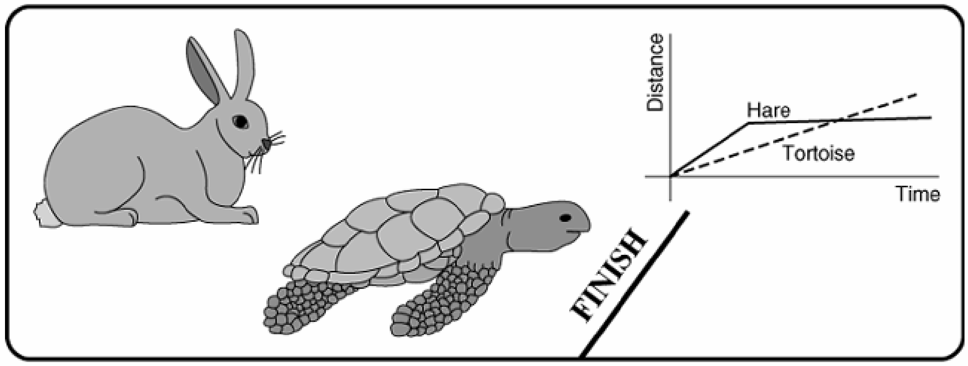
Name______________________________Date________________Partners______________________________

INTRODUCTION TO MOTION



Slow and steady wins the race.

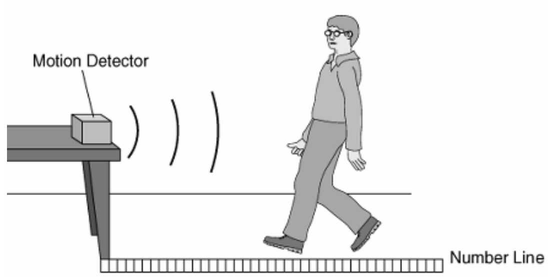
–Aesop's fable: The Hare and the Tortoise

OBJECTIVES

- To explore how various motions are represented on a velocity—time graph
- To discover the relationship between position—time and velocity—time graphs
- To begin to explore acceleration—time graphs

OVERVIEW

In this lab you will examine two different ways that the motion of an object that moves along a line can be represented graphically. You will use a motion detector to plot distance—time (position—time) and velocity—time graphs of the motion of your own body and a cart. The study of motion and its mathematical and graphical representation is known as *kinematics*



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INVESTIGATION 1: VELOCITY—TIME GRAPHS OF MOTION

You have already plotted your position along a line 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—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. Thus, when you examine the motion of an object moving along a line, the direction the object is moving is indicated by the algebraic sign (positive or negative) of the velocity.

Graphs of velocity-time are more challenging to create and interpret than those for position. A good way to learn to interpret them is to create and examine velocity—time graphs of your own body motions, as you will do in this investigation.

You will need the following materials:

- motion detector
- number line on floor in meters

Activity 1-1: Making Velocity Graphs

1. Set up to graph velocity. Open the experiment file called **Velocity Graphs L2.A1-1**. Check that switch on motion detector is on the “broad” beam.

2. You will want to walk at different speeds to match the motion as described in (a)—(d) below. Each member of the group should try at least one of these. **Print** out one graph that includes all the data you decide to keep. Ask your TA how to choose what data is displayed on the screen and printed out. Basically you click on and off various runs under the DATA icon to show on the screen. Make sure you denote on your print out with letters (a) – (d) to indicate what you were trying to do.

a. **Hit “start”** to begin graphing and make a velocity graph by walking *away* from the detector *slowly and steadily*. Try again until you get a graph you’re satisfied with. You may want to **adjust the velocity scale** so that the graph fills more of the screen and is clearer.

b. Make a velocity graph, walking *away* from the detector *medium fast and steadily*.

c. Make a velocity graph, walking *toward* the detector *slowly and steadily*.

d. Make a velocity graph, walking *toward* the detector *medium fast and steadily*.

