Name____________________Date____________Partners____________________

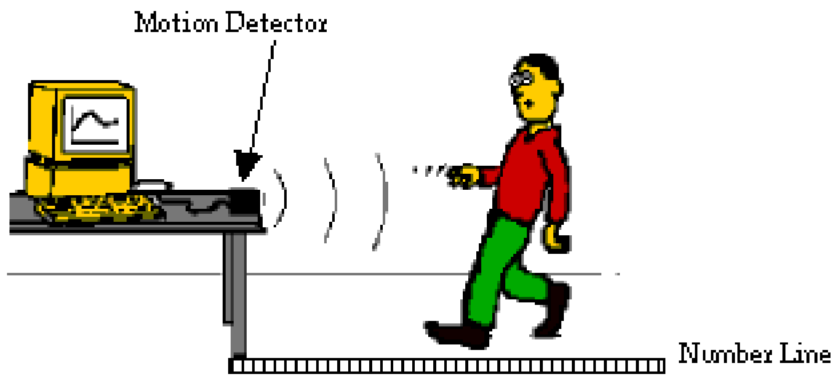
LAB 1: INTRODUCTION TO MOTION

OBJECTIVES

- To discover how to measure motion with a motion detector
- To see how motion looks as a position-time graph
- To see how motion looks as 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 can be represented graphically. You will use a motion detector to plot position-time and velocity-time 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.*



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Note: These materials have been modified for use at the College of San Mateo, 1999-2010.

INVESTIGATION 1: POSITION-TIME GRAPHS OF YOUR 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.

How does the position-time graph look when you move slowly? When you move quickly? What happens when you move toward the motion detector? When you move away? After completing this investigation, you should be able to look at a position-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.

You will need the following materials:

- Laptop computer with power supply
- RTP Lab 1 files
- Motion Detector
- LabPro Interface

Set up the lab equipment as follows.

- Plug in the laptop computer using the provided power supply and turn it on.
- Plug in and connect the LabPro interface to the computer using the USB cable.
- Connect the Motion Detector to the DIG/SONIC 2 input using its cable. Set the switch on the motion detector to human or basketball (not cart).

- The motion detector detects the closest object directly in front of it (including your arms if you swing them as you walk). The motion detector sends out a sound wave to measure the distance to this nearest object by measuring the time it takes the sound wave to return to the detector after bouncing off the object.
- Your computer screen will display position-time graphs. The origin is chosen to be at the motion detector. The positive x direction will be in a straight line away from the motion detector. The position displayed on the computer screen will be your location on an imaginary number line extending away from the detector.

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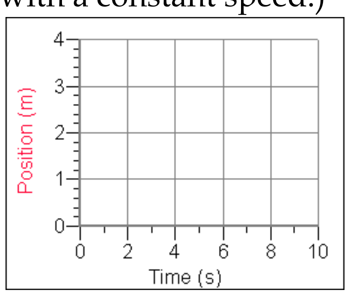
- The motion detector will not correctly measure distances less than 15 cm. (*When making your graphs, don't go closer than 15 cm from the motion detector.*)
- As you walk (or jump, or run), the graph on the computer screen displays how far away from the detector you are.

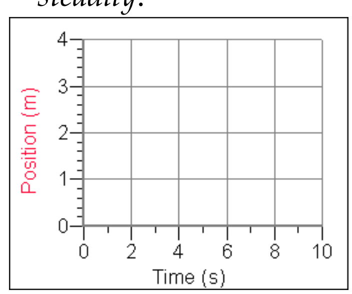
Activity 1-1: Making Position-time Graphs

1. Open the "Physics" folder on the desktop. Open the "RTP Lab 1" folder. Open the experiment file "L1A1-0." Click "OK" on the Page Information window. A position-time graph should appear on the screen. You should also see a green "Collect" button on the right end of the toolbar. If the button is not green, check that everything is connected and consult your instructor.
2. Each group member should record all answers on his/her copy of the lab. You should discuss the questions with other members of your group, but you should each write your own responses to them on your worksheet. The worksheets will be collected at the end of each class period, whether the experiment is finished or not.
3. Make position-time graphs for different walking speeds and directions. For each graph, click once on the green "Collect" button in the toolbar at the top of the screen to create each graph. Sketch your results on the graphs below.

a. Make a position-time graph walking away from the detector (origin) *slowly and steadily*. (Steadily means with a constant speed.)



b. Make a position-time graph walking away from the detector (origin) *medium fast and steadily*.



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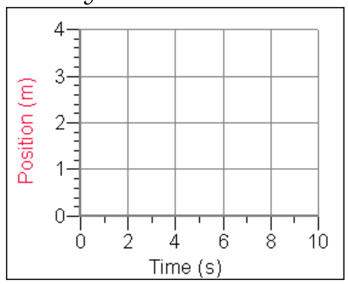
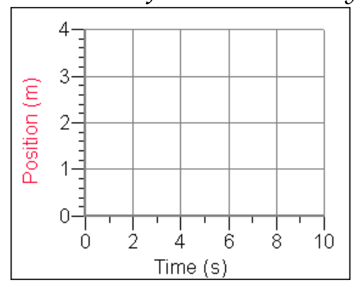
c. Make a position-time graph walking toward the detector (origin) *slowly and steadily*.



d. Make a position-time graph walking toward the detector (origin) *medium fast and steadily*.

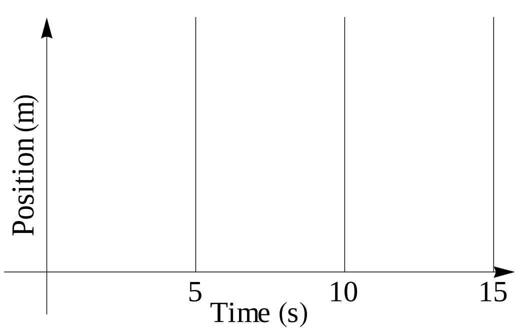


Question 1-1: Describe the difference between the graph you made by walking away *slowly* and the one made by walking away *faster*.

