on the `definition` tab and in the equation box type

  `‘‘KE’’ + ‘‘PE’’`

- Setup your Logger Pro display to show three graph windows. In one window, plot distance vs. time. In the second window, plot KE and PE vs time. In the last window plot ME vs. time.

10.2 Motion without friction

- **Q1** Draw a free body diagram that represents all forces acting on the cart *while it is receiving its initial push up the track.* Is the person pushing performing positive or negative work on the cart? Explain.

- **Q2** Assume that there is no friction acting on the cart. Draw a free-body diagram that represents the forces acting on the cart as it moves up the track. For each force shown, state whether the force performs positive, negative, or zero work. Give your reasoning in each case.

- **Q3** Draw a free-body diagram that represents the forces acting on the cart as it moves down the track. For each force shown, state whether the force performs positive, negative, or zero work and give your reasoning in each case.

- **Q4** Kinetic energy (KE) is equal to (1/2)mv^2 and gravitational potential energy (PE) is equal to mgh. Sketch the behavior you expect for each of these quantities as a function of time as the cart goes up and down the track.

- Perform the trial. When doing so, make sure the cart starts at a point at least 0.5 m from the motion sensor. Make sure that you record the motion of the cart as it is pushed and while it is caught. The distance vs. time graph must be correct in order for other graphs to be meaningful, *i.e.* this plot should have a smooth parabolic shape. If possible, have your instructor check your results before proceeding.

- **Q5** State at which points in the cart's motion the kinetic energy is (a) smallest and (b) largest? Why is this the case?
- **Q6** State at which points in the cart's motion the gravitational potential energy is (a) smallest and (b) largest? Why is this the case?
- **Q7** When gravity is the only force performing work on an object, the total energy is constant. Do you observe this to be the case or very nearly so? Make a print out of your graph and include it in your results.

10.3 Total energy with friction present

- Lower the friction pad on your cart (perhaps by using a piece of paper as a wedge) so that the pad drags as the cart rolls. The friction should be great enough to impede the motion significantly, but the cart should still be able to roll up and down the track. Repeat the trial made in the previous section.
- **Q8** Is the total energy constant in this case? Describe its general behavior as a function of time.
- **Q9** Draw a free-body diagram that represents the forces acting on the cart as it moves up the track. For each force shown, state whether the force performs positive, negative, or zero work and give your reasoning in each case.
- **Q10** Draw a free-body diagram that represents the forces acting on the cart as it moves down the track. For each force shown, state whether the force performs positive, negative, or zero work and give your reasoning in each case.

Lab 11

Rotational Kinematics

11.1 Equipment and computer setup

The equipment consists of a Pasco rotational motion sensor with pulley attachment, support rod clamped to table top, thread, 2 gram mass, Vernier caliper, and a meter stick. Attach the rotary motion sensor to the metal rod so that the wheel assembly points upward.

Plug the rotary motion sensor into the DIG/Sonic 1 slot on the Lab Pro interface. Next, start the Logger Pro program on the computer. Once Logger Pro is started select the green oval Lab Pro icon from the toolbar. In the dialog box, select the DIG/Sonic 1 button (the button should then be highlighted) and then choose `Rotary Motion [Pasco]` under the sensor menu. After doing this, make sure all the other input channels set to have "`none`" for their sensors.

Before proceeding, additional configuration is needed so that angles are measured radians and angular velocity is measured in rads/sec. To do this, follow these steps:

- Angular displacement, θ

  From the toolbar, select `Data` → `New Column` → `Formula`. In the dialog box for the long and short names write `theta` and for units write `rads`. Click on the `definition` tab and in the equation box write `2.0*3.14159*''Position''`. The factor `2.0*3.14159` is the normal conversion factor between revolutions and radians. *Note: it may be necessary to later add a minus sign to this definition if counter-clockwise rotations are not positive valued as expected. If this is the case, select `Data` → `Modify Column` and add a minus sign to the equation.*

- Angular velocity, ω

  Select `Data` → `New Column` → `Formula`. For the long and short names write `omega` and for units write `rads/sec`. Click on the `definition` tab and in the equation box write `derivative(''theta'')`. This just means that we are taking the rate of change of θ with respect to time.

11.2 Simple rotations

In some of the following exercises, you will need to use some of the statistical functions of Logger Pro. If you need help with these, please ask the instructor.

