PHYSICS 211

LAB #2: Force and Newton's Laws

A Lab Consisting of 4 Activities

Name: ______________________________
Section: ______________________________
TA: ______________________________
Date: ______________________________

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

Written by Cooper, Dick, and Weissman

Physics Lab 211-2

Equipment List

Motion detector
Force probe
Level
211 friction cart with reflector
211 magnet cart without reflector
Standard cart track setup
Meter stick
Rod and clamp setup to hold force probe
Double pulley setup
Standard red extension spring
String loop for holding spring at the top of the incline
Masses
    50 gram (1)
    100 gram (3)
50 gram mass hanger
String with loops an each end
Chain
Meter stick

Computer File List

MacMotion file "211-02 Force Score and Seven..."
MacMotion file "211-02 Force/Accel 1"
MacMotion file "211-02 Force/Accel 2"
MacMotion file "211-02 Spring"
MacMotion file "211-02 Spring.CLB"

Investigation 1: Weight and Mass

Goals:

- To find out how to use a force probe to measure forces
- To study the characteristics of *weight*

Activity 1: May the Force Probe Be With You

Introduction: The force probe you will use in this and later laboratories measures the amount of force applied to the probe. It is not critical that you understand precisely how the force probe works...ok, if you must know, the force probe uses strain gauge technology. When you push or pull on the probe's hook, a beam inside is bent one way or the other. Two strain gauges attached to each end of the beam are strained less or more by this bending. The change in strain causes a change in the electrical resistance of the gauges, which in turn results in a change in a voltage within the force probe's electronics. This voltage change is proportional to the change in force. MacMotion translates this voltage change into Newtons and can define zero force points. The switch on the sensor allows you to select either of two ranges of force measurement: +/- 10N or +/- 50N. In the 211 labs, you will always use the 10N range.

Procedure:

1. Open the *MacMotion* program. Double click on the *MacMotion* icon. Set up to graph force.
   - **Open...** (under the **File** menu) the file ***FORCE SCORE AND SEVEN...*** in the **Lab 2** folder. A graph like that shown in Figure 1 should appear on the screen:

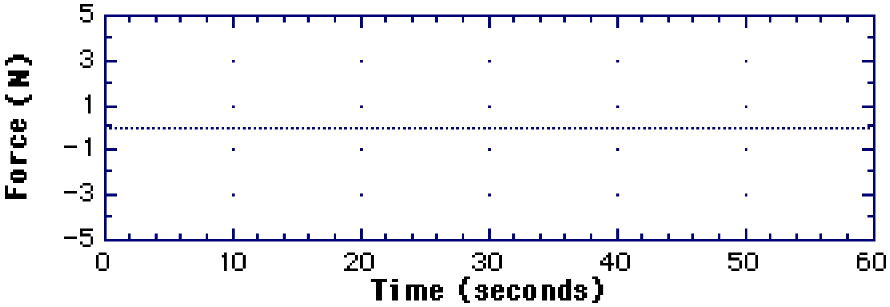


Figure 1. Force Score graph format for Activity 1

2. Set up the force probe. Clamp the force probe to a support with its hook pointing vertically downward as in Figure 2. The probe should be plugged into DIN 1 of the Laboratory Interface Box (flat gray box).

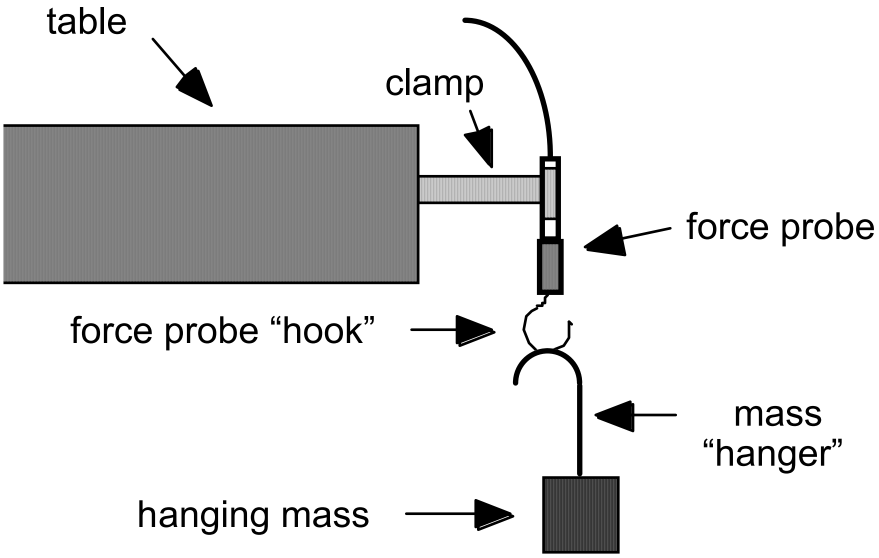


Figure 2. Experimental setup for Activity 1

Procedure: (continued)

3. "Zero" the force probe. With nothing hanging on the force probe, zero the probe by selecting **Zero Force** from the **Collect** menu, or by clicking on the **Zero** button at the bottom of the screen. This will take a few seconds.

***Note -** In this activity, **"**zeroing" the force probe assures that zero will be displayed on the screen when no force is applied by (or on) the probe. Any small mechanical change in the force probe--including changing its orientation--will change the zero setting. Therefore, zero the probe frequently in the orientation in which it will be used just before taking measurements.

4. Get a feel for the force probe by plotting a force vs. time graph.
   - With the hook of the force probe pointing vertically downward, click on **Start** to graph force. Note what the graph looks like while alternately pushing up and pulling down on the hook gently.

Question:

- Does the force probe record a push as a positive force or as a negative force? What about a pull?

____

Procedure: (continued)

5. Prepare to measure the weights of different hanging masses. Rescale the y-axis of your graph from **0** to **10 N** by double-clicking on the graph, then changing the y-axis limits. The resulting graph should look like that shown in Figure 3.

