Physics 200 Lab 2: Changing Motion

Objectives

- To understand the meaning of acceleration, its magnitude and its direction
- To discover the relationship between velocity and acceleration graphs
- To learn how to represent velocity and acceleration using vectors
- To learn how to find average acceleration from velocity-time and acceleration-time graphs
- To investigate the behavior of freely-falling objects

Overview

In the previous lab, you looked at position-time and velocity-time graphs of the motion of your body. Your goal in this lab is to learn how to describe various kinds of motion in more detail. When the velocity of an object is changing, it is also important to know how it is changing. The rate of change of velocity with respect to time is known as acceleration. To get a feeling for acceleration, it is helpful to create and learn to interpret velocity-time and acceleration-time graphs for some relatively simple motions with the motion detector.

INVESTIGATION 1: VELOCITY AND ACCELERATION GRAPHS

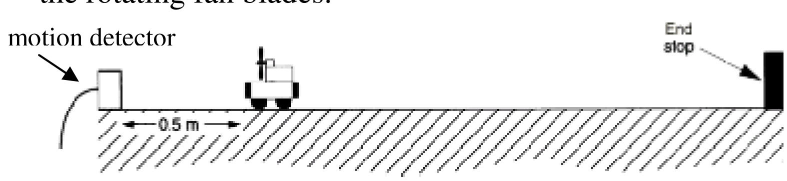
In this investigation you will be asked to predict and observe the shapes of velocity-time and acceleration-time graphs of a cart moving along a smooth track with steadily increasing speed. This could be done by moving the cart with your hand, but it is difficult to get a smoothly changing velocity in this way. Instead, you will use a fan driven by an electric motor to drive the cart.

Activity 1-1: Speeding up in the positive direction

1. Make sure the switch of the fan unit is off, then place two batteries and two dummy cells (metal pieces the same size and shape as batteries) in the battery compartment of the fan unit. To preserve the batteries, switch on the fan unit only when you are making measurements.

Set up the cart on the track with the fan unit and motion detector as shown below so that the cart will move away from the motion detector when the fan is turned on. Fasten the fan unit securely to the cart, and be sure the fan blade does not extend beyond the end of the cart facing the motion detector. (If it does, the motion detector may collect bad data from the rotating blade.) Check to see that the track is level.

Please try to keep the carts from crashing into anything or falling to the floor! Their low-friction quality depends on keeping the bearings in their wheels in good shape. Also, use caution around the rotating fan blades.



