

# PHYSICS 211

## LAB #1: Kinematics

A Lab Consisting of 5 Activities

Name: \_\_\_\_\_

Section: \_\_\_\_\_

TA: \_\_\_\_\_

Date: \_\_\_\_\_

Lab Partners: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Circle the name of the person to whose report your group printouts will be attached. Individual printouts should be attached to your own report.

# Physics Lab 211-1

## Equipment List

Motion detector

Level

211 friction cart with reflector

Standard cart track setup

Meter stick

## Computer File List

*MacMotion* file 0211-01 Constant Velocity

*MacMotion* file 0211-01 Data Entry 1

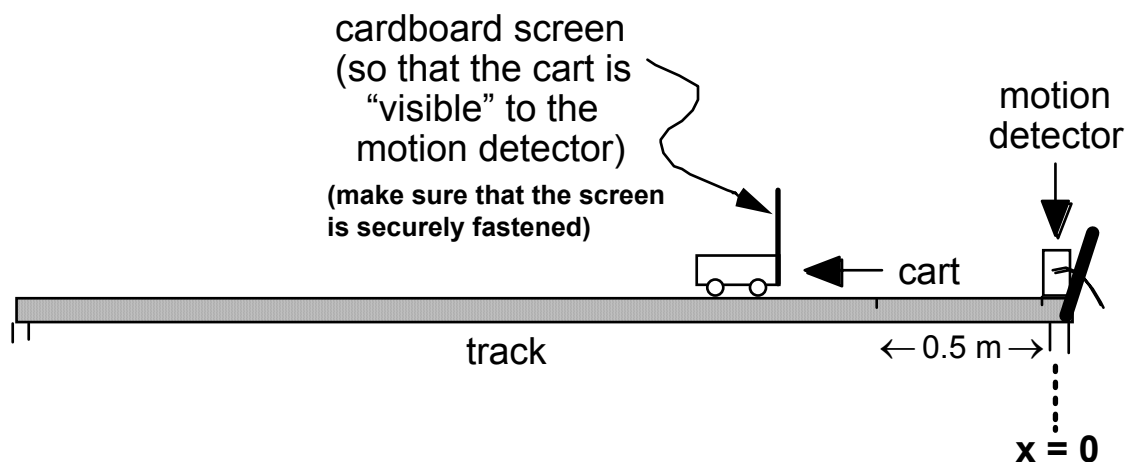
## Investigation 1: Motion with Constant Velocity

**Goal:** To study the relationship among distance, velocity, and acceleration vs. time graphs of an object with constant velocity.

### Activity 1: What's Your Position On This Motion?

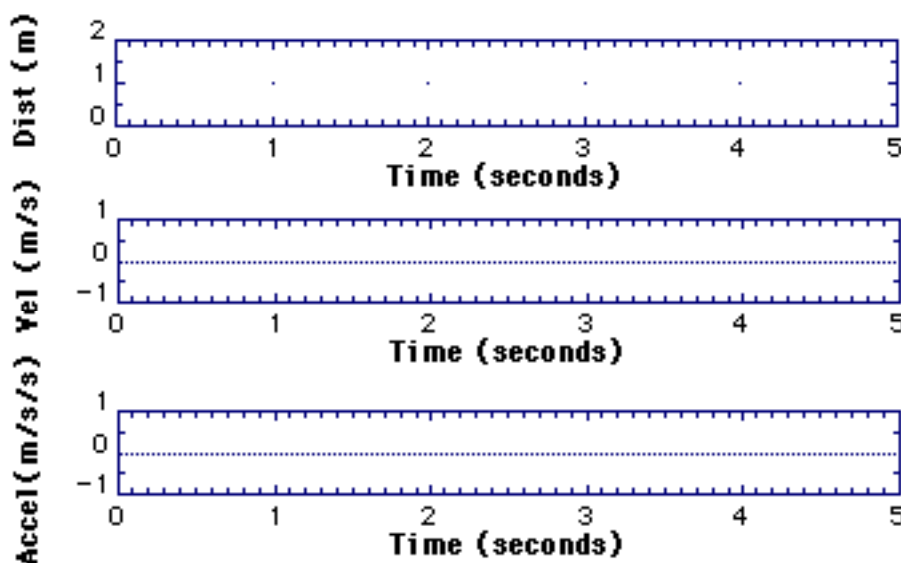
**Procedure:**

1. Set up the cart on the track as shown in Figure 1. The friction pad on the underside of the cart *should not* contact the surface of the track. Make sure that the track is level.



**Figure 1.** Experimental set-up for Activity 1

2. Set up to graph distance, velocity, and acceleration.
  - Pull down the **File** menu and select **Open....** Click once on **Desktop**, twice on **211 LAB FILES**, then twice more on the **Lab 1** folder. The files you need for this laboratory will be kept in this folder. Double click on **CONSTANT VELOCITY** to load it. The graph in Figure 2 should appear on the screen.



**Figure 2.** Constant Velocity graph format for Activity 1

- Predictions:**
- Based on the distance vs. time graph given in Figure 3, use a dashed line to sketch as precisely as possible your predictions for the velocity vs. time and acceleration vs. time graphs in Figure 3.
  - Deduce numerical values for the average velocities and average accelerations in both Regions I and II; record your predictions in the “Predicted” column of Table 1.

