PHYSICS 211

LAB #5: Collisions

A Lab Consisting of 3 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.

Physics Lab 211-5

Equipment List
Motion detector
Force probe
Level
211 friction cart with reflector
211 magnet cart with reflector
106 compression spring taped to steel strap for magnetically attaching the spring to the 211 magnet cart
Standard cart track setup minus the foam cushion with the two track barriers on the fixed end adjusted to allow for impulse activity and "magnetic" collision activity
Double- looped strings (2- one about 25 cm, the other about 50 cm)
Standard red extension spring attached to the 25 cm string
Velcroed 500 gram mass

Computer File List
MacMotion file "211-05 Elastic"
MacMotion file "211-05 Impulse 1"
MacMotion file "211-05 Inelastic"

Investigation 1: Elastic Collisions

Goals: • To study conservation of momentum and kinetic energy during elastic collisions

Activity 1: Don't Leave Me Broken-Carted

Introduction: Most of you have probably taken an "independent study" course on elastic collisions at the local pool hall (in fact, that's not a bad idea for a new Discovery course...). When physicists want to study elastic collisions, and hitting the "eight-ball" into the corner pocket just isn't challenging enough, they shoot neutrons, protons, etc., at other atomic particles...and they call their shots!

Procedure:

1. First, make sure that the track is level. Next, measure the masses of both the "incident" cart + spring and the "target" cart, and record these values below.

incident cart+spring, m_1 = _______ [kg] **target cart, m_2 = _______** [kg]

2. Configure the *MacMotion* graph.
   - **Open...** (under the **File** menu) the file ***Elastic*** in the **Lab 5** folder. A graph like that shown in Figure 1 should appear.

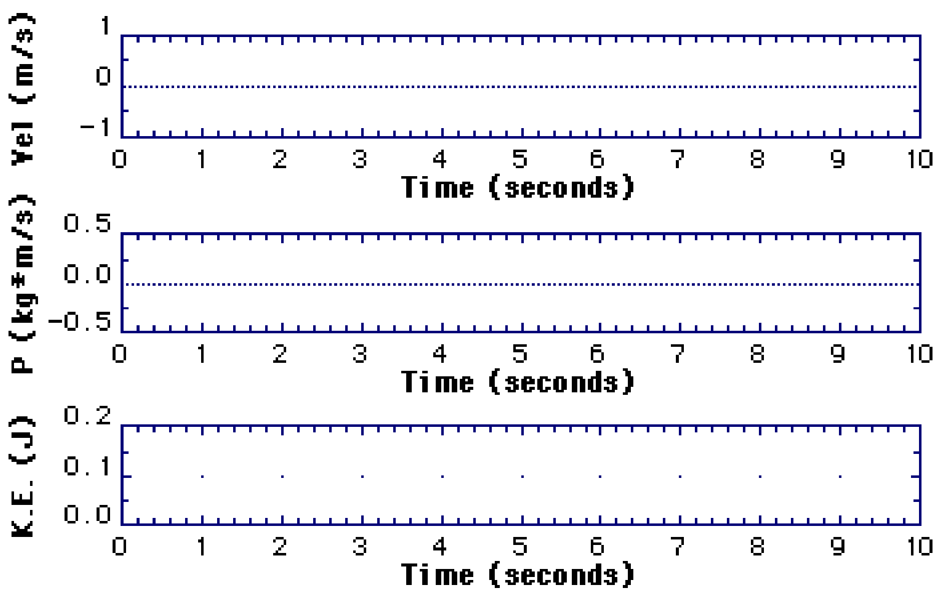

Figure 1. Elastic graph format for Activity 1

Procedure: (continued)

3. **Modify** the momentum formula for the momentum vs. time graph.

   • Under the **Data** menu, first select **Modify...**, then select **Momentum**. A window like that shown in Figure 2 should appear.

   • Replace the "**0**" in the "formula" space with the relationship for momentum:

   (mass of incident cart+spring) * "vel"

   where "(mass of incident cart+spring)" is replaced with the mass you measured earlier for the "incident cart" with spring attached, m_1, in units of kg. Click **OK** when you're through.

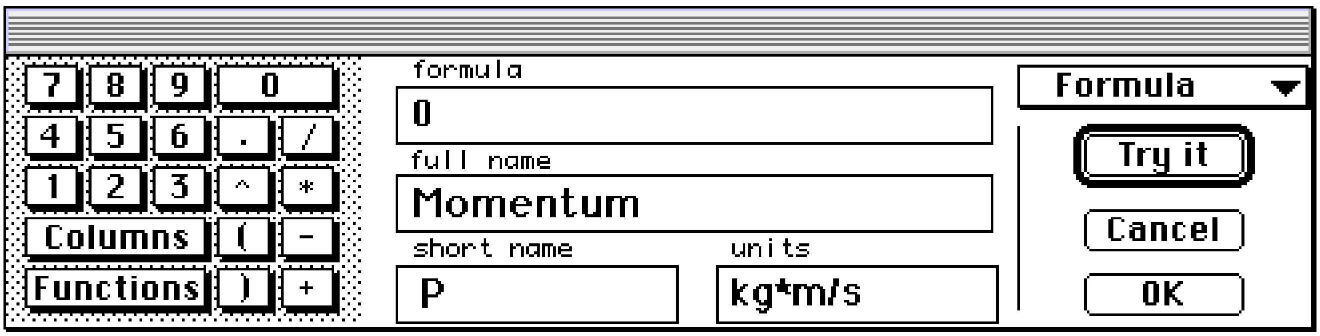

Figure 2. Window for modifying the momentum formula

4. **Modify** the kinetic energy formula for the kinetic energy vs. time graph.

