PHYSICS 211

LAB #4: Energy

A Lab Consisting of 3 Activities

Name: _____

Section: _____

TA: _____

Date: _____

Lab Partners: _____

_____

_____

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

Written by Cooper, Dick, and Weissman

Physics Lab 211-4

Equipment List
Motion detector
Extension cord for motion detector
211 friction cart with reflector
Standard cart track setup
Meter stick
Rod and clamp setup to hold motion detector about 7.5 feet above the floor
Positioning string (0.5 m long) taped to motion detector clamp
Basketball inflated to a Ògood bounceÓ pressure
Brass ring to hold the basketball when it's not in use on the computer table
106 extension spring attached to double- loop string
200 gram mass

Computer File List
MacMotion file Ò211-04 BasketballÓ
MacMotion file Ò211-04 Data Entry 1Ó
MacMotion file Ò211-04 SlidingÓ

Investigation 1: Energetics of a Bouncing Basketball

Goals:
- To study conservation of energy, and the conversion of potential energy to kinetic energy, during free fall motion of a ball
- To study what happens to total energy as a ball bounces

Activity 1: Fol-low the Boun-cing Ball

Introduction: If you're playing or watching basketball, most likely the last thing on your mind is physics (if this isn't true, see your TA after class - you're exhibiting some tell-tale signs that you should be a physics major). But, of course physics is important for describing even something simple such as how a basketball bounces. In fact, in this activity you will use a bouncing basketball to study the energetics of a freely falling object under the constant force of gravity.

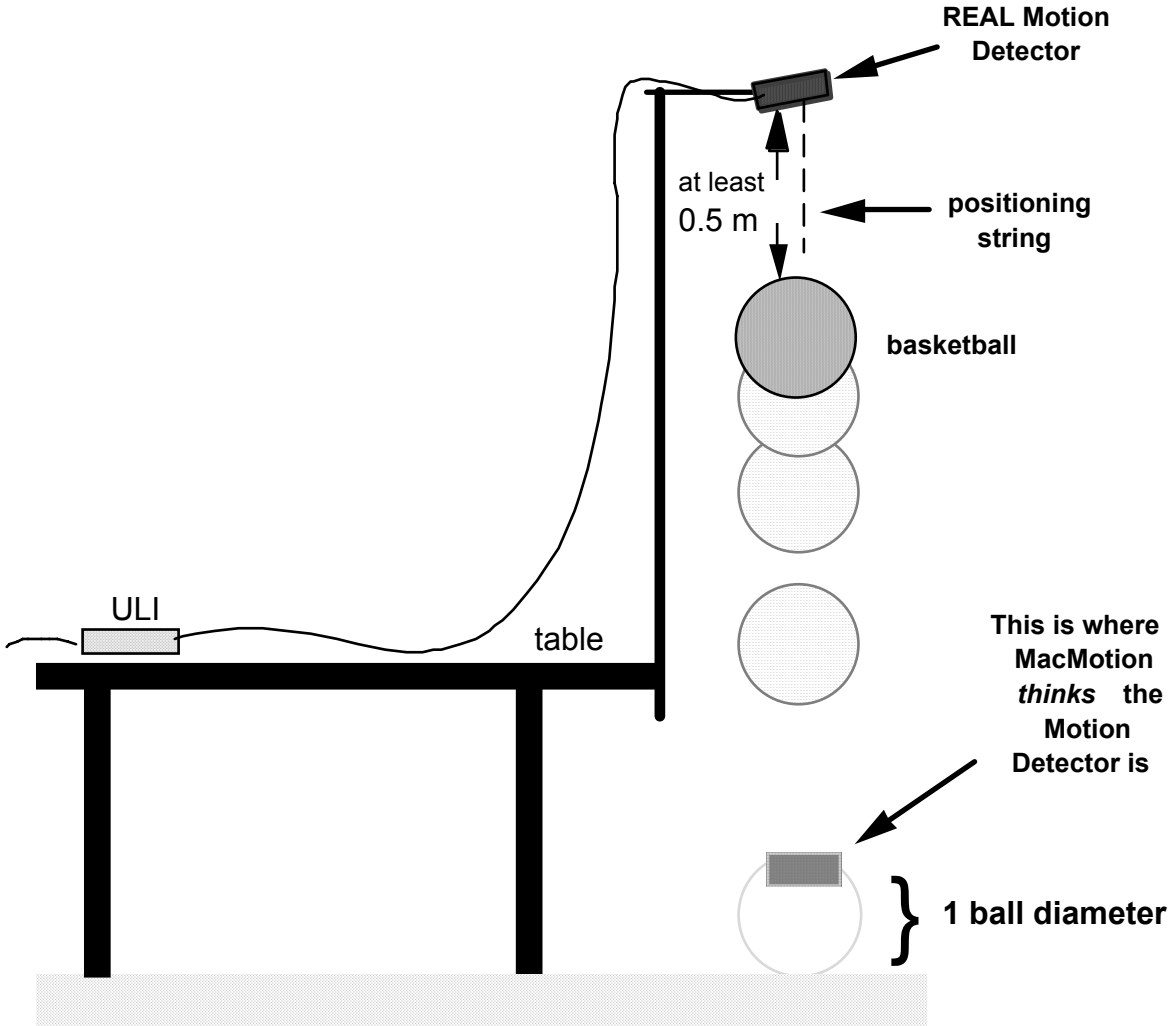**Procedure:**   1. Set up the motion detector as shown in Figure 1.

Figure 1. Experimental setup for Activity 1

Procedure:
(continued)

2. Configure the *MacMotion* graph. You will first analyze the gravitational potential energy of the ball. The distance one would like to measure is the height of the ball from the floor (since it is convenient to set the ball's "zero" of gravitational potential energy at the floor), but you cannot simply place the motion detector on the floor (Smash!).

   You will tell the computer to display distance as if the detector were on the floor. First, find out how far the floor is from the motion detector.

