Date__________Partners____

Introduction to Motion

Objectives:

- To investigate how motion appears on a position versus time graph
- To investigate how motion appears on a velocity versus time graph and the relationship between the two graphs
- To investigate a simple example of non-constant velocity

Overview:

In this unit you will examine ways that the motion of an object can be represented graphically. You will use a motion detector to plot position and velocity graphs of the motion of your own body and of a cart. The study of motion and its mathematical and graphical representation is known as *kinematics.*

A sonar ranging device such as our motion detector uses pulses of ultrasound that reflect from an object to determine the object's position relative to the detector. It detects the closest object directly in front of it including your arms or the track that the cart rides on. **The motion detector will not be able to measure anything closer than about ½ meter.**

Activity 1 –Position vs. Time Graphs

The purpose of this activity is to begin to learn how to relate graphs of position vs. time to the motions they represent. You will use a motion detector and your own motion.

As you walk, the graph on the computer screen displays how far away from the detector you are. It is common to refer to the distance of an object from some origin as the *position* of the object. Since the motion detector is at the origin of the coordinate system, the graphs you will make are *position vs. time* graphs.

1. Turn on the interface box. Open the Science Workshop program.

2. Click on **File** on the top menu bar and click on **Open.** If a dialog box comes up with a message asking if you want to save the untitled experiment, just click on “Don’t Save”. When the file list comes up, double click on the phy151 folder. Then double click on 1-1A. This opens an experiment file that already has everything configured for this part of the lab.

3. There are two windows. The one on the left has buttons labeled “REC”, “MON”, and “STOP” at the top. You will click on the REC button when you want to begin recording data. This experiment is set to automatically stop recording data after 10 seconds. You can stop it any time before that by clicking on STOP. If you click on MON, data will be collected but not saved. This is useful as a trial.

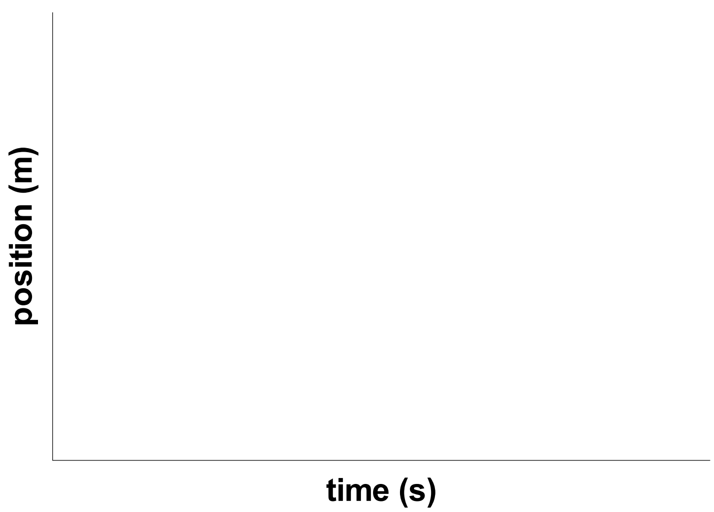
   The window on the right has a blank graph for position vs. time. In this activity, Science Workshop will plot a graph of your position vs. time as you move.

4. Mount the motion detector on a support rod near the computer at a height so that it is aimed at your midsection when you are standing in front of the detector. Make sure that you can move at least 2 meters away from the motion detector. NOTE: You will be moving backwards for part of this activity, so make sure there the area behind you is clear for at least 2 meters. Position the computer monitor so you can see the screen while you move away from the motion detector.

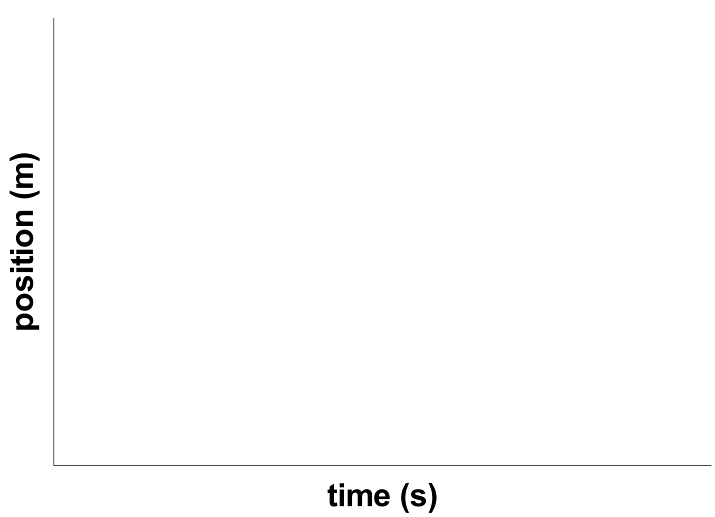
5. To see what happens, make the set-up window active, click on the MON button and walk away from the motion detector. You should see the graph of position vs. time plotted as you walk. Notice that the plot disappears when it stops. If you had used the REC button, it would have remained.