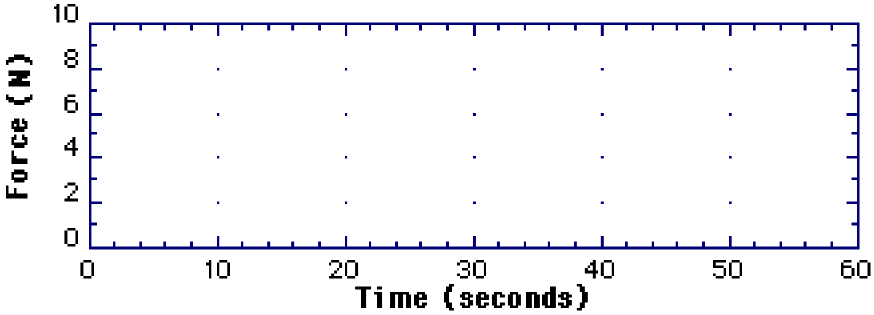


Figure 3. Force Score graph format for Activity 1

Predictions:

- How do you expect the weight of an object measured by the force probe to change as a function of increasing mass?

  ____

  ____

- For each of the hanging mass values given in column 1 of Table 1, record your prediction for the weight that will be measured by the force probe in the "Weight" column.

6. Check your predictions. With no mass initially on the force probe, **Start** graphing. Wait for 10 seconds, then hang a 100 gram mass with the hanger from the force probe hook (make sure you account for the 50 gram mass of the hanger in the total mass). Every 10 seconds thereafter, add 100 grams until you have a total of 400 grams.
7. Analyze your data. From your graph, read the measured force for each mass value and record your results in Table 1. To get the most accurate readings, you may want to record the mean values of your data by selecting **Analyze Data A** from the **Analyze** menu and highlighting (with the mouse) a region over which you want your data averaged. Finally, compute the percent difference between the force probe results and your predictions for the weights.

Hanging Mass (kg) m	Predicted Weight (N) $F_{gravity} = mg$	Force Probe Reading (N)	% Difference
0			
0.100			
0.200			
0.300			
0.400			

Calculate this

Measure this

$$\%difference = \left(\frac{measured - predicted}{predicted}\right)(100\ \%)$$

Table 1. Results for Activity 1

☐ TA Discussion Checkbox

Questions:

- If you hang a 50 gram mass from a massless string attached to the force probe, what value of force would be measured? What is the tension at both the end and middle of the string?

- Now, if you replace the string with a massless rubber band, then hang the 50 gram mass from the band so that it stretches 1 cm, do you predict that the tension in the center of the band will be greater, less than, or equal to that in the previous question?

- If you are on the moon ($g_{moon} \sim {}^{1}/_{6} g_{earth}$), what value will the force probe read if you hang a 0.1 kg mass on it?

Investigation 2: Newton's Second Law: How Force Relates to Motion

Goal: To study the relationship between force and acceleration.

Activity 2: A Force For Change

Introduction: In this activity you will test the relationship between force and acceleration, $F_{net} = ma$, under conditions in which the force is not constant.

Procedure:

1. Prepare to graph net force, F, acceleration, a, and the ratio F/a.
   - **Open...** the file ***FORCE/ACCEL 1*** in the **Lab 2** folder. The graphs in Figure 4 should appear on the screen.

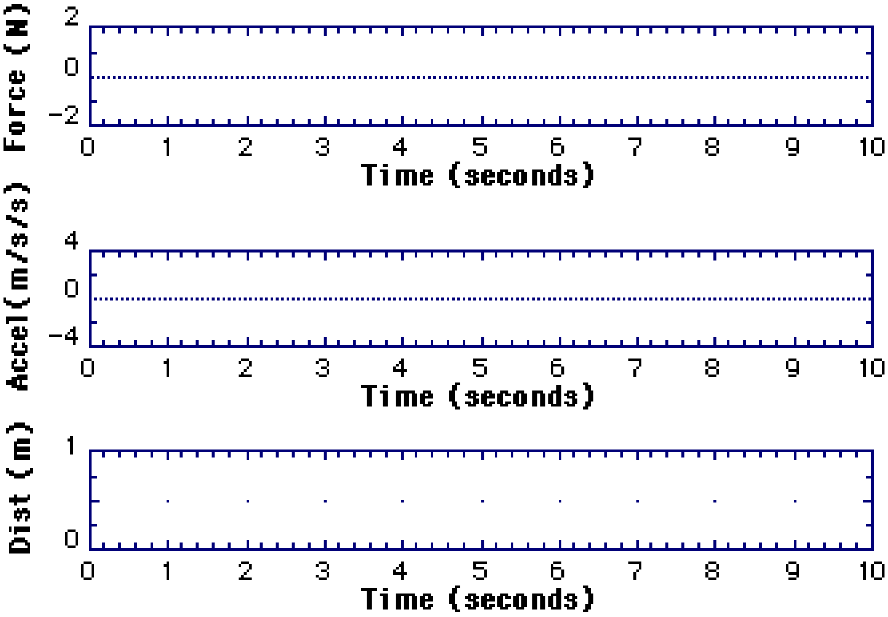


Figure 4. Force/Accel 1 graph format for Activity 2

2. Set up the motion detector and the force probe.
   - Place the motion detector on the floor directly beneath the force probe.
   - Measure and record the masses of a 250 gram hanging mass (including hanger) and of the spring provided, for your later analysis.

$m_{hang.\ mass}$ = ___________ [kg] m_{spring} = ___________ [kg]

   - Hang the spring on the force probe, and then hang the 250 gram mass on the spring, as shown in Figure 5. Secure the masses in the hanger with tape so they don't fall and destroy the motion detector (which would cost the equivalent of about three or four CD's!).