   • **Open...** (under the **File** menu) the file **Basketball** in the **Lab 4** folder. A set of graphs like those shown in Figure 2 will be displayed.
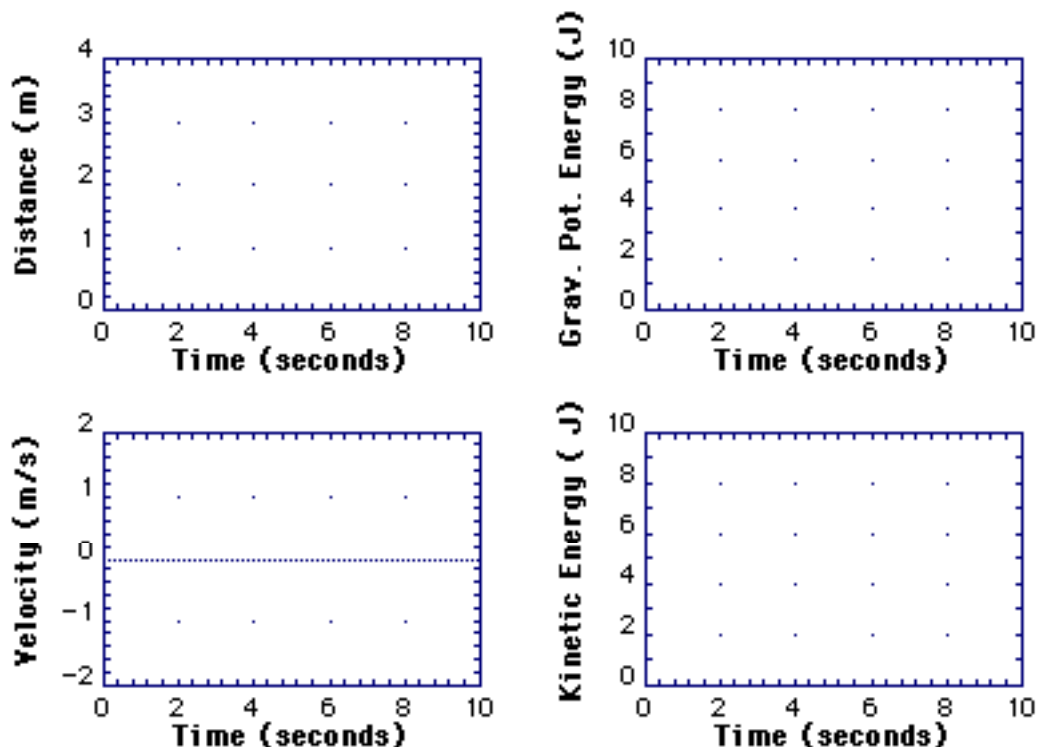

Figure 2. Basketball graph format for Activity 1

   • Put the basketball on the floor underneath the motion detector, then **Start** graphing. This position is roughly what the motion detector will measure when the ball hits the floor, and so you will define it as your "zero."

   • Select **Analyze Data A** (in the **Analyze** menu) and find the distance from the motion detector to the stationary ball on the floor. You can average over a region to get a more accurate number.

Average distance = _____ m

Procedure:
(continued)

3. Now, tell the computer to pretend that the motion detector is somewhere else (i.e., one basketball diameter above the floor).

   • Select **Configure Distance Probe** from the **Collect** menu.

   • Select "**Distance away is Negative**".

   • Find the line "**offset zero by _____**". In this box, you must enter the negative of the distance measured in step 2 above. *For example:* If you found that the motion detector gave a reading of 2.34 meters, put **-2.34** in for the offset.

   MacMotion will now behave as if you have put the motion detector pointing upwards one basketball diameter above the floor.

4. You will need to know the mass of the basketball, m . Weigh the ball now using one of the balances and record the mass of the ball below. You may want to use a roll of tape to keep the basketball stationary (don't forget to subtract the mass of the roll of tape).

   Mass of basketball = _____ kg

5. Record the initial height, h, at which the ball will be dropped.

   • Have one person hold the ball *steadily* under the motion detector so that it is barely touching the "positioning string" (see Figure 1) for the initial ball height, h. **Start** graphing while the ball is held steadily in this position, and record the resulting measured height below.

   h = _____

Predictions:

• What is the gravitational potential energy of the ball, $P.E._{gravity} = mgh$, at the initial height of the ball (including units)?

_____

• What is the total energy of the ball at this initial height (including units)?

_____

• What do you predict will be the kinetic energy of the ball after it falls 1 meter below its initial height (including units)?

_____

Predictions:
(continued)

•Sketch in Figure 3 your predictions for the kinetic energy, K.E., potential energy, P.E., and total energy, E, of the ball as it completes several bounces on the floor. Be sure to label any distinctive features you expect.
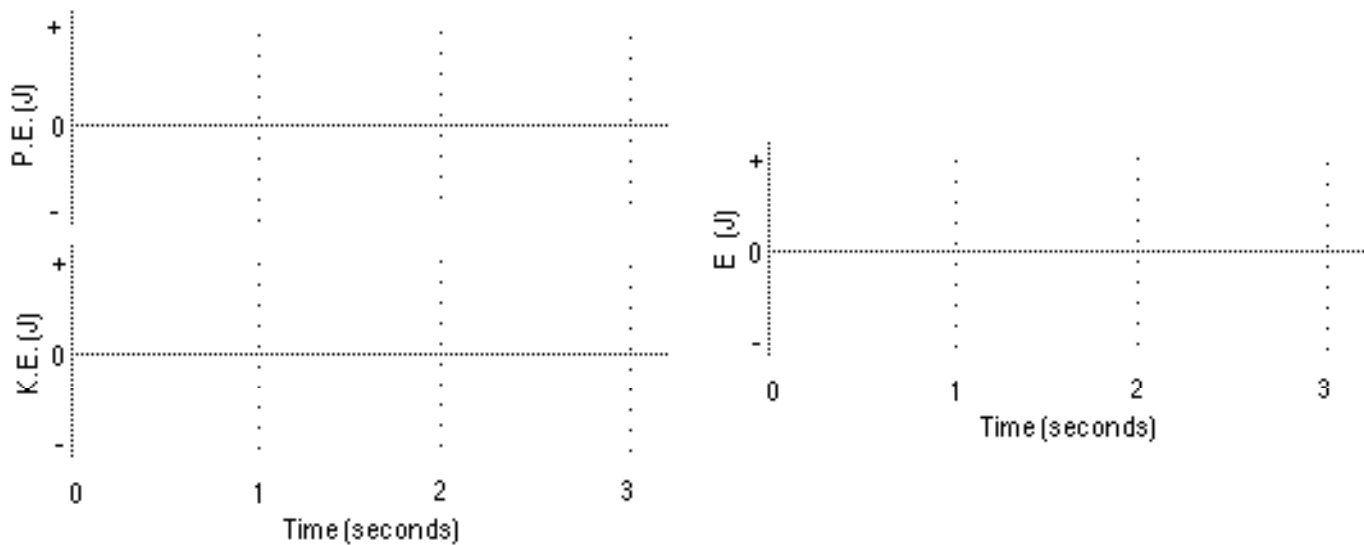

Figure 3. Predictions for kinetic, potential, and total energy in Activity 1

Procedure:
(continued)

6. Make the measurement and test your predictions.

 • Have someone again hold the basketball below the motion detector so that it is barely touching the "positioning string," i.e., at the initial height, h. It is probably best to hold the ball on the sides so that you can release it without imparting an initial velocity.