6. Make position vs. time graphs for the following motions. Use the REC button. Use the STOP button if you need to stop the graph before it stops itself. When each graph is complete, sketch the graph in the space below:

   a. Start at the ½-meter mark and walk <u>away</u> from the detector *steadily and slowly*.



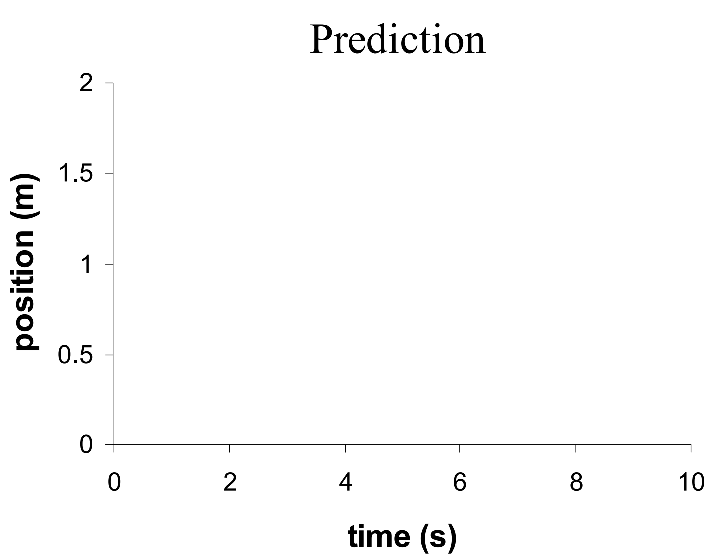
   b. Walk <u>toward</u> the detector *steadily and somewhat faster*.



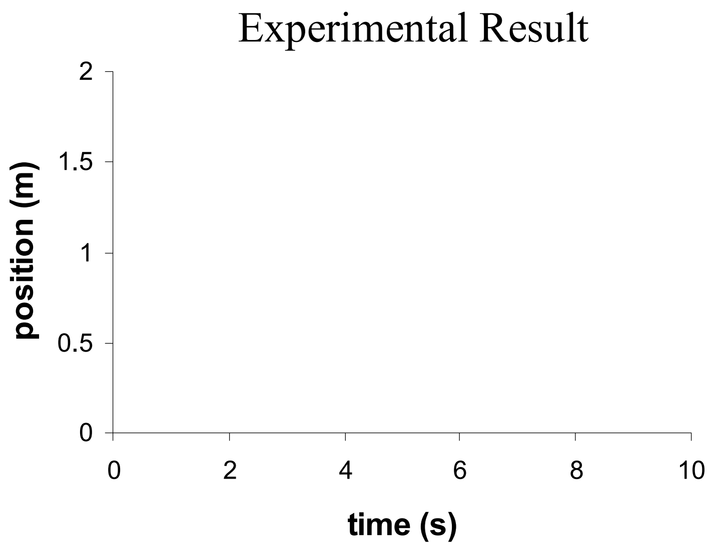
7. What feature of the graphs tells you which one is for the faster motion?

What feature of the graphs tells you which one is for motion toward the motion detector?

8. Predict the position vs. time graph produced when a person starts at the 1-meter mark, stands still for 1 second, walks away from the detector steadily and somewhat quickly for 3 seconds, stops for 3 seconds, and then walks toward the detector slowly.

