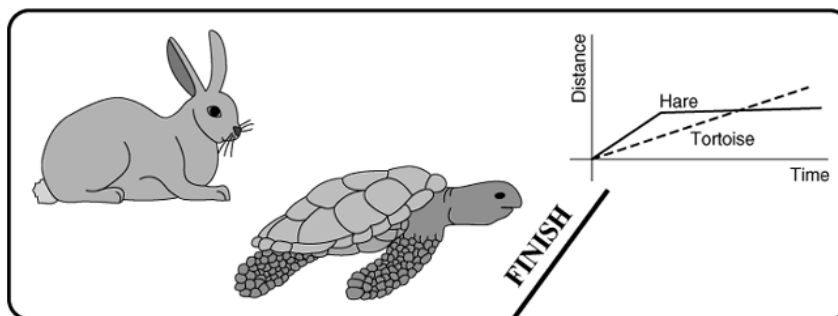


Name \_\_\_\_\_ Date \_\_\_\_\_ Partners \_\_\_\_\_

## LAB 2: ONE DIMENSIONAL MOTION



*Slow and steady wins the race.*

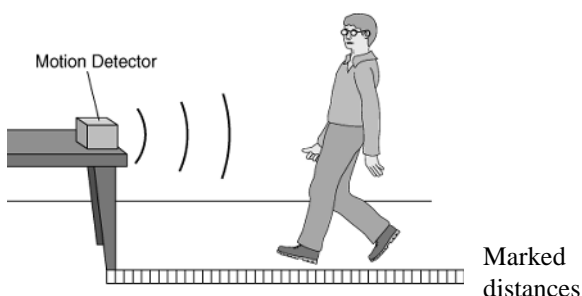
–Aesop’s fable: The Hare and the Tortoise

### OBJECTIVES

- To learn how to use a motion detector and gain familiarity with *Data Studio*.
- To explore how various motions are represented on a distance-time graph
- 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 begin your examination of the motion of an object that moves along a line and how it can be represented graphically. You will use a motion detector to plot distance-time (position-time) motion of your own body, examine two different ways that the motion of an object that moves along a line can be represented graphically and 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 representations is known as *kinematics*.

**INVESTIGATION 1: DISTANCE (POSITION) – TIME GRAPHS OF YOUR MOTION**

The purpose of this investigation is to learn how to relate graphs of distance as a function of time to the motions they represent.

You will need the following materials:

- motion detector
- masking tape marked on floor in meters

**Questions to consider:**

How does the distance-time graph look when you move slowly? Quickly? What happens when you move toward the motion detector? Away? After completing this investigation, you should be able to look at a distance-time graph and describe the motion of an object. You should also be able to look at the motion of an object and sketch a graph representing that motion.

**Comment:** “Distance” is short for “distance from the motion detector.” The motion detector is the origin from which distances are measured. The motion detector

- detects the closest object directly in front of it (including your arms if you swing them as you walk).
- transfers information to the computer via the interface so that as you walk (or jump, or run), the graph on the computer screen displays your distance from the motion detector.
- will not correctly measure anything much closer than 20 cm. When making your graphs don’t go closer than 20 cm from the motion detector.

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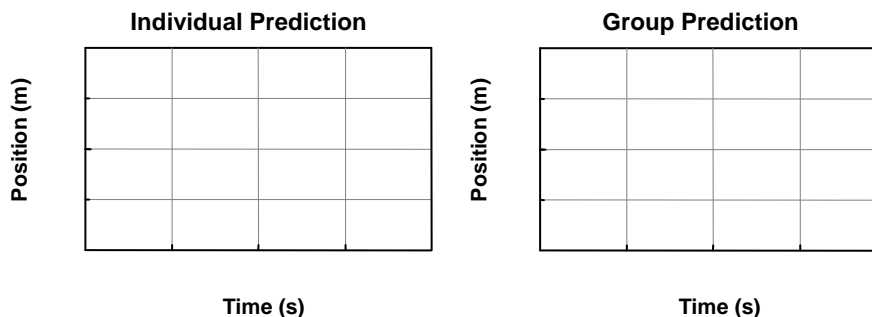
**ACTIVITY 1-1: DETERMINING THE INITIAL SPEED**

1. Be sure that the interface is connected to the computer. Open *Data Studio*. Click on *Create Experiment* on the opening page or under File, click on New Activity, which will go to the page where you can click on *Create Experiment*.
2. Click on Digital Channel Input 1 on far left. A list of sensors appears. Find the Motion Sensor line, double click on the Icon beside the Motion Sensor line, and the software will connect the Motion Sensor to the 750 Interface. You should physically have the Motion Detector plugged into the Interface in the same manner. Close the Setup by clicking on the **X** in the upper right.
3. On the left side of the screen under Data, click on Position and drag it down to the graph icon in the display window. A graph should appear on the right side of the screen displaying Position vs. Time.
4. Note that you can change the scale on both axes by moving the mouse to the numbers, click and drag them to decrease or increase the scale. Try this for both scales.