 • Hold the ball stationary and **Start** graphing.

 • One second after you hear the clicks begin, release the ball.

 • Make sure your experiment is done such that you can see the ball bounce at least *six* times on the graph (i.e., before the ball "wanders" out of view of the motion detector). *Important:* if you do not see six bounces on your graph, repeat the above procedure until you do.

7. Use *MacMotion* to calculate the gravitational potential energy of the basketball as a function of time. Gravitational potential energy is defined as

$$P.E._{gravity} = mgh \qquad \text{(Eq. 1)}$$

where h is the height above or below the plane where we define $P.E._{gravity}$ to be equal to zero. We take g = 9.81 meters/sec^2 as usual.

Procedure:
(continued)

By defining the zero of the ball's potential energy to be the point at which the ball hits the floor, the distance *h* you measured using MacMotion and recorded earlier is equal to *h* in Eq. 1.

- Define the gravitational potential energy formula by first selecting **Modify...** under the **Data** menu, then selecting **Grav. Pot.   Energy**. A window like that shown in Figure 4 should appear.
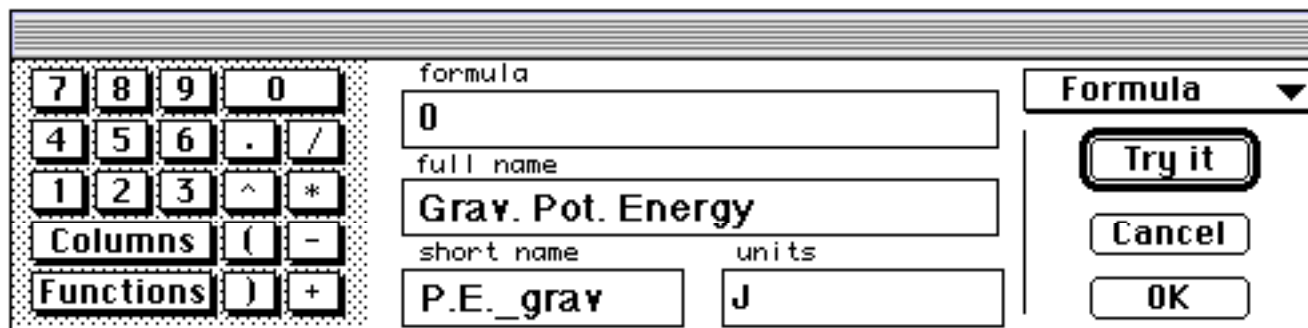

Figure 4. Window for modifying the gravitational potential energy graph

- Replace the "**0**" in the "formula" space of Figure 4 with the relationship for gravitational potential energy

$$9.81 * (\text{mass of ball}) * \text{"Dist"}$$

where you enter the actual mass of your basketball.

For example, if you measured the mass of the basketball to be 0.602 kg, your dialog box should look like Figure 5. If necessary, rescale the resulting P.E. plot to best see your results.

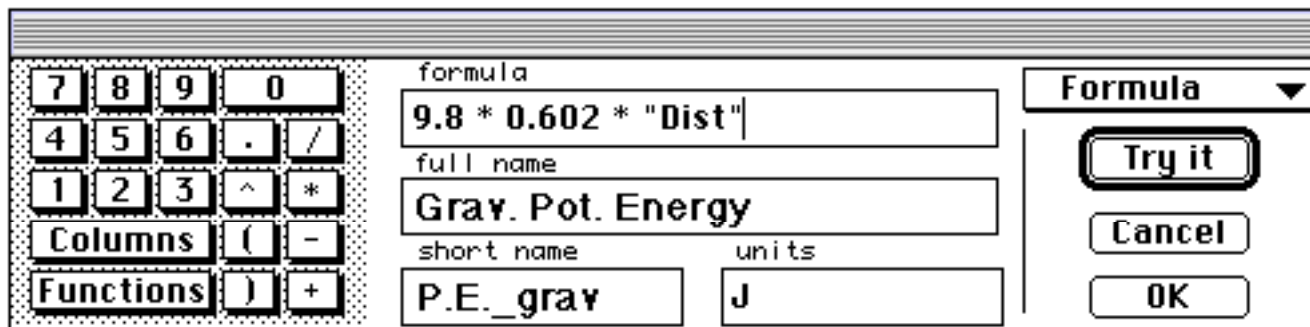- Click **OK** when you're sure of your formula.

Figure 5. Example formula entry window for potential energy

8. Make a record of your experiment and analysis.

- Set **Graph Title...** to *BOUNCE-1* and append your group's names.
- **Print** one copy of this graph for your group.

Question: •Look at your measured P.E. vs. time graph. Are both the initial value (at t = 0) and time-dependence of the measured P.E. consistent with your predictions?

_____

_____

Procedure: 9. Use *MacMotion* to test your predictions for the translational kinetic energy
(continued)   of the basketball.

Note: The translational kinetic energy of an object is given by the formula

$$K.E. = \frac{1}{2}mv^2 \qquad\qquad \text{(Eq. 2)}$$

where *m* is the mass as measured previously and *v* is the velocity (as measured here using the motion detector).

The *translational kinetic energy* is associated with the movement of the *center of mass* of an object. Often the word *translational* is dropped. In future investigations involving rolling objects, we will see the need to be more specific and keep it.

Produce a calculated column for *translational kinetic energy*.