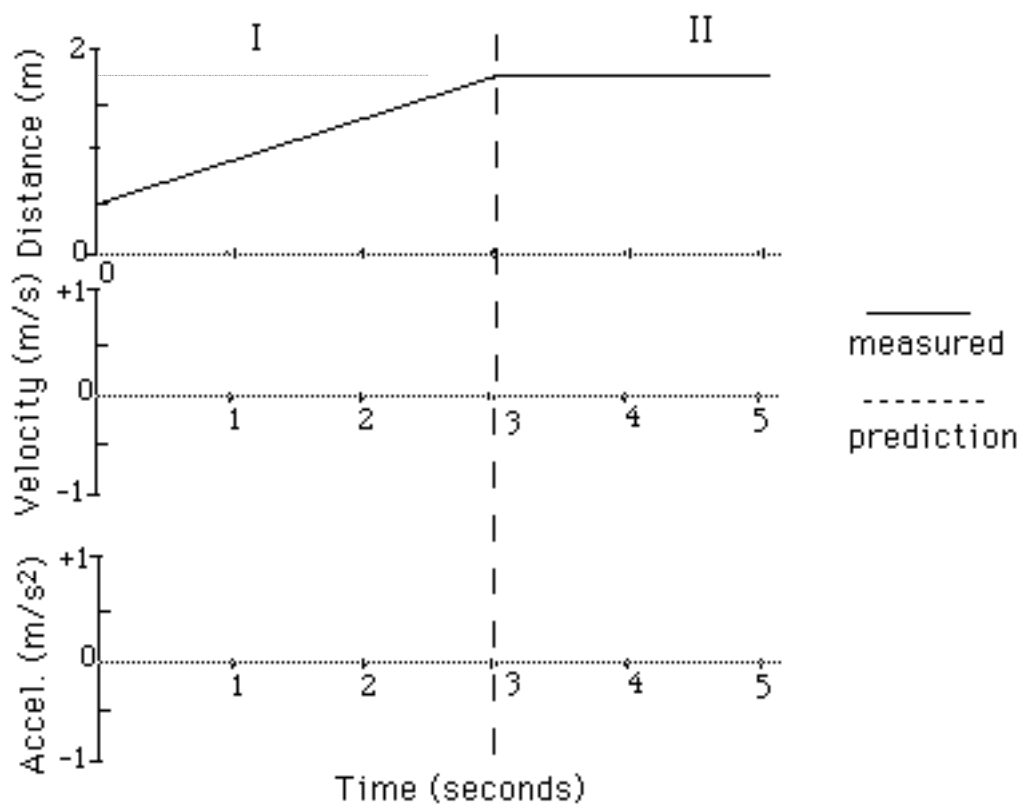
**Note:** The *average velocity* during a particular time interval is the change in *distance* divided by the change in time; in other words, it is the average *slope* of the distance vs. time graph in that interval.

Thus, the average velocity is given by,

$$v_{\text{average}} = \frac{\Delta \text{position}}{\Delta \text{time}} = \frac{(\text{position}_{\text{end}} - \text{position}_{\text{beginning}})}{(\text{time}_{\text{end}} - \text{time}_{\text{beginning}})} \quad (\text{Eq. 1})$$

Similarly, the *average acceleration* is the change in *velocity* divided by the change in time, or,

$$a_{\text{average}} = \frac{\Delta \text{velocity}}{\Delta \text{time}} \quad (\text{Eq. 2})$$



**Figure 3.** Predictions for Activity 1

**Procedure:**  
(continued)

3. Test your predictions by making the graphs.
  - Click on **Start** to begin graphing. When you hear the clicks of the motion detector, give the cart a quick shove with your hand, then stop it at an appropriate time later in order to make a *reasonable* reproduction of the distance vs. time plot shown in Figure 3. Repeat until you get a "nice" set of graphs (for a discussion of what we mean by "nice," see Appendix A on page 18).
  - When you have made a reasonable duplicate of the given distance vs. time graph, use a solid line to sketch your actual graphs of distance, velocity, and acceleration over your predicted graphs (dashed lines) in Figure 3. Change the scales of the graph if necessary so that the region of interest "fills" the graphs. To do this, double click on the background of any graph. When the "dialog box" appears, just type over the numbers which set the scale.
4. Analyze your data for comparison with your predictions. Select **Analyze Data A** from the **Analyze** menu. For Region I of Figure 3 *only*, pick eight values of velocity and acceleration; record these values in the blanks below, and determine the mean values. Record these averages in the "Mean Value" columns in Table 1.

Velocity: \_\_\_\_\_  
 \_\_\_\_\_

Acceleration: \_\_\_\_\_  
 \_\_\_\_\_

Mean velocity: \_\_\_\_\_ m/s

Mean acceleration: \_\_\_\_\_ m/s<sup>2</sup>

Velocity (m/s)	Predicted Value (from Fig. 3)	Mean Value From Your Recorded Data	Acceleration (m/s <sup>2</sup> )	Predicted Value (from Fig. 3)	Mean Value From Your Recorded Data
Avg. Vel. I			Avg. Accel. I		
Avg. Vel. II			Avg. Accel. II		

**Table 1.** Activity 1 results

**Question:**

- How well were you able to reproduce the distance vs. time graph in Figure 3? How would you need to move the cart to achieve a more accurate reproduction?

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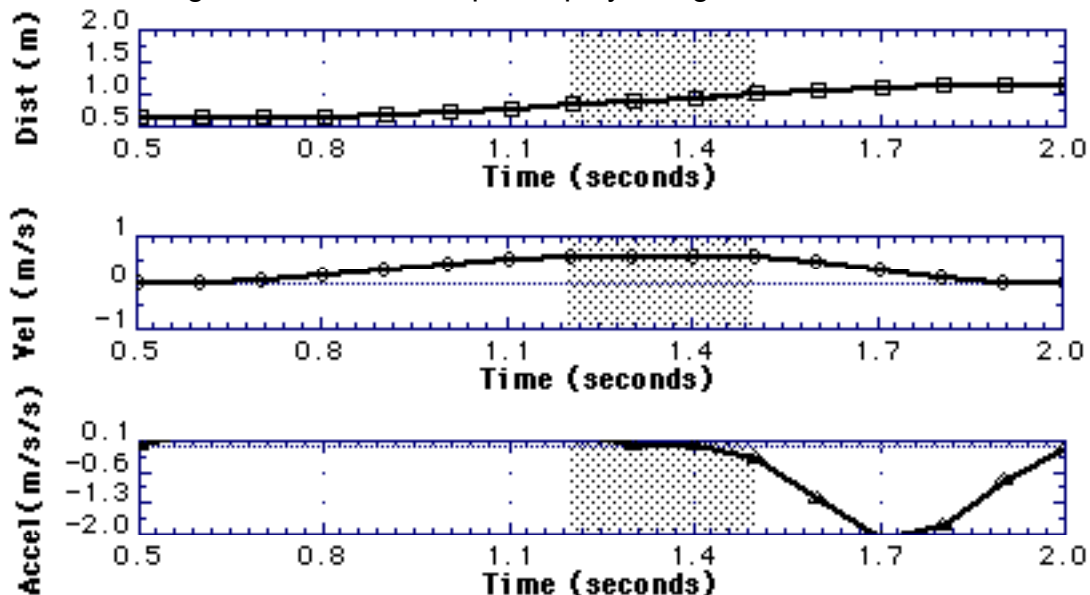


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**Procedure:**  
(continued)

5. New Tool: Automatic Averaging!

- You can also let the computer do most of the work of averaging your data. Move the cursor (i.e., the vertical line) to one end of Region I you considered in Figure 3. Now press and hold the mouse button down and move the cursor to the other end of this interval. Release the mouse button. Notice that the region of interest is now shaded. This is the computer's way of letting you know that it is looking only at this region. See the example display in Figure 4.