   • Select **Modify...** under the **Data** menu, then select **Kinetic Energy**. A window like that shown in Figure 3 should appear.

   • Replace the "**0**" in the "formula" space with the relationship for kinetic energy:

   0.5 * (mass of incident cart+spring) * "vel" ^ 2

   Click on **OK**.

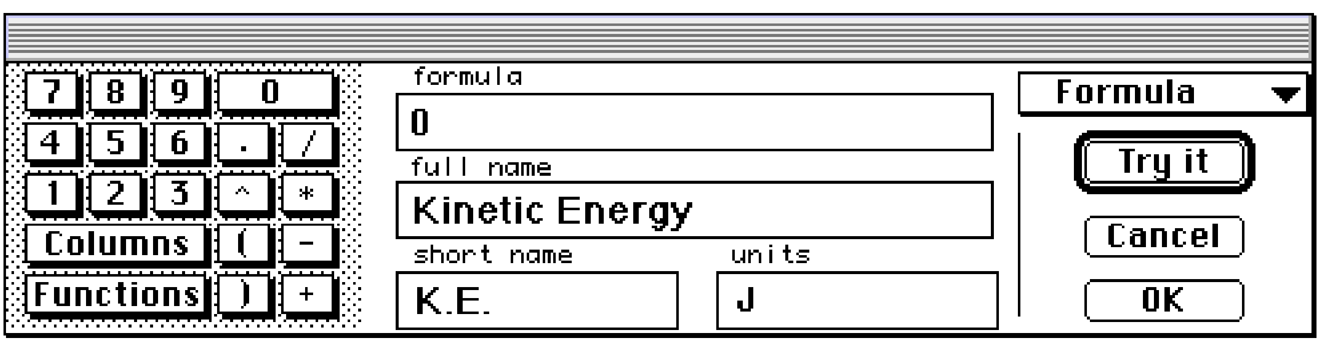

Figure 3. Window for modifying the formula for kinetic energy

Predictions:

- If you push an "incident" cart so that it collides completely elastically with a stationary "target" cart, do you expect the total momentum of the carts to be conserved? Do you expect the total kinetic energy of the carts to be conserved? Write 'yes' or 'no' beside each of the following quantities, and explain your answers below.

Momentum? _______ Kinetic Energy? ________

Explanation:

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- Consider the case in which the "target" cart has an infinite mass, so that it remains stationary when struck with the "incident" cart. (You can think of the "target" cart as a barrier in this case.) Sketch as a function of time your predictions for the momentum and kinetic energy of the "incident" cart before, during, and after the collision.

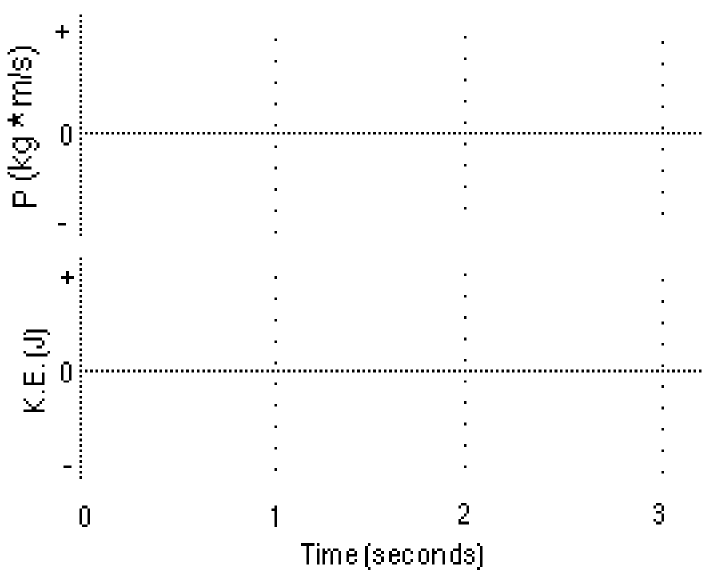

Figure 4. Predictions for cart position, momentum, and kinetic energy

Predictions: (continued)

If you push the "incident" cart having mass m_1 with an initial velocity v_{1i} so that it collides *completely elastically* with a stationary (v_{2i}=0) "target" cart having mass m_2 (see Figure 6), then the ratio of the final and initial "incident" cart velocities, v_{1f}/v_{1i}, is given by

$$\frac{v_{1f}}{v_{1i}} = \frac{m_1 - m_2}{m_1 + m_2} \qquad \text{(Eq. 1)}$$

Note: The relationship in Eq. 1 is derived using the following facts:

(1) Momentum is conserved in an elastic collision, i.e.,

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

(2) In a completely elastic collision, the relative speed of the objects is unchanged by the collision (this is a consequence of the conservation of both momentum and kinetic energy in a completely elastic collision), i.e.,

$$v_{1f} - v_{2f} = -(v_{1i} - v_{2i})$$

The above expression for the ratio v_{1f}/v_{1i} is obtained by combining these two equations in such a way that v_{2f} is eliminated.