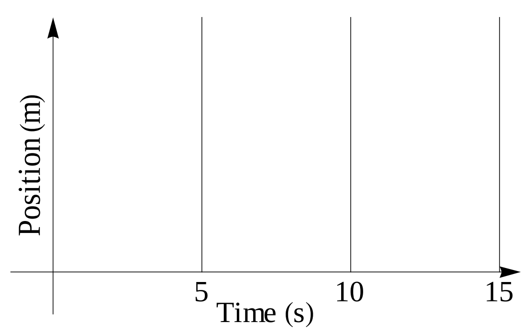
Question 1-2: Describe the difference between the graphs made by walking *toward* and the ones made walking *away from* the motion detector.

Prediction 1-1: Predict the position-time graph produced when a person starts 1 meter from the detector, walks away from the detector slowly and steadily for 5 seconds, stops for 5 seconds, and then walks toward the detector quickly. **Draw your prediction on the left axes below using ink**. (Note: All predictions should be done in ink. All results should be done in pencil.)

PREDICTION



FINAL RESULT



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5. Test your prediction. Open the RTP Lab 1 experiment file **L1A1-1 (Away and Back)**.

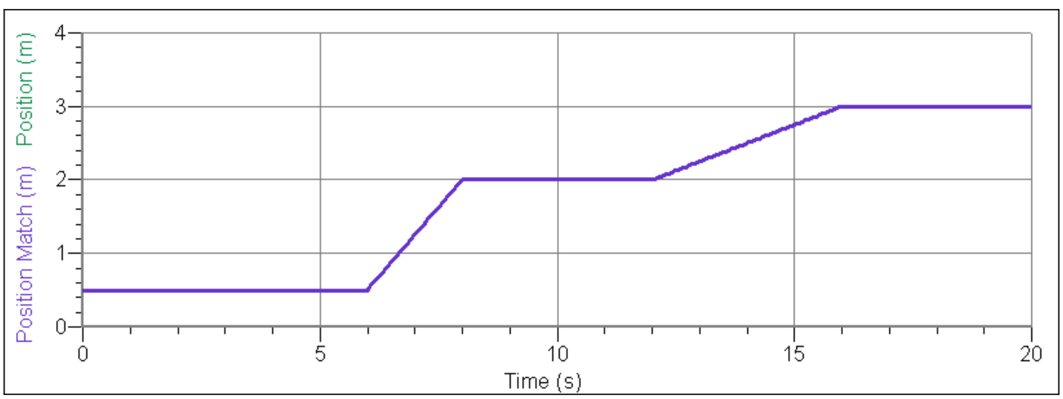
   Move in the way described above. You can place a meter stick on the floor to obtain your starting position. When you are satisfied with your graph, draw your group's final result on the right axes.

Question 1-3: 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.*

Activity 1-2: Matching a Position Graph

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

1. Open the experiment file called **L1A1-2 (Position Match).** A position graph like that shown below should appear on the screen. (If it doesn't, see your instructor.)



Comment: This graph is stored in the computer as "Run 2". New data from the motion detector are always stored as "Latest", and can therefore be collected without erasing the **Position Match** graph.

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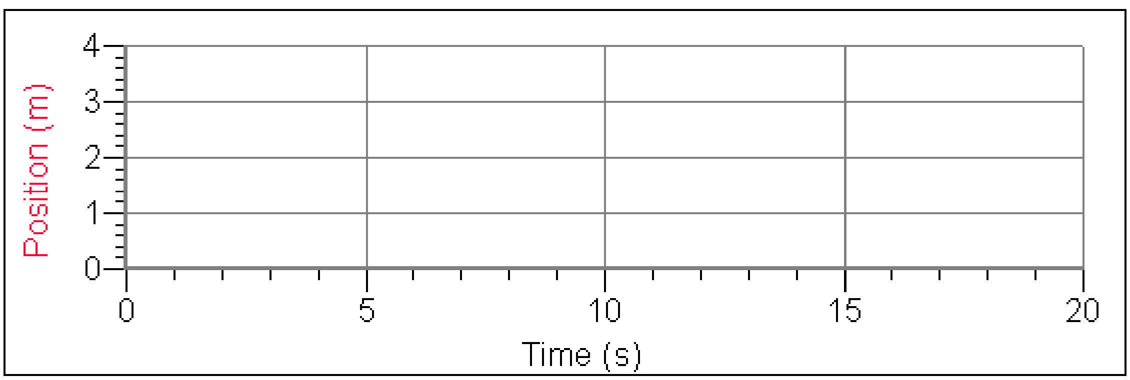
2. Move to match the **Position Match** graph on the computer screen. You may try a number of times. It helps to work as a team. Get the times right. Get the positions right. Each person should take a turn. Draw in your best graph above.

Question 1-4: What was the difference in the way you moved to produce the two differently sloped parts of the graph?

Activity 1-3: Other Position-Time Graphs

Open the RTP Lab 1 experiment file **L1A1-3 (Other Graphs)**.

1. Sketch your own position-time graph on the following axes with a dashed line in ink. Use straight lines, no curves. Now see how well someone in your group can duplicate this graph on the screen by walking in front of the motion detector.



2. Draw the best attempt by a group member to match your position-time graph in pencil on the same axes. Use a solid line.

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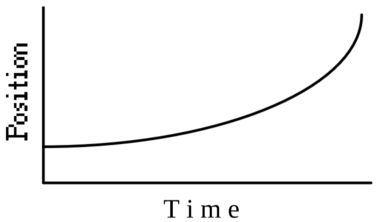
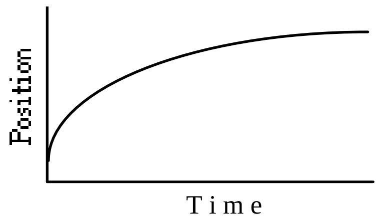
3. Can you make a curved position-time graph? Try to make each of the following graphs.