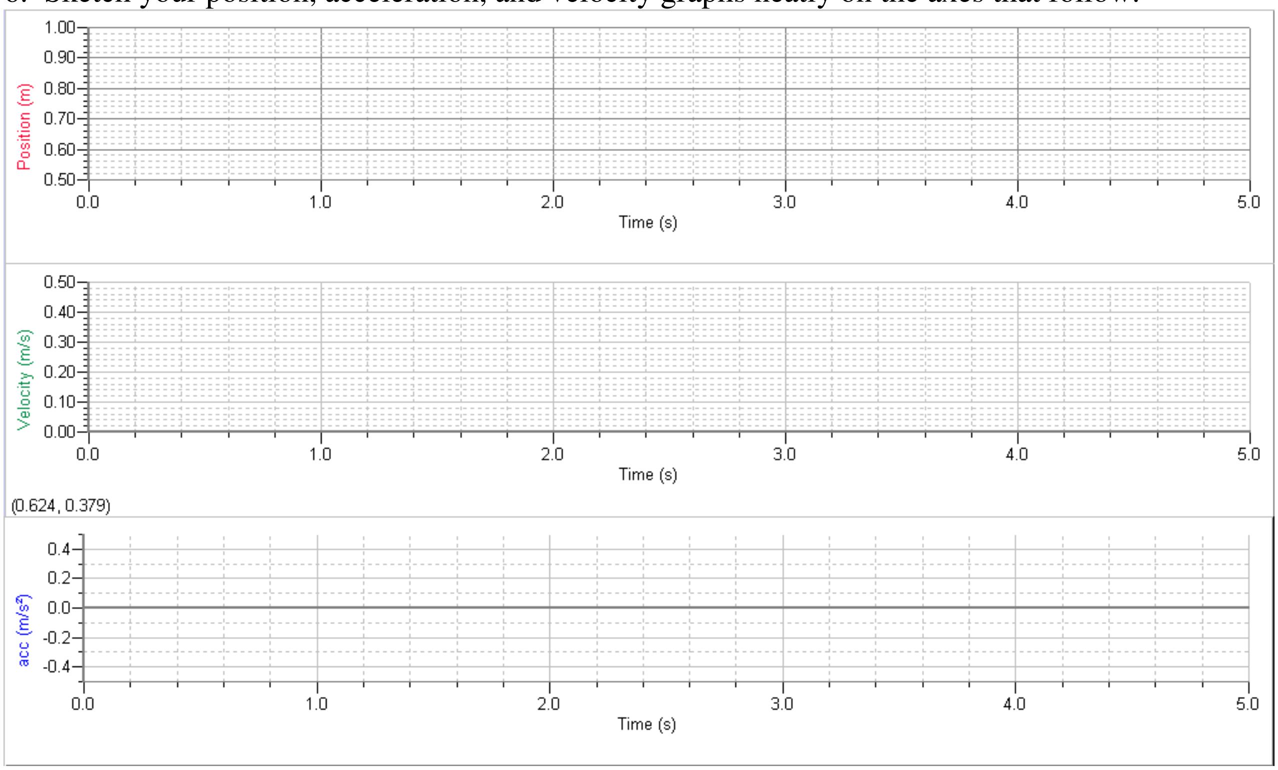
2. Start Logger Pro and open the experiment file called Speeding Up (L02A1-1) to display position, velocity, and acceleration vs. time axes.

3. Use the position-time graph to make sure that the detector can "see" the cart all the way to the end of the track. (Click on Collect or hit Enter to start graphing.) If it can't, adjust the motion detector till it can. Remember to keep the cart at least 0.5 m from the motion detector!

4. Click on the velocity graph so it will be the active graph. Hold the cart with your hand on its side, begin graphing, switch the fan on, and when you hear the clicks of the motion detector, release the cart from rest. Don't put your hand between the cart and the detector. Be sure to stop the cart before it hits the end of the track. Repeat, if necessary, until you get a nice set of graphs.

5. Adjust the axes if necessary so that the graphs fill the axes. Go under Experiment on the menus and select Store Latest Run so the graphs remain persistently displayed on screen. Also save your data for analysis in Investigation 2. (Name your file Speedup1.)

6. Sketch your position, acceleration, and velocity graphs neatly on the axes that follow.



Question 1-1: What is the most important way in which your position graph differs from the position graphs for steady (constant velocity) motion that you observed in Lab 1?

Question 1-2: Which feature of your velocity graph signifies that the motion was toward the positive direction?

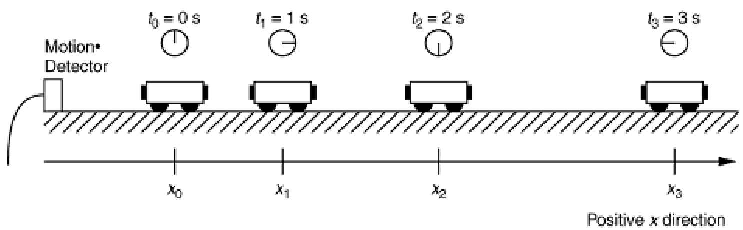
Question 1-3: Which feature of your velocity graph signifies that the cart was speeding up?

Question 1-4: How does the velocity vary in time as the cart speeds up? Does it increase at a steady (constant) rate or in some other way?

Question 1-5: How does the acceleration vary in time as the cart speeds up? Is this what you expect based on the velocity graph? Explain.