- Using the general relationship for v_{1f}/v_{1i} given in Eq. 1, predict the ratio, v_{1f}/v_{1i}, you expect to measure based on the "incident" and "target" masses given in Table 1 (in this Table, m_1 and m_2 refer to your measured values for these carts recorded earlier). In your predictions, make sure to keep track of the sign of the velocity (i.e., + or - velocity).

Expt. #	mass of "incident" cart + spring [kg]	"target" cart mass [kg]	Predicted v_{1f}/v_{1i}	Measured v_{1f}/v_{1i}	% Difference
1	m_1 =	m_2 =			----------
2	m_1 + 0.5 kg =	m_2 =			
3	m_1 =	m_2 + 0.5 kg =			
4	m_1 =	$m_2 = \infty$ (barrier)			

Table 1. Measured and predicted values for v_{1f}/v_{1i} in Activity 1

Procedure:
(continued)

5. Now, test your predictions by performing the experiment shown in Figure 5.
   - Place the spring on the "incident" magnet cart. The magnets in the bumper of this cart should hold the spring's support in place. Orient the cart on the track as shown in Figure 5.
   - Place the "target" cart between the "incident" cart and the metal support as shown.
   - Click **Start**, then push the "incident" cart towards the stationary "target" cart with an initial velocity that is $\leq$ 0.4 m/s.
   - Repeat the experiment until you get a 'nice' set of results.
   - Analyze your data to determine the measured ratio v_{1f}/v_{1i}. Record this result in Table 1.
6. Move the graph of *this first experimental run* (Expt. #1) to **Data B** by selecting **Data A -> Data B** in the **Data** menu.

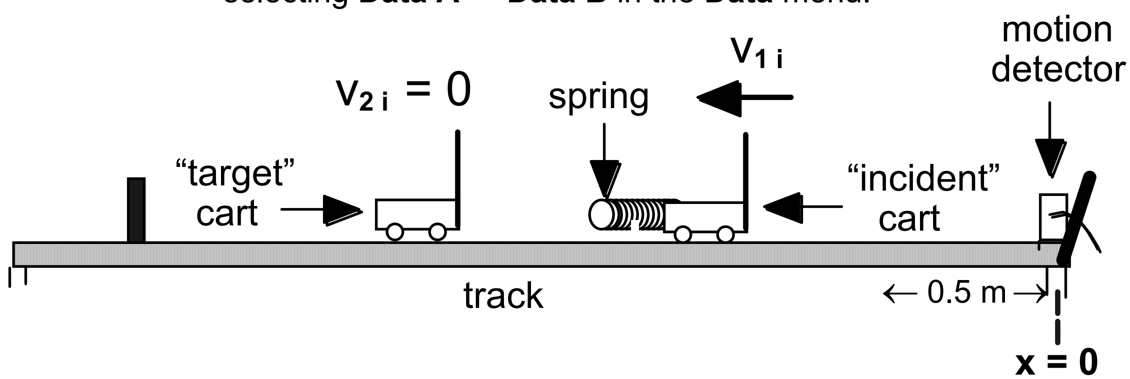

Figure 5. Experimental setup for Activity 1

7. Repeat the experiment in step 5 above for each of the mass combinations in Experiments #2 - #3 in Table 1 by adding to the appropriate carts the masses given (ignore Experiment #4 for now...you'll consider this situation starting with step 9). Analyze your results for the measured ratio v_{1f}/v_{1i}, and record this result in Table 1.
8. Make a record of Experiments #1 and #3.
   - Set **Graph Title...** to ***ELASTIC-1*** and add your group's names.
   - **Print** one copy of this graph for your group.

☐ TA Discussion Checkbox

Question:

- When the spring reaches its maximum compression during the above elastic collision, what is the (simple) relationship between the velocities of the "target" cart, V, and the "incident" cart, v_{1i}? What value does V approach when the "target" mass is very large? When the "target" mass is very small?

Procedure: (continued)

9. Perform Experiment #4, by colliding the "incident cart" with a fixed barrier (which is equivalent to a "target" with infinite mass).
   - Remove the "target cart," and remove the spring attachment from the "incident cart" (you can place the spring attachment on top of the cart to keep the cart's mass the same as in previous experiments). Place the "incident cart" with the magnets approximately 0.5 meters from the metal barrier, orienting the cart so that the magnets facing the barrier as shown in Figure 6. A short distance between the cart's initial position and the barrier will minimize energy loss from friction.
   - Click **Start**, then *gently* ($v_o \leq 0.4$ m/s) push the cart towards the barrier. Make sure that the cart is repelled by the magnets, and does not actually strike the barrier.
   - Repeat the experiment if your initial velocity is too large ($v_o > 0.5$ m/s), or if you don't get a 'nice' set of results.