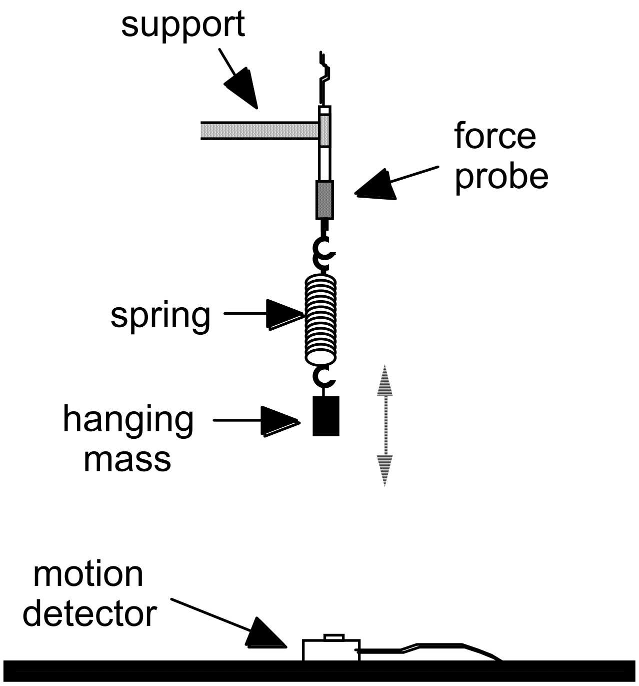
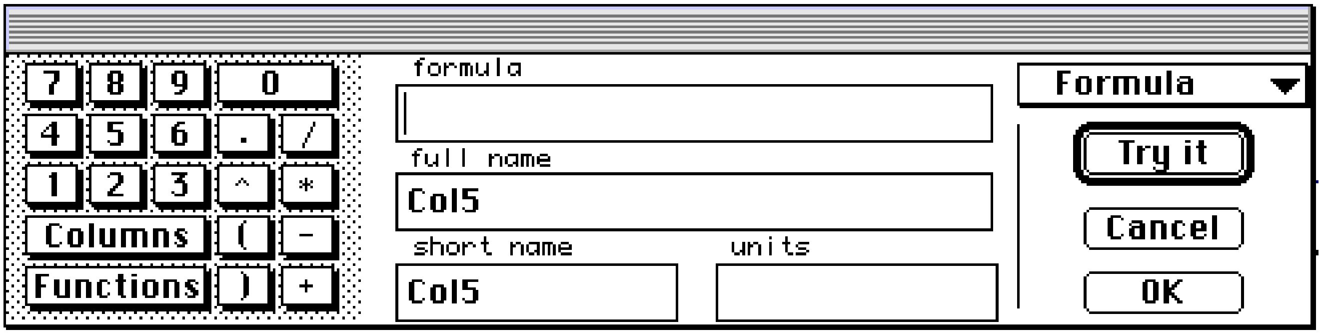


Figure 5. Experimental setup for Activity 2

Procedure: (continued)

3. Define the F/a graph. You will have to redefine the Dist (m) graph in Figure 6 in order to plot the ratio F/a. To do this, move the mouse pointer over the **Dist (m)** label of the bottom graph on your screen, and hold down the mouse button, revealing the menu. Select the **New Column** option. This will give you a window which looks like Figure 6 below.



full name: Col5

short name: Col5

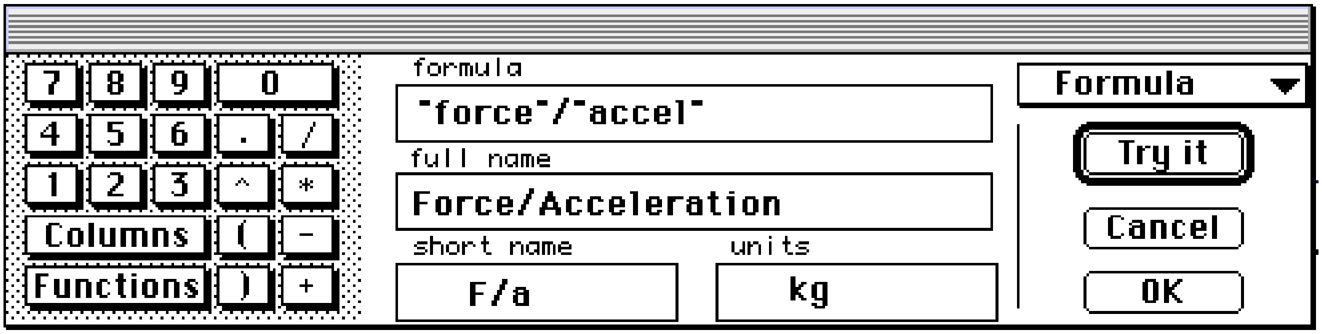
units:

Figure 6. New Column window for defining a new formula to plot

Procedure:
(continued)

4. You can now define, name, and label the lower graph by clicking in the appropriate boxes and entering the names shown in Figure 7. The resulting *MacMotion* graph should look like Figure 8. **Note:** Don't forget to put the quotes "..." around **force** and **accel** in the formula field!

5. *Make sure* that you rescale the F/a plot so that the vertical axis goes from 0 to 1 kg, as shown in Figure 8!



formula: "force"/"accel"

full name: Force/Acceleration

short name: F/a

units: kg

Figure 7. Display for defining the function F/a

Predictions: • Assume that the force probe reads F=0 when the mass is hanging statically on the end of the spring. Using the three graphs provided in Figure 8, sketch your predictions for the force on the force probe, the acceleration of the hanging mass, and the ratio F/a, <u>when the hanging mass is allowed to oscillate</u> over the motion detector. Be as specific as you can where possible:

- What relationship do you expect to observe between the measured force and acceleration?
- What value or values do you expect for the ratio F/a, and how do you expect the ratio F/a to depend on time? Write your prediction(s) for the value(s) of F/a in Table 2.