• You will need to define the kinetic energy formula, by first selecting **Modify...** under the **Data** menu, then selecting **Kinetic Energy**. A window like that shown in Figure 6 should appear.
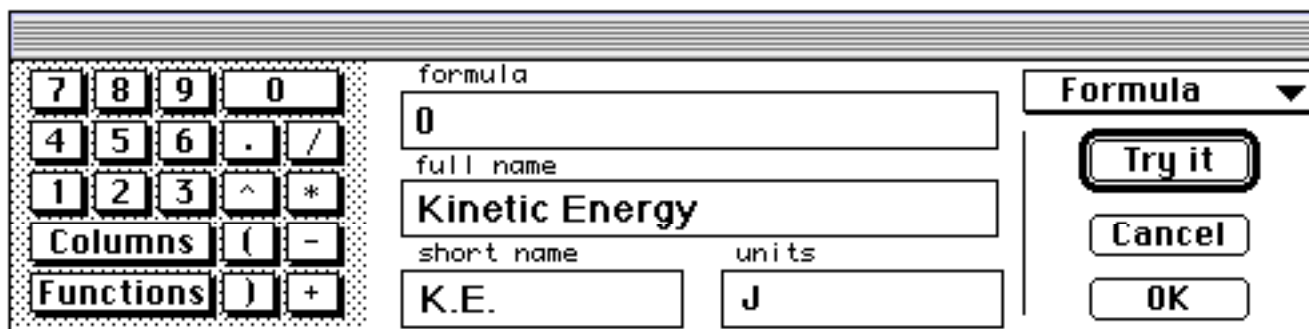

Figure 6. Window for defining the kinetic energy formula

Procedure:
(continued)

• Replace the "**0**" in the "formula" space of Figure 4 with the relationship for kinetic energy

$$0.5 * (\text{mass of ball}) * \text{"vel"} \wedge 2$$

where "(mass of ball)" is the actual numerical mass you measured earlier in kg.

For example, if you measured the mass of the basketball to be 0.602 kg, your dialog box should look something like Figure 7.

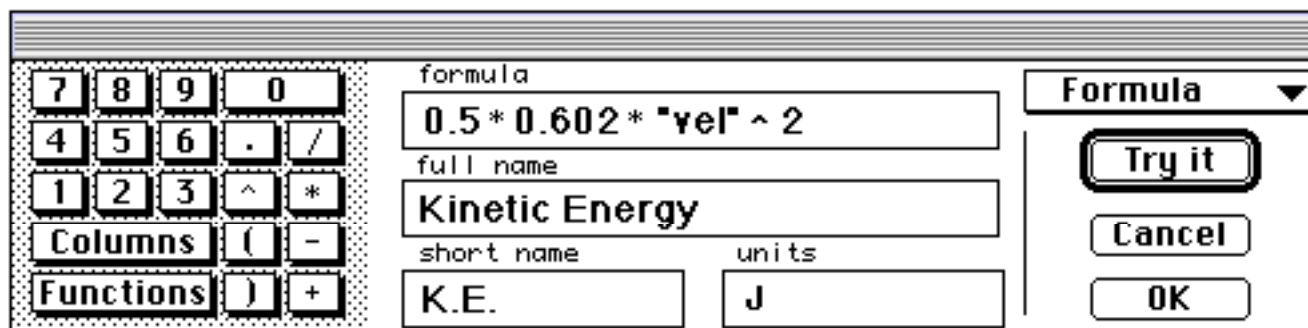• When you have entered the correct formula, click **OK**. The vertical axis should now be labeled K.E. (J).

Figure 7. Example formula entry for kinetic energy in Activity 1

Questions:

• Is your measured K.E. vs. time plot what you expected? How does the kinetic energy behave when the ball bounces?

_____

_____

_____

• Is the value of K.E. after the ball has fallen roughly 1 meter *below its initial position* close to what you predicted? What is the percent difference between the measured and predicted values?

_____

Procedure:
(continued)

10. Now, examine the total energy of the bouncing basketball by making a graph of the *sum of Potential and Kinetic energies* versus time.

• Click on the y-axis label of the velocity graph, then drag down to choose **Total Energy** to get the total energy graph.

• Define the proper formula for the total energy by selecting **Modify...** under the **Data** menu, then selecting **Total Energy**. A graph like that shown in Figure 8 should appear.

• Replace the "**0**" in the formula space with the relationship for total energy, "K.E." + "P.E._grav". Click on **OK**.
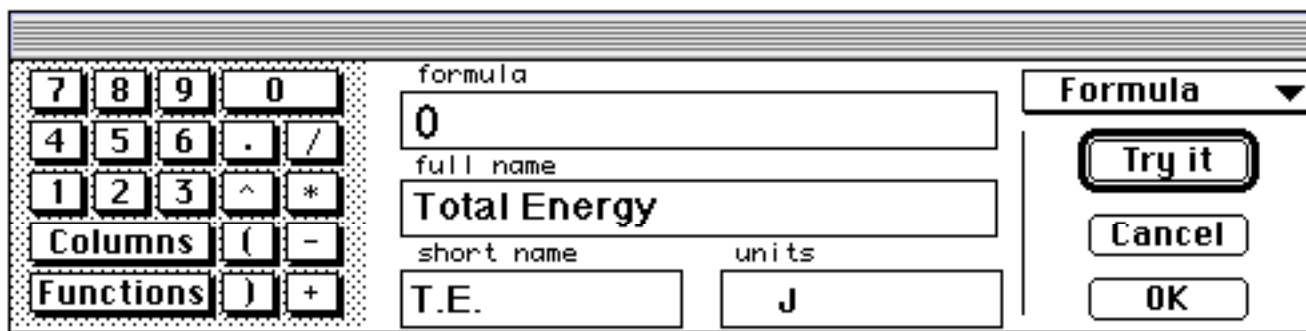
Figure 8. Example formula entry for total energy in Activity 1

11. Rescale all of your graphs so they are on the same scale.

12. Make a printed record of your experiment.
   • **Set Graph Title...** to *BOUNCE-2* and append your group's names.

   • **Print** *one* copy for the group.

☐
TA Discussion
Checkbox

Questions:

• Look at the total energy graph during a period of free fall (i.e., when the ball is not in contact with the ground or your hand). Describe the most significant feature of this graph in this region.

_____

_____

• What is the value of the ball's acceleration between bounces? Why?

_____

_____

• What happens to the total energy after each bounce? Roughly what fraction of the ball's energy is lost, and where does this energy go?