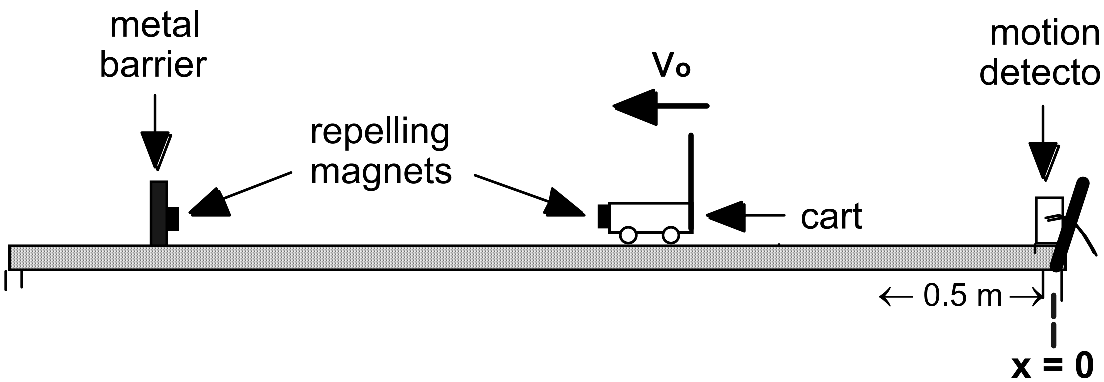

Figure 6. Experimental setup for Experiment #4 in Activity 1

10. Analyze your results for the measured ratio v_{1f}/v_{1i}, and record this result in Table 1.

11. Make a record of your experiment.
    - Set **Graph Title...** to ***ELASTIC-2*** and add your group's names.
    - **Print** one copy of this graph for your group.

Questions:

- Is the <u>magnitude</u> of the "incident" cart's momentum roughly unchanged in the last collision (Experiment #4)? What might account for small changes in the magnitude of the "incident" cart's momentum during this collision?

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- If there was any energy loss in your last 'elastic' collision (Experiment #4), where does the energy go?

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Investigation 2: Impulsive Collisions

Goals:

- To estimate average forces involved in a common impulsive collision
- To study the relationship between an impulse on an object, $I = \int F dt$, and the change in that object's momentum

Activity 2: For a Fleeting Momentum

Introduction: What's the best way to leash your dog? Well, if you don't want to kill him when he breaks into a sprint towards the mail carrier, you might want to use the fact that in an impulsive collision, the change in momentum of an object, Δp, is equal to the *area* under the force vs. time curve associated with the impulsive force on that object, $I = \int F dt$. What does all this mean, you ask? You'll see below, when you compare two very different ways of leashing "Fido."

Procedure:

1. Measure the mass of Fido the cart (the one without the magnets).

m_{Fido} = __________ [kg]

2. Configure the *MacMotion* graph.

   - **Open...** the file ***Impulse 1*** in the **Lab 5** folder. A graph like that shown in Figure 7 should appear.
   - Under the **Data** menu, select **Modify...** and then select **Momentum**. Replace the "**0**" in the formula space with the formula for your cart's momentum. Click on **OK**.

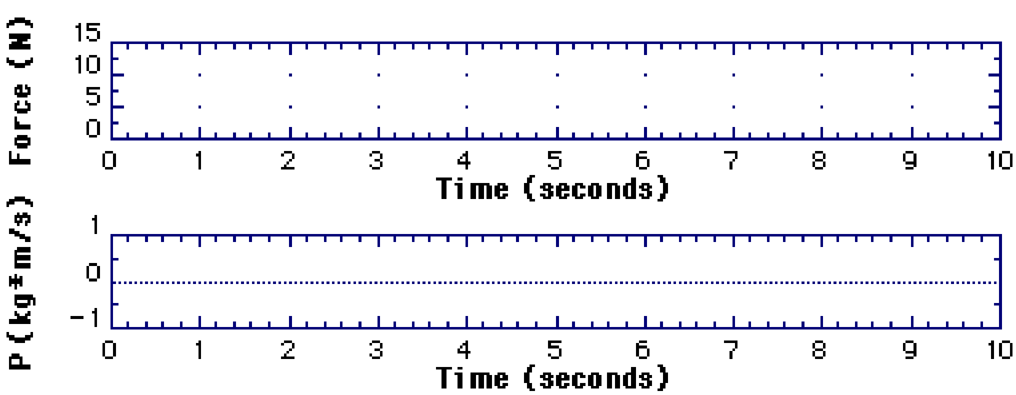

Figure 7. Impulse 1 graph format for Activity 2

Procedure: (continued)

3. Attach the force probe to the end of the track using the Velcro pad on the end of the table, as shown in Figure 8. Orient Fido as shown in Figure 8, and connect the force probe to Fido using the long string ("leash") provided. The "leash" should go over the metal support shown; the support is there to prevent Fido from hitting the probe during the experiment.