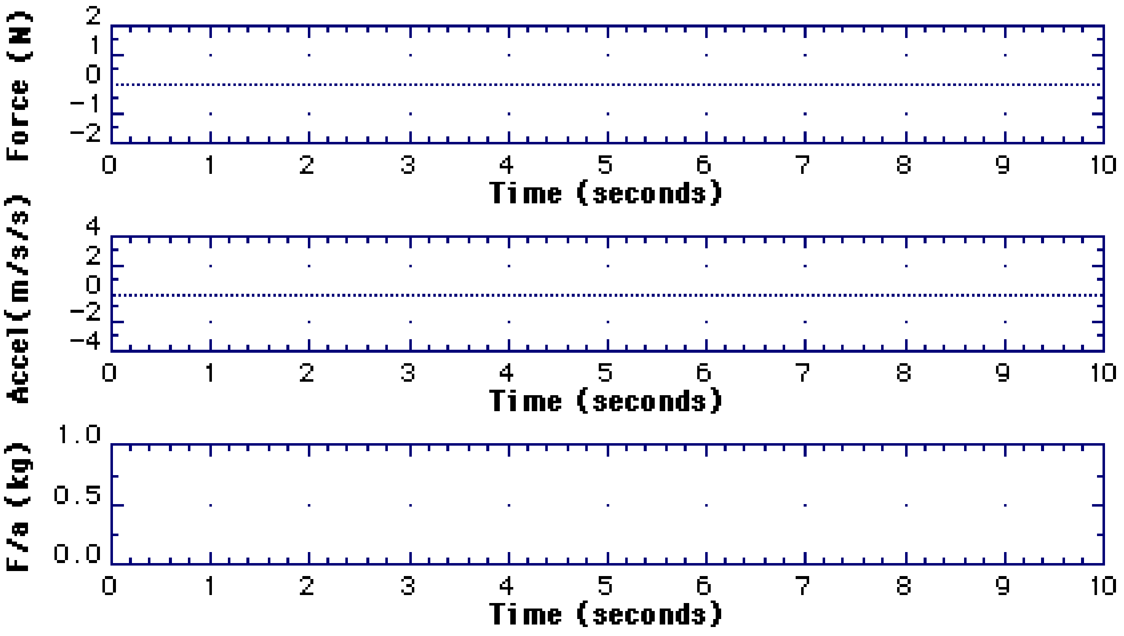


Figure 8. Predictions for Activity 2

Procedure:

6. **Zero** the probe with the mass and spring suspended from it. **Note:** this procedure insures that the force probe measures a zero value when the hanging mass is in equilibrium, i.e., $F_{net} = F_{spring} + F_{grav} = 0$. During this zeroing process it is important that the mass is stationary.

7. Perform the measurement and test your predictions.
   - Lift the hanging mass about 5 cm and release it, thereby setting it into oscillatory motion. **Start** graphing.

   Note: If your acceleration results look “funny,” i.e., if you see extra peaks or flattened peaks in the acceleration graph, your detector may be either too far or too close to the hanging mass. Ask your TA to adjust the hanging mass position.

8. Make a record of your measurement of net force, acceleration, and F/a.
   - **Set Graph Title...** to "***FMA TANGO***" and add your group's names.
   - **Print** one copy of this graph. Note points of significant disagreement between your results and predictions.

9. Analyze your data for comparison with your predictions. Select **Analyze Data A** from the **Analyze** menu. Use the averaging capability of the computer to obtain the mean measured values for F/a (try not to include “spikes” when averaging your data for mean values). Record this value in the “Measured” column of Table 2 and compute the percent difference from your predictions.

Quantity	Predicted Value	Measured Value	% Difference
F/a			

Table 2. Results and predictions for Activity 2

☐ TA Discussion Checkbox

Questions:

- What quantity is given by the ratio F/a? If you found a significant difference between your measured and predicted values of this quantity, provide possible explanations for this difference.

- Did you find that the acceleration vs. time plot “follows” the force vs. time plot in the sense that both force and acceleration increase and decrease at the same times, have maximum and minimum values at the same times, etc.? Did you predict this?

Activity 3: Push Me-Pull You

Introduction: If you apply a large enough force on an object--like a cart on a table or an uncooperative lab partner--you can get that object to move with an increasing velocity, i.e., with an acceleration. In this investigation you will find that a constant *net* force applied to an object will cause a *constant* acceleration.

You have performed experiments similar to these in Lab 1. This time the force probe is also used and you should focus on the comparison of information provided by the force probe with that from the motion detector. These are *independent* data-gathering tools.

Procedure:

1. Set up the graph to plot the cart acceleration and the force measured by the force probe as a function of time.
   - **Open...** the file ***FORCE/ACCEL 2*** in the **Lab 2** folder. The graphs shown in Figure 9 should appear on the screen.

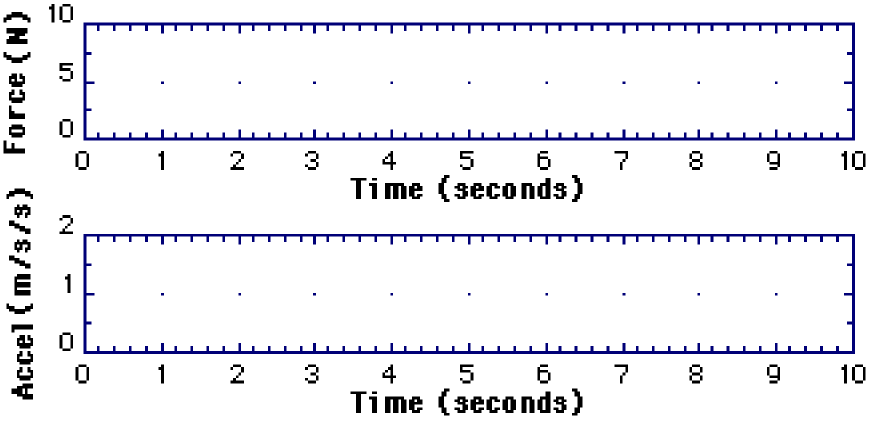


Figure 9. Force/Accel 2 graph format for Activity 3

2. Attach the force probe to the cart with the Velcro pad, so that the probe is oriented with respect to the cart as shown in Figure 10.

3. Use a balance to measure the mass of the cart with the force probe attached, and to check the mass of a 100 gram hanging mass (including hanger). Record these values below.

Cart mass: M = ________ [kg]

Hanging mass: m = ________ [kg]

4. Set up the equipment as in Figure 10, making sure that the cart's friction pad doesn't contact the track at all, and that the string is in the groove of the pulleys. Also, it's *important* that you make sure that the track is level.