5. To start the experiment, click on the Start button. Notice then that this button is replaced by a Stop button that allows you to stop the experiment.
6. You can erase data by clicking on Experiment on the top row and then clicking on Delete Last Data Run. Be careful of Deleting All Data if you don't mean to do so.
7. Check that the switch on the motion detector is set to broad beam. Mount the motion detector on the edge of the table; ask your TA for specific instructions.
8. **Begin graphing** and make distance-time graphs for different walking speeds and directions.
  - a. Start at the  $\frac{1}{2}$  meter mark and make a distance-time graph, walking away from the detector (origin) slowly and steadily. Start the computer before walking and stop the computer when finished. Do not erase the data.
  - b. Make a distance-time graph, walking away from the detector (origin) medium fast and steadily. Start computer before walking and stop when finished.
  - c. Start at the 2 meter mark and make a distance-time graph, walking toward the detector (origin) slowly and steadily. Start and stop computer as before.
  - d. Make a distance-time graph, walking toward the detector (origin) medium fast and steadily. Start and stop computer as before.
  - e. Click on Stop when finished. You should have all four graphs on computer.
9. **Print** one set of graphs for your group.

**Comment:** If you do not erase the graph, it will remain stored in the computer so that it is **persistently displayed on the screen**. You can also go to the Data icon and click on and off this run so the data are or are not displayed.

**Prediction 1-1:** Predict the position-time graph produced when a person starts at the 1 m mark, walks away from the detector slowly and steadily for 5 s, stops for 5 s, and then walks toward the detector twice as fast. Draw your prediction on the left axes below. Label the axes appropriately. Compare your predictions with those made by others in your group. Draw your group's prediction on the right-hand axes below. The individual prediction should be done before coming to lab.



10. Test your prediction by using the computer to graph your position over a range of 2 m for a time interval of 15 s. Move in the way described in Prediction 1-1, and graph your motion.

11. When you are satisfied with your graph, **print** one copy of the graph for your group.

**Question 1-1:** Is your prediction the same as the final result? If not, describe how you would move to make a graph that looks like your *prediction*.

12. Everyone should gather around the computer for the next few steps to make sure everyone learns how to do these manipulations with *Data Studio*.
13. Keep the previous graph of your motion on the screen. Change scales as desired or use the Autoscale (scale to fit) icon on the Graph window toolbar on far left. Click the Autoscale to see what happens.
14. Click on the Smart Tool and drag the crosshair to individual data points to read the data at that point.
15. To highlight regions of data, go to a beginning spot and “click-and-drag” a window around the region of interest. Data will be highlighted with yellow background. Highlight the first region of data when you walk away from the motion detector.
16. To fit data, click on the Fit icon and choose the function you desire, in this case Linear Fit. Note the parameters (slope and y-intercept) are immediately given on the screen. To remove them, go back and “unclick” Linear Fit.
17. Note that if you leave Linear Fit on, but choose a different highlighted region, the fit will be applied to the new region.
18. Let's now examine the region where the person was at rest. Highlight the second region of your data which should be level. Then click on the Statistics icon (which appears as a  $\Sigma$ ). Click on Mean and the mean value over that region will be displayed. Note the varying functions that can be obtained with the Statistics functions.
19. If you have multiple runs on the screen, note that the various tools work on the run that is highlighted in the box in yellow. You can choose which data runs are displayed by clicking on the Data icon and clicking on and off the runs as you desire.
20. Now find the slopes of the two regions in which you were walking. Remember that the return path was supposed to be twice as fast as the initial path. Use the Tools to find the velocity (slope) of each path:

First path slope: \_\_\_\_\_ Second path slope: \_\_\_\_\_

**Question 1-2:** How did you do? Was the speed in the second path about twice that in the first?

### **INVESTIGATION 2: POSITION-TIME GRAPHS OF MOTION**

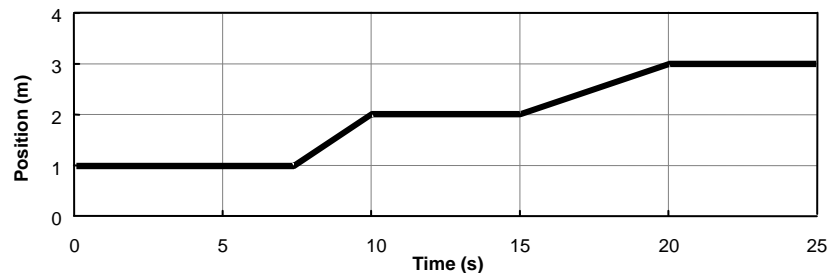
The purpose of this investigation is to learn how to relate graphs of position as a function of time to the motions they represent.

You will need the following materials:

- motion detector
- number line on floor in meters

#### **ACTIVITY 2-1: MATCHING A POSITION-TIME GRAPH**

By now you should be pretty good at predicting the shape of a position-time graph of your movements. Can you do things the other way around: reading a position-time graph and figuring out how to move to reproduce it? In this activity you will move to match a position graph shown on the computer screen.



1. In *Data Studio*, select “Open” and navigate to the “635” folder. Do not try to save the previous activity (you will be prompted to do this). Open the experiment file called **L02.A2-1 Position Match**. A position graph like that shown above will appear on the screen. Clear any other data remaining from previous experiments. It is a good idea to **always** click on the “Setup” icon on the computer screen to see if your cables are correctly connected to the PASCO interface, now and in the future.

**Comment:** This graph is stored in the computer so that it is **persistently displayed on the screen**. New data from the motion detector can be collected without erasing the **Position Match** graph.

2. Try to move so as to duplicate the **Position Match** graph on the computer screen. You may try a number of times. It helps to work as a team. Each person should take a turn.

**Question 2-1:** What was different in the way you moved to produce the two differently sloped parts of the graph you just matched?

### **INVESTIGATION 3: 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 vs. 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

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#### **ACTIVITY 3-1: MAKING VELOCITY GRAPHS**

1. Open the experiment file called **L02.A3-1 Velocity Graphs**. This will allow you to graph velocity. Check that the switch on the 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. Ask your TA how to choose what data are displayed on the screen (and printed out). Basically you click on and off various runs under the **DATA** icon to show on the screen
  - a. **Begin graphing** and make a velocity graph by walking *away* from the detector *slowly and steadily*. Try again until you obtain 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*. STOP the data taking after each try. Then START for the next experiment.
  - c. Make a new velocity graph, walking *toward* the detector *slowly and steadily*.
  - d. Make a new velocity graph, walking *toward* the detector *medium fast and steadily*.

3. **Print** out one graph that includes all the data you decide to keep. Make sure you denote on your print out with letters a) – d) to indicate what you were trying to do.

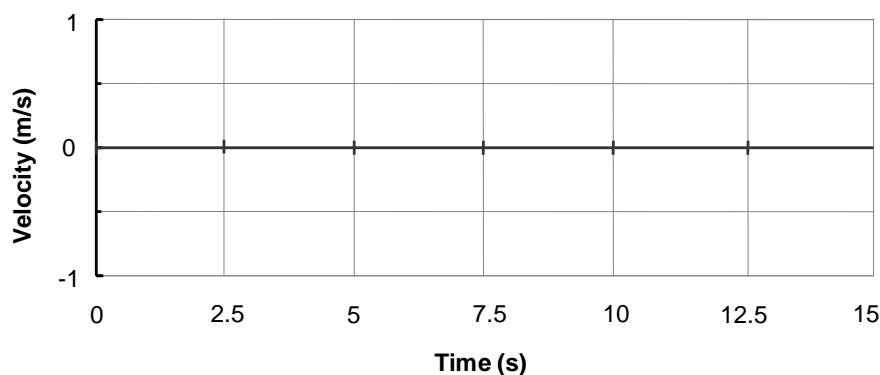
**Question 3-1:** What is the most important difference between the graph made by *slowly* walking away from the detector and the one made by walking away *more quickly*?

**Question 3-2:** How are the velocity-time graphs different for motion *away* than for motion *towards* the detector?

**Prediction 3-1:** Each person draw below in your own manual, 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
- then stand still for about 5 s
- then walk toward the detector steadily about twice as fast as before.

Do the predictions before coming to lab. Label your predictions and compare with your group to see if you can all agree. Use a solid line to draw in your group prediction.