_____

_____

Activity 2: Slip Slidin' a Weight

Introduction: In this activity you will simulate an object *sliding* without friction down an inclined plane using a cart rolling down an inclined track. This activity will allow you to approximately simulate the "flow" of energy you've experienced when (i) sliding down a playground slide, or (ii) skiing down a hill   (we'll ignore for now the more complicated transfer of energy you've   experienced when colliding into innocent skiers at the foot of the hill).

Procedure: 1. Prepare the setup as shown in Figure 9.

>   • For this activity, there should be *no friction* set on the cart.

>   • The ramp should be securely fastened. The angle θ in Figure 9 is crucial and should not vary as you perform the experiment.

>   • The detector should be tilted slightly upward to best see the cart.

>   • Attach a 200 gram mass on top of the cart with the Velcro pad. <u>Be sure to secure the mass with tape.</u>
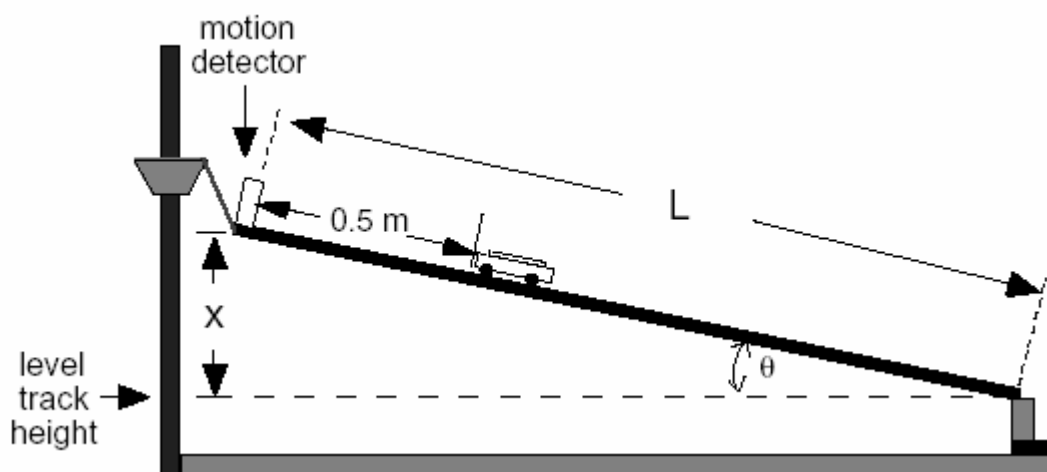

Figure 9. Experimental setup for Activity 2

2. Set up the computer.

>   • **Open...** the file *SLIDING* in the **Lab 4**   folder. A graph like that shown in Figure 10 should appear. Note that opening this file will reset the motion detector so that

>   • moving away from the motion detector is positive

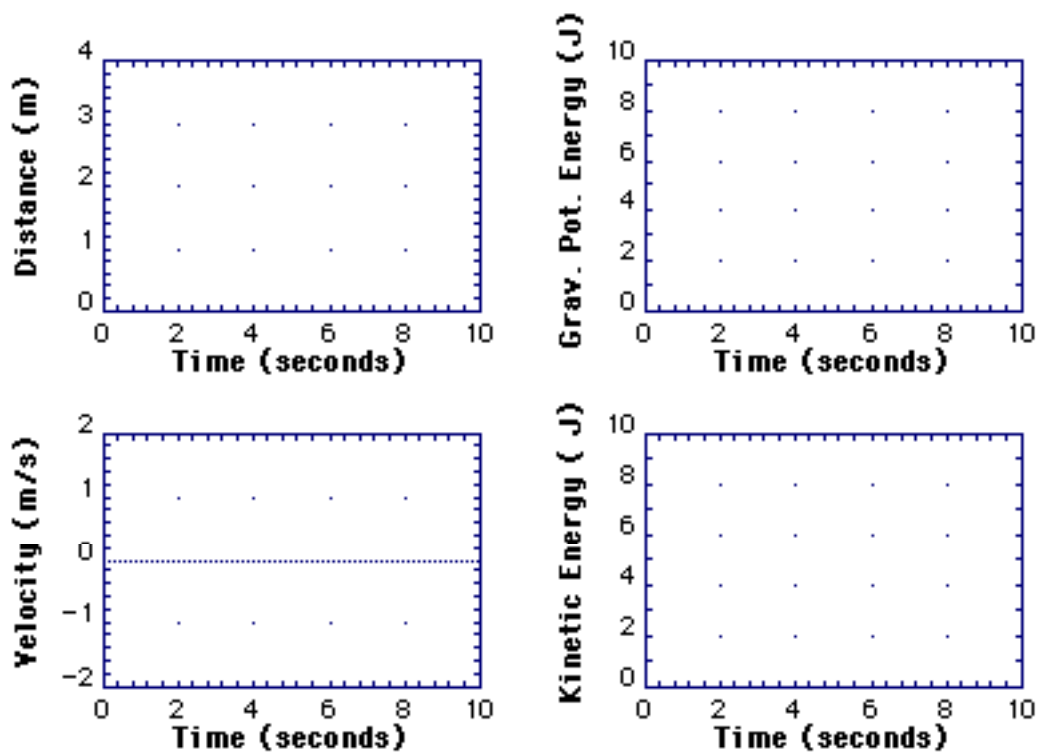>   • the motion detector is at 0 meters

Figure 10. Sliding graph for Activity 2

Procedure: 3. Measure the important parameters of your experimental setup.
(continued)

    • Find the height, *x*, and length, *L* (see Figure 9). With these parameters, you should be able to deduce the angle θ. Your results depend sensitively on this angle, so let your lab technique shine.

      •• Record this number in degrees and radians below. When you enter it in formulas later, *always enter it in radians*; *MacMotion does not understand degrees!*

$$\theta = \underline{\hspace{1.5cm}} \textbf{ degrees}$$

$$\theta = \underline{\hspace{1.5cm}} \textbf{ radians}$$

    • You also need to know the mass of the cart (don't forget to include the 200 gram mass you added earlier). Measure and record the total mass using one of the balances.

$$\textbf{Total mass of cart} = \underline{\hspace{2cm}} \textbf{ kg}$$

Procedure:
(continued)

4. Make a graph of the cart's motion.

     • Hold the cart stationary approximately 0.5 m from the motion detector, and click **Start** to begin graphing.

     • About one second after the clicks start, release the cart.

5. Now let's consider the energetics of this cart "sliding" down the ramp. We again need to know the cart's height at any time to compute the potential energy.