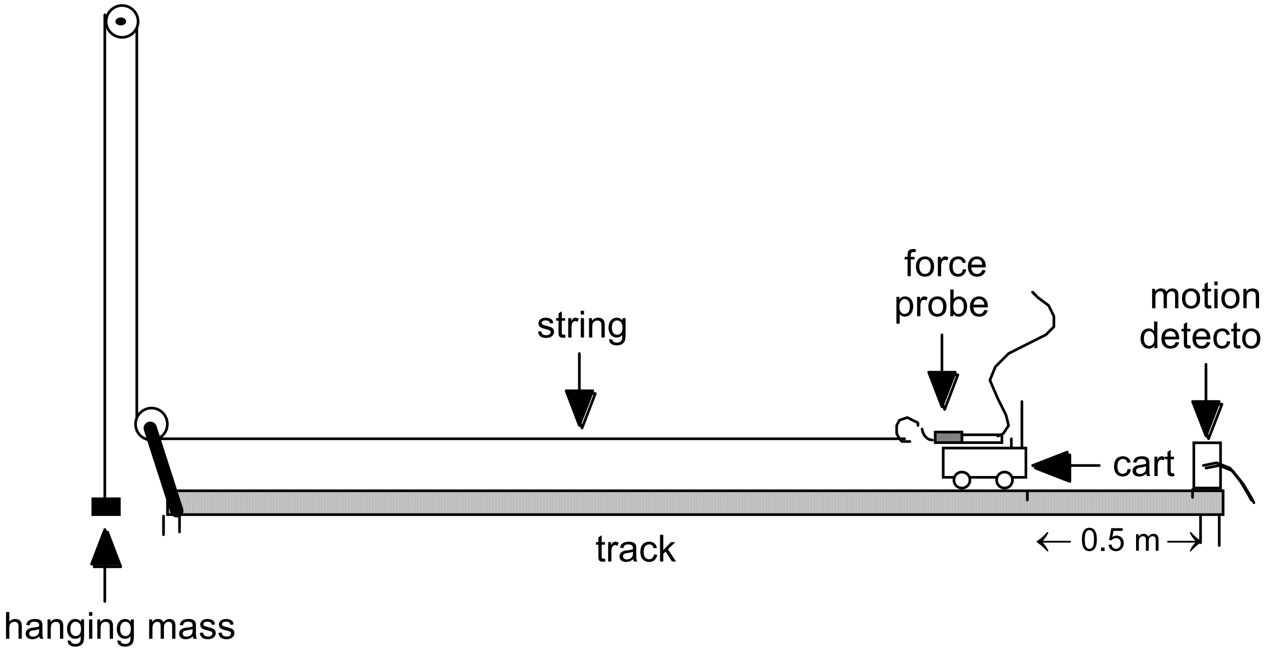


Figure 10. Experimental setup for Activity 3

Predictions:

- Suppose that you hold the cart shown in Figure 10 stationary. Sketch in Figure 11 *using a solid line* your predictions for the cart's acceleration and the force (i.e., string tension, T) measured by the force probe.
- If you now release the stationary cart so that it is allowed to accelerate, will the tension measured by the force probe be greater than, equal to, or less than that when the cart is stationary? Sketch in Figure 11 *using a dashed line* your predictions for the cart's acceleration and the tension measured by the force probe in this case.

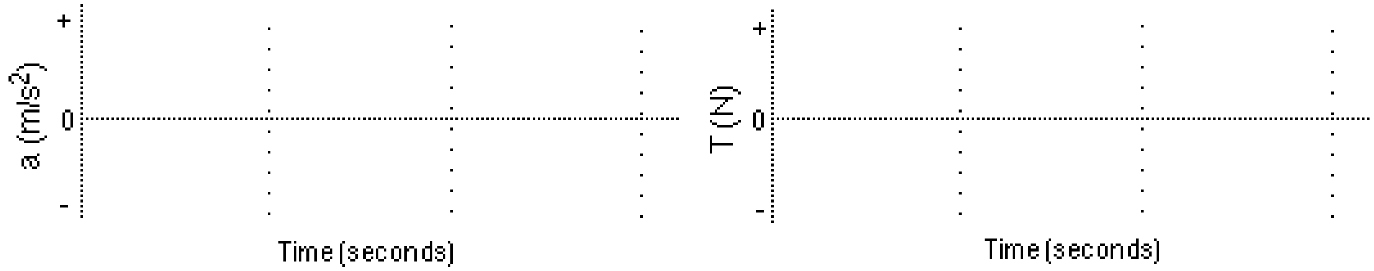


Figure 11. Predictions for Activity 3

Predictions: (continued)

- Verify your first prediction. Study the free body diagrams for cases A and B in Figure 12, and make sure you understand the derivation of the formulæ given below for both the tension in the string, T, and the acceleration of the cart, a, in the (A) stationary and (B) moving cases.