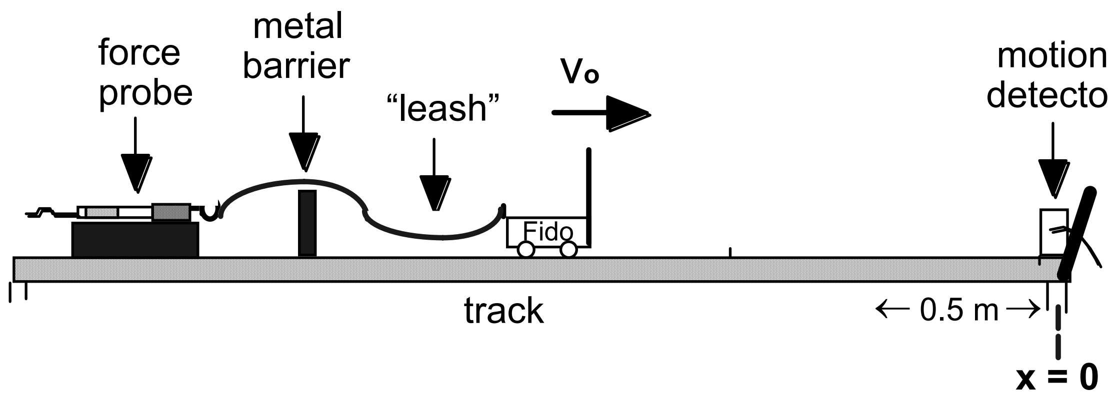

Figure 8. Experimental setup for impulse with a string "leash" in Activity 2

Predictions:

- If Fido sprints away from the force probe as shown in Fig. 8, assuming that the string connecting the force probe to Fido is initially slack, sketch in Figure 9 your predictions for Fido's momentum vs. time. Also, sketch your prediction for the force measured by the force probe as a function of time. Label key features and "events" in your predictions.

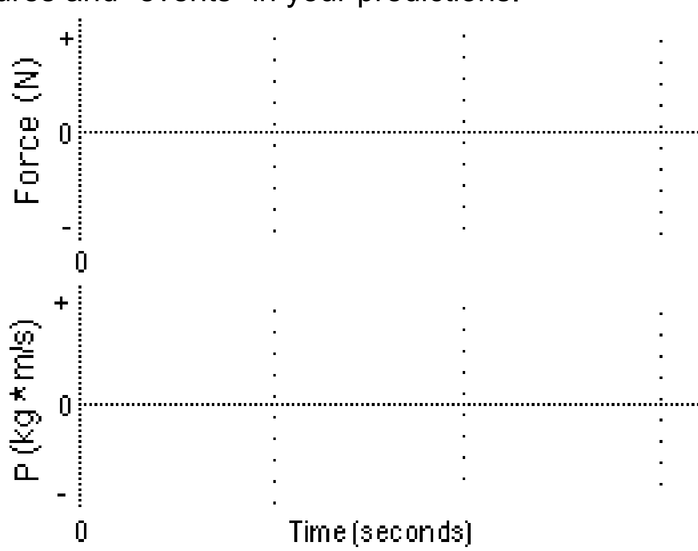

Figure 9. Predictions for Fido's momentum and the measured force

- What relationship, if any, do you expect to observe between Fido's momentum and the force measured by the force probe when Fido reaches the end of his leash (HINT: Your answer should involve the impulse, $I = \int F dt$)? Write a mathematical relationship below, if possible.

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Procedure: (continued)

4. Test your predictions. First, **Zero** the force probe while it is in the horizontal position shown in Figure 8 (with no force applied).

5. Perform the measurement.
   - Place Fido close to the metal support (barrier), so that the leash has quite a bit of "play."
   - **Start** graphing, then gently push Fido with enough force that he stretches the leash, then rebounds. **Zero** the force probe before each attempt if you need more than one try to get a "good" set of data.

6. Analyze your data.
   - Determine the area under the force vs. time impulse curve, $\int F dt$, by selecting **Integral** under the **Analyze** menu, then dragging the cursor across the impulse on the Force graph until you have highlighted the area under your measured F vs. t curve. The value of the integral should appear on the top of the graph. Record this value in Table 3.
   - Determine the measured change of Fido's momentum, $\Delta p = p_f - p_i$, where p_f is the momentum observed just after the impulse, and p_i is the momentum observed just before the impulse. Record the measured Δp in Table 3.
   - Calculate the percent difference between the measured change in the cart's momentum, Δp, and the measured value of the impulse, $I = \int F dt$.

Type of "Leash"	Measured Δp	Measured $I = \int F dt$	% Difference between Δp and I
String Only			
Spring + String			

Table 3. Measured Δp and impulse I in Activity 2

TA Discussion Checkbox

Questions:

- How does the measured impulse, I, compare with the measured change in Fido's momentum, Δp? Is this what you predicted?

Predictions:

- If you now make a leash between Fido and the force probe that consists of a spring *and* a string, as shown in Figure 10, then repeat the above experiment with roughly the same initial velocity, describe how you think the force vs. time profile of the impulse on Fido will change.