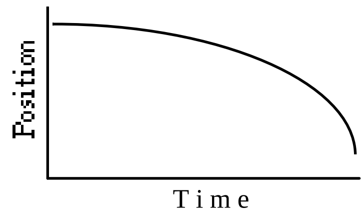
Graph A



Graph B



Graph C



4. Describe how you must move to produce a position-time graph with each of the shapes shown.

Graph A answer:

Graph B answer:

Graph C answer:

Question 1-5: What is the general difference between motions which result in a *linear* position-time graph and those that result in a *curved* position-time graph?

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INVESTIGATION 2: VELOCITY-TIME GRAPHS OF MOTION

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 which 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 which 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, its velocity can be positive or negative meaning the velocity is in the positive or negative direction.

Velocity-time graphs are more challenging to create and interpret than position-time graphs. 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.

Activity 2-1: Making Velocity Graphs

1. Open the experiment **L1A2-1 (Velocity Graphs)** which displays a velocity-time graph. The **Velocity** axis should range from **-1** to **1** m/s and the **Time** axis from **0** to **5** s, as shown on the next page.
2. Graph your velocity for different walking speeds and directions, and sketch your graphs on the axes. (**Just draw *smooth* patterns; leave out smaller bumps that are mostly due to your steps.**)

   For each graph, repeat the motion until you get a graph you're satisfied with. (While you are trying to improve your graphs, you may want to store good runs by going to “Experiment” on the menu bar and selecting “Store Latest Run”. If you do this, the run will become a thinner line indicating that it is now stored and no longer the “Latest” run.)

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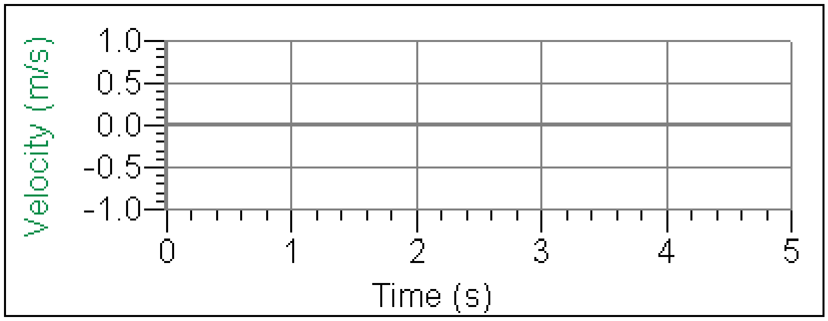
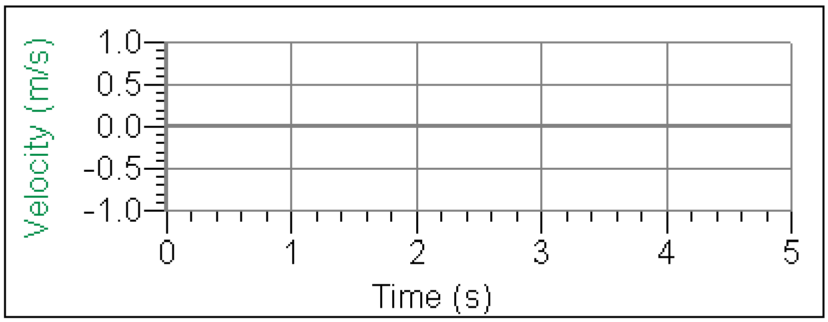
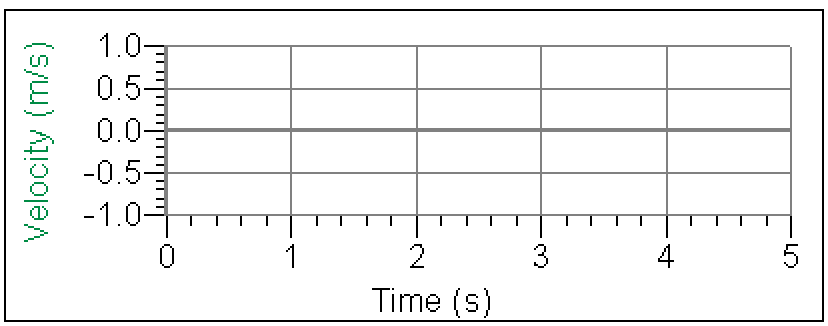
a. Make a velocity graph by walking *away* from the detector *slowly and steadily*.



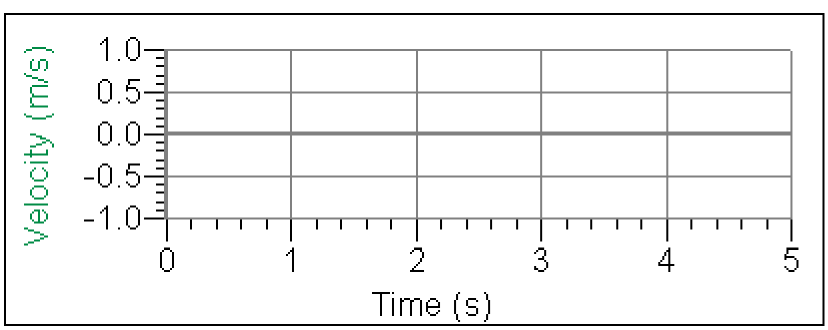
b. Make a velocity graph, walking *away* from the detector *medium fast and steadily*.



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*.



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Question 2-1: What is the most important difference between the graph made by *slowly* walking away from the detector and the one made by walking away *faster*?