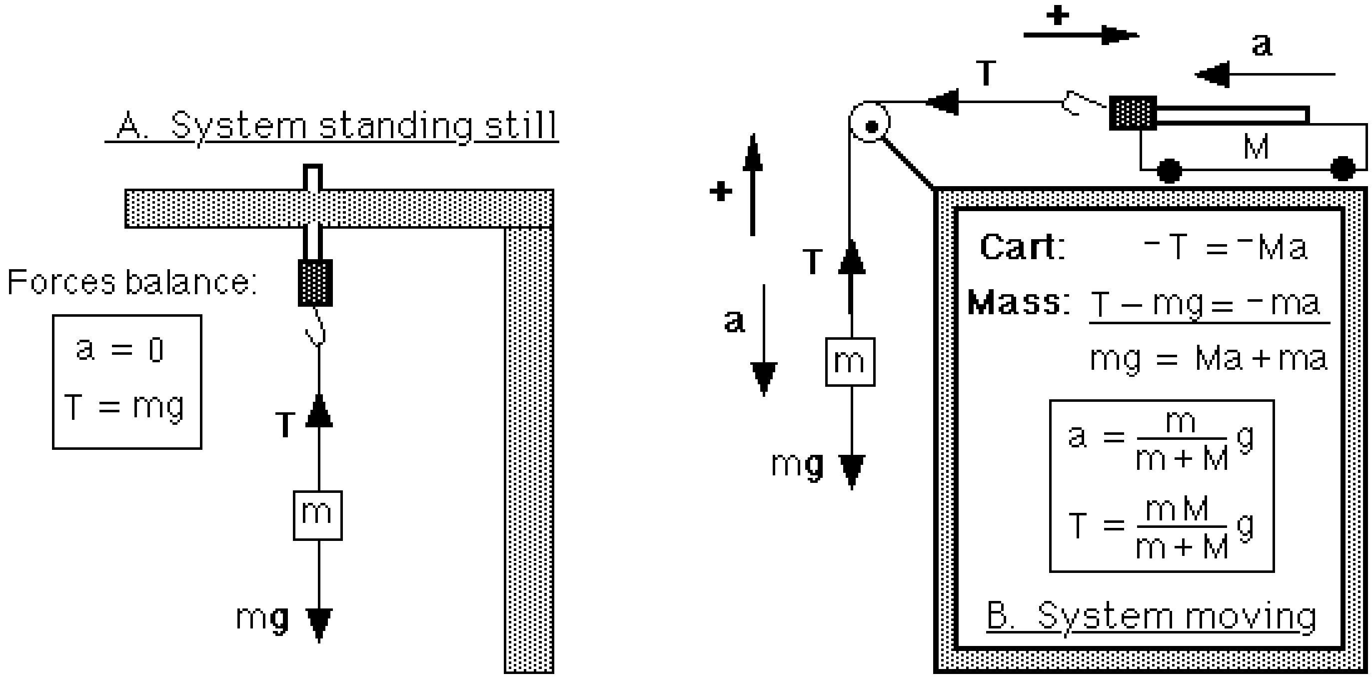


Figure 12. Free body diagrams for (A) a stationary system, and for (B) a moving cart + hanging mass system

Summary:	(A). Stationary System	(B). Freely Accelerating System
Tension, T:	$T = mg$	$T = \frac{mM}{m + M} g$
Acceleration, a:	$a = 0$	$a = \frac{m}{m + M} g$

- Using the measured values for the mass of the cart and hanging mass, use the equations above to predict values for the cart acceleration and the tension measured by the force probe for both (A) stationary and (B) moving cases shown above. Record your predictions in Table 3.

Cart	T (Predicted) [N]	T (Measured) [N]	% Difference	a (Predicted) [m/s^2]	a (Measured) [m/s^2]	% Difference
Stationary						-------
Moving						

Table 3. Results and predictions for Activity 4

Procedure:
(continued)

5. Test your predictions by making a measurement of acceleration and force.
    - Remove any mass hanging at the end of the string shown in Fig. 10.
    - **Zero** the force probe (with no mass on the string).
    - Clear any previous graphs (**Clear Data A** and **Clear Data B**).
    - Hang a 100 gram mass over the pulley.
    - **Start** graphing. At t = 3 seconds, release the cart. Be sure the motion detector "sees" the cart the whole way down the track. You may need to guide the probe's cable so that it doesn't hinder the cart's motion.
    - Repeat until you get good graphs.
6. To better see your results, *rescale* the y-axis of the *force versus time plot* so that it ranges from **0** to **2 N**. Do this by double-clicking on the force graph and changing the y-axis minimum and maximum values.
7. Make a labeled record of your experiment.
    - **Set Graph Title...** to "***NON-ZERO ACCELERATION***" with names.
    - **Print** one copy. On the printout, indicate where you released the cart.
8. Analyze your data for comparison with your predictions. Select **Analyze Data A** from the **Analyze** menu. Determine the mean measured values for tension and acceleration for both (A) stationary and (B) accelerating cases. Record these averages in Table 3 and compute the percent difference from your predictions if the values are nonzero.

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

☐
TA Discussion
Checkbox

Questions:

- Does the tension in the string change when you allow the cart + mass system to accelerate? Did you predict this?

- Did your predictions for the cart's acceleration when moving agree well with your measurements? If not, what are the possible sources of error?

- In the case of the moving system, if you doubled the mass of the cart, by what amount do you predict the acceleration of the cart would change compared to that measured above? Explain.

Investigation 3: Hooke’s Law and the Spring Force

Goals: To study Hooke’s force law for a spring, and to determine the force constant of a spring.

Activity 4: It’s Spring Time in Urbana

Introduction: Tension, weight, and the normal force are examples of passive forces, i.e., forces which are not explicit functions of position or velocity. By contrast, some forces with which you are familiar do depend on position or velocity. For example, when stretched or compressed, a spring exerts a tension or compression force on an object attached to the spring. Over a limited range of extension or compression, it turns out (as you will see) that the force exerted by the spring is directly proportional to the extension or compression distance. Over this range, the spring is said to obey Hooke’s Law, $F_{sp} = -kx$, where x is the amount of extension or compression, and k is the spring constant. In this activity you will verify Hooke’s law for a spring and measure the associated spring constant, k.

Procedure:

1. Configure the *MacMotion* graphs.
   - **Open...** the file ***SPRING*** in the **Lab 2** folder. A graph like that shown in Figure 13 should appear on the screen.