1. Predict the value of the angular displacement in radians when a disk is rotated through 2.5 revolutions.

   - Prediction = radians

   Make the measurement by hitting the collect button on Logger Pro and spinning the disk through 2.5 counter-clockwise revolutions.

   - Observed displacement = radians

2. What do you expect will happen when the rotation is clockwise? State your prediction below, then make and record the measurement.

   - Observed displacement = radians

3. You want to make an angular displacement of -50 radians. Predict how many revolutions the disk must be spun through.

   - Prediction = revolutions

   Now make the measurement

   - Measurement = revolutions

4. Next we focus on the angular velocity, ω. Observe what happens in the angular velocity window when the wheel is spun manually while holding the rotational speed as constant as possible.

   All members of the group will compete to see who can hold the rotational speed closest to 15 rads/sec over a period of 10 seconds. While doing this, the person trying to spin the wheel at this constant speed is not allowed to look at the computer screen or a clock.

5. Spin the wheel such that it increases its velocity at as constant as rate as possible. It is not necessary to do this for a full 10 seconds. Approximately 2 seconds should be adequate.

   When a reasonably good curve is obtained, perform a straight line fit *to the data in the relevant region of the graph*. Regions can be selected by dragging the mouse in the graph window. Straight line fits are performed by selecting the proper menu item under "analysis."

   The analysis will report the slope of the straight line fit to the ω vs. time data.

   - What is the value of the slope?
   - What angular quantity does the slope represent?

   If printing is working, print a plot of the ω vs. time data with the straight line fit for each member of the group.

6. Give the wheel a good counter clockwise spin and let it rotate freely. Because of friction, the wheel will gradually lose angular speed. To estimate the angular acceleration, perform a straight line fit to a section of the resulting ω vs. time plot

   - Measured value of α =
   - Is α positive or negative? Why is this the case?

7. Repeat the above, but spin the wheel clockwise.

   - Measured value of α =
   - Is α positive or negative? Why is this the case?

11.3 Relation between rotational and linear motion

Remove the solid metal disk from the rotational sensor. Next, use a Vernier caliper to measure the diameter of the inside groove of the middle wheel on the wheel assembly. Use this measurement to determine and record the value of the wheel's radius.

- radius =

Wrap an approximately 1.5 meter strand of thread on the groove. Pull the free end of the thread over the pulley. Attach this end to the 2 gram mass.

See if it is possible to drop the mass from a height of one meter such that the attached string turns the wheel on the rotary motion sensor over the entire meter the hanger falls. You will use the computer to monitor the rotations of the wheel when the mass is dropped through one meter.

Hold the mass exactly one meter above the ground. Click on the `Collect` button. Once data taking is initiated on the computer, drop the mass. You should be able to see what portion of the motion corresponds to the time during which the mass was falling to the ground.

1. How many radians did the wheel turn through, $\Delta\theta$, while the mass fell to the ground?

2. What was the net distance, Δs, moved by a point on the inner groove of the middle wheel (where the string is wrapped) during the time the hanger fell to the ground? Give your reasoning.

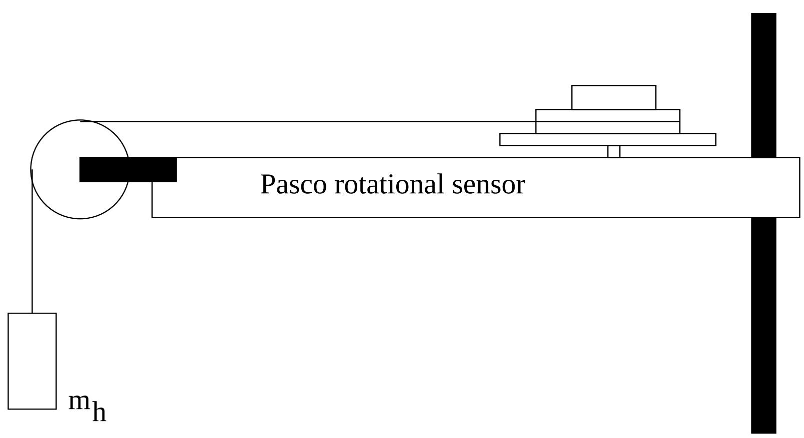
3. What is the value of $\Delta s/r$ where r is the wheel's radius? How does this compare to the value of $\Delta\theta$ you obtained?