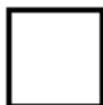
**Figure 4.** Automatic averaging procedure

- Now select **Statistics...** from the **Analyze** menu. A window will appear with the computer's calculations of the mean (and other statistical data) during the shaded interval for distance, velocity, and acceleration.
- Practice using this tool by checking the average you obtained above. Record the mean velocity and acceleration in Region I of Figure 3 obtained from this procedure:  
Mean velocity: \_\_\_\_ m/s      Mean acceleration: \_\_\_\_ m/s<sup>2</sup>
- Click **OK** to remove the Statistics window when you have noted the values of interest.

**Question:**

- Are the values obtained with automatic averaging close to your previously calculated values? What is the percent difference between the two values?

\_\_\_\_\_



TA Discussion  
Checkbox

← Ask your TA to come over, check and discuss your results, and mark this box.

## Investigation 2: Motion with Constant Acceleration

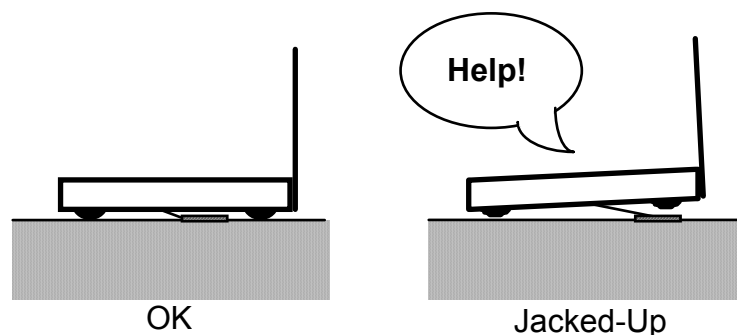
**Goals:** • To study the relationship between distance, velocity, and acceleration vs. time graphs when an object experiences a constant, non-zero acceleration.

**Introduction:** Acceleration is the *time rate of change* of velocity. In this investigation you will look at velocity and acceleration graphs of the motion of a cart rolling on a track.

### Activity 2: Time to Slow Down

**Introduction:** When a cart on a frictional surface is pushed, it will slow down after it is released. A full understanding of this process must await discussion of Newton's Laws and frictional forces; for now, we simply exploit the fact that friction causes the cart to slow down so that we can examine the relationship between velocity and acceleration.

- Procedure:**
1. Set up to graph distance, velocity, and acceleration. The graphs should be set up as in Activity 1 (see Figure 2).
    - If the graph is set up properly, but still has your results from Activity 1, then select **Clear Data A** under the **Data** menu to clear your previous results.
    - If not, pull down the **File** menu and select **Open** from the **File** menu. Click once on **Desktop**, twice on the **211 LAB FILES** folder, then twice again on the **Lab 1** folder. Double click on **CONSTANT VELOCITY** to load it. The graph shown in Figure 2 should appear on the screen.
  2. Leave the cart and track set up as shown in Figure 1.
    - Adjust the cart's friction pad using the knob on the top of the cart so that there is a significant amount of friction when you move the cart back and forth on the track; however, be sure that all the wheels touch and still roll smoothly on the track. In other words, don't let the cart get "jacked up" on the friction pad as illustrated in Figure 5.

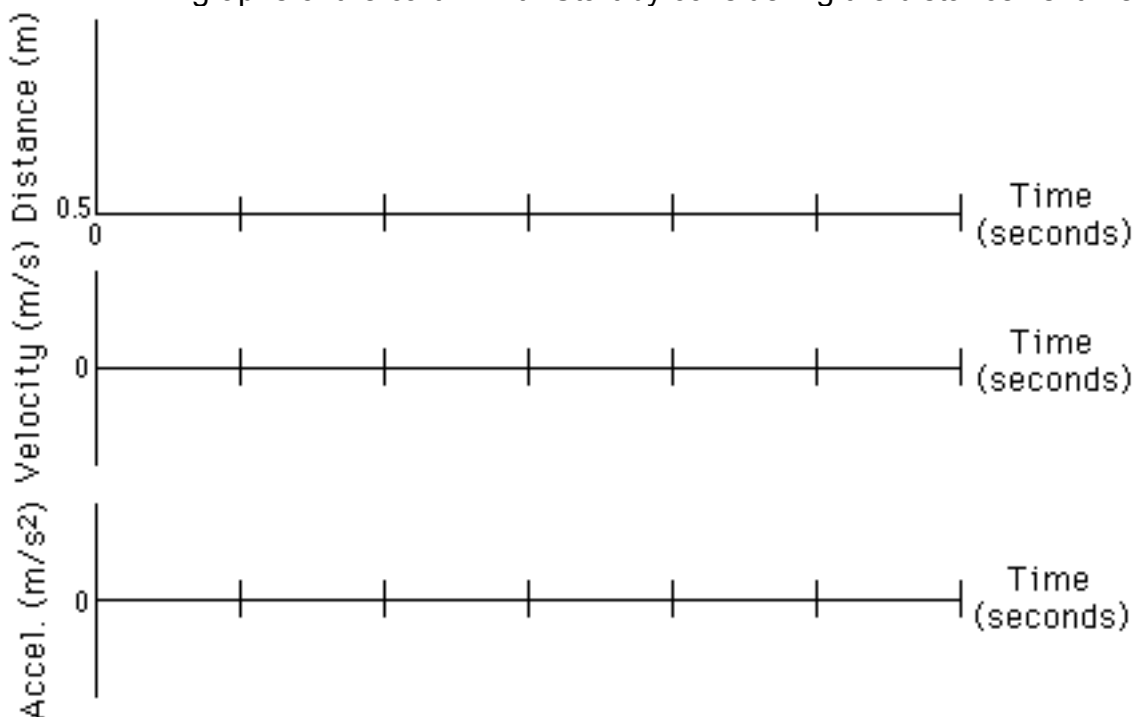


**Figure 5.** Right and wrong friction pad adjustments

**Predictions:**

- If you give a cart with friction a push away from the motion detector and release it, will the acceleration be positive, negative or zero (after it is released)?
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- If a cart starts at the 0.5 meter mark at time = 0 seconds, and is pushed gently away from the detector and released, sketch in Figure 6 your predictions for the resulting distance, velocity, and acceleration vs. time graphs of the cart. Hint: Start by considering the distance vs. time graph.



**Figure 6.** Predicted graphs for Activity 2, part 1

**Procedure:**  
(continued)

3. Test your predictions by graphing the motion of the cart as it coasts away from the detector on the level track.
  - Start with the back of the cart at the 0.5 meter mark. When you begin to hear clicks from the motion detector, give the cart a gentle push away from the detector and let it coast to a stop near the end of the track (be sure that your hand is not between the cart and the detector).
  - You may have to try a few times to get a good run (i.e., until you can see the whole motion and the graphs are clear). If necessary, change the scales in order to make your graphs clearer.