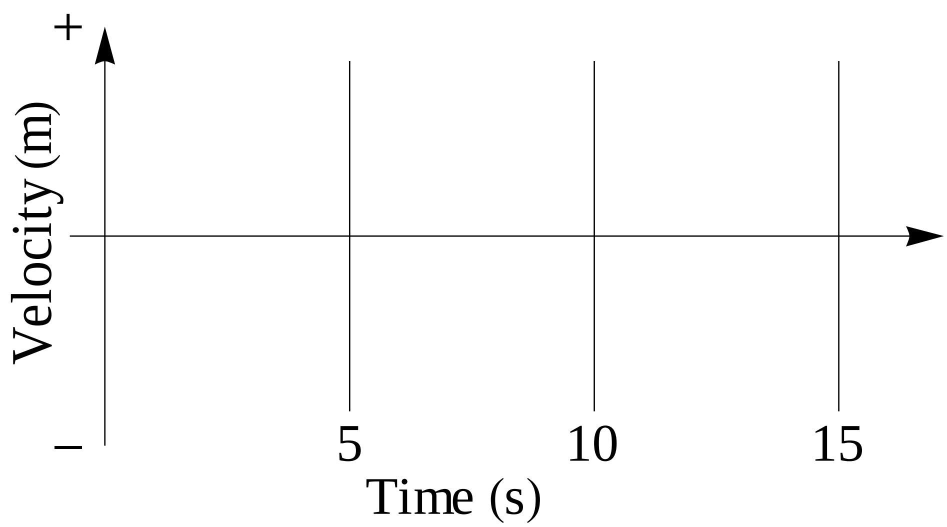
Question 2-2: How are the velocity-time graphs different for motion *away* and motion *toward* the detector?

Prediction 2-1: Predict a velocity graph for a more complicated motion and check your prediction.

Using ink, draw your prediction of the velocity graph produced if you:

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

YOUR PREDICTION



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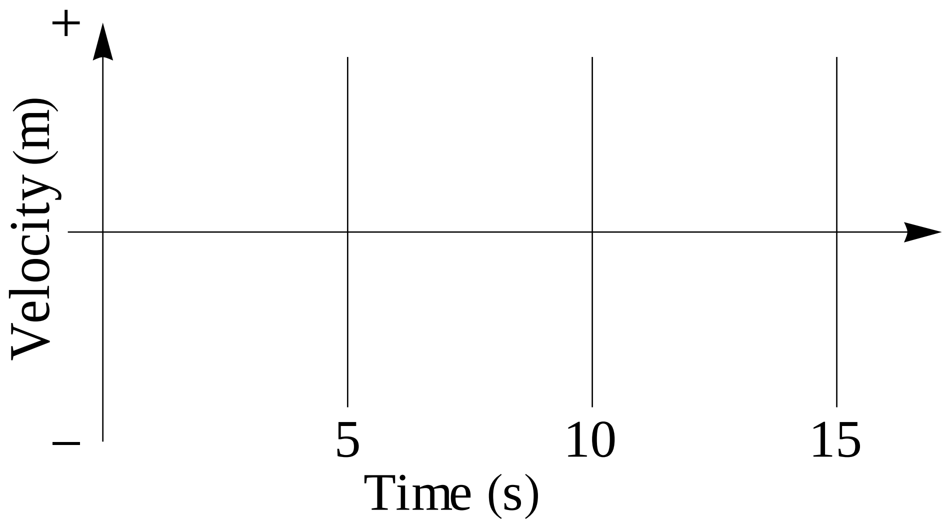
Compare your prediction with the predictions of the rest of your group. Discuss any differences and come up with a group prediction. Use ink to draw your group prediction.

GROUP PREDICTION

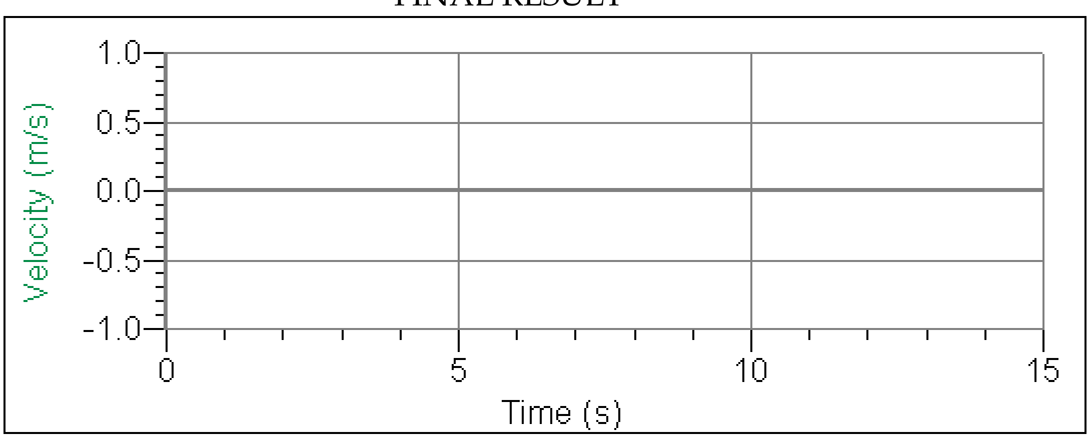


You will need to adjust the length of time of data collection to 15 seconds. To do this go to "Experiment" on the menu bar and select "Data Collection". In the window that appears, change the "Length" of data collection from 5 to 15 seconds and click "Done".

3. Test your prediction. Repeat your motion until you think it matches the description.

   Draw the best graph on the axes below. **Be sure the 5 s stop shows clearly.**

FINAL RESULT



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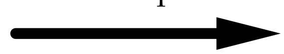
Comment: Velocity is the rate of change of position with respect to time. Velocity includes **both** speed and direction. The magnitude of your velocity is your speed, how fast you move. As you have seen, for motion along a line (e.g., the positive x axis) the sign (+ or -) of the velocity indicates the direction. In these labs, when you move away from the detector (origin), your velocity is positive, and when you move toward the detector, your velocity is negative.

The faster you move, the larger the magnitude of your velocity. When you move in the negative direction (*toward* the motion detector), your velocity is more negative the faster you move. That is -4 m/s is twice as fast as -2 m/s, and both motions are toward the detector.