Question 1-1: What is the most important difference between the graph made by *slowly* walking away from the detector and the one made by walking away *more quickly*?

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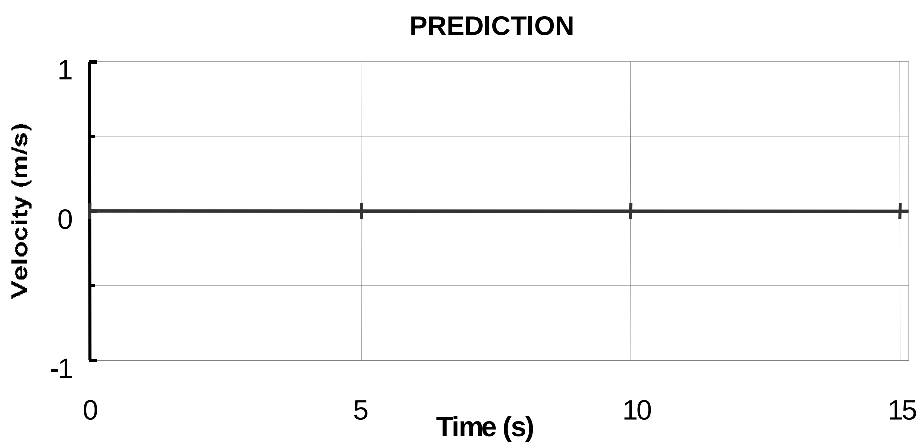
Question 1-2: How are the velocity—time graphs different for motion *away* and motion *toward* the detector?

Prediction 1-1: Draw below using a *dashed line* your *prediction* of the velocity—time graph produced if you, in succession,

- walk away from the detector slowly and steadily for about 5 s
- stand still for about 5 s
- walk toward the detector steadily about twice as fast as before.

Add the predictions of your partners on the same graph using different lines, dot-dashed, for example. Label your predictions and discuss with your group to see if you can all agree. Use a solid line to draw in your group prediction.



3. Test your prediction. (**adjust the time scale** to 15 s.) Be sure to think about your starting point! **Begin graphing** and repeat your motion until you think it matches the description. **Print** out one copy of the best graph for your group report.

Activity 1-2: Matching a Velocity Graph

In this activity, you will try to move to match a velocity—time graph shown on the computer screen. This is much harder than matching a position graph as you did in the previous investigation. Most people find it quite a challenge at first to move so as to match a velocity graph. In fact, some velocity graphs that can be invented cannot be matched!

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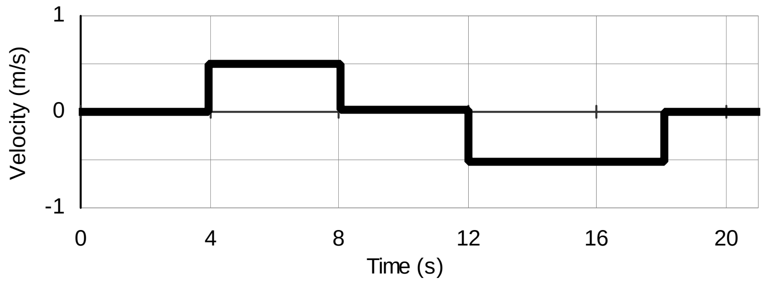
1. Open the experiment file called **Velocity Match L2.A1-2** to display the velocity—time graph shown below on the screen.



Prediction 1-2: Describe in words how you would move so that your velocity matched each part of this velocity—time graph.

0 to 4 s:

4 to 8 s:

8 to 12 s:

12 to 18 s:

18 to 20 s:

2. **Hit "start,"** and move so as to imitate this graph. Try to do this without looking at the computer screen. You may try a number of times. Work as a team and plan your movements. Get the times right. Get the velocities right. Each person should take a turn. It is quite difficult to obtain smooth velocities. We have smoothed the data electronically, but your results may still oscillate significantly. Looking at the screen for feedback can actually make things worse.