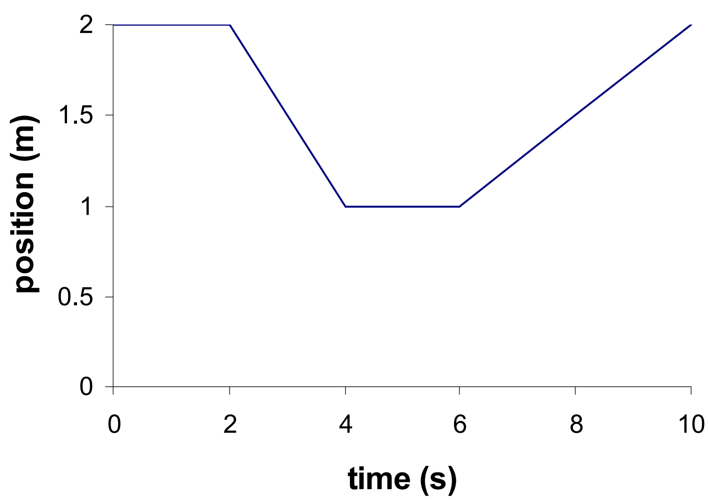


Test your prediction. Move in the way described and graph your motion. When you are satisfied with your graph, sketch your group's final result.



9. Now let's try to reproduce a position vs. time graph. **Open** the file 1-1B. (Don't save 1-1A.) You will see that there is a plotted position vs. time graph in this experiment window.

   The graph to match will look something like this:



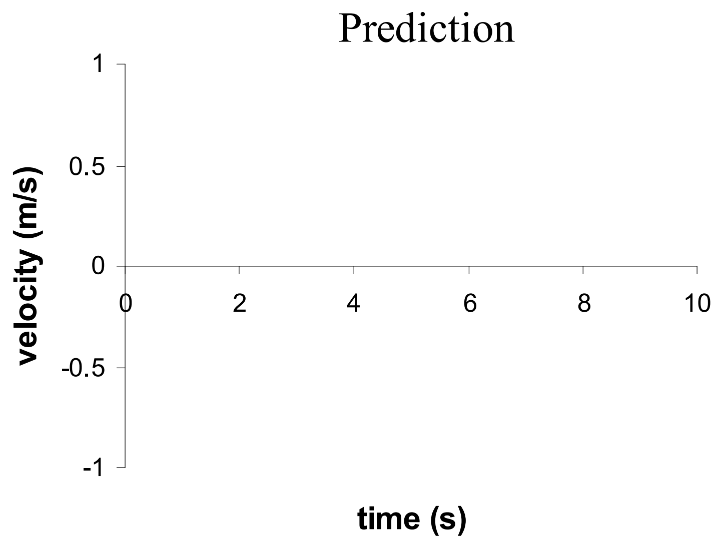
   Record your motions as you move to match the graph on the computer screen. Each person in your group should make a few tries. Save your best run as 1-1Cs.

   What were the most difficult features of the graph to match? Speculate on why that feature was not actually possible to match perfectly.

Activity 2 – Velocity vs. Time Graphs and the Relationship to Position vs. Times Graphs

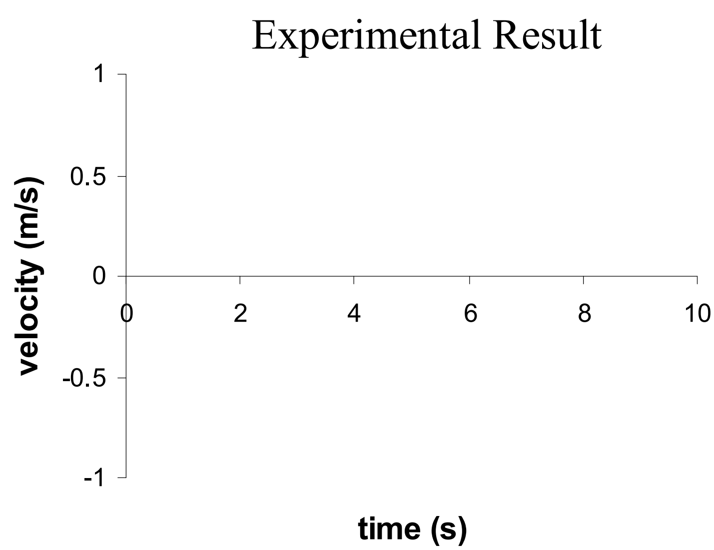
You have already plotted your position as a function of time. Another way to represent your motion during an interval of time is with a graph that describes how fast and in what direction you are moving. This is a *velocity vs. time* graph. *Velocity* is the rate of change of position with respect to time. It is a quantity that takes into account your speed (how fast you are moving) and also the direction you are moving. The sign of the velocity describes the direction of one-dimensional motion.