Question 1-6: During the time that the cart is speeding up, is the acceleration positive or negative? Explain how speeding up while moving in the positive direction results in this sign of acceleration (hint: remember that acceleration is the time rate of change of velocity)?

Question 1-7: The diagram below shows the positions of a cart at equal time intervals.



At each indicated time, sketch a vector above the cart that might represent the instantaneous velocity of each cart at that time. Then show in the space below the x-axis how you would find the vector representing the change in velocity between the times 1 s and 2 s in the diagram above. (Remember that the change in velocity is the final velocity minus the initial velocity.) Based on the direction of this vector and the direction of the +x axis, what is the sign of the acceleration? Does this agree with your answer to Question 1-6?

! Checkpoint 1

<u>Activity 1-2: Speeding up more</u>

Prediction 1-1: Suppose that you accelerate the cart at a greater rate. How would your position, velocity and acceleration graphs be different? Sketch your predictions with dashed or different colored lines on the previous set of axes.

Test your predictions. This time accelerate the cart with four batteries in the battery compartment instead of two. Leave your original graphs persistently displayed on the screen. When you get a nice set of graphs, save your data as speedup2 for analysis in Investigation 2.

Question 1-8: Did the shapes of your graphs agree with your predictions? If not, comment on the differences.

Question 1-9: How is the magnitude (size) of acceleration represented on a velocity-time graph? How is the magnitude (size) of acceleration represented on an acceleration-time graph?

! Checkpoint 2

INVESTIGATION 2: MEASURING ACCELERATION

In this investigation you will quantitatively examine the motion of a cart accelerated along a level surface (that is, you'll get numerical results), using the files from the previous activity.

Activity 2-1: Velocity and acceleration of a cart that's speeding up

1. Make sure the data from the first activity (the one with the data for the cart accelerated along the ramp with half batteries and half dummy cells (Investigation 1, Activity l-l) is still on the screen. (If not, load the data from the file SPEEDUPl.)

2. Find the average acceleration of the cart from your acceleration-time graph. Go under Analyze on the menu, then use Examine to select the portion of the graph you want to use. Then use Statistics to get an average and a standard deviation for your first activity (Run 1). (Only use values from the portion of the graph after the cart was released and before the cart was stopped.)

Average (mean) acceleration (m/s^2)__________ ± standard deviation (m/s^2) __________

Comment: Average acceleration during a particular time interval is defined as the average rate of change of velocity with respect to time: the change in velocity divided by the change in time. By definition, the rate of change of a quantity graphed with respect to time is also the slope of the curve. Thus, the (average) slope of an object's velocity-time graph is also the (average) acceleration of the object.

3. Click on the velocity-time graph to make it active. Go under Analyze and select Automatic Curve Fit; then select *mt + b Linear* to get a best-fit line to the appropriate portion of the Run 1 velocity-time graph. From the line's slope and the standard deviation in the slope, obtain the acceleration and its uncertainty.

Average (mean) acceleration __________ ± __________ m/s^2

Question 2-1: Does the average acceleration you determined from the slope of the v vs. t graph agree with the average acceleration you found from the acceleration graph, within uncertainties? Is this what you expect? How would you account for any differences?

4.Select the position-time graph. Go under Analyze and select Automatic Curve Fit; then select $at^2 + bt + c$ *Quadratic* to get a best quadratic fit to the appropriate portion of the Run 1 position-time graph. Compare your result to the equation relating x and t for constant acceleration, $x=v_0t+1/2\ a\ t^2$ (note the “a” doesn’t refer to the same thing in these two equations!). Use the appropriate coefficient from the best quadratic fit to determine the acceleration (the computer won’t give you an uncertainty from this type of fit).

Average acceleration __________±_______m/s^2

Question 2-2: Does the average acceleration you determined from the fit to the x vs. t graph agree with the average acceleration you found from the acceleration graph, within uncertainties? Is this what you expect? How would you account for any differences?