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- For the impulse you described above, predict whether the following quantities will be greater than, less than, or equal to the values for these quantities measured with the string alone: (a) the maximum force, $\mathbf{F_{max}}$, (b) the duration of the impulse, Δt, and (c) the value of the impulse $I = \int F dt$.

$\mathbf{F_{max}}$: __________ Δt: __________ $I = \int F dt$: __________

Explain your reasoning for the answers above.

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Procedure: (continued)

7. Test your predictions. Put the spring between the force probe and the string as shown in Figure 10. Make sure the spring is placed over the metal support shown.

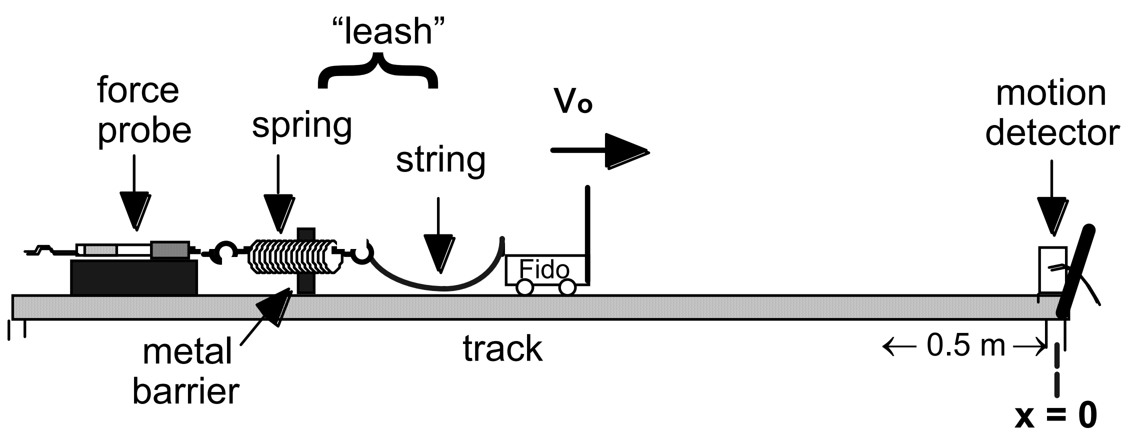

Figure 10. Experimental setup for impulse with a spring + string "leash"

Procedure: (continued)

8. **Zero** the force probe while it is in the horizontal position shown in Figure 10 (with no force applied).

9. Move your graphs from the previous experiment (the string only "leash") to **Data B** for later comparison by selecting **Data A -> Data B** in the **Data** menu.

10. Perform the measurement.

    • Again, place Fido close to the metal support, so that the string+spring "leash" has quite a bit of "play."

    • **Start** graphing, then push Fido *with a momentum that is as close as possible to that obtained in your earlier experiment* (green data with string only). Again, you should zero the force probe before each new attempt if you need more than one try to get a "good" set of data.

11. Analyze your data.

    • Determine the area under the force vs. time impulse curve, $\int Fdt$, by selecting **Integral** under the **Analyze** menu, then by dragging the cursor across the impulse until you have highlighted the area under your measured F vs. t curve. The value of the integral should appear on the top of the graph. Record this value in the appropriate column of Table 3.

    • Determine your measured change of Fido's momentum, $\Delta p = p_f - p_i$, where p_f is the momentum observed just after the impulse, and p_i is the momentum observed just before the impulse. Record your measured Δp in the appropriate column of Table 3.

    • Calculate the percent difference between the measured change in Fido's momentum, Δp, and the measured value of the impulse on Fido, $I = \int Fdt$.

12. Make a record of your experiment and analysis.

    • Set **Graph Title...** to ***IMPULSIVE*** and add your group's names.

    • **Print** one copy of this graph for your group.

Questions:

- Did the addition of the spring to the leash significantly influence the *shape* of the impulse exerted on Fido? How? Is this what you predicted?

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- Assuming that your initial momentum was roughly the same in both cases, did the addition of the spring significantly influence the *value* of the impulse you measured compared to that measured with the string alone. Explain. Is this what you predicted?

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- Based on your results, what is the most humane way to leash Fido? Why?

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Investigation 3: Completely Inelastic Collisions

Goals: • To study a completely inelastic collision between two carts.

Activity 3: Looks Like I'm Stuck With You

Introduction: In earlier activities you investigated collisions which were nearly elastic, i.e., only a small amount of energy (< 10%) was lost in the collisions. In this activity, you will study the opposite extreme: a collision which is completely inelastic.

Procedure:

1. In the following experiment, you will use the "magnet" cart as the "incident" cart, and you will use the "non-magnetic" cart as the "target" cart.
   - Measure the masses of both the "target" cart and the "incident" cart (see Figure 11), and record these values below.

incident cart, m_1 = _______ [kg] **target cart, m_2 = _______** [kg]

2. Prepare the setup shown in Figure 11.
   - Orient the "incident" cart on the track so that its reflector is closest to the motion detector.
   - Orient the "target" cart on the track so that its Velcro pads are facing the Velcro pads on the "incident" cart.