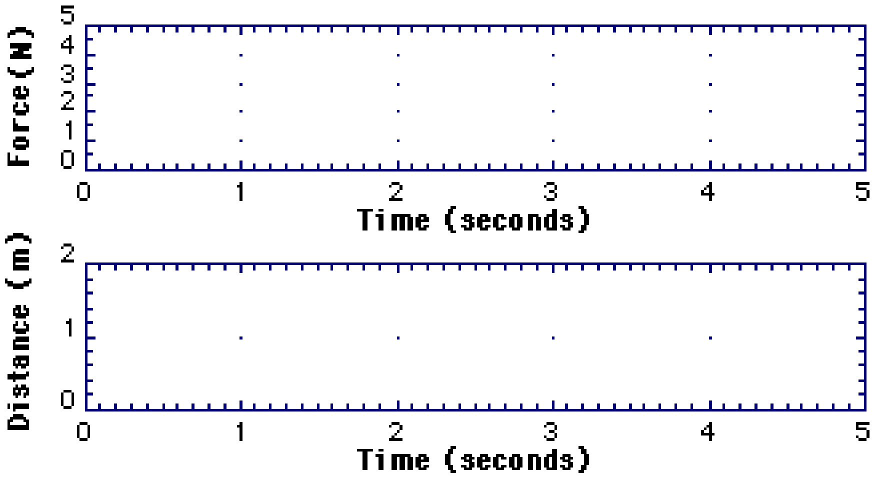


Figure 13. Spring graph format for Activity 4

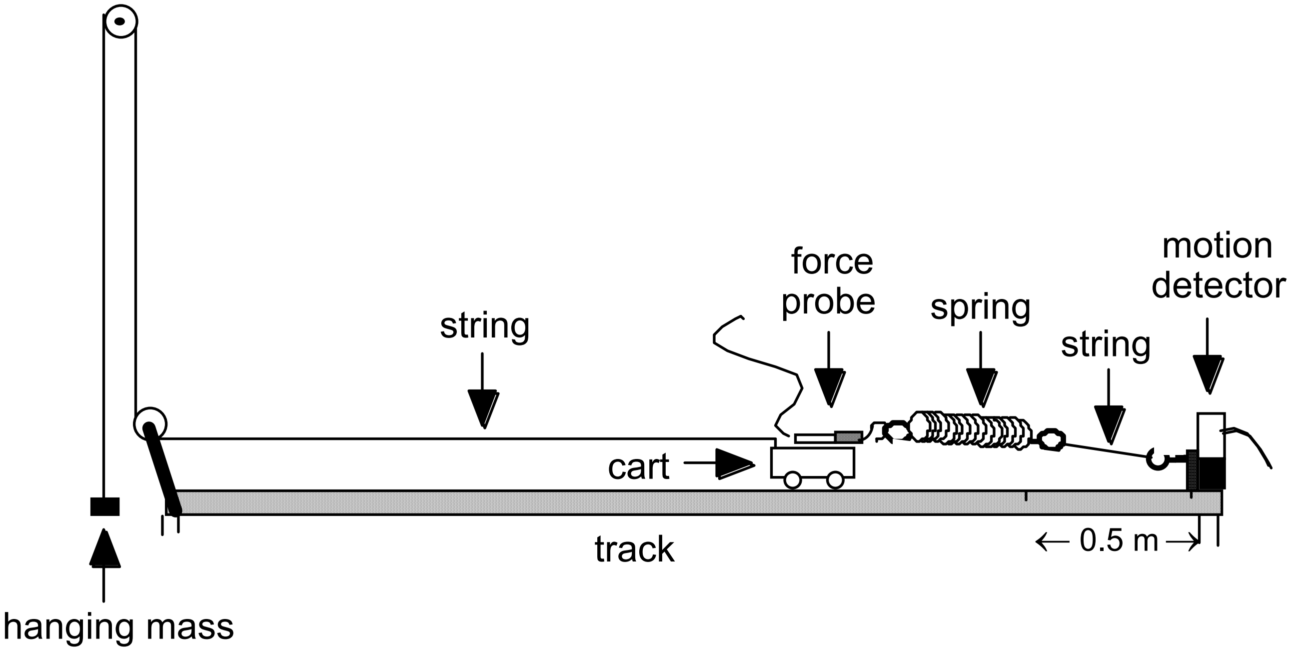


Figure 14. Experimental setup for Activity 4

Procedure: (continued)

2. Set up the track, cart, motion detector, and force probe as shown in Figure 14.
   - Exchange the cart with the large card taped on the back (used in Activity 3) with the plain, "cardless" cart provided.
   - Using the Velcro pad, attach the force probe onto the cart in the orientation shown in Figure 14.
   - Hook the hanging mass to the small smooth knob on one end of the cart.
   - Hook the spring provided between the force probe and the post mounted on the side of the track using the available string.
3. Measure the stretching of the spring provided for several different forces:
   - **Zero** the force probe with the spring attached, but with no hanging weight.
   - *Carefully* measure the position of the spring for each of the four hanging masses listed in Table 4 below. Make sure that the mass on the spring is completely stationary before making a measurement. You can obtain very accurate readings of both spring position and force by:
     - Plotting a distance vs. time graph to obtain the spring extension.
     - Plotting a force vs. time graph to obtain the spring force.
   - Record your force and spring position results in Table 4. Use mean values for these quantities, obtained by choosing **Analyze Data A**, then highlighting the flat regions of the force and distance plots and reading the mean values under **Statistics**.

Hanging Mass [kg] m	Force [N] F	Cart Position [m] x
0.150		
0.200		
0.250		
0.300		

Table 4. Spring force and cart position for Activity 4

Procedure: (continued)

4. Analyze your data. Plot the measured spring force, *F*, as a function of the measured cart position, *x*.
   - **Open** the file called ***DATA ENTRY 2*** in the **Lab 2** folder.
   - Select **Data A Table** under the **Windows** menu. You should see a new window labeled "**Data A**" similar to that shown in Figure 15. Enter numerical data directly into the table in the spaces shown.

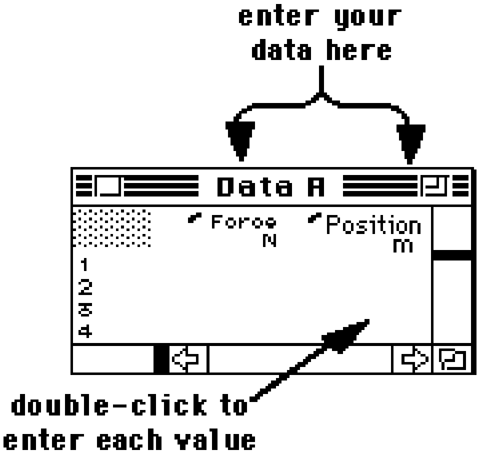


Figure 15. Table for entering the spring force and cart position for Activity 4

   - Record your spring force and position values in the two columns in the on-screen table (see Figure 15).
   - 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. Rescale so that there is not a lot of blank space.