Draw in your group's best match on the axes above.

Question 1-3: Is it possible for an object to move so that it produces an absolutely vertical line on a velocity—time graph? Explain.

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Question 1-4: Did you have to stop to avoid hitting the motion detector on your return trip? If so, why did this happen? How would you solve the problem? If you didn't have to stop, why not? Does a velocity graph tell you where to start? Explain.

INVESTIGATION 2: RELATING POSITION AND VELOCITY GRAPHS

You have looked at position—time and velocity—time graphs separately. Since position—time and velocity—time graphs are different ways to represent the same motion, it is possible to figure out the velocity at which someone is moving by examining her/his position—time graph. Conversely, you can also figure out how far someone has traveled (change in position) from a velocity—time graph.

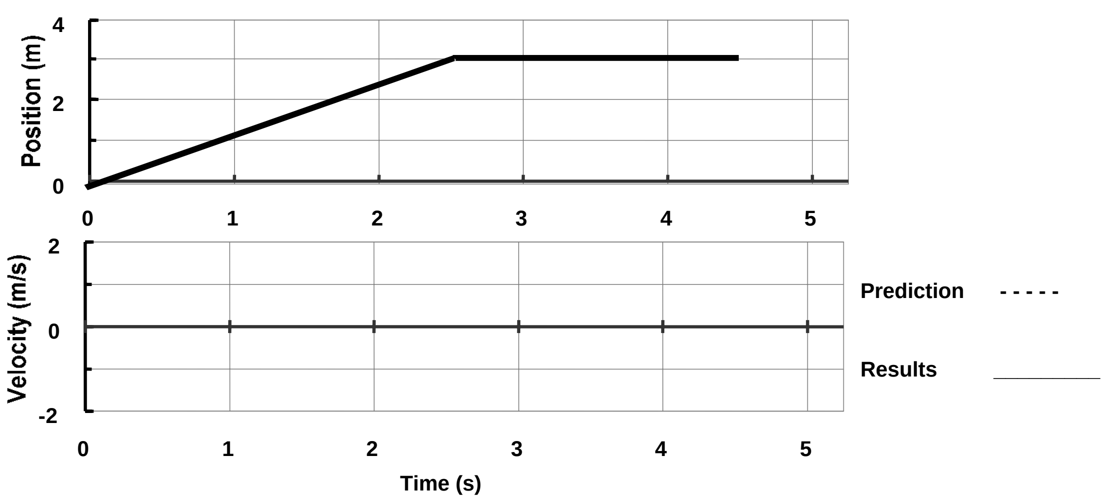
To explore how position—time and velocity—time graphs are related, you will need the following materials:

- motion detector
- number line on floor in meters

Activity 2-1: Determining Velocity Graphs From Position Graphs

1. Open the experiment file called **Velocity from Position L2.2-1** to set up the axes shown that follow.

Prediction 2-1: Determine the velocity graph from a position graph. Carefully study the position—time graph that follows and predict the velocity—time graph that would result from the motion. Use a ***dashed line*** to sketch what you believe the corresponding velocity—time graph on the velocity axes will be.



2. Test your prediction. After each person has sketched a prediction, **begin graphing**, and do your group's best to make a position graph like the one shown. Walk as smoothly as possible.

When you have made a good duplicate of the position graph, sketch your actual graph over the existing position—time graph. Use a *solid line* to draw the actual velocity—time graph on the velocity graph where you drew your prediction. (Do not erase your prediction.) Save your best data, you will need it later.

Question 2-1: How would the position graph be different if you moved faster? Slower?

Question 2-2: How would the velocity graph be different if you moved faster? Slower?

Activity 2-2: Calculating Average Velocity

In this activity, you will find an average velocity from your velocity—time graph in Activity 2-1 and then from your position—time graph.