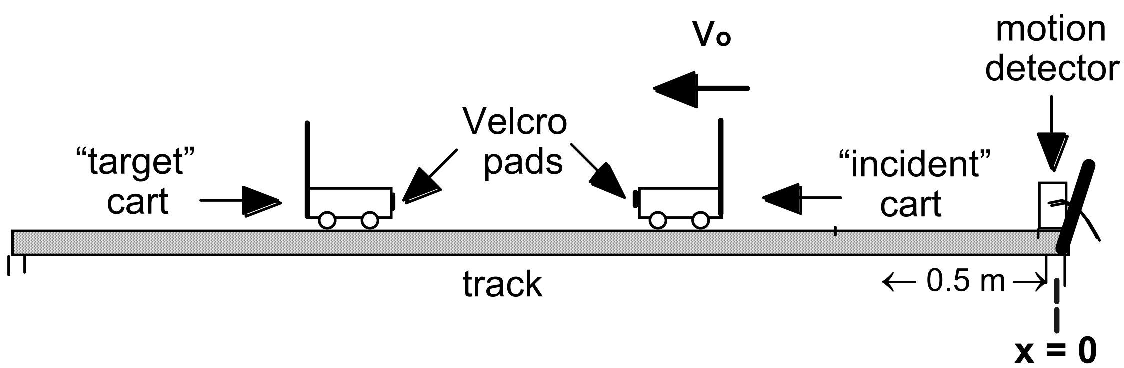

Figure 11. Experimental setup for Activity 3

Predictions: • Assume that you push the "incident" cart with a momentum m_1v_1 along the track away from the motion detector and towards a stationary "target" cart having a mass m_2. At a time t_o the "incident" cart collides completely inelastically with the "target" cart; the resulting total momentum is $(m_1+m_2)v_2$. Sketch in Figure 12 your predictions for the *total momentum* and *total kinetic energy* of the two cart system as a function of time. Make sure to label key features, such as the collision at t_o.

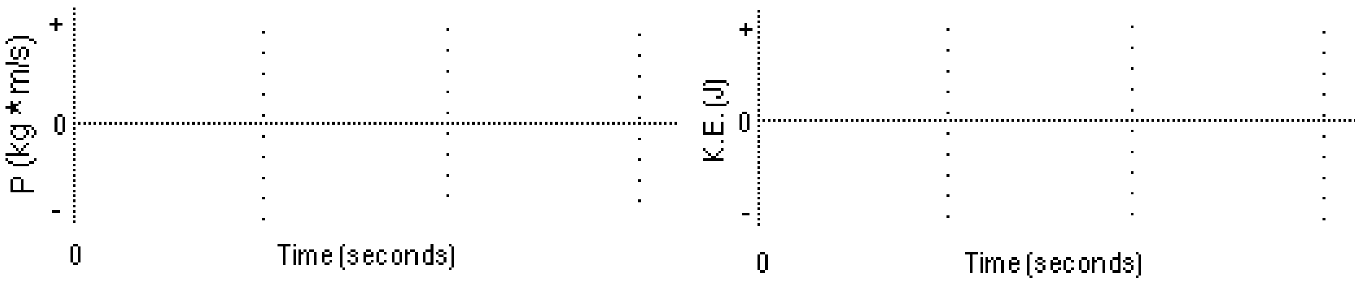

Figure 12. Predictions for total momentum and kinetic energy

• Do you expect the total momentum of the two cart system to be conserved in the "inelastic" collision described above? Do you expect total kinetic energy of the system to be conserved? Write 'yes' or 'no' beside each of the following quantities, and explain your answers below.

Total Momentum? _______ Total Kinetic Energy? ________

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In the completely inelastic collision described above, the fractional change in the kinetic energy can be written (make sure you understand how this relationship is obtained).

$$\frac{\Delta K.E.}{K.E.} = \frac{K.E._{final} - K.E._{initial}}{K.E._{initial}} = \frac{\frac{1}{2}(m_1+m_2)v_2^2 - \frac{1}{2}m_1v_1^2}{\frac{1}{2}m_1v_1^2} = \boxed{\frac{-m_2}{m_1+m_2}} \quad \text{(Eq. 2)}$$

• For each of the "incident" and "target" cart mass combinations given in the bottom of Table 4 (where m_1 and m_2 are the cart mass values you measured earlier), use the relationship above to predict a numerical value for the fractional change in energy for these two carts in the inelastic collision described above. Record your answers in the bottom of Table 4.

Procedure:
(continued)

3. Prepare to test your predictions. First, configure the *MacMotion* graph.
   - **Open...** the file ***Inelastic*** in the **Lab 5** folder. A graph like that shown in Figure 13 should appear.