Lab 12

Rotational Inertia

12.1 Setup

Use a Vernier caliper to measure the radius of the inside groove on the middle wheel of a Pasco rotational sensor and record the value you obtain. Next, attach a Pasco rotational sensor to a vertical support. Wrap a 1.5 m piece of string around the middle wheel on the rotational sensor. It may be helpful to use tape to fix the string to wheel so that isn't necessary to reattach the string repeatedly. Pass the string over an attached pulley wheel and suspend a mass of five grams to the hanging end of the string. A diagram of the setup appears below.



You will need to determine the angular acceleration of the rotation sensor. Use the instructions for Activity 17B to configure **Logger Pro 2.0** to measure θ in radians and ω in radians/sec. The angular acceleration α is obtained by finding the slope of a linear fit to the ω vs. time data.

12.2 Theory

Application of Newton's 2nd law to the hanging mass, m_h, yields the following equation:

$$m_h a_h = m_h g - F_T \tag{12.1}$$

where we take the downward direction to be positive. Here F_T is the string tension and a_h is the downward acceleration of the mass, m_h.

If the string is wrapped around a wheel of radius r_w, then the length of string, Δs, that is unwound when the wheel spins through an angle $\Delta\theta$ is given by $\Delta s = r_w \Delta\theta$. Likewise, the rate (in m/s) at which the string is unwound is $v_{unwind} = r_w \omega$ where ω is the angular velocity of the wheel. Finally, as the wheel's angular velocity increases, the rate at which string is unwound increases. The rate of increase in the velocity at which string is released is given by $a_{unwind} = r_w \alpha$ where α is the angular acceleration.

Since the string and hanging mass move together a_{unwind} and a_h must be equal. Since this is true, we can write Eq. (12.1) as

$$m_h r_w \alpha = m_h \, g - F_T. \tag{12.2}$$

The tension in the string applies a torque to the pulley wheel equal to $\tau = F_T r_w$. Using Eq. (12.2) for F_T we can rewrite this torque as $\tau = r_w m_h (g - r_w \alpha)$. The angular acceleration that results is $\alpha = \tau / I$ where I is the rotational inertia for the everything that is turning with the wheel. Using $I = \alpha/\tau$ and the expression for τ given earlier, we have the following result for I

$$I = \frac{m_h r_w (g - r_w \alpha)}{\alpha} \tag{12.3}$$

Thus, by observing the angular acceleration α that results for a certain hanging mass, m_h, the rotational inertia, I, of the spinning object can be determined by using Eq. (12.3).

12.3 Measurements

- First, determine the rotational inertia of the bare rotational sensor, I_{sensor}. Release the 5 gram hanging mass and record ω vs. t (this should be quite fast).

  The angular acceleration, α, is given by the slope of ω vs. t while the mass falls to the ground. Select the region of the graph which corresponds to this time interval. Next, go to the `analyze` menu and select `linear fit`. A straight line fit should appear through the part of the graph you have selected. The slope of the line is indicated on the screen. Write down this value of the slope as your result for α.

  Q1 Use Eq. (12.3) to determine I_{sensor}.

- Next securely attach the solid disk to the rotational sensor. Repeat the experiment as above. The angular acceleration should be much less on account of the increase in rotational inertia. Write down your value for α.

- **Q2** Use this new value of α to obtain the rotational inertia. The rotational inertia you measure is $I_{disk} + I_{sensor}$ (why?). To obtain I_{disk}, subtract I_{sensor} from your new I value.

- Next place the solid ring in the appropriate slots on the solid disk. Repeat the experiment to obtain the new α (it should be much smaller). Obtain a new result for I using Eq. (12.3).

- **Q3** This new value for I consists of $I_{ring} + I_{disk} + I_{sensor}$. Determine the value of I_{ring} itself by subtracting the values you obtained previously for I_{disk} and I_{sensor}.

12.4 Comparison to theory

Rotational inertia depends on two things: (1) the mass of the object and (2) how the mass is distributed about the axis of rotation. For objects with relatively simple shapes, exact formulas can be obtained for I.

- **Q4** The rotational inertia for a disk with respect to rotations about an axis through the center is given by $I_{disk} = M_{disk}R_{disk}^2/2$. Obtain M and R for your disk and see how the I value you obtain from this formula compares to your measurement.

- **Q5** The rotational inertia for a ring is given by $I_{ring} = M(R_{inner}^2 + R_{outer}^2)/2$. Compare the value of I obtained from this formula to the measurements you have made.