1. You will here find your average velocity from your velocity graph in Activity 2-1. Choose a region where your velocity is relatively constant and pick 10 adjacent velocity values. **Do not choose a region where the velocity is zero.** Use the **Smart Tool** in *DataStudio* to read values of velocity and write them in the table below. Use these values to calculate the average (mean) velocity using a calculator. For reference, note the time at the first point and last point. You will need this later.

Velocity values (m/s)			
1		6	
2		7	
3		8	
4		9	
5		10	

Average (mea

Comment: Average velocity during a particular time interval can also be calculated as the change in position divided by the change in time. (The change in position is often called the *displacement*.) For motion with a constant velocity, this is also the slope of the position—time graph for that time period.

As you have observed, the faster you move, the steeper your position—time graph becomes. The *slope* of a position—time graph is a quantitative measure of this incline. The size of this number tells you the speed, and the sign tells you the direction.

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2. Calculate your average velocity from the slope of your **position** graph in Activity 2-1. Make sure you use the same time region here that you just used in step 1. Use the **Smart Tool** again to read the position and time coordinates corresponding to the two end points (of your ten-point velocity region).

	Position (m)	**Time (s)**
Point 1		
Point 2		

3. Calculate the change in position (displacement) between points 1 and 2. Also calculate the corresponding change in time (*time interval*). Divide the change in position by the change in time to calculate the *average* velocity. Show your calculations below.

Change in position (m)	
Time interval (s)	
Average velocity (m/s)	

Question 2-3: Does the average velocity you just calculated from the position graph agree with the average velocity you found from the velocity graph? Do you expect them to agree? How would you account for any differences?

Activity 2-3: Using Statistics and Fit to Find the Average Velocity

In Activity 2-2, you found the value of the average velocity for a steady motion in two ways: from the average of a number of values on a velocity—time graph and from the slope of the position—time graph. The **statistics feature** in *DataStudio* (look for the Σ icon) allows you to find the average (mean) value directly from the velocity—time graph. The **fit routine** should allow you to find the line that best fits your position—time graph from Activity 2-1. The equation of this line includes a value for the slope.

1. *Using **statistics***: You must first **select the portion** of the velocity—time graph for which you want to find the mean value. Make sure you select the same region here that you used in step 1 of Activity 2-2. Next use the **statistics feature** Σ to read the mean value of velocity during this portion of the motion.

Average (mean) value of the velocity: ____________ m/s

Question 2-4: Compare this method to the one in Activity 2-2 (step 1) where you determined the average by hand. Which method is easiest? Why?

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2. *Using **fit***: You must first **select the portion** of the position—time graph that you want to fit. Use the same 10-point region you have been using.

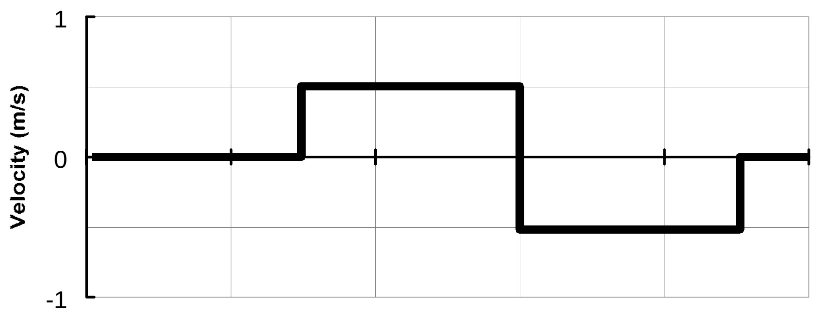
Next, use the **fit routine**, select a linear fit, $y = mx + b$, and then find the equation of the line.