<u>Activity 2-2: Speeding Up More</u>

Now repeat the above analysis for the latest data (where you used 4 batteries in the fan unit). From Statistics for the acceleration-time graph:

Average (mean) acceleration (m/s^2)__________ standard deviation (m/s^2) __________

From a straight-line fit to your velocity-time graph:

Average acceleration__________±________m/s^2

From a quadratic fit to your position-time graph:

Average acceleration__________ ±_______m/s^2

Question 2-3: Do the average accelerations obtained from the velocity graph and from the position graph agree with the average acceleration you found from the acceleration graph? How would you account for any differences?

Question 2-4: Compare this average acceleration to that with half batteries and half dummy cells (Activity 2-l). Is it significantly larger? Is this what you expected?

! Checkpoint 3

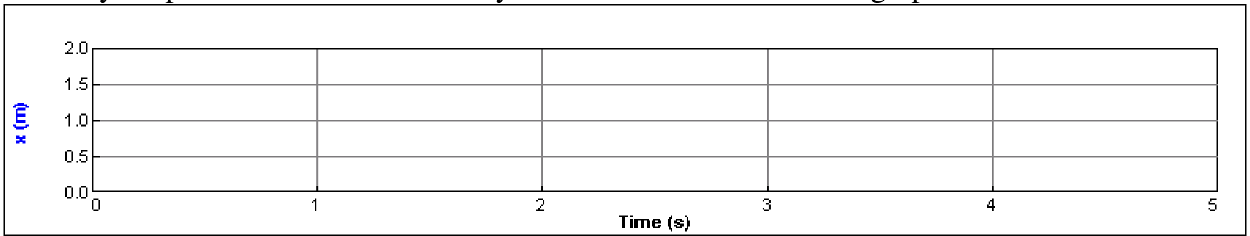
INVESTIGATION 3: SLOWING DOWN AND SPEEDING UP

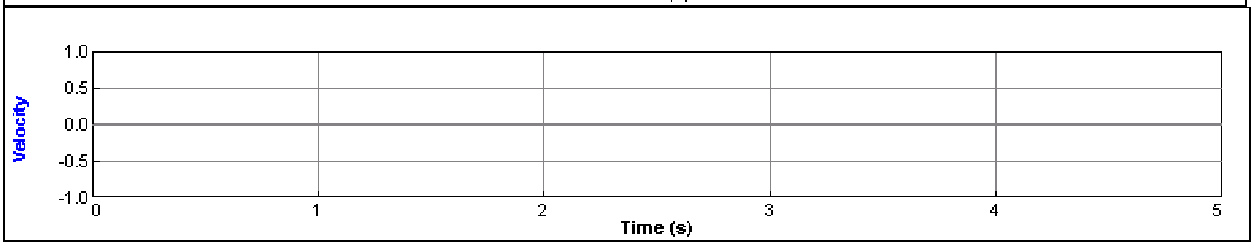
In this investigation you will examine the motion of the cart toward the motion detector (in the –x direction) and speeding up.

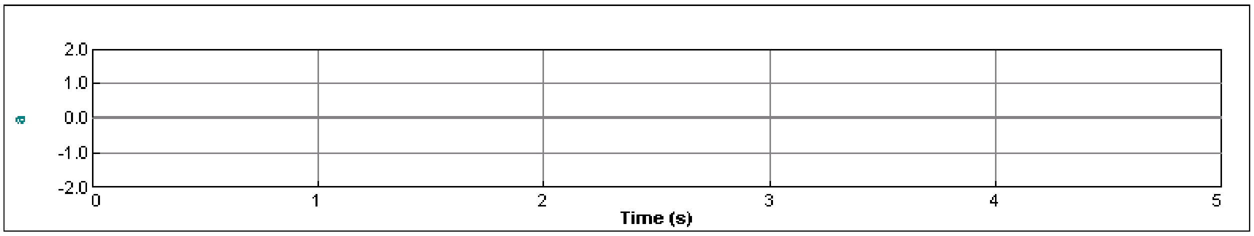
Activity 3-1: Speeding Up Toward the Motion Detector

Prediction 3-1: Suppose that you start with the cart at the far end of the ramp, and let the fan push it *toward* the motion detector. Will the sign (direction) of the acceleration be positive, negative, or zero?