12.5 Dependence of I on r

A light metal bar with sliding weights will be used to investigate the dependence of I on the distance of the mass from the rotational axis. To rotate this bar, you will need to mount the rotational motion detector on its side. Attach the bar to the detector so that the bar will rotate about its center.

- Place the weights so that they are half-way between the center and the end. Make sure they are the same distance from the center (you can test to see what happens when the weight distribution is uneven). Following the previously described procedure, determine the rotational inertia for the bar-mass system.

- Move the weights to the end of the bar and determine the rotational inertia for the new arrangement.

- **Q6** By approximately how much did the rotational inertia increase when the masses where moved to the ends? Did it double or was the increase greater than that? Why is this the case?

Lab 13

Spring Oscillations

In the first part of this lab, you will evaluate the force constant for two dissimilar springs.

13.1 Spring constant

1. Suspend a spring vertically from a support and measure the equilibrium length of the spring, l_o.

2. As you add a mass to the bottom of the spring, the force, $F = M\,g$, stretches the spring to a length l. By adding mass to the end of the spring and measuring the resulting spring length, generate a table that looks something like the following (don't neglect the mass of the weight hanger):

M (kg)	$F = Mg$ (Newtons)	l (meters)	$[\,l - l_o\,]$ (meters)
0.000	0.000		
0.100			
0.200			
0.300			
0.400			

3. **Q1** Be sure to include this data in your activity write-ups.

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

$$F = k\,[\,l - l_o] \tag{13.1}$$

where F is the force stretching the spring. Thus, a plot of F versus $[l - l_o]$ should be a straight line with a 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) Go to the program menu on the computer and start the Graphical Analysis program via
`Programs` → `Vernier Software` → `Graphical Analysis`.

(b) Type in your $[l - l_o]$ vs. F data with $[l - l_o]$ as the x-column and F as the y-column. The data will be plotted in the graphics screen as it is typed in.

(c) You should obtain something that resembles a straight line. The spring constant, k, is the slope of this line. To obtain the slope, box in the data in the plot window. Go to the analysis menu and select a regression fit. This fit will print a value for the slope of the line. Record this value, including the proper units.

(d) **Q2** Print the value of k next to the data obtained for that spring.

(e) Repeat this procedure for your second spring. You will then have two springs, each with its own spring constant k.

13.2 Oscillation frequency

We will now monitor the vertical oscillations of 300 grams of mass suspended from the bottom of the spring.

1. Obtain the mass of the spring, m_{sp}, that you will use.

2. Attach a motion sensor to the Lab Pro interface and then start the Logger Pro program.

3. Place the motion sensor on the floor below the mass. The distance between the sensor and the mass must be at least 0.5 m.

4. Set your mass and spring system into motion and then hit "collect" on the computer. You should obtain a motion plot.

5. **Q3** Use the motion plot to determine the repeat time for the motion, known as the period, T. To obtain the most accurate value possible, obtain the time it takes to make several oscillations and divide the total time by the number of oscillations. Also, use the "examine" tool to obtain precise time values.

   The frequency, f, represents the number of times the motion repeats per unit time. Your measured value for f is given by $f = 1/T$ where T is the value obtained previously.

   List your values for f and T including the appropriate units.

6. **Q4** The theoretical result for f is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_{eff}}}. \tag{13.2}$$

   where $m_{eff} = m_{hanging} + 0.33 \times m_{sp}$. Determine the percentage difference between the measured value for f and the theoretical result.

7. **Q5** Instead of 300 grams, attach 600 grams to the spring. Determine the f and T values for this case.

8. **Q6** Determine the percentage difference between the measured and theoretical values for f.

13.3 Energy considerations

1. Suspend a mass of 300 grams from one of the springs. Use Logger Pro and the sensor placed below the suspended mass to determine the equilibrium distance, d_{eq}, between the mass and the sensor.

2. Next, create formulas for evaluating kinetic, potential and total energies on Logger Pro:

   - Kinetic Energy, KE

     Go to `Data`, `New Column` and `Formula`. For the long and short names write `KE` and for units write `J`. Click on the `definition` tab and in the equation box write

     `0.5*`M_{eff}`*(''Velocity'')*(''Velocity'')`.

     In the above formula, the number you should put in for M_{eff} is $(M_{hanging} + 0.5 \times M_{spring})$.