**Questions:**

- Is the sign of your acceleration graph what you predicted? How does *slowing down* while moving *away* from the detector result in this sign of acceleration?
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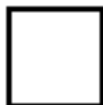
**Procedure:**  
(continued)

4. (a) Calculate the average acceleration by measuring the slope of your velocity vs. time graphs (see Equations 1 and 2). You can do this by using **Analyze Data A** (or **B**) to read the velocity and time coordinates for two typical points of **Data A** (or **B**). Record your results in the appropriate column of Table 2 (see Equations 1 and 2).  
  
(b) Also, use the computer's averaging capability discussed previously to determine the average measured acceleration over a selected time interval for your data. Record your result in the appropriate column of Table 2 below, then determine the percent difference between this estimate of the acceleration, and that determined in (a).

$$\% \text{difference} = 100 * \frac{\{(\text{slope of } v \text{ vs. } t) - (\text{mean acceleration})\}}{\text{mean acceleration}} \quad (\text{Eq. 3})$$

Data	Slope of velocity vs. time graph	Mean Measured Acceleration	%Difference
slowing down away from the detector			

**Table 2.** Acceleration results in Activity 2



TA Discussion  
Checkbox

5. Print out your results.
  - Use **Set Graph Title** in the **File** menu to label your graph with the title ***Slowing Down*** and with the names of each group member.
  - **Print** *one* copy of this graph for your group.

**Questions:**

- How would the velocity vs. time graph look if you pushed the cart *toward* the detector?

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- How would the acceleration vs. time graph look if you pushed the cart *toward* the detector?

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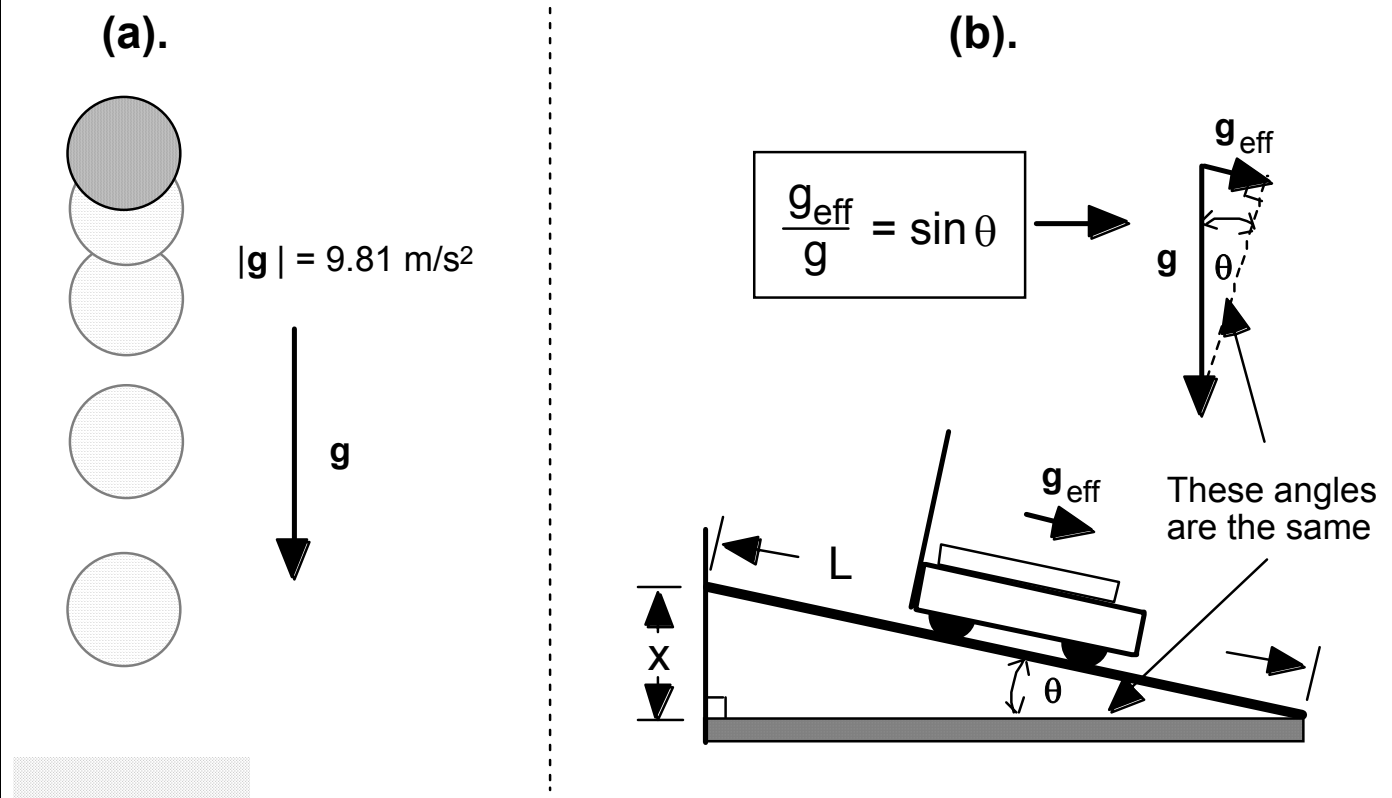
## Investigation 3: Motion in the Presence of Gravity

**Goals:** • To study how gravity affects the motion of objects

**Introduction:** In Investigation 2 you looked at velocity and acceleration graphs for objects with a changing velocity. In this investigation you will look at examples of *accelerated motion* due to the presence of gravity. **Note** - A full appreciation of gravitational acceleration must await the discussion of Newton's Laws and the gravitational force. For this investigation, it is sufficient for us to know the fact that a falling object experiences a "gravitational" acceleration,  $g = 9.81 \text{ m/sec}^2$ .