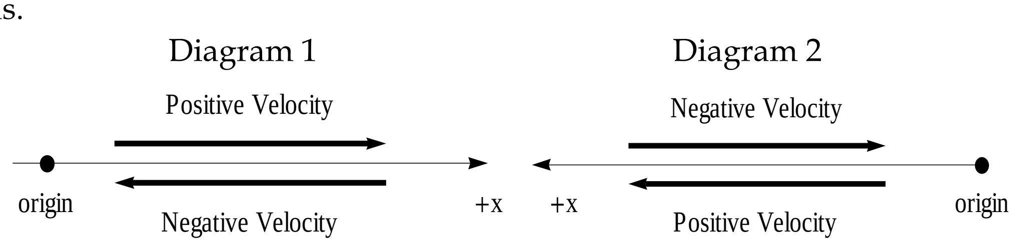
These two ideas of speed and direction can be combined and represented by *vectors*. A velocity vector is represented by an arrow pointing in the direction of motion. The length of the arrow is drawn proportional to the speed; the longer the arrow, the larger the speed. If you are moving toward the right, your velocity vector can be represented by the arrow shown below.



If you were moving twice as fast toward the right, the arrow representing your velocity vector would look like

while moving twice as fast toward the left would be represented by the following arrow

What is the relationship between a one-dimensional velocity vector and the *sign* of velocity? This depends on the way you choose to set the positive x axis.



In both diagrams above, the top vectors represent velocity toward the right. In diagram 1, the x axis has been drawn so that the positive x direction is toward the right, as it is usually drawn. Thus the top arrow represents *positive* velocity. However, in diagram 2, the positive x direction is toward the left. Thus the top arrow represents *negative* velocity. Likewise, in both diagrams the bottom arrows represent velocity toward the left. In diagram 1 this is *negative* velocity, and in diagram 2 it is *positive* velocity.

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Question 2-3: Sketch below velocity vectors representing the three parts of the motion described in Prediction 2-1. Assume the motion detector is on the left side of this page.

Walking slowly away from the detector:

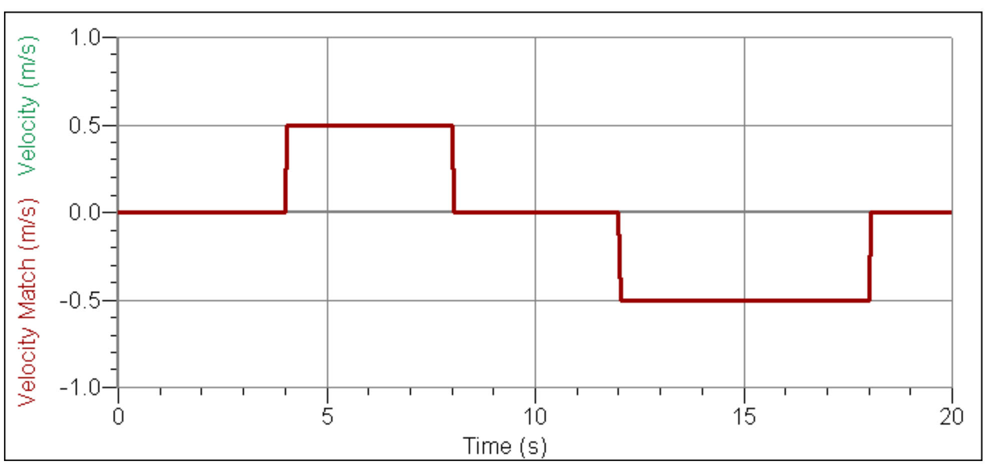
Standing still:

Walking toward the detector twice as fast as before:

Activity 2-2 Matching a Velocity Graph

In this activity, you will try to move to match a velocity graph shown on the computer screen. This is often 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!

Open the experiment **L1A2-2 (Velocity Match).** The velocity graph shown below will appear on the screen.



Move to match this graph. 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.

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

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Question 2-4: Describe how you moved to match each part of the graph.

Question 2-5: Is it possible for an object to move so that it produces an absolutely vertical line on a velocity time graph? Explain.

Question 2-6: Did you run into the motion detector on your return trip? If so, why did this happen? How did you solve the problem? Does a velocity graph tell you where to start? Explain.

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INVESTIGATION 3: RELATING POSITION AND VELOCITY GRAPHS

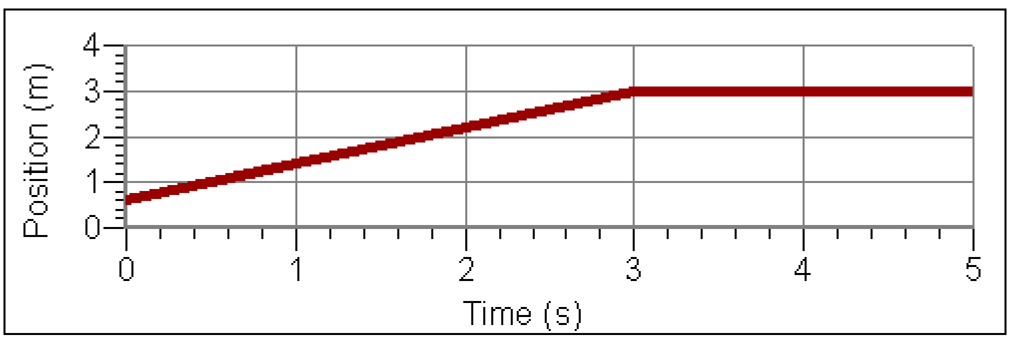
You have looked at position-time and velocity-time graphs separately. Position-time and velocity-time graphs are different ways to represent the same motion. Information about the velocity can be obtained from a position-time graph. Information about change in position can be obtained from a velocity-time graph.