   - Potential Energy, PE

     Go to `Data`, `New Column`, and `Formula`. For the long and short names write `PE` and for units write `J`. Click on the `definition` tab and in the equation box write

     `0.5*k*(''Distance''-deq)*(''Distance''-deq)`.

     Here, `k` should be the value of the spring constant for the spring. For `deq` you should use the equilibrium distance as measured by the computer.

   - Total Energy, ME

     Go to `Data`, `New Column`, and `Formula`. For the long and short names write `ME` and for units write `J`. Click on the `definition` tab and in the equation box write

     `''KE'' + ''PE''`.

3. Setup your Logger Pro display to show two graph windows. In one window, plot distance vs. time. In the other window, plot KE, PE, and ME vs. time.

4. Stretch the spring about 1 cm (small oscillations work best), release to set the mass in oscillation and hit `''collect.''` Your data should show smooth oscillations for all quantities. Once you have obtained good data, print a copy of the resulting graphical display for each student in the group.

5. **Q7** What happens to the kinetic energy as a function of time? Mark points on the graph where it is largest and smallest. Describe in words at which points in the motion of the mass is its kinetic energy (a) largest and (b) smallest, i.e. is the kinetic energy largest when the position of the mass close to or far from the equilibrium point.

6. **Q8** What happens to the potential energy as a function of time? Mark points on the graph where it is largest and smallest. Describe in words at which points in the motion of the mass is its potential energy (a) largest and (b) smallest.

7. **Q9** How does the total mechanical energy behave as a function of time? Is the total energy conserved (or at least nearly so according to our measurements)?

Lab 14

Speed of Sound and Sound Wave Reflection

14.1 Setup

The apparatus consists of long and short PVC tubes, a Vernier microphone and a meter stick. The long tube should be over one meter long.

1. Plug the microphone into channel 1 of the Lab Pro interface. Start Logger Pro on the computer. The graph labels in the Logger Pro window should indicate that a microphone has been detected by the Lab Pro interface.

2. Select `experiment` → `sampling` and set the sampling rate to 10,000 /sec. The experiment length should be 0.050 s. Next select the "mode" tab and choose the "real-time collect" mode.

3. While nobody is talking, hit the "collect" button. The sound reading obtained indicates the background level when no sound pulses are directed toward the microphone.

4. Knowing this background value, go to "experiment" and then "triggering." Activate "enable triggering." Set the numerical value for the trigger level to be slightly above the background sound level reading.

5. While being quiet, hit the collect button. Data collection shouldn't start immediately. However, when a sound is made near the microphone then readings should start. Verify that this works as expected.

6. Under `data` → `column options` → `time` configure the time display so that it shows five figures after the decimal. This extra precision will be used later to obtain an accurate value for the sound speed.

7. Once again, hit the collect button and make a sound to verify that the set up is working properly.

14.2 Reflection of sound waves from open and closed tube ends

- Place a tube near the front of the microphone. Make a sound by hitting the other end of the tube such that your palm seals the tube end when you strike the tube. It is not apparent from listening to the sound, but the sound not only passes through the open end, but it is reflected back into the tube where it makes a full round trip before emitting sound again at the open end.

- With all group members quiet, hit the collect button and record the sound of the thud. You should see a repeating pattern corresponding to the sound wave making repeated trips through the tube.

- If your tube is sufficiently long and you made a good sharp thud on the tube, the pattern you have should be a series of clearly separated pulses. If this is not the case, repeat the collection until you get nice sharp pulses.

- **Q1** Make a sketch of the pulse pattern you observe.

- **Q2** Pulses come out of the end near the microphone one after another. How are adjacent pulses different?

- This time give the tube end a quick thud and pull back your hand quickly so that both ends of the tube are open immediately after the sound is made (ask the instructor for a demonstration if necessary).

- **Q3** Make a sketch of the pulse pattern you observe for this case.

- **Q4** What is the most significant difference between this wave pattern and the wave pattern that emerges from the tube with one end closed?

14.3 Speed of sound

- **Q5** Make a simple sketch of the tube. Show the path the *first sound pulse* makes in traveling from where the sound originates to the microphone.

- **Q6** Make a simple sketch of the tube. Show the path the *second sound pulse* makes in traveling from where the sound originates to the microphone.