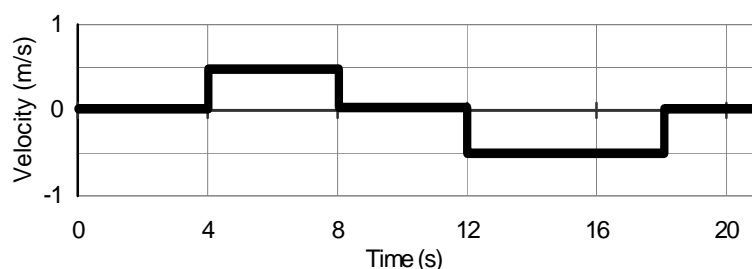
4. Test your prediction. Open experimental file **L02.A3-1 Velocity Graphs Two**. Be sure to think about your starting point! **Begin graphing** and repeat your motion until you think it matches the description.

5. **Print** out one copy of the best graph for your group report.

### ACTIVITY 3-2: 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 position graphs as you did in the previous investigation so do **not spend a lot of time on this activity**. Most people find it quite a challenge to move so as to match a velocity graph. In fact, some velocity graphs that can be invented cannot be matched!

1. Open the experiment file called **L02.A3-2 Velocity Match** to display the velocity-time graph shown below on the screen.



**Prediction 3-2:** Describe in words how you would move so that your velocity matched each part of this velocity-time graph. Do this before coming to lab.

0 to 4 s:

4 to 8 s:

8 to 12 s:

12 to 18 s:

18 to 20 s:

2. **Begin graphing**, and move so as to imitate this graph. Try to do this without looking at the computer screen. You may try a few times. Work as a team and plan your movements. Get the times right. Get the velocities right. 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 velocity-time graph shown above. **As we stated earlier, don't spend a lot of time trying to improve this. It is difficult!**

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

**Question 3-4:** 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 4: 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 the relation between position-time and velocity-time graphs, you will need the following materials:

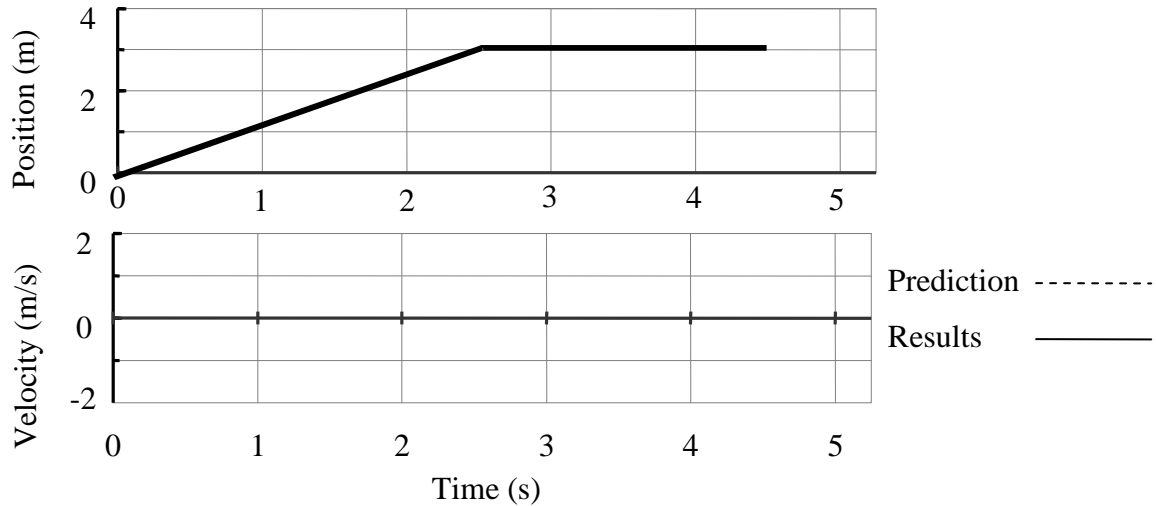
- motion detector
- number line on floor in meters

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#### **ACTIVITY 4-1: DETERMINING VELOCITY GRAPHS FROM POSITION GRAPHS**

1. Open the experiment file called **L02.A4-1 Velocity from Position** to set up the axes shown that follow. **Clear** any previous graphs. Remember to check "Setup"!

**Prediction 4-1:** Do this before coming to lab. 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.



- Test your 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 decent 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 or your data in the computer.

**Question 4-1:** How would the position graph be different if you moved faster? Slower?

**Question 4-2:** How would the velocity graph be different if you moved faster? Slower?

**ACTIVITY 4-2: CALCULATING AVERAGE VELOCITY**

In this activity, you will find an average velocity from your velocity-time graph in Activity 4-1 and then from your position-time graph.