1. In the space below draw on the graph your group's prediction for what the velocity vs. time will look like for the run you saved as 1-1Cs.



2. On the bottom left of the graph window there are 6 buttons, 4 in the first row and 2 on the bottom. This is the Graph Tools Area. Click the bottom right button, highlight "Digital 1", and then select "Velocity" from the side menu. This will now add a velocity vs. time graph of your motion to the position vs. time graph. If you need to rescale the velocity axis, click next to the vertical axis label and enter the appropriate maximum and minimum values for the scale in the dialog box.

3. Sketch below your actual graph of the motion, using smooth lines to "average out" the bumpiness.



Explain carefully the magnitude and sign of the velocity for the various parts of the graph. (How is the graph different when walking quickly or walking slowly, when walking toward the detector or walking away?)

4. We want to calculate the slope of the best straight-line segment of your position vs. time graph. In the Graph Tools Area, the second button on the first row has an "xy" in it. Click on that button. You will now have a cross-hair cursor. When you move it to anywhere in the graph area, the coordinates of that location are displayed next to the labels on the axes.

   Record the coordinates of two widely separated points on the best straight-line segment of your position vs. time graph and calculate the slope of the line. (Click anywhere to remove the cross-hair cursor.)

5. We will use the velocity vs. time graph to obtain the average velocity for that same time interval.

   Click on the Σ button that is also in the first row of buttons in the Graph Tools Area. This opens up a "statistics" area to the right of the graphs. Move the cursor to the velocity vs. time graph. Click and hold, then drag the cursor to draw a box that will enclose the points on this graph that you will average. (You may need to auto-scale the graph first—top right button in the Graph Tools Area.)

   Now click the Σ button **in the statistics area** of the velocity vs. time graph and select "All of the Above".

   How does the value of the mean velocity compare to the slope of the position vs. time graph?

Activity 3 – Non-Constant Velocity

In this activity, you will look more closely at the relationships among position, velocity, and acceleration (rate that the velocity changes). The object in motion will be a cart that will ride on a cushion of air on a tilted air track.

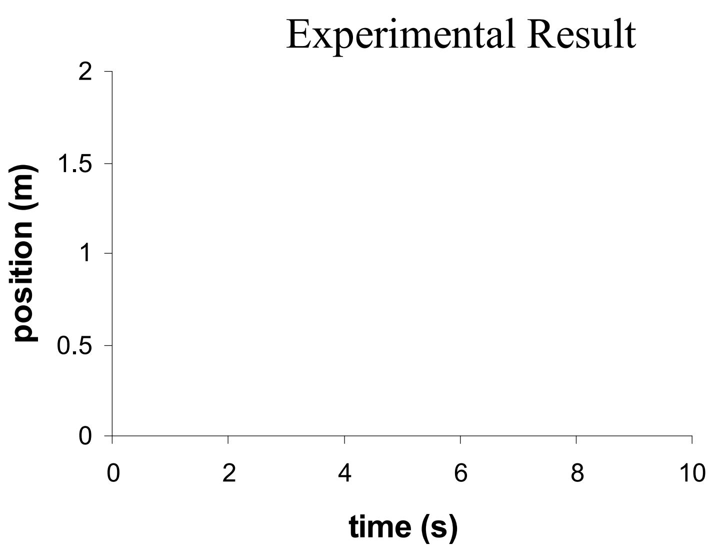
1. Place the motion detector at the higher end of the air track. Place the cart on the track at the low end of the track with the wood plate facing the motion detector. Turn on the Variac transformer and the air blower.