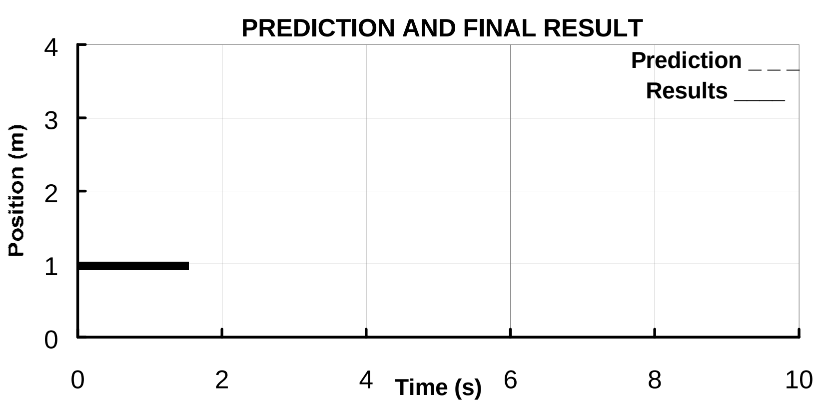
Record the equation of the fit line below, and compare the value of the slope (m) to the velocity you found in Activity 2-2.

Question 2-5: What is the meaning of b?

Activity 2-4: Predicting Position Graphs From Velocity Graphs

1. Carefully study the velocity graph shown below. Using a *dashed line*, sketch your *prediction* of the corresponding position graph on the bottom set of axes. (Assume that you started at the 1 m mark.)





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2. Test your prediction. First shut off the **analysis feature,** clear previous data, and **adjust the time axis** to 0 to 10 s before you start.

3. After each person has sketched a prediction, your group should try to duplicate the velocity—time graph by walking. Try to do it without looking at the computer monitor.

When you have made a good duplicate of the velocity—time graph, draw your actual result over the existing velocity—time graph.

4. Use a *solid line* to draw the actual position—time graph on the same axes with your prediction. (Do not erase your prediction.)

Question 2-6: How can you tell from a velocity—time graph that the moving object has changed direction? What is the velocity at the moment the direction changes?

Question 2-7: How can you tell from a position—time graph that your motion is steady (motion at a constant velocity)?

Question 2-8: How can you tell from a velocity—time graph that your motion is steady (constant velocity)?

INVESTIGATION 3: INTRODUCTION TO ACCELERATION

There is a third quantity besides position and velocity that is used to describe the motion of an object: acceleration. Acceleration is defined as the *rate of change of velocity with respect to time* (just like velocity is defined as the *rate of change of position with respect to time*). In this investigation you will begin to examine the acceleration of objects.

Because of the jerky nature of the motion of your body, the acceleration graphs are very complex. It will be easier to examine the motion of a cart. In this investigation you will examine the cart moving with a constant (steady) velocity. Later, in another lab you will examine the acceleration of more complex motions of the cart. You will need the following:

- motion detector
- PASCO motion cart without friction pad
- 2-m motion track
- level

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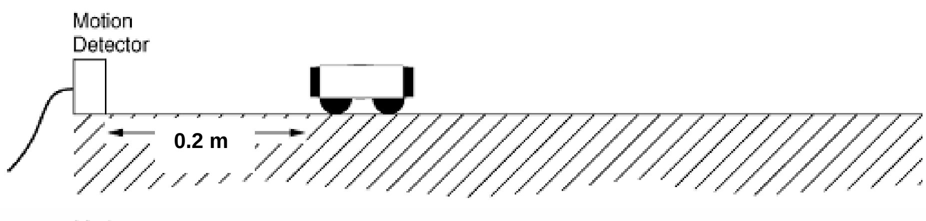
Activity 3-1: Motion of a Cart at a Constant Velocity