- **Q7** How does the difference in distance traveled by these first two pulses compare to the length of the tube you use

- **Q8** Measure the difference in arrival times for two adjacent pulses using the maximum precision available. Use the “examine” feature of Logger Pro to obtain this precision.

- **Q9** Use the above information to determine the speed of sound.

- **Q10** Compare your result to the expected value as given in the textbook (table 16.1 on page 468).

  It is reasonable to be expect that you should be within 3% of the expected value. If you are not, repeat the experiments and try to reduce possible sources of experimental error. If you are more than 15% from the expected value, then you should consult with the instructor to determine the likely source of error.

Lab 15

Speed of Sound II

15.1 Introduction

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

$$f\,\lambda = v. \tag{15.1}$$

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. (15.1) to obtain the sound velocity, v. In principle, the v value for each tuning fork should be the same; sound velocity is nearly independent of frequency.

We will use a property called resonance to determine λ for each tuning fork. This is how it works. If a tuning fork is place above an open column, then sound waves will be sent down the column and some of this sound energy will be reflected back. When these reflected waves return to the open end at the top, it is possible for these reflected waves to be reflected back downward. The process can repeat many times.

For a set of *special* column lengths,

$$L = \lambda/4 + c,\ 3\lambda/4 + c,\ 5\lambda/4 + c,\ \cdots, \tag{15.2}$$

the reflected sound waves are exactly in phase with each other; here, c is an end correction factor, a constant that depends on the geometry of the open end (top) end of the tube. The amplitudes of these in-phase waves add and the net sound wave amplitude in the tube is greatly enhanced. 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 rather quiet. 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, L, where resonance is observed can be used to determine λ and, thus, the sound velocity, v.

15.2 Determination of sound velocity

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, top end of the tube. The fork is set into vibration by striking it soft rubber mallet. When the tuning fork is vibrating, L is adjusted by slowly varying the height of the water reservoir, causing the water level in the tube to change.

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 both tuning forks, find all the L values that produce resonance. (There should be two or 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 two estimates for v, one from each fork. Give the percentage difference between the two values of v that you have obtained.

Lab 16

Specific heat

16.1 Introduction

When a warm and cold object are brought into contact, heat flows from the warm object to the cold. Heat will continue to flow until the temperatures of the objects become equal.

If Q is the heat transferred to an object ($Q > 0$) or transferred from an object ($Q < 0$), there will be a proportional change in the temperature of the object, as long as the heat transfer is not too large and the object is held at either constant volume or constant pressure;

$$Q \propto \Delta T. \tag{16.1}$$

The larger the mass of the object, the smaller ΔT will be for a given value of Q, *i.e.* more heat is required to raise the temperature of a large object. Another factor influencing the relationship between Q and ΔT is the type of material used. Some materials require very little heat to raise the temperature a large amount.

Taking these factors into consideration, the relationship between Q and ΔT is given as

$$Q = c\, m\, \Delta T \tag{16.2}$$

where m is the object's mass and c is the specific heat for the object which is determined by the objects composition.

16.2 Equal amounts of water

In this first experiment, equal amounts of cold and hot water will be combined. First, you will formulate a prediction for the final temperature and then you will test the prediction.

1. **Q1** When the hot and cold water are combined, heat will flow from the hot to the cold water. Let Q_1 be the heat flow from the hot water and Q_2 be the heat flow into the cold water. How do Q_1 and Q_2 compare?

2. Using this relationship between Q_1 and Q_2 and the relationship between Q and ΔT in Eq. (16.2), determine the relationship between ΔT_1 and ΔT_2. Take into account that the hot and cold water are made of the same substance and have equal mass.

3. $\Delta T_1 = T_{f,1} - T_{o,1}$ with a similar definition for ΔT_2. Substitute these definitions into your relationship between ΔT_1 and ΔT_2.

4. **Q2** When the hot and cold water are mixed and fully equilibrated $T_{f,1} = T_{f,2} = T_f$. Determine an expression for T_f in terms of $T_{o,1}$ and $T_{o,2}$.

5. Now we will perform the experiment. Obtain equal amounts of hot and cold water from the tap. Place each in a separate Styrofoam cup and then measure and record their initial temperatures.

6. **Q3** Right after the temperatures are obtained and recorded, combine the hot and cold water. Gently stir the water and record the final temperature, T_f. Compare the measured value of T_f to the predicted value.