     • With the help of the triangles shown in Figure 11, write down a formula for the height h as a function of the distance from the motion detector d and the angle θ.
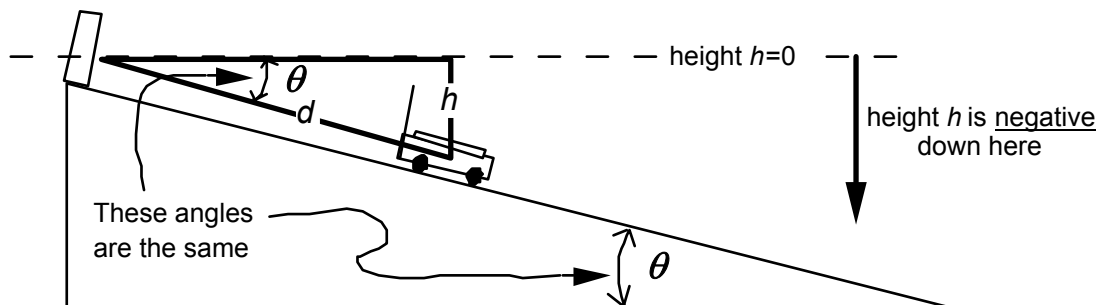
     Expression for h: h = _____

Figure 11. Diagram for determining the relationship between h, d, and θ

Predictions: What is the kinetic energy and velocity of the cart after it has rolled a distance $\Delta d = d_2 - d_1$ down the incline from a *stationary* initial position (where d_1 and d_2 are the initial and final cart positions, respectively)?

To answer this, use conservation of energy, $E_{init} = E_{final}$ (consider Figure 11):

$$E_{init} \qquad\qquad\qquad\qquad E_{final}$$

$$mgh_1 \qquad = \qquad mgh_2 + \tfrac{1}{2}mv^2$$

where h_1 and h_2 are the initial and final cart heights, respectively (see Figure 11), and v is the cart velocity.

Using the conservation of energy relationship above, derive expressions for the cart's kinetic energy and velocity as a function of m, g, Δd (= d_2-d_1), and θ (ask your TA to check your expressions when you're done):

(Eq. 3)

K.E. = _____

(Eq. 4)

v = _____

• After the cart has rolled a distance Δd =1 meter *from its initially stationary position*, what do you predict will be the velocity and kinetic energy of the cart? Record your predictions in Table 1.

Predictions:
(continued)

•Sketch in Figure 12 your predictions for the cart's kinetic energy, K.E., potential energy, P.E., and total energy, E, as it rolls down the incline. Label any important features.
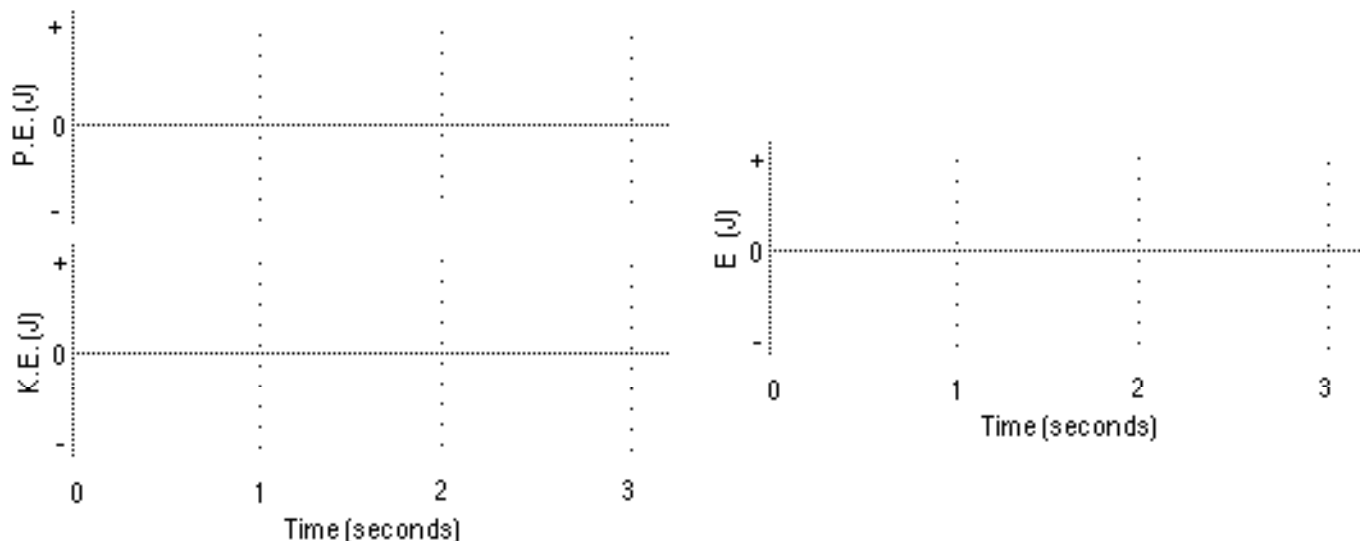

Figure 12. Predictions for kinetic, potential, and total energy in Activity 2

Procedure:
(continued)

6. Check your predictions. First, create a graph of *gravitational potential energy* vs. time.

   • Click and hold down the y-axis label ("force") of the force vs. time graph and drag down to select **Grav. Pot. Energy**.

   • Select **Modify...** under the **Data** menu, then select **Grav. Pot. Energy**. A window like that shown in Figure 13 should appear.

   • Replace the "**0**" in the "formula" space with the relationship for gravitational potential energy. Use your height formula for **h** in Step 5 above to enter the formula

   $$(\text{mass of cart}) * 9.81 * (h)$$

   where h is your own expression for the height. (Hint: It should contain a sin() function.) Enter the value of the angle you previously calculated in the parentheses. Don't forget to use *radians*!