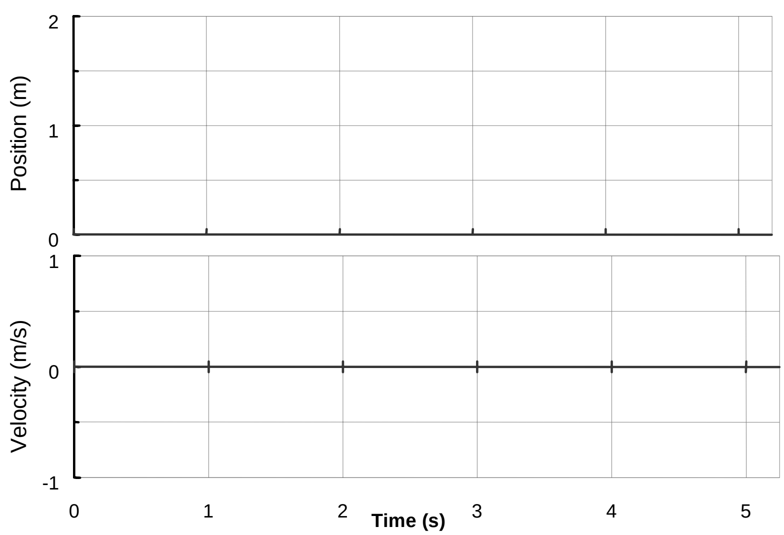
To graph the motion of a cart at a nearly constant velocity you can give the cart a quick push with your hand and then release it.

1. Set up the motion detector at the end of the ramp. Set switch to narrow beam. Be sure that the track is level.



2. Open the experiment file called **Constant Velocity L2.3-1.**

Prediction 3-1: Based on your observations of the motions of your body, how should the position and velocity graphs look if you move the cart at a constant velocity away from the motion detector starting at the 0.3-m mark? Sketch your predictions with dashed lines on the axes that follow.



3. Test your prediction. Be sure that the cart is never closer than 0.2 m from the motion detector and that your hand is not between the cart and motion detector. **Begin graphing**. Try several times until you get a fairly constant velocity. Sketch your results with solid lines on the axes. **Print** out one copy for your group report.

Question 3-1: Did your position—time and velocity—time graphs agree with your predictions? If not, explain. What type of curve characterizes constant velocity on a position—time graph?

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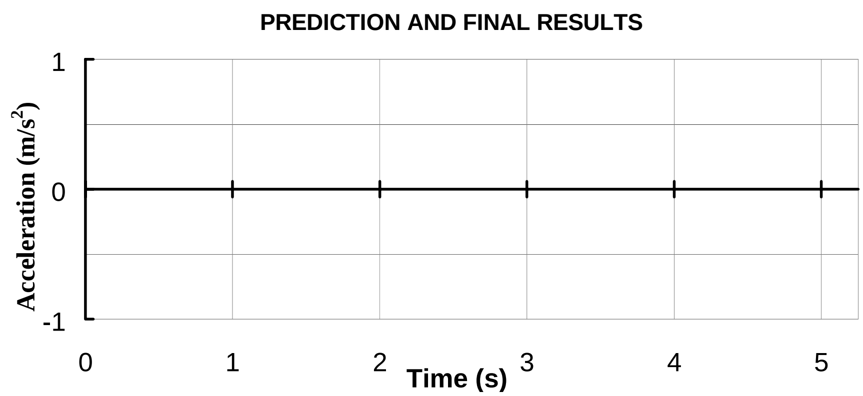
Activity 3-2: Acceleration of a Cart Moving at a Constant Velocity

Prediction 3-2: Sketch with a dashed line on the axes that follow your prediction of the acceleration of the cart you just observed moving at a constant velocity away from the motion detector. Base your prediction on the definition of acceleration.



4. **Display** the real acceleration graph of the cart by “dragging” acceleration data onto the existing graph. Sketch the acceleration graph using a solid line on the axes above. **Print** out one copy of the graph for your group report. Label it.

Question 3-2: Does the acceleration—time graph you observed agree with your prediction? If not, explain.

5. Find the average acceleration of the car using one of the techniques that you used earlier to find the average velocity. Indicate how this was done.

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