16.3 Unequal amounts of water

In this second experiment, cold and hot water will be combined in a two-to-one ratio (two parts hot to one part cold). Following the same procedure in the previous experiment, you will formulate a prediction for the experiment and then test your prediction.

1. When the hot and cold water are combined, heat will flow from the hot to the cold water. Let Q_1 be the heat flow from the hot water and Q_2 be the heat flow into the cold water. How do Q_1 and Q_2 compare?

2. Using this relationship between Q_1 and Q_2 and the relationship between Q and ΔT in Eq. (16.2), determine the relationship between ΔT_1 and ΔT_2. Take into account the hot and cold water are made of the same substance and there is twice as much hot water as cold.

3. $\Delta T_1 = T_{f,1} - T_{o,1}$ with a similar definition for ΔT_2. Substitute these definitions into your relationship between ΔT_1 and ΔT_2.

4. **Q4** When the hot and cold water are mixed and fully equilibrated $T_{f,1} = T_{f,2} = T_f$. Determine an expression for T_f in terms of $T_{o,1}$ and $T_{o,2}$.

5. Now we will perform the experiment. Obtain hot and cold water from the tap with a two-to-one ratio for the hot to cold water volumes. Place each in a separate Styrofoam cup and then measure and record their initial temperatures.

6. **Q5** Combine the hot and cold water. Gently stir the water and record the final temperature. Compare the measured value of temperature to the predicted value.

16.4 Different substances

You will heat 200 grams of steel to nearly 100 degrees Celsius by immersing it in boiling water for several seconds. You will then drop it into cool water and then record the final temperature after equilibrium is attained. Before proceeding to the experiment you will develop some equations for using your results to determine the specific heat for steel.

1. When the hot steel and cold water are combined, heat will flow from the steel to the cold water. Let Q_{st} be the heat flow from the hot water and Q_{H_2O} be the heat flow into the cold water. How do Q_{st} and Q_{H_20} compare?

2. Using this relationship between Q_{st} and Q_{H_20} and the relationship between Q and ΔT in Eq. (16.2), determine the relationship between ΔT_{st} and ΔT_{H_2O}. Since the two substances are different, the specific heats, c_{st} and c_{H_20}, will not cancel from the equation representing this relationship.

3. In this experiment, we will consider c_{st} as an unknown to be determined. T_f, $T_{o,st}$, T_{o,H_20}, m_{st}, and m_{H_20} are all measurable quantities and we take c_{H_20} to be 4190 J/(kg ^{o}C). Use the relationship you derived above to show that

$$c_{st} = -c_{H_20} \frac{m_{H_20}\ \Delta T_{H_20}}{m_{st}\ \Delta T_{st}} \tag{16.3}$$

4. While bringing a beaker of water to boiling, obtain the mass of the empty Styrofoam cup which you will use to hold cool water. After obtaining the mass of the empty cup, pour in cool water leaving plenty of room for when you will drop in the hot steel. Weigh the filled cup. The difference in mass of the filled and empty cup gives you the mass of the water. Also obtain the value for the steel mass.

   - $m_{H_20} =$
   - $m_{st} =$

5. You will also want to construct a cover for your Styrofoam cup. When you finally drop the hot steel into the cup of cool water, it will take some time before the temperature of the water stops changing. You don't want to lose heat to the surrounding air during this time. Your cover should include a slot for a thermometer.

6. When the water in the Pyrex beaker has finally reached boiling temperature, lower the steel into the boiling water.

7. Before you remove the steel and place it into the cool water, measure both the temperature of the boiling water and the cool water. To obtain the temperature of the cool water accurately, stir it gently for a few seconds with your thermometer before taking a reading.

   Record your temperatures here.

   - $T_{o,st}$ (the boiling temperature) =
   - T_{o,H_20} (the temperature of the cool water) =

8. After leaving the steel in the boiling water for a sufficiently long time so that steel obtains the same temperature as the boiling water, remove the hot steel from the boiling water, drop drop it into the cool water and then cover the container. Begin monitoring the temperature of the water, occasionally stirring the water lightly. Record the final temperature, T_f, where the thermometer reading stops changing.

   - T_f =

9. **Q6** You now have enough information to calculate the specific heat of steel using Eq. (16.3). Show your calculations and final result.

10. **Q7** Is the specific heat you obtain for steel larger or smaller than that of water? How does your value for c_{st} compare to the expected value of 460 J/(kg ^{o}C)?