### Activity 3: Inclined to Let It Slide

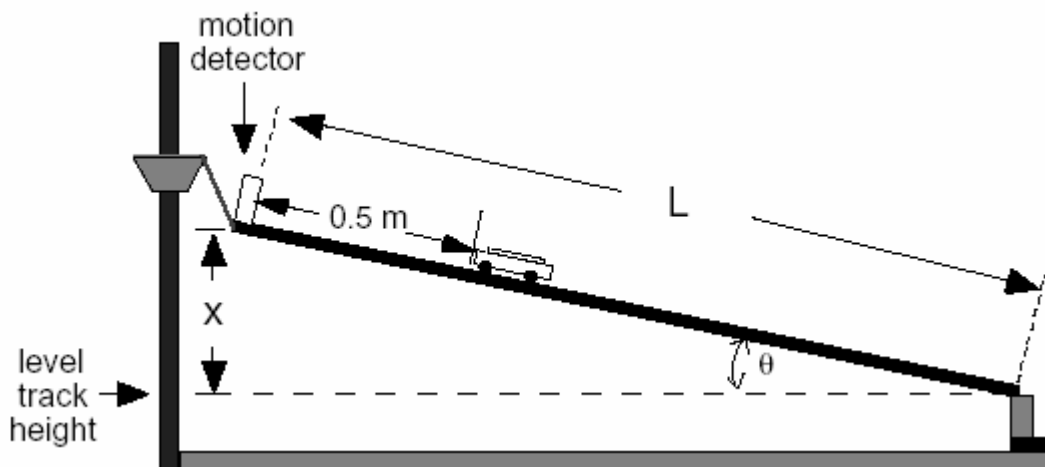
**Important Aside:** In the previous investigation, you pushed a cart in the presence of friction to make it accelerate on a level ramp. In this investigation you will examine the acceleration of an object due to gravity. As you heard in lecture, an object in "free-fall" experiences a downward (i.e., towards the earth) acceleration of magnitude  $g = 9.81 \text{ m/sec}^2$  (see Figure 8 (a)). In this investigation, you will study the "frictionless" motion of a cart on an inclined track. In this case, the cart experiences not the total gravitational acceleration,  $g$ , but rather a component of the gravitational acceleration which we'll call  $g_{\text{eff}}$  (see Figure 8 (b)); nevertheless, the motion of the cart is in many respects analogous to that of an object in "free-fall," as you shall see.



**Figure 8.** (a) "Free Fall" motion vs. (b) "Frictionless" motion down an incline

**Procedure:**

1. Set up the motion detector, track and cart as shown in Figure 9.
  - Raise the detector end of the track *at least* 15 cm above its level track position (i.e., so that  $x \geq 15$  cm; see Figure 9), making sure that the motion detector has a good view of the cart all the way down the ramp. *There should be no friction set on the cart.*



**Figure 9.** Experimental arrangement for Activity 3

2. Set up to graph distance, velocity, and acceleration. The graph should be the same as that used in Activities 1 and 2 (see Figure 2).
  - Clear your previous results by selecting both **Clear Data A** and **Clear Data B** under the **Data** menu.
  - If the graph does not look like Figure 2, **Open CONSTANT VELOCITY** in the **Lab 1** folder (under the **File** menu).
3. Measure the angle of the inclined track.
  - Study Figure 9 and carefully measure the values of  $x$  and  $L$  in your experiment, then deduce the inclination angle  $\theta$ .

$x =$  \_\_\_\_\_       $L =$  \_\_\_\_\_       $\theta = \sin^{-1}(x/L) =$  \_\_\_\_\_

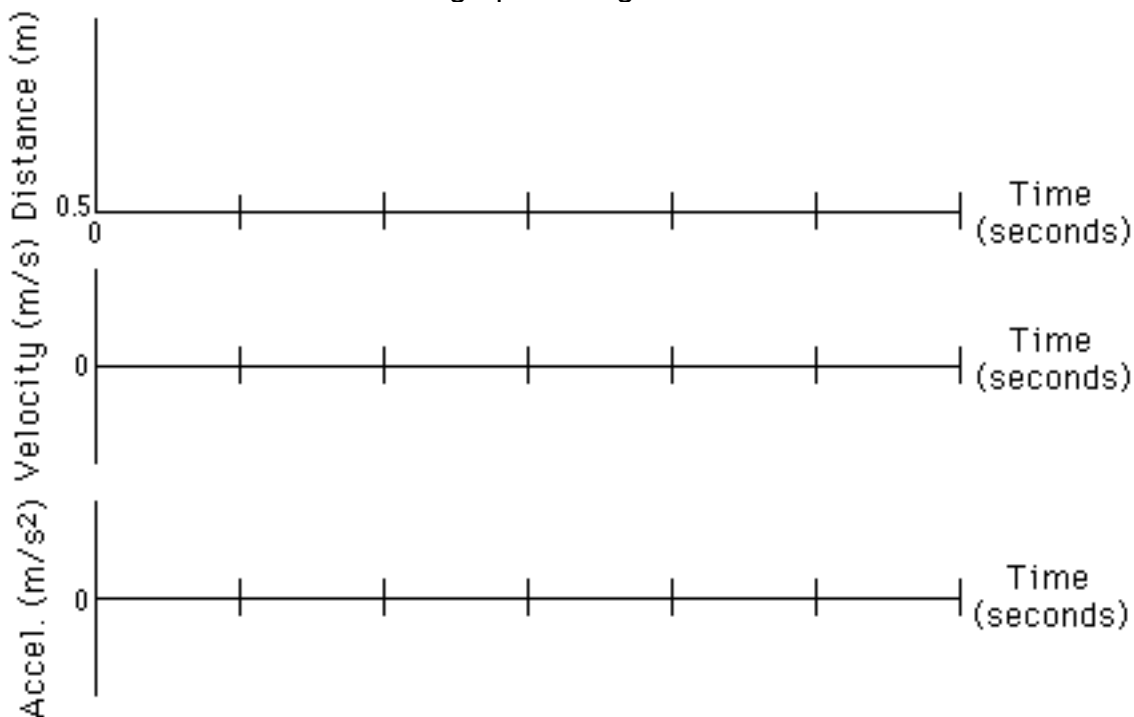
**Predictions:**

- If your cart is allowed to roll freely down the track without friction, what magnitude and direction do you predict for the cart's acceleration? Your prediction should be made as precisely as possible, using the measured values of  $x$  and  $L$  and Figure 8 (b). Write your answer below and in Table 3.

$a =$  \_\_\_\_\_ [m/s<sup>2</sup>]

**Predictions:**  
(continued)

- Sketch with dashed lines your predictions for the distance, velocity, and acceleration vs. time graphs in Figure 10.



**Figure 10.** Predictions for a cart rolling down the incline

**Procedure:**  
(continued)

4. Test your predictions and graph by rolling the cart down the incline and graphing its motion. Sketch your results.
  - Click on **Start**. Wait until you hear clicking, then release the cart about 0.5 m from the detector. Repeat if necessary. Sketch your results using a solid line on the same graphs as your predictions.
5. Analyze your results. Use the computer's averaging capability discussed previously to measure the average acceleration of the cart rolling down the incline. Record your measurement in Table 3, and determine the percent difference between your measured and predicted results:

$$\% \text{difference} = 100 * \frac{(\text{measured} - \text{predicted})}{\text{predicted}} \quad (\text{Eq. 4})$$

Quantity	Predicted	Measured	% Difference
Acceleration			

**Table 3.** Predictions and results for Activity 3

**Question:**

- Are your results consistent with your predictions? Why or why not?