In this investigation, you may want to save your work and continue during the next class period. If you need to save a set of data, ask your instructor for directions on how to save. **Do not save anything without checking with your instructor first.**

Activity 3-1 Predicting Velocity Graphs from Position Graphs

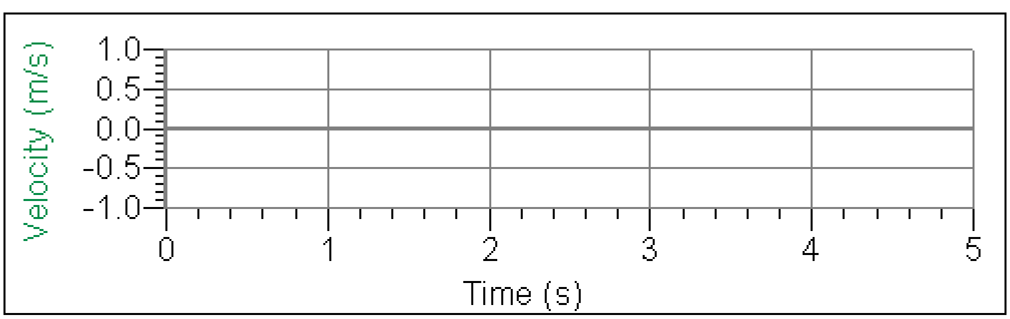
1. Open the experiment **L1A3-1 (Velocity from Position)**. The top graph displays **Position** from **0** to **4** m for a time of **5** s. The bottom graph displays **Velocity** from **-1** to **1** m/s for **5** s. Clear any previous graphs.

Prediction 3-1: Predict a velocity graph from a position graph. Carefully study the position-time graph shown below and predict the velocity-time graph that would result from the motion.



Use ink to draw your prediction of the corresponding velocity-time graph on the velocity axes.

YOUR PREDICTION



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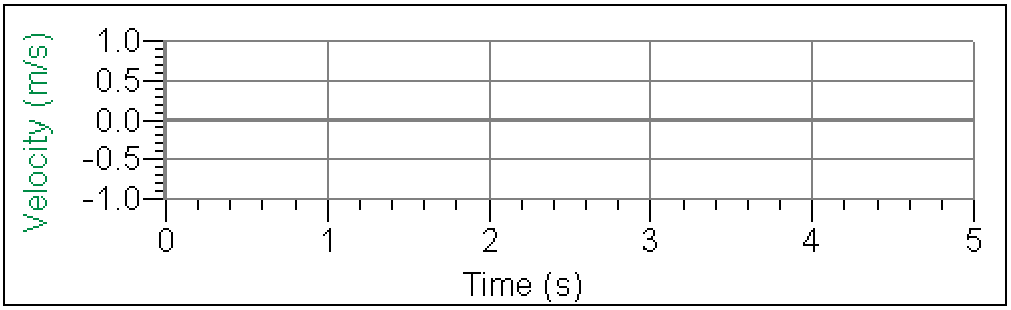
Compare your prediction with the predictions of the rest of your group. Discuss any differences and come up with a group prediction. Use ink to draw your group prediction.

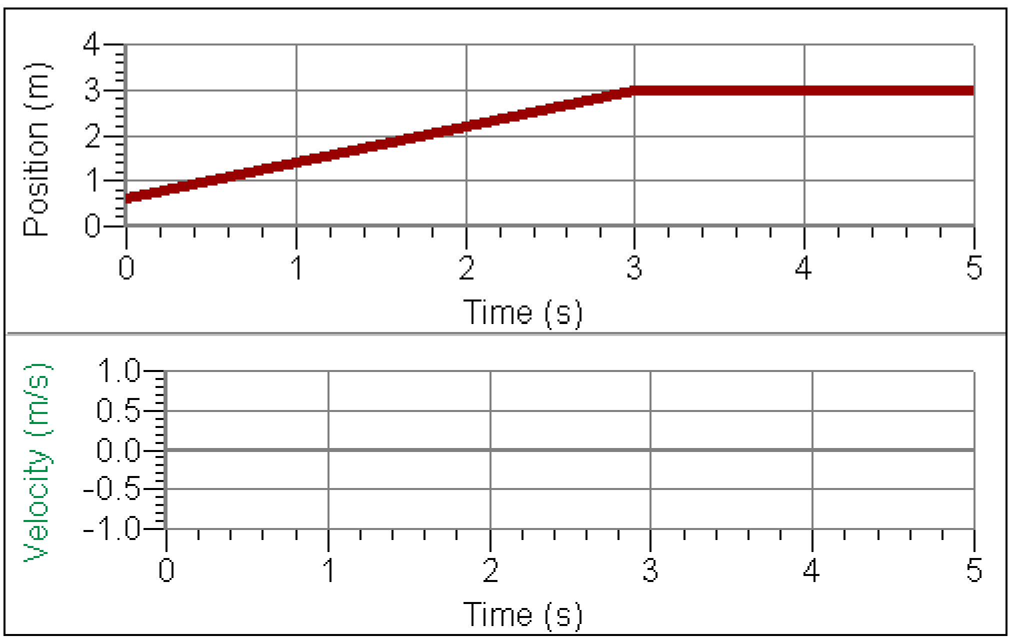
GROUP PREDICTION



2. Test your prediction. 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 below. Also sketch your actual velocity graph.

FINAL RESULT



Question 3-1: How would the position graph be different if you moved faster? Slower?

Question 3-2: How would the velocity graph be different if you moved faster? Slower?

Activity 3-2: Calculating Average Velocity

In this activity, you will find an average velocity from your velocity graph in Activity 3-1 and then from your position graph.

1. Find your average velocity from your velocity graph in Activity 3-1. Click anywhere on the velocity graph and select "Examine" in the "Analyze" menu. Read ten values from the portion of your velocity graph where your velocity is relatively constant and record them in the table below. Calculate the average (mean) velocity and enter it.

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

Average value of the velocity: _________m/s

Comment: Average velocity during a particular time interval can also be calculated as the change in position divided by the time interval. (The change in position is the *displacement.*) By definition, this is also the *slope* of the position-time graph for that time period.

2. Calculate your average velocity from the slope of your position graph in Activity 3-1. Click anywhere on the position graph and select "Examine" in the "Analyze" menu. Read the position and time coordinates for two typical points *while you were moving*. (For a more accurate answer, use two points as far apart as possible but still typical of the motion, and within the time interval over which you took velocity readings in (1).)

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

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

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

Question 3-3: Is the average velocity positive or negative? Is this what you expected? Explain

Question 3-4: 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?

Comment: We can obtain a slope for the best-fit line for all of the data on the position-time graph or any portion of the data. The Logger Pro software accomplishes this with its linear fit function.