Questions:

- Does your data exhibit the linear relationship between the spring force and spring displacement described by Hooke's law, $F = -kx$? If it appears to you that your results don't get the right "sign" on this force law, you might want to read Appendix A on the last page of Lab 2.

Procedure: (continued)

5. Determine the spring constant, k, of the spring by “fitting” your data
   - Select **Fit...** under the **Analyze** menu. A window like that in Figure 16 will appear in which you specify the kind of mathematical formula to try.

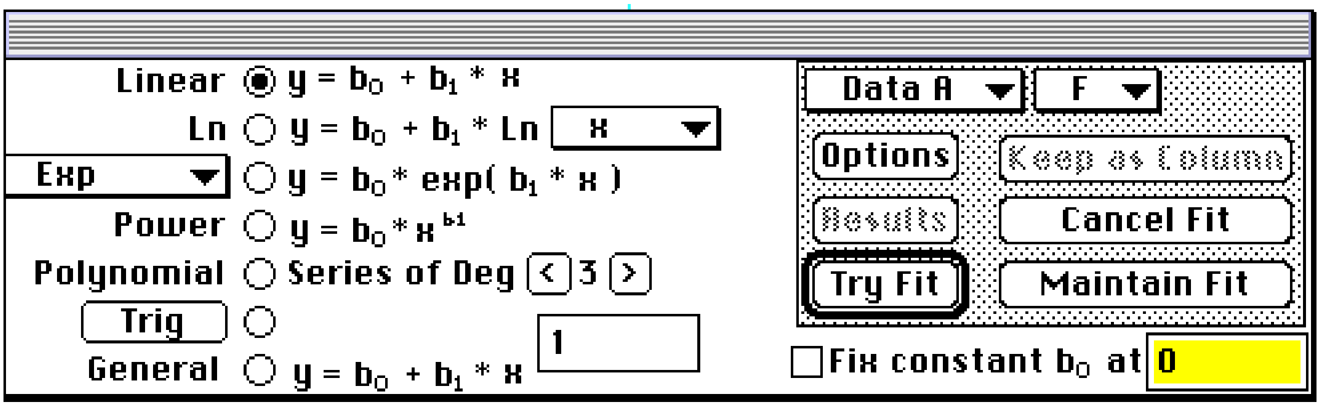


Figure 16. Window for defining the fitting function for Activity 4

   - Make sure that **Linear** is selected (since you expect a linear relationship between F and x), and then click on **Maintain Fit**. You should now see a straight line on top of your graph, which is the computer’s "best fit" through all the data points. If it doesn't look right, 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 = ________

6. What is the relationship between this “best fit” slope through your data, b_1, and the spring constant, *k*?

____

7. Use this relationship, as well as the fitted slope through your data, to obtain and record a measured value for k (include units).

k = ______________

8. Make a record of this fit to your data.
   - **Set Graph Title...** to "***HOOKE’S LAW***" and append your group's names.
   - **Print** one copy of this graph.
   - Record your measured spring constant, k, on the plot.

☐ TA Discussion Checkbox

Appendix A

Sign Problem?

You may be surprised by the fact that as you increased the size of the hanging mass, m, and consequently the size of the spring extension, Δx, your *MacMotion* graph recorded an increased *positive* value for the force as a function of increasing Δx! Is this measured positive value in contradiction to Hooke's law, which predicts a relationship between the spring force and spring extension given by $F_{spring} = - k \Delta x$? The answer is no! To clear up any apparent contradiction, first study Figure 17 and notice that as you increase the size of the hanging mass, the spring force will tend to pull on the force probe "hook." Now, recall from Activity 1 that a "pull" on the force probe is by default recorded on the *MacMotion* graph as a positive force, thus the positive force value you observe in this activity. Is this in contradition to Hooke's Law? No! Hooke's Law tells us that the spring force is always in the opposite direction to the extension or compression of the spring, $F_{spring} = - k \Delta x$. Since increasing the hanging mass extends the spring by an amount Δx in the direction shown in Figure 17, Hooke's law tells us that the spring force, F_{spring}, will act in the direction opposite the spring extension, Δx, i.e., will "pull" on the force probe hook as shown in Figure 17, in agreement with your observation (hopefully!). If this point is still confusing to you, ask your TA for help.

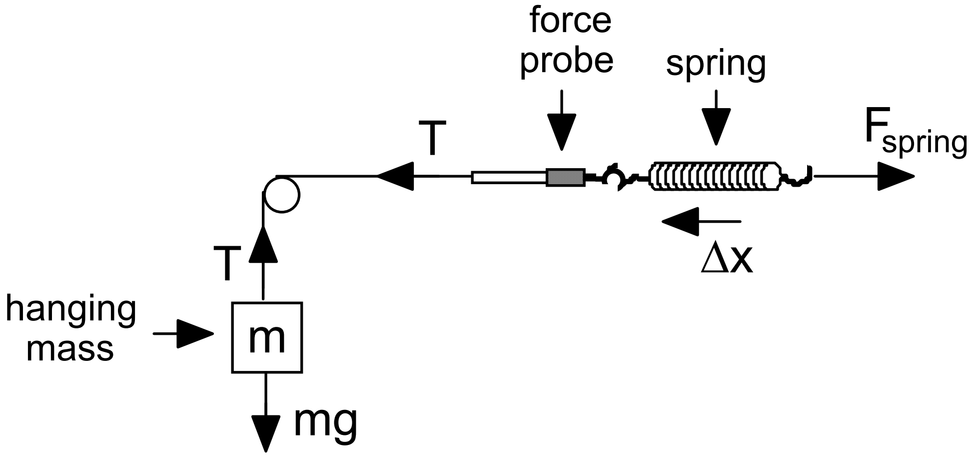


Figure 17. Directions of forces present in Activity 4