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### Activity 4: The Little Cart That Couldn't

**Introduction:** As discussed previously, allowing a cart to accelerate down a steep ramp is similar to dropping a ball from a height. In this activity, you will give the cart a push *up* the ramp and let it return. This process is similar to throwing a ball straight up in the air, then letting it drop, but its duration is longer and therefore easier to study.

- Procedure:**
1. Leave the motion detector, ramp and cart in the same configuration as in Activity 3 (see Figure 9). Again, there should be no friction set on the cart.
  2. The distance, velocity, and acceleration graphs should be the same as in the past three activities (see Figure 2).
  3. Make your predictions.
    - Predict the expected behavior of a ball thrown in the air and of a cart rolling up, then down, an incline.

**Predictions:**

- You throw a ball straight up in the air. What is the velocity at the moment that the ball reaches its highest point and is about to start back down? At this same moment, is the acceleration positive, negative or zero? (Assume that the positive direction is *upward*.)

**Velocity:** \_\_\_\_\_ **Acceleration:** \_\_\_\_\_

- If you give your cart a quick shove up the track (inclined at the same angle  $\theta$  as that used in Activity 3), what do you predict will be the magnitude and sign of both the cart's velocity and acceleration at the moment that the cart reaches its highest point? Also record your prediction for the acceleration in Table 4.

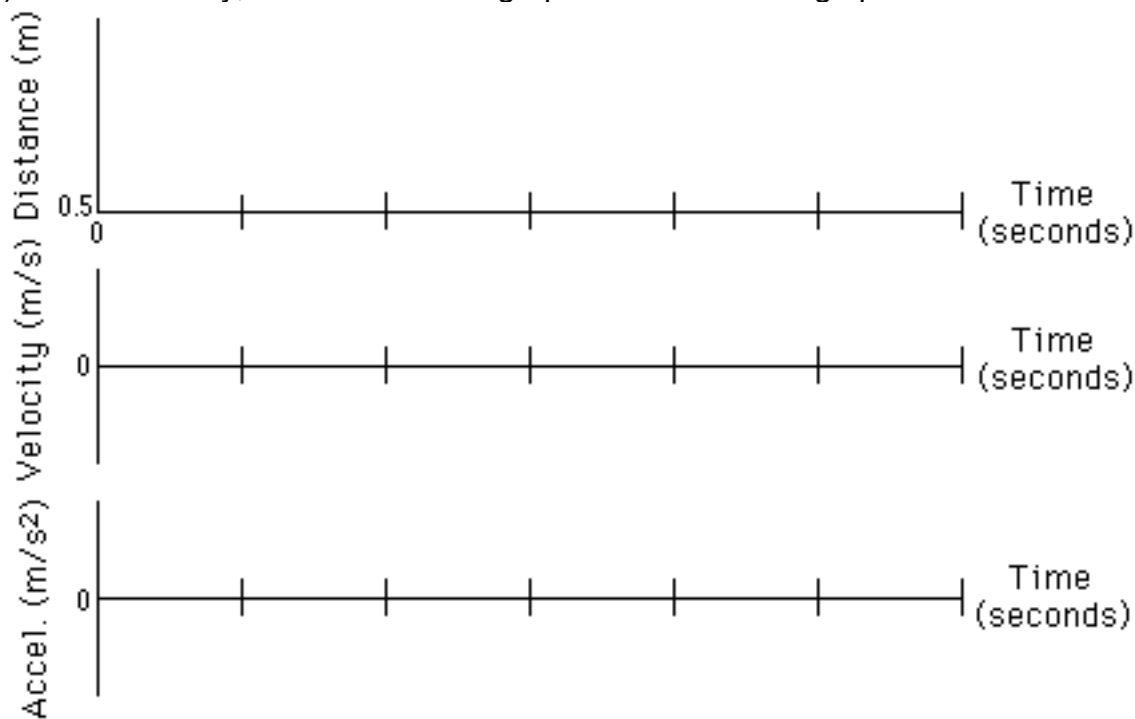
(Assume that the positive direction is *down* the ramp--away from the detector.)

**Velocity:** \_\_\_\_\_ **Acceleration:** \_\_\_\_\_

- What will be the acceleration of the cart just before it reaches the bottom of the incline? (Assume again that the positive direction is *down the ramp*)

**Acceleration:** \_\_\_\_\_

**Predictions:** • Use dashed lines to sketch on Fig. 11 your predictions for the distance, (continued) velocity, and acceleration graphs of a cart moving up and down the incline.



**Figure 11.** Predictions for a cart rolling up and down the incline

**Procedure:**  
(continued)

4. Test your predictions. Graph the cart rolling up and down the incline.
  - Click on **Start**. Wait until you hear the clicking of the motion detector, then push the cart so that it travels up the incline and back. Repeat if necessary to obtain a “nice” set of curves. Sketch your results in Figure 11 using a solid line.
5. **Analyze** your results. Use the computer’s averaging capability to determine the average measured acceleration of the cart rolling up and then down the incline. Record your measurement in Table 4, and determine the percent difference between your measured and predicted results.

Quantity	Predicted	Measured	% Difference
Acceleration			

**Table 4.** Predictions and results for Activity 4

6. Print your results.
  - **Set Graph Title...** to label it with your names and the title **UP AND DOWN THE INCLINE**. **Print** one copy of your graph for the group.



TA Discussion  
Checkbox

**Questions:**

- Take your printout and label *all three* graphs with—  
"A" where your hand left the cart.  
"B" where the cart reached the top (and is about to start down).  
"C" where the cart reached the bottom again.  
Explain how you determined each of these points.

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- Did the cart stop at the top? How can you tell?

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- According to your acceleration graph, what is the acceleration at the instant the cart reaches the top? Is it positive, negative or zero? Does this agree with your prediction? (Assume that the positive direction is *down the ramp*).

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- If you tossed a ball straight up into the air, what would be the magnitude and sign of the ball's acceleration when it reaches the highest point of its motion? (Assume that the positive direction is *up*).

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### Activity 5: Realize the Gravity of Your Situation

**Introduction:** Imagine that you don't know the value of the acceleration due to gravity,  $g$ , and that the local chapter of Weight Watchers has urgently requested that you determine this value. In this activity you will follow a procedure for estimating the local value for  $g$ .