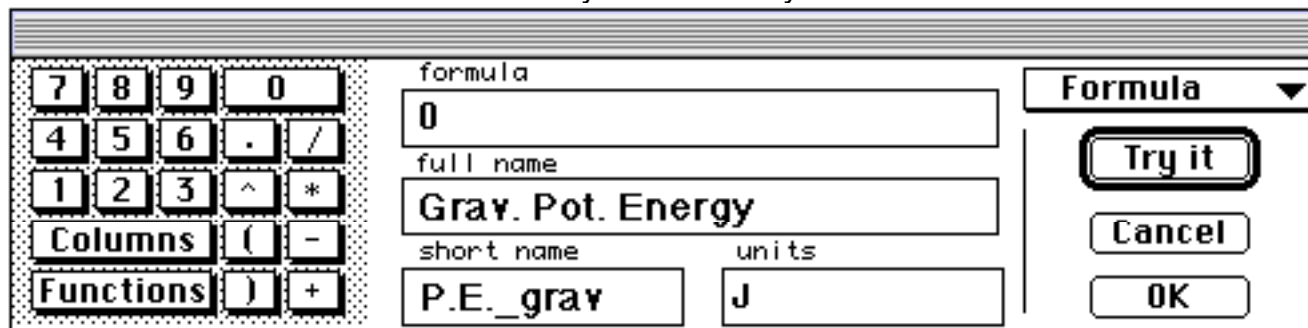   • Click **OK** when you're sure of your formula.

Figure 13. Window for modifying the gravitational potential energy graph

Procedure:
(continued)

7. Plot the kinetic energy. Create a column for *translational kinetic energy*.

- Click on the y-axis label ("acceleration") of the acceleration vs. time graph and drag down to select **Kinetic Energy**.

- Select **Modify...** under the **Data** menu, then select **Kinetic Energy**. A window like that shown in Figure 14 should appear.

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

$$0.5 * (\text{mass of cart}) * \text{"vel"} ^ 2$$

where "(mass of cart)" is replaced with the mass you actually measured earlier, in kg. Click on **OK**.

Figure 14. Window for modifying the formula for kinetic energy

8. Check your predictions. Measure the cart's velocity and kinetic energy after the cart has rolled $\Delta d = 1$ meter *beyond its initial position*. Complete Table 1.

| Object	Predicted K.E. for $\Delta d = 1$ m	Measured K.E. for $\Delta d = 1$ m	% Difference	Predicted velocity for $\Delta d = 1$ m	Measured velocity for $\Delta d = 1$ m	% Difference
cart						

Table 1. Predictions and results for potential energy in Activity 2

9. Create a column for *total energy*.

- Click on the y-axis label ("velocity") of the velocity vs. time graph and drag down to select **Total Energy**.

- Select **Modify...** under the **Data** menu, then select **Total Energy**.

- Replace the "**0**" in the formula space with the relationship for total energy, "K.E." + "P.E._grav". Click on **Try It** and then **OK**.

10. Make a record of this experiment and analysis.

- **Set Graph Title...** to *CART ANALYSIS* and append your names.

- **Print** a copy for each member of your group.
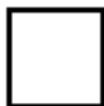
TA Discussion
Checkbox

Questions:

• How well does your measured cart kinetic energy and velocity compare with your predictions? Try to explain any discrepancies.

_____

_____

• Does it make sense to have a total energy of less than zero joules? After all, the cart is moving pretty fast at the end. Please comment.

_____

_____

_____

• Look at your total energy plot. Is energy conserved in your experiment? In particular, is there evidence that friction plays a role in your experiment?

_____

_____

• If friction is evident, what is the source of this friction? Describe a simple experimental procedure with which you could check your hypothesis.

_____

_____

_____

_____

Activity 3: Spring Into Action

Introduction: In Activity 2, you studied the relationship between the gravitational potential and kinetic energies of a cart on an inclined track. In this activity, you will add a spring to this system in order to study how the spring's potential energy affects the energetics of a mass "falling" in response to gravity (one relies heavily upon this energy contribution when "Bungee Jumping").
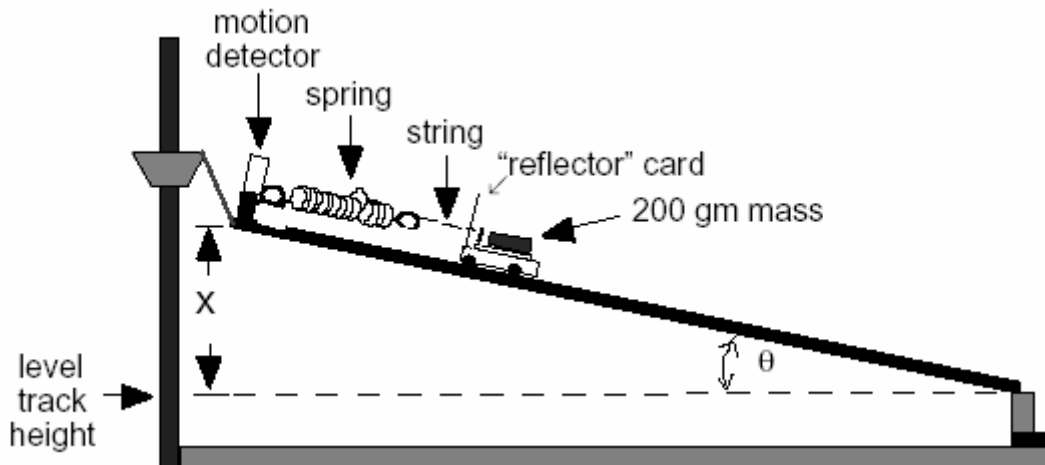

Figure 15. Experimental setup for Activity 3

Procedure: 1. Prepare the setup shown in Figure 15.

- Again, there should be *no friction* set on the cart.
- Don't change the inclination angle θ from that used in Activity 2.
- Leave the 200 gram mass on the top of the cart, as in the last activity.
- Hook the spring provided between the motion detector and the string attached to the cart through the hole in the reflector (see Figure 15).

2. Record the value for the spring constant, k, that your TA will provide.

$$k = \underline{\hspace{2cm}} \text{ [N/m]}$$

3. Set up the computer.

- Keep the *MacMotion* graph the same as in the previous activity.
- Move your graphs from Activity 2 to **Data B** for later comparison by selecting **Data A -> Data B** in the **Data** menu.

4. Set the initial "zero" position of the cart.

- Move the cart down the incline until the spring is taut, but not extended. **Start** graphing while holding the cart stationary in this position. We'll define this unstretched spring position as our "zero."
- Select **Analyze Data A** (in the **Analyze** menu) and find the distance from the motion detector to the cart in this position.