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3. Select (highlight) approximately the same portion of the position-time graph which you used in the previous step. Highlight the region by placing the cursor at the beginning of the desired region, holding the mouse button while dragging to the end of the region, and releasing the button. The region should remain highlighted. Select "Linear Fit" in the Analyze menu.

   Record the equation of the fit line below.

   Equation:

Question 3-5: Compare the value of the slope to the velocity found in step 2. Which value do you think is more accurate? Why?

Comment: We can also obtain the average (mean) value of the velocity using the Logger Pro software.

4. Select approximately the same portion of the velocity-time graph which you used in step 1. Select "Statistics" from the Analyze menu. Record the mean value displayed in the dialog box.

   Mean value of velocity:

Question 3-6: Compare this value to the one you found from ten measurements in step 1. Which method do you think is more accurate? Why?

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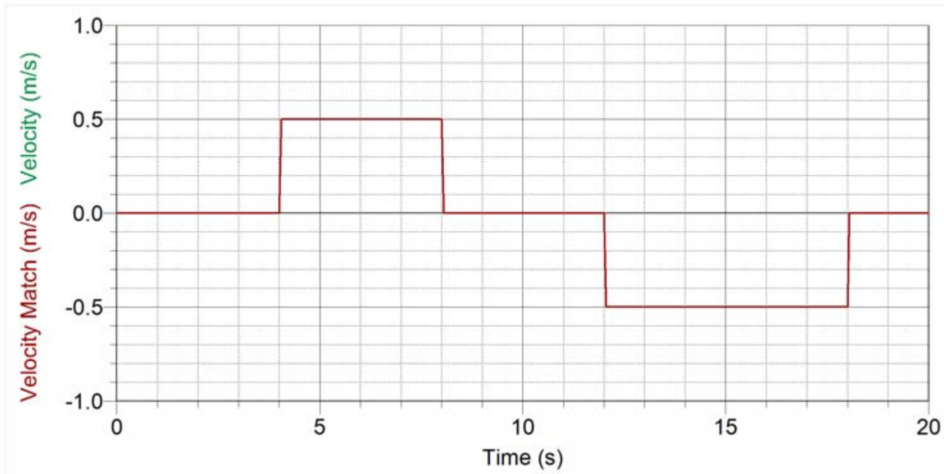
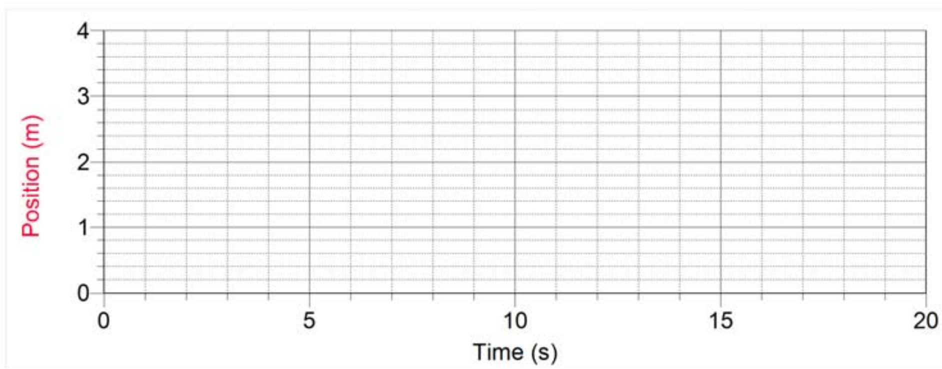
Activity 3-3 Predicting Position Graphs from Velocity Graphs

Prediction 3-2: Carefully study the following velocity graph. Using ink, sketch a *dashed line* showing your *prediction* of the corresponding position graph on the bottom set of axes. (Assume that you started at the 1-meter mark.)





1. Test your prediction. Open the experiment **L1A3-3 (Position from Velocity).**
2. Do your group's best to duplicate the top (velocity-time) graph by walking.

   When you have made a good duplicate of the velocity-time graph, draw your actual result over the existing velocity-time graph above.
3. Use a *solid line* to draw the actual position-time graph on the same axes with your prediction.

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Question 3-7: How can you tell from a **velocity-time** graph that the moving object has changed direction?

Question 3-8: What is the velocity at the moment the direction changes?

Question 3-9: Is it possible to actually move your body (or an object) to make vertical lines on a position-time graph? Why or why not? What would the velocity be for a vertical section of a position-time graph?

Question 3-10: How can you tell from a **position-time** graph that your motion is steady (motion at a constant velocity)?

Question 3-11: How can you tell from a **velocity-time** graph that your motion is steady (constant velocity)?

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INVESTIGATION 4: INTRODUCTION TO ACCELERATION

There is a third quantity besides position and velocity which is used to describe the motion of an object--acceleration. Acceleration is defined as *the rate of change of velocity 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 only examine a cart moving with a constant (steady) velocity. Later, in Lab 2 you will examine the acceleration of more complex motions of a cart.

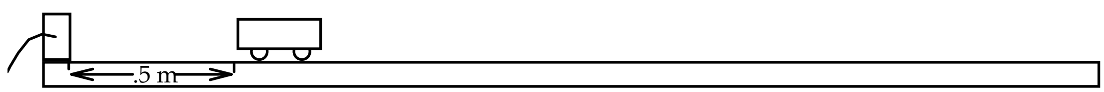
This investigation will be done as a class activity. Your group will not need its own equipment.

The instructor will be using a constant motion cart.

Activity 4-1: Motion of a Cart at a Constant Velocity

To graph the motion of a cart at a constant velocity you can set it in motion along a smooth level surface.

Your instructor will set up a motion detector at one end of the instructor desk. The switch on the motion detector will be set to cart. The experiment file **L1A4-1 (Constant Velocity)** will be used.



Prediction 4-1: Based on your observations of the motions of your body, predict the shape of the position-time and velocity-time graphs if the cart moves at a constant velocity away from the motion detector. In ink, sketch your predictions with dashed lines on the axes which follow.