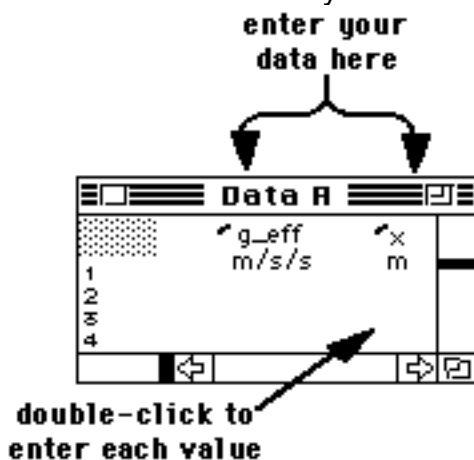
- Procedure:**
1. Record your values of  $x$  and the measured acceleration from Activity 3 in the Run 2 row of Table 5. Record your value of  $L$  to the right of Table 5.
  2. Repeat the experiment in Activity 3 for two additional (different) values of the track position,  $x$ , making sure that you choose values so that  $x \geq 10$  cm (see Figure 9). In each case, record the measured values of the mean acceleration in Table 5 below. Again, when determining the acceleration, you should take the mean acceleration over the region of interest by selecting the region with your cursor, then by reading the mean acceleration under **Statistics** in the **Analyze** menu.

Run #	Acceleration ( $g_{eff}$ )	$x$
1	0	0
2		
3		
4		

$L = \underline{\hspace{2cm}}$

**Table 5.** Measured acceleration vs. track height,  $x$

3. Make a plot of the measured acceleration ( $g_{eff}$ ) vs.  $x$ . A file appropriate to plotting your selected data, called **DATA ENTRY 1**, has been put in the **Lab 1** folder, which is in the **211 Lab Files** folder on the **Desktop**. **Open** this file (under **File** menu).
  - Select **Data A Table** under the **Windows** menu. You should see a new window labeled "Data A" similar to that shown in Figure 12. You can enter numerical data directly into the table in the spaces shown.



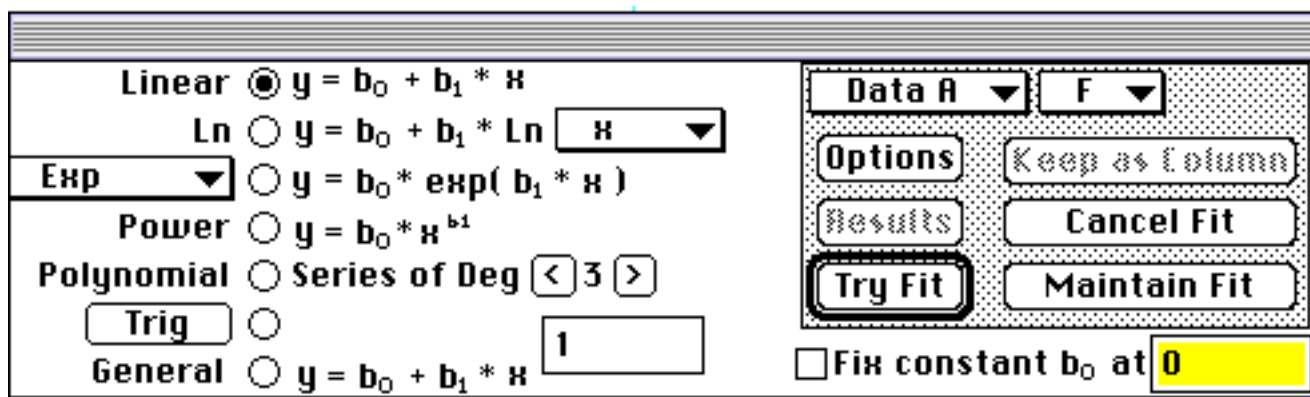
**Figure 12.** Data Entry table for entering the measured acceleration,  $g_{eff}$ , and track height,  $x$ .

**Procedure:**  
(continued)

- Record your four  $g_{\text{eff}}$  and position ( $x$ ) values in the two columns in the on-screen table, as shown in Figure 12.
- When all your data has been entered, click once on the graph window to bring it to the front and view your points.
- Double-click on the graph window and adjust the scale so that your points are visible. Do not make your scale so large that there is a lot of blank space.

4. Create a fit to your data.

- Select **Fit...** under the **Analyze** menu. The dialog box in Figure 13 will appear, where you can specify the mathematical formula to try.



**Figure 13.** Dialog box for defining a fitting function

- Make sure that Linear is selected (since your plot should be linear), as in Figure 13, and then click on **Maintain Fit**. You should now see a straight line on top of your graph. The computer has tried to draw a "best fit" through all the data points. If it doesn't look right, try to figure out what went wrong or ask your TA.
- Re-adjust your display scale if necessary to better view the points.

Below, record the slope of the "best fit" through your data:

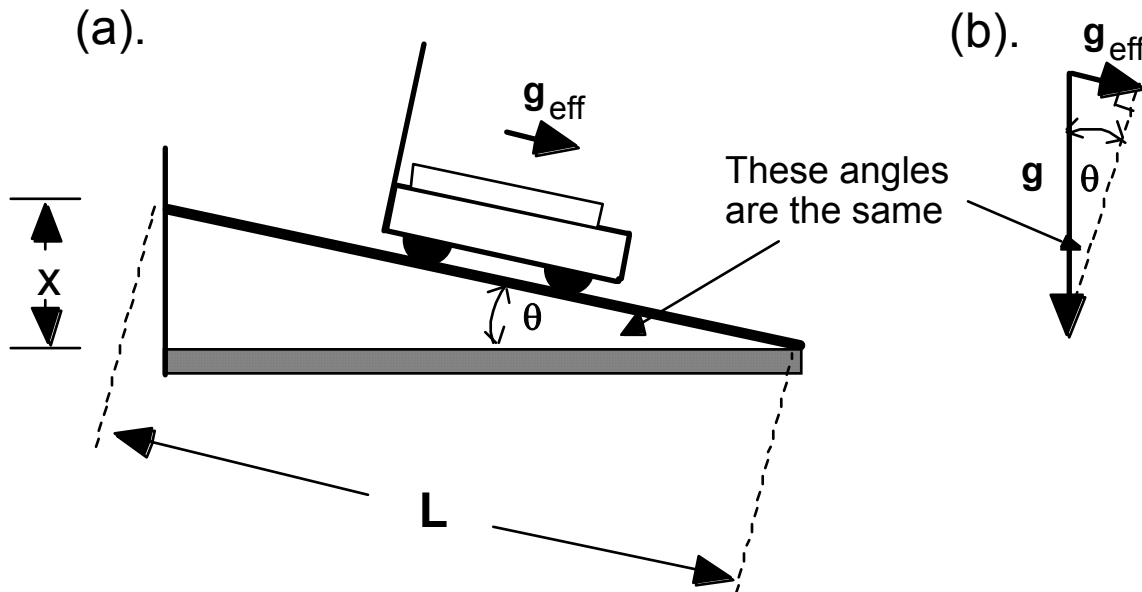
$b_1 =$  \_\_\_\_\_

**Procedure:**  
(continued)

5. Determine the relationship between  $g$  and  $g_{eff}$ .

- Now that you have measured the slope through your  $g_{eff}$  vs.  $x$  data, you need to determine the relationship between  $g$  and  $g_{eff}$ . Recall (see Figure 14 (b)) that  $g_{eff}$  can be written in terms of the angle  $\theta$  as:

$$g_{eff} = g \sin \theta$$



**Figure 14.** Geometrical relationship between  $g$  and  $g_{eff}$

- By using this result for  $g_{eff}$  as a function of the angle  $\theta$  above and comparing Figures 14 (a) and (b), you should be able to write  $g_{eff}$  in terms of the track height,  $x$ , track length,  $L$ , and the “unknown” constant  $g$ .

$$g_{eff} = \underline{\hspace{2cm}}$$

- Note that the above relationship is the same linear equation that you have plotted in your graph. Using the above result for  $g_{eff}$ , vs.  $x$ , write a mathematical relationship for the slope ( $b_1$ ) of the  $g_{eff}$  vs.  $x$  plot in terms of the parameters,  $g$  and  $L$ .

$$b_1 = \underline{\hspace{2cm}}$$

**Questions:**

- Assume for a moment that the value of  $g$  is unknown. Using your measured value for the slope ( $b_1$ ) of  $g_{eff}$  vs.  $x$ , obtain an estimate of  $g$  from your data, and compare your value with the accepted value of  $g$  in Table 6.

Quantity	Your Value	Accepted	% Difference
$g$		9.81 m/s <sup>2</sup>	

**Table 6.** Measured vs. accepted values for  $g$

- How well does your measurement of  $g$  agree with the accepted value?

## Appendix A

### HOW NICE IS NICE?

NOTE: By a "nice set of graphs" we mean that the graphs should show the motion of the cart over the range of interest (neither too late nor too early) and that the graphs should be smooth where the motion is smooth.

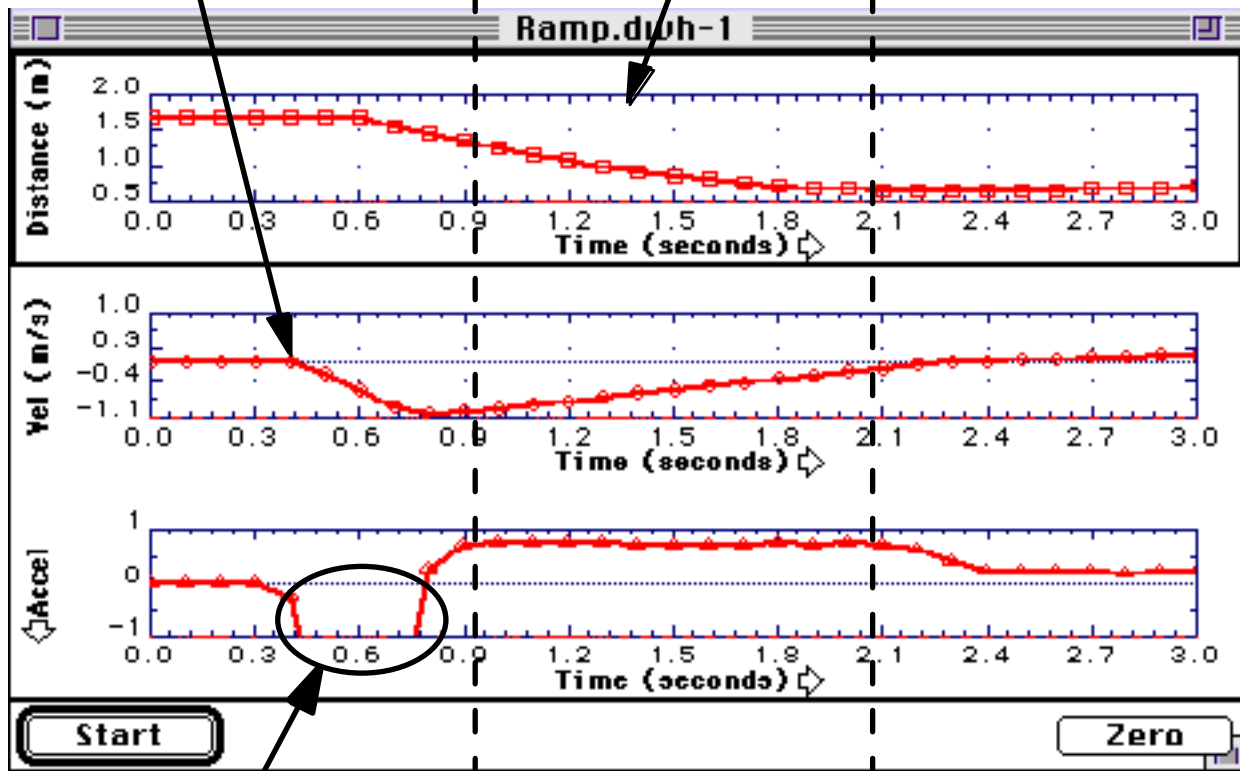
Problems can occur if the motion detector gets "fooled" into thinking the cart is somewhere else (by your arm, for example). In this case the cart appears to "jump" on the graph. Also, if the cart gets stuck the graphs can turn out looking irregular (i.e., "jerky").

Below is an example of a nice set of graphs with several points and regions marked. You will very soon be able to identify regions like this yourself.

#### EXAMPLE GRAPH:

The Distance graph gives you the "big picture": The cart starts far away from the motion detector (at the top of the ramp) and then moves closer. The curve between the dashed lines bends, showing that the velocity changes as the cart gets closer.

Until this time, the Velocity was zero. The cart wasn't moving yet.



Here the cart is experiencing a large Acceleration (off the scale). It is due to a hand pushing the cart up the ramp...

In this region, the cart's motion is smooth. You can see this by noting that the Velocity and Acceleration graphs do not have jagged peaks.