- Here you will find your average velocity from the velocity graph that you obtained in Activity 4-1. 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 *Data Studio* 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 and last points. You will need them later.

Time at first point \_\_\_\_\_ Time at last point \_\_\_\_\_

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

Average (mean) value of the velocity: \_\_\_\_\_

This is **method 1** of determining the average velocity.

**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.

- Calculate your average velocity from the slope of your **position** graph in Activity 4-1. 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)	

This is **method 2.**

**Question 4-3:** 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?

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#### ACTIVITY 4-3: USING STATISTICS AND FIT TO FIND THE AVERAGE VELOCITY

In Activity 4-2, 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 *Data Studio* (look for the  $\Sigma$  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 4-1. 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 4-2. Next use the **statistics feature**  $\Sigma$  to read the mean value of velocity during this portion of the motion.

Average (mean) value of the velocity: \_\_\_\_\_ This is **method 3.**

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

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.

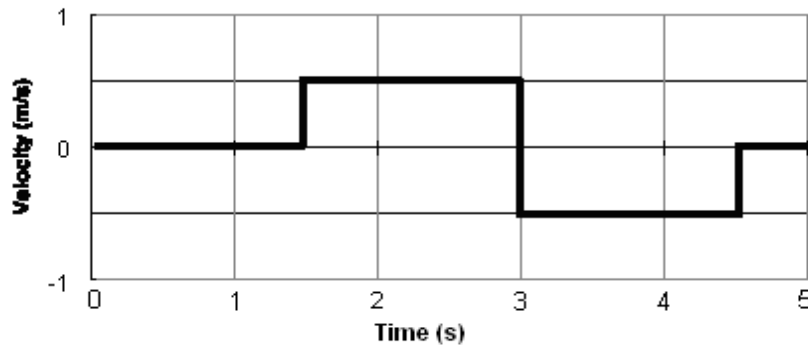
Next, use the **fit routine**, select a linear fit,  $y = mx + b$ , and then find the equation of the line.

Record the equation of the fit line below. What is the velocity and compare it to the velocity you found in Activity 4-2. This is **method 4**.

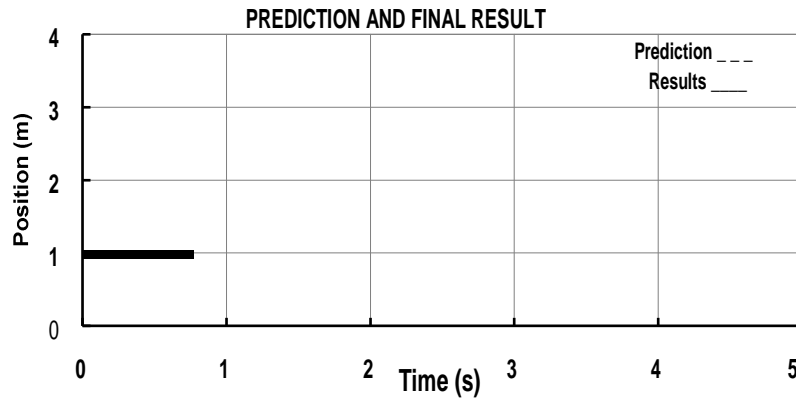
**Question 4-5:** What does  $b$  represent?

3. Print your graph.

**ACTIVITY 4-4: PREDICTING POSITION GRAPHS FROM VELOCITY GRAPHS**



**Prediction 4-2:** Carefully study the velocity graph shown above. Using a *dashed line*, sketch your *prediction* of the corresponding position graph below. (Assume that you started at the 1 m mark.)



Test your prediction.

1. First shut off the **analysis features** (fits and statistics), and **adjust the time axis** to 0 to 5 s as needed before you start.
2. Each person has already made 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.

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

**Question 4-6:** 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 4-7:** How can you tell from a position-time graph that your motion is steady (motion at a constant velocity)?