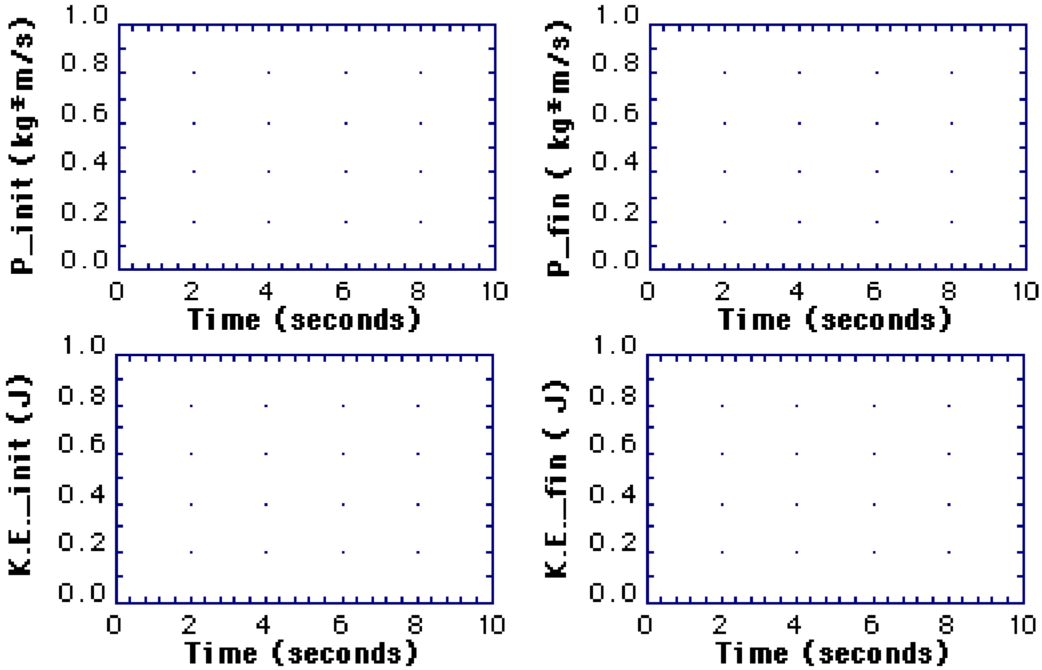

Figure 13. Inelastic graph format for Activity 3

4. Prepare to plot the initial and final momenta of the two cart system.
   - Prepare to plot the initial momentum of the two cart system for the first cart mass combination (m_1, m_2) in Table 4 by selecting **Modify...** under the **Data** menu, then by selecting **Initial Momentum**. Replace the "**0**" in the formula space with the formula for the initial momentum of the system:

$$(m_{initial}) * \text{"vel"}$$

   where $m_{initial}$ is the actual mass you expect to be associated with the initial momentum during this inelastic collision. Click on **OK**.

   - Prepare to plot the initial kinetic energy of the two cart system described above, by selecting **Modify...** under the **Data** menu, then by selecting **Initial Kinetic Energy**. Replace the "**0**" in the formula space with the formula for the initial kinetic energy of the system:

$$0.5 * (m_{initial}) * \text{"vel"} \wedge 2$$

   where $m_{initial}$ is the actual mass you expect to be associated with the initial kinetic energy of the system during this inelastic collision. Click on **OK**.

Procedure: (continued)

5. Prepare to plot the final momentum and kinetic energy of the two cart system after the inelastic collision.
   - Repeat step 4, entering the mass, m_{final}, you expect to be associated with the final momentum and final kinetic energy of the system.

6. Test your predictions by performing the experiment.
   - With the carts arranged as shown in Figure 11, click **Start**, then push the “incident” cart towards the “target” cart. The two carts should stick together during the collision.

7. Identify the time, t_o, at which the initial impact between the two carts occurred, and record this value below.

   t_o = ______ [sec]

8. Analyze your results for this completely inelastic collision.
   - Use the analysis capabilities of *MacMotion* under the **Analyze** menu to determine the *initial momentum* and *kinetic energy* of the two-cart system (i.e., measured just before the collision at t_o), and the *final momentum and kinetic energy* of the two-cart system (i.e., measured just after the collision at t_o). Complete Table 4.

9. Repeat steps 4 through 8 for the second (m_1, m_2+500g) mass combination given in Table 4.
   - *Make sure* you change the $K.E._{final}$ and P_{final} formulæ to include the new final mass value; use **Modify....** under the **Data** menu.

Masses		Measured Initial Momentum	Measured Final Momentum	% Change
“incident”	“target”			
m_1	m_2			
m_1	m_2+500g			

Masses		Measured Initial K.E.	Measured Final K.E.	Predicted $\frac{\Delta K.E.}{K.E._{initial}}$	Measured $\frac{\Delta K.E.}{K.E._{initial}}$	% Difference
“incident”	“target”					
m_1	m_2					
m_1	m_2+500g					

Table 4. Momentum (top) and K. E. (bottom) results for a completely inelastic collision

☐
TA Discussion Checkbox

Questions:

- Did you find that momentum was roughly conserved in this collision? How about the kinetic energy? Did your predictions for the change in kinetic energy compare well with your measurements? Explain.

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- Is it possible to have a collision in which *all* the kinetic energy of the colliding objects is lost? If not, why not? If so, provide an example.

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- Two identical satellites, in orbit around the earth, are traveling in opposite directions in the same circular orbit when they collide head-on. Describe their subsequent motion if the collision is (a) elastic and (b) completely inelastic.

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