Sketch your predictions for the velocity-time and acceleration-time graphs on the axes that follow.



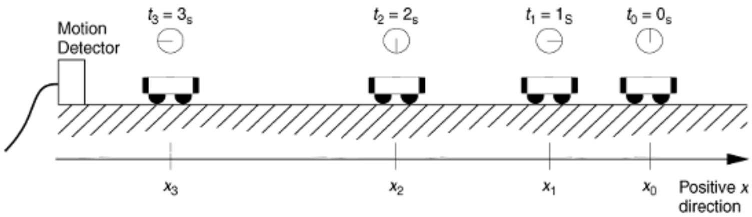




1. Test your predictions. First clear any previous graphs. Click on the velocity graph to make it the active one. Graph the cart moving *toward* the detector (that is, in the negative x direction) and *speeding up.* Turn the fan unit on, and when you hear the clicks from the motion detector, release the cart from rest from the far end of the ramp. (Be sure that your hand is not between the cart and the detector.) Stop the cart when it reaches the 0.5-m line, and turn the fan unit off immediately. Sketch these graphs in a different color or style on the axes above.

Question 3-1: Which feature of your velocity graph shows that the cart was moving in the negative x direction?

Question 3-2: During the time that the cart was speeding up, is the acceleration positive or negative? Does this agree with your prediction? Explain how *speeding up* while moving in the –x direction results in this sign of acceleration. **(Hint:** Look at how the velocity is changing.)



Question 3-3: The diagram shows the positions of the cart at equal time intervals. At each indicated time, sketch a vector above the cart that might represent the velocity of the cart at that time while it is moving toward the motion detector and speeding up.
Show below the x-asix how you would find the vector representing the change in velocity between the times 1 and 2 s in the diagram above. Based on the direction of this vector and the direction of the positive x axis, what is the sign of the acceleration? Does this agree with your answer to Question 3-2?

Question 3-4: When an object is speeding up, what must be the direction of the acceleration relative to the direction of the object's velocity? Are they in the same or different directions? Explain, using your results from this investigation and from investigation 1.