**Question 4-8:** How can you tell from a velocity-time graph that your motion is steady (constant velocity)?

### ***INVESTIGATION 5: 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 erratic. 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 Lab 3 you will examine the acceleration of more complex motions of the cart. You will need the following:

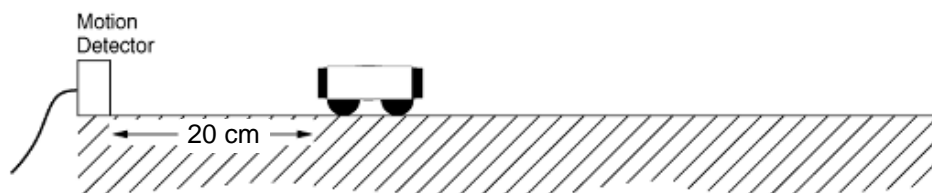
- motion cart without friction pad

- 2-m motion track
- Level
- motion detector

**ACTIVITY 5-1: MOTION OF A CART AT A CONSTANT VELOCITY**

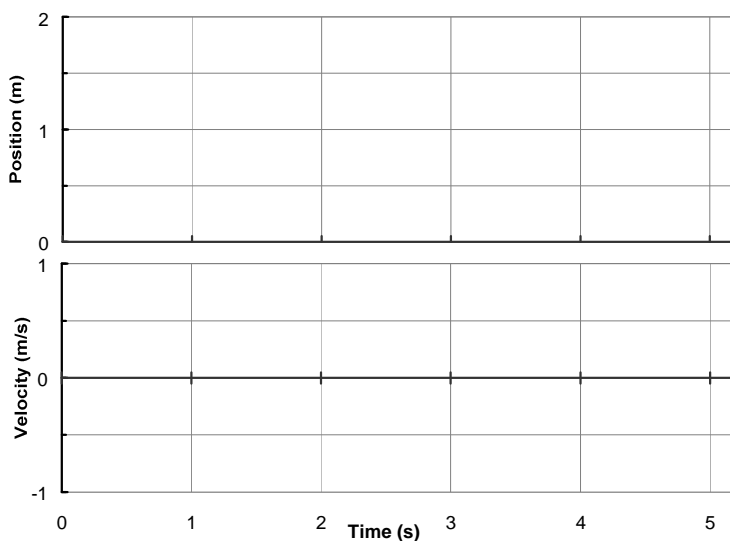
To graph the motion of a cart at a constant velocity you can give the cart a quick push with your hand and then release it.

1. Clip the motion detector on the end of the ramp. Ask your TA for help if it is not clear how to do this. Set switch to narrow beam and aim the motion detector at the cart. Be sure that the track is level.



2. Open the experiment file called **L02.A5-1 Constant Velocity**.

**Prediction 5-1:** Do this before coming to lab. 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.



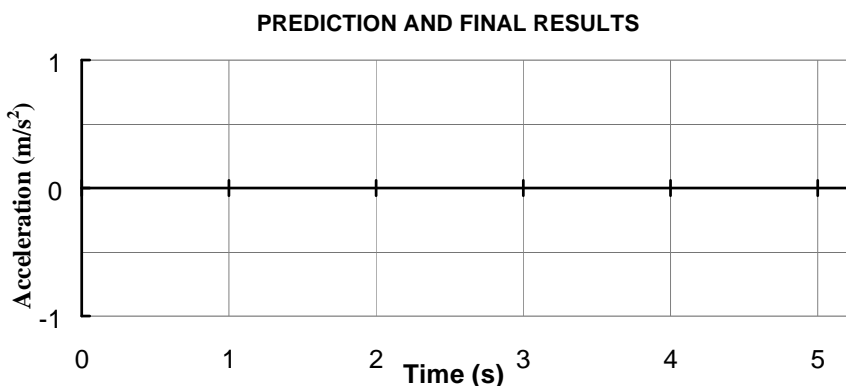
3. Test your prediction. Give the cart a quick push and release it. Be sure that the cart is never closer than 20 cm from the motion detector and that your hand is not between the cart and motion detector. **Begin graphing right after releasing the cart.** Try several times until you get a fairly constant velocity. Sketch your results with solid lines on the axes.
4. **Print** out one copy for your group report.

**Question 5-1:** Did your position-time and velocity-time graphs agree with your predictions? Discuss. What type of curve characterizes constant velocity on a position-time graph?

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**ACTIVITY 5-2: ACCELERATION OF A CART MOVING AT A CONSTANT VELOCITY**

**Prediction 5-2:** 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.



1. You will use the data you took in the previous activity. **Display** the real acceleration graph of the cart by “dragging” acceleration data from the left column onto existing graph. Sketch the acceleration graph using a solid line on the axes above. Ask your TA for help if needed.
2. **Print** out one copy of the graph for your group report. Label it.

**Question 5-2:** Does the acceleration-time graph you observed agree with your prediction? Discuss.

3. Find the average acceleration of the car using one of the techniques that you used earlier to find the average velocity. Show your work. Which technique did you use?