Average distance = _____ m

Procedure:
(continued)

• Tell the computer to pretend that the origin is at this cart position. Select **Configure Distance Probe** from the **Collect menu.**

• Find the line "**offset zero by _____**". In this box, you must enter the *negative* of the distance between the motion detector and the cart at the unstretched spring position which you recorded above. Please ask your TA if you are confused by this.

Predictions:

• Write the equation for the potential energy stored in a spring in terms of the extension of the spring from its unstretched value, x_{eq}.

$$\text{Spring P.E.} = \underline{\hspace{3cm}}$$

• If you allow the cart to roll down the incline with the spring connected, will the total energy be conserved? What elements contribute to the total energy?

_____

_____

• For one trip of the cart down and back up the incline, sketch in Figure 16 below your predictions for the kinetic energy of the cart, K.E., the gravitational potential energy of the cart, P.E. (grav.), and the potential energy stored in the spring, P.E. (spring), vs. time as the cart slides down the incline.
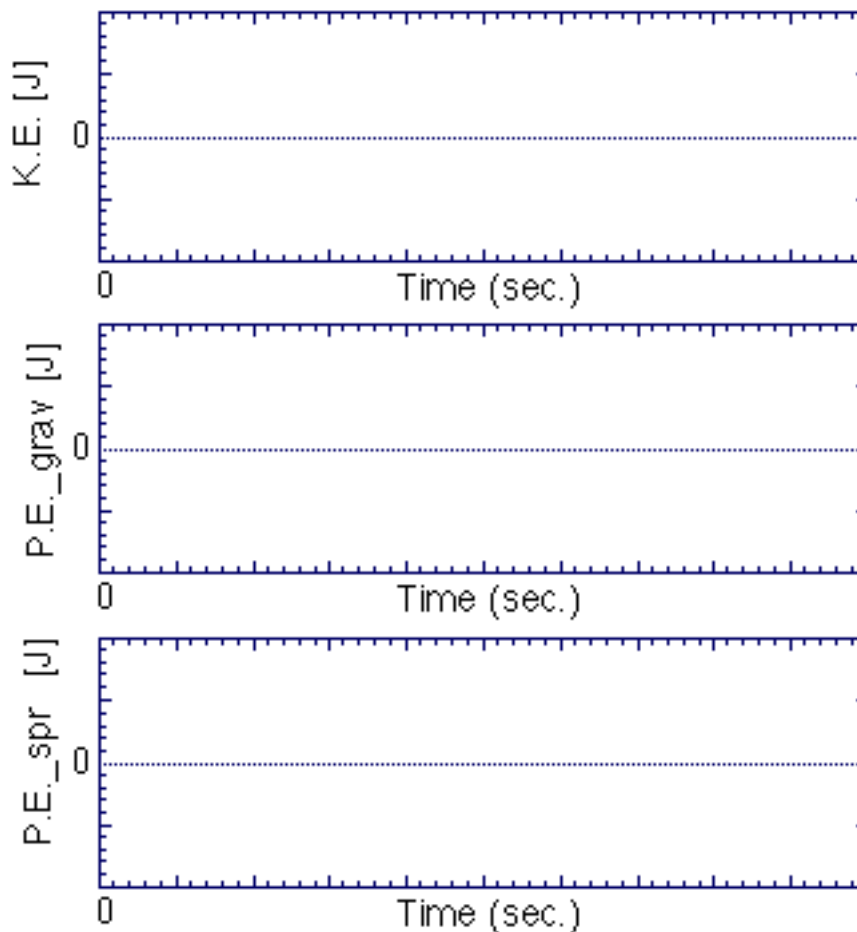

Figure 16. Predictions for the kinetic, gravitational potential, and spring potential energies

---

Procedure:
(continued)

5. Create a graph of *spring potential energy* vs. time.

   - Click on the y-axis label ("distance") of the distance vs. time graph, and drag down to select **Spring Pot. Energy**.

   - Select **Modify...** under the **Data** menu, then select **Spring Pot. Energy**.

   - Replace the "**0**" in the formula space with the relationship for spring potential energy,

   $$0.5 * (k) * \text{“dist”} \wedge 2$$

   where k is the spring constant value that you obtained from your T.A.

   - Click **OK** when you're sure of your results.

6. For the time being, *don't change* the other three graphs, i.e., the kinetic energy of the cart, K.E., the gravitational potential energy, P.E. (grav.), and the sum of the gravitational potential and kinetic energies, E.

7. Test your prediction by making and analyzing a graph of the cart's motion.

   - Hold the cart stationary at the unstretched spring position (your new origin), and click **Start** to begin graphing.

   - About one second after the clicks start, release the cart.

   - Check that your graphs are "good." Repeat if necessary.

8. Make a record of this experiment.

   - **Set Graph Title...** to *SPRING VS. NO SPRING* and add your names. Next, **Print** *one* copy for your group.

TA Discussion
Checkbox

Question:
- Compare the kinetic and gravitational potential energy plots from Activity 2 (without the spring) to those quantities measured with the spring in this activity. What are the key differences?

_____

_____

_____

Procedure:
(continued)

9. While you should expect the total energy will be conserved in this experiment, you should have also found that the sum of the kinetic and gravitational potential energies is not conserved. To check whether the total energy is conserved, you will need to change the energy vs. time plot to include the potential energy of the spring.

- Compute the true total energy. Select **Modify** under the **Data** menu, then choose **Total Energy**. You will be presented with a window that will allow you to change the formula for computing energy.

- Change the formula to compute the total energy by entering

     "K.E." + "P.E._grav" + "P.E._spr"

  or use the "Columns" button to select the appropriate quantities (see Figure 14).

  Click on **OK**.

10.   Rescale the y-axes of your energy plots so that your results fill the plot region.

11. Make a record of this experiment and analysis.

- **Set Graph Title...** to *CART WITH SPRING* and append your names.

- **Print** one copy *for each member* of your group.

Questions:

- Is the sum of the kinetic, gravitational potential, and spring potential energies roughly conserved in your experiment? What are the possible sources of energy loss, if any?

_____

_____

_____

- Consider only the data obtained with the spring attached (Data A in red). For *each* of the P.E. (grav.), P.E. (spring), and K.E. graphs: (a) label the key features of *one cycle* of the cart's motion,

   "**A**" where the cart was released at the top of the incline

   "**B**" where the cart reaches maximum velocity

   "**C**" where the spring reaches its maximum extension

   "**D**" where the spring returns near its initial position