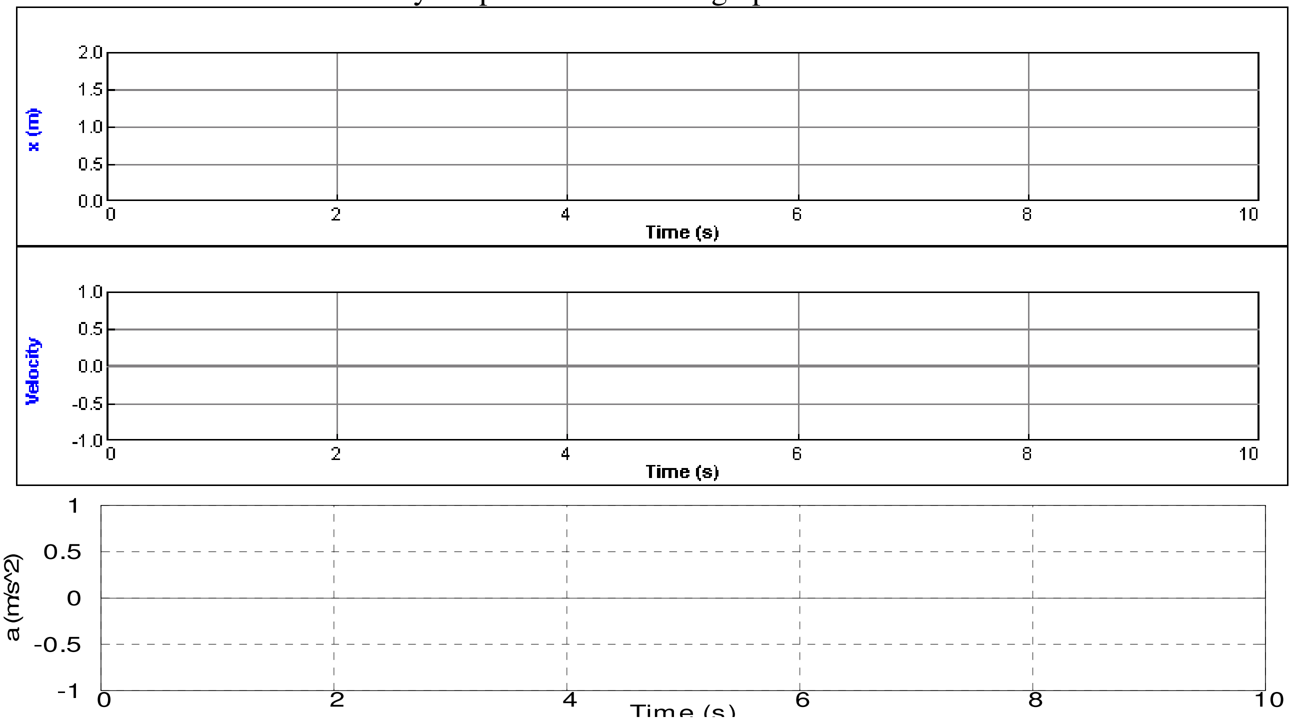
! Checkpoint 4

Activity 3-2: Slowing down and speeding up
In this activity you will look at what happens when the cart slows down, reverses its direction and then speeds up in the opposite direction. How does the velocity change with time? What is the cart's acceleration? The setup should be the same as for Activity 1-1. The fan unit should have the maximum number of batteries. Change the maximum time on your graphs to 10 s.

Prediction 3-2: You start the fan and give the cart a push *away* from the motion detector. It moves away, slows down, reverses direction, and then moves back toward the detector. Try it first without using the motion detector!
Now, for each part of the motion-*away from the detector, at the turning point,* and *toward the detector*-**predict below** whether the velocity is positive, zero, or negative. Also predict whether the acceleration is positive, zero, or negative.

Moving away (+x)	velocity:	acceleration:
At the turning point	velocity:	acceleration:
Moving toward (-x)	velocity:	acceleration:

On the axes that follow sketch your predictions of the graphs of this entire motion.



1. Test your predictions. Begin graphing with the back of the cart near the 0.5-m mark. Turn on the fan unit, and when you begin to hear the clicks from the motion detector, give the cart a gentle push away from the detector so that it travels at least 1 m, slows down, and then reverses its direction and moves toward the detector. Be sure to stop the cart at least 0.5 m from the motion detector and turn off the fan unit immediately. You may have to try a few times to get a good round trip. Make sure the graph includes data showing what happened when the cart started and stopped, as well as when the cart was moving on its own. When you get a good round trip, sketch the graphs on the axes above using a different color or style.

Question 3-5: Label the graphs with
A where the cart started being pushed.
B where the push ended (where your hand left the cart).
C where the cart reached its turning point (and was about to reverse direction).
D where you stopped the cart.
Explain how you know where each of these points is.

Question 3-6: What was the velocity of the cart at its turning point? Does this agree with your prediction?

Question 3-7: According to your acceleration graph, what is the acceleration at the instant the cart reaches its turning point? Is it positive, negative, or zero? Is it significantly different from the acceleration during the rest of the motion? Does this agree with your prediction?

Question 3-8: Explain the observed sign of the acceleration at the turning point. **(Hint:** Remember that acceleration is the rate of *change* of velocity. When the cart is at its turning point, what will its velocity be in the next instant? Will it be positive or negative?)

Question 3-9: How do your predictions compare to the graphs you got experimentally? Discuss any differences between them. Pay particular attention to the acceleration graph.

Activity 3-3: Sign of Push and Stop

On your acceleration graphs for the previous activity, look at the time intervals when you pushed the cart to start it moving and when you pushed to stop it.

Question 3-10: What is the sign of the acceleration for each of these intervals? Explain why the acceleration has this sign in each case.