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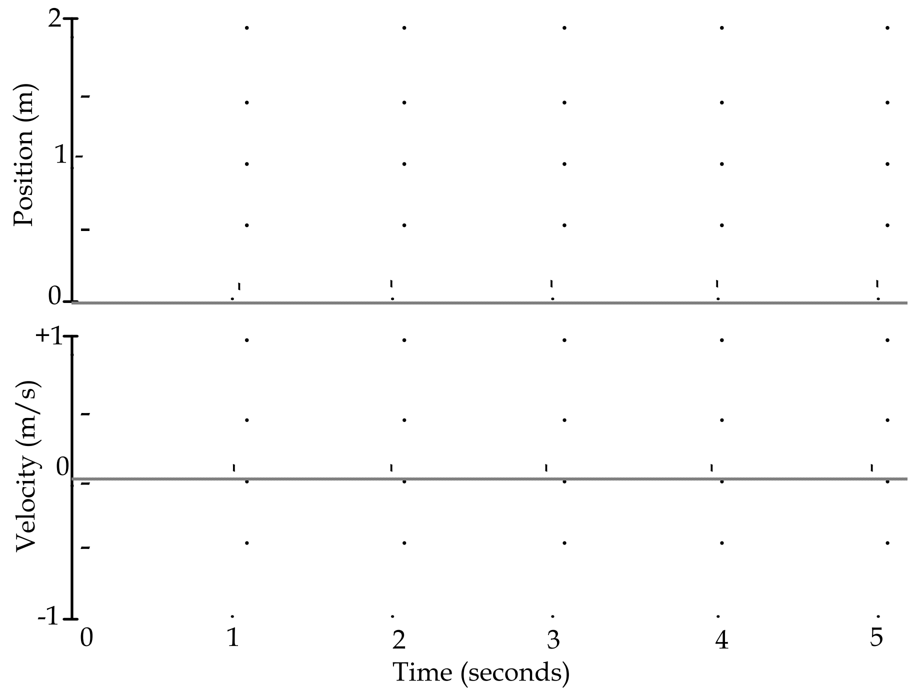
PREDICTION AND FINAL RESULTS



Your instructor will perform the experiment. Sketch the results with solid lines on the axes.

Question 4-1: Do the shapes of the position-time and velocity-time graphs agree with your predictions? What characterizes constant velocity motion on a **position-time** graph?

Question 4-2: What characterizes constant velocity motion on a **velocity-time** graph?

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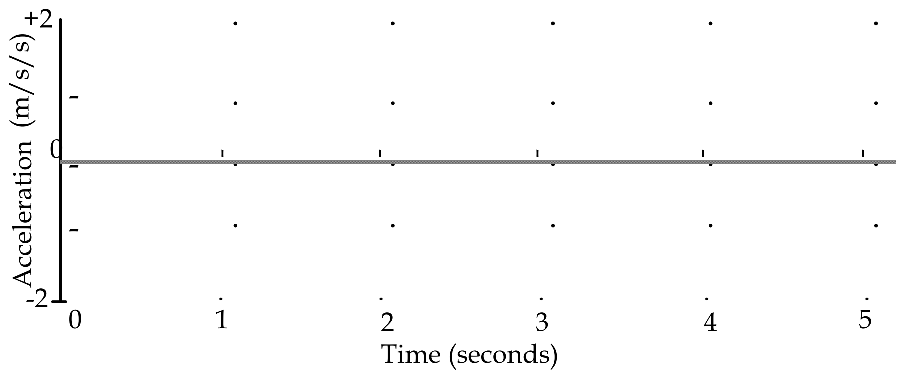
Activity 4-2: Acceleration of a Cart Moving at a Constant Velocity

Prediction 4-2: Consider the motion of the cart you just observed at a constant velocity away from the motion detector. Based on the definition of acceleration, use ink to draw your prediction of the acceleration for the motion.

PREDICTION AND FINAL RESULTS



Your instructor will display the real acceleration graph of the cart in place of the position graph by holding the mouse button down with the cursor on the **Position** label on the graph and selecting **Acceleration**. Sketch the acceleration graph using a solid line on the axes above.

Comment: To find the average acceleration of the cart during some time interval (the average rate of change of its velocity with respect to time), you must measure its velocity at the beginning and end of the interval, calculate the difference between the final value and the initial value and divide by the time interval.

Question 4-3: Does the acceleration-time graph you observed agree with this method of calculating acceleration? Explain. Does it agree with your prediction?

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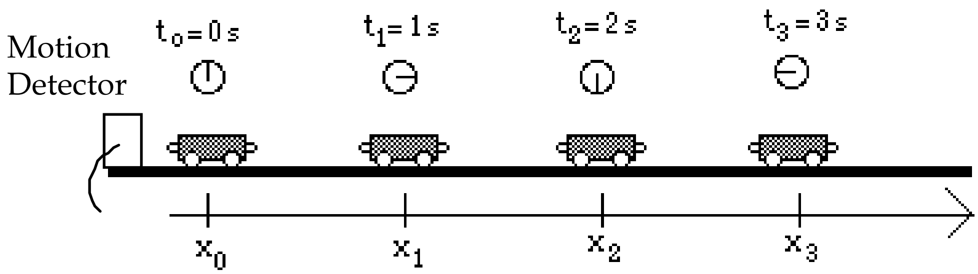
Question 4-4: The diagram below shows the positions of the cart at equally spaced times.



At each indicated time, sketch a vector above the cart which might represent the velocity of the cart at that time while it is moving at a constant velocity away from the motion detector.

Comment: To find the average acceleration vector from two velocity vectors, you must first find the vector representing the *change in velocity*. The change in velocity is a vector obtained by subtracting the initial velocity vector from the final velocity vector. (Recall that subtracting a vector is the same as adding the negative of the vector.) To obtain the acceleration divide the change in velocity vector by the time interval.

Question 4-5: Use a vector diagram to show the calculation of the change in velocity between the times 1 s and 2 s. From this vector, what value would you calculate for the acceleration? Explain. Is this value in agreement with the acceleration graph on the previous page?

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