2. Open the 1-3 Experiment file. You should have a blank position vs. time graph.

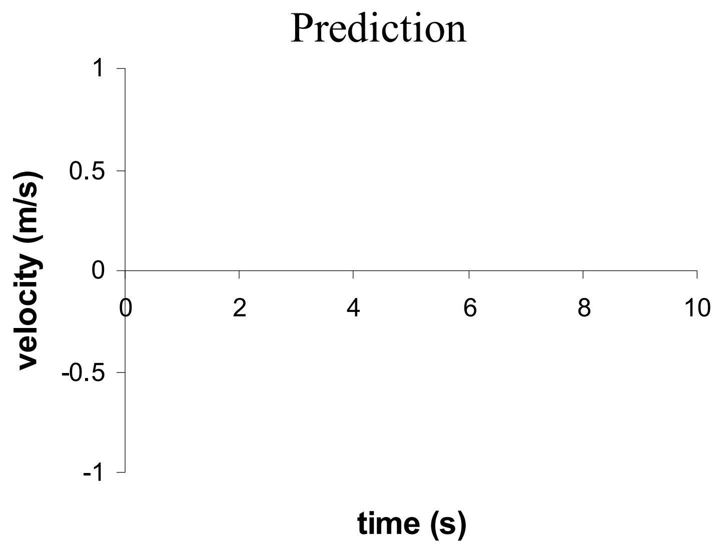
3. You want to collect position vs. time data for the car going up the track, coming to a stop at the highest point of its motion, and then coming down the track. The car should not get closer than 0.5 m to the detector when it stops but you want to get as close as possible to that. One technique is to release the car from the top, let it bounce at the bottom and then start collecting data on the way back up. You want to remember to STOP collecting data before the car gets back to the bottom of the track. You can use the MON mode for a practice run.

4. Collect data using RECord. Repeat until you get a smooth and complete graph of the motion.

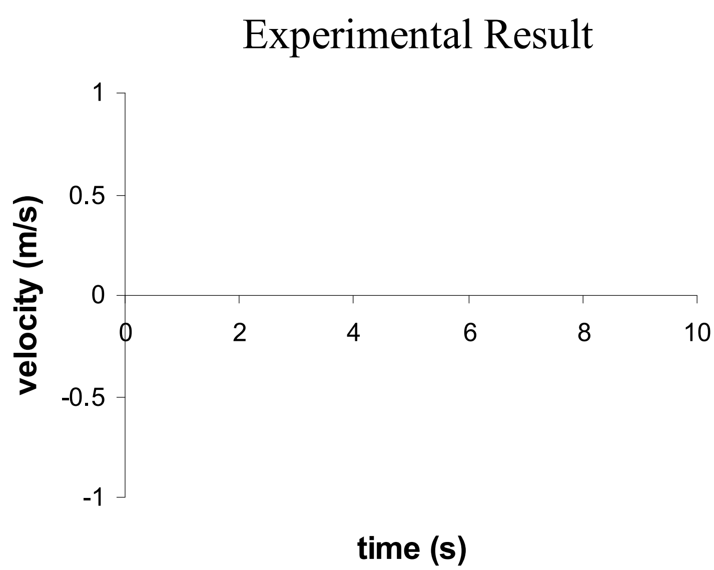
5. For your best run, sketch below a graph of position vs. time.



6. In the space below draw your group's prediction for what the velocity vs. time will look like for this motion.



7. Click the bottom right button in the Graph Tools Area, select "Digital 1" and then select "velocity". This will add the velocity vs. time graph to the display. Sketch the resulting graph in the space below. Again, rescale by clicking in the vertical axis area and entering new values, if needed.



8. Now let's look at the slope of the velocity vs. time graph.

   What are the units of the slope of this graph?

   Use the "xy" cursor and two widely spaced points on the straightest portion of the velocity vs. time graph to calculate the slope. (When through, click to turn the cross hair cursor off.)

   What physical quantity is represented by this slope?

9. We can also use the statistics button to produce a best-fit line to a segment of the data. Use the cursor to select a good straight-line segment of your velocity vs. time graph. Click on the Σ button to activate the statistics tools. (You'll need to hit the auto-scale button again to see the whole graph.)

   In the Statistics area of the velocity vs. time graph, click the Statistics Menu button and select **"Curve Fit, Linear Fit"** in the Statistics menu. A linear equation of the form $y = a_1 + a_2 x$ will be shown with best-fit values for the constants a_1 and a_2.

   What actual physical quantities are represented by *y* and *x* in this fit equation?

   Which of the two constants is the slope of the velocity vs. time graph?

Explain why the technique for finding the slope in step 9 is superior to that in step 8.

10. To display a graph of the acceleration, click on the bottom right button in the Graph Tools Area, select "Digital 1" and "acceleration".

    Is the graph of the acceleration what you expected? Explain.

How does the average value of the acceleration from this graph compare to the value of the slope of the velocity vs. time graph?

11. Considering all three graphs:

The velocity of the cart was zero at one time.

Where was the cart in its actual motion on the track at that time? What was happening in the position vs. time graph at that time? Was the acceleration zero at that time?

When the velocity changed direction, did the acceleration change direction?