! Checkpoint 5

INVESTIGATION 4: ACCELERATION OF FREELY FALLING OBJECTS

Activity 4-1: Falling objects

How does a freely falling object move? Investigate this using a motion sensor placed on the floor to track the motion of a falling object (place a wire cage over the motion sensor to protect it from the falling objects).

Question 4-1: Does the object appear to move with constant acceleration? If so, find the value of the acceleration using the method from Investigation 2 that you think is best.

Question 4-2: If you tape additional mass onto the object, will it have the same acceleration? Try it. Summarize the results.

Question 4-3: Try dropping the object from different heights. Does this affect the motion? If so, how? Does it affect the value of the acceleration?

Question 4-4: Try other types of objects. Do they all appear to fall with a constant acceleration? Is the value of the acceleration the same as for the original object? Do you see a pattern here?

! Checkpoint 6

Determination of the Local Acceleration of Gravity

OBJECTIVE: Determine the local value of the acceleration of gravity, "g".

DISCUSSION: There are many methods that can be used to determine the value of "g". The approach to be utilized in this experiment consists of measuring the time of passage of fixed distances (a "picket fence") as they travel past a sensor (a photogate).

The data generated in this experiment - the time "Δt" between interrupts - can be converted to the velocity of your moving PICKET FENCE by the computer program. The slope of the resulting Velocity Vs Time graph will yield g, the quantity of interest. When you are finished, you will want to print out copies of the Position Vs Time graphs and the Velocity Vs Time graphs with the best fit curve parameters displayed on them. Each lab partner should have a copy.

PROCEDURE - START-UP:

1. Your photo gate sensor (U-shaped object on a vertical rod/stand) should be connected to the first digital input port of your LabPro Interface. Please verify this.

2.. Assuming that your computer is already turned on, double click on the *Logger Pro* icon. It should be found on your "desk top" (ask your instructor for help if you have problems). Follow this path to get to the needed program:

  a) Select *file* (in the upper left corner of the menu)
  b) Select *Open*
  c) Select *Physics with Computers*
  d) Select *Experiment 05 Picket Fence Free Fall*

In this window, select *experiment*, and click on *OK* .
You are now ready to collect data. As a quick test to determine if the photogate is working, move your hand up and down between the ends of the "U" to see if the little red light located on the back of the "U" blinks on and off.

3. To collect data, follow this procedure:

  a) Click on *Collect*
  b) Hold the picket fence above the photogate
  c) Release the picket fence so that it passes through the photogate in free fall
     Be sure to have someone catch the picket fence before it hits the floor!!
     (The computer will not start to collect data until the beam is broken.)
     Position and velocity data points should appear on their respective graphs
  d) Click on *Experiment* ; Click on *Store latest run* . This will store this run.
  e) Repeat this procedure three more times, until four trials are displayed. Each time the picket fence is dropped, release it at a height that is different from the previous drops.

ANALYSIS

1. To analyze your velocity data, follow this procedure:
    a) Click on Analyze; Select Automatic Curve Fit ; Select *mx + b* *Linear* .
    The linear fit will appear with values for m and b and their associated standard deviations.
    b) Repeat this procedure for the other three data sets.

2 To analyze your position data, follow this procedure:
    a) Click on Analyze; Select Automatic Curve Fit ; Select $A + Bx + Cx^2$ *quadratic*.
    The quadratic fit will appear with values for a, b, and c will appear.
    b) Repeat this procedure for the other three data sets.

3. Print a copy of your data for each lab partner in your group

4) To see some numbers, go to the upper menu and click on *Window*. Select *New Tall Window* and then *Table*. A table should appear for the "Latest" data set, showing columns for Time, DeltaT, Distance, Velocity, and Accel.

5) Print a copy of this table for each lab partner in your group.

6) Compare the values of g found in your four trials. Are they consistent? Do they agree? Calculate the % difference between each of the four values and the accepted value for g, 9.80 m/sec^2.

*** PLEASE STOP & CHECK with your instructor**