Laboratory 2

Introduction to Motion

Name ______________________ Partners ______________________

Lab Date & Time ______________________ Instructor ______________________

I. Objectives

A. Describe the motion of an object given its position–time graph.

B. Draw a position–time graph of an object from a verbal description of the motion.

C. Draw vector diagrams to obtain the change in position of an object from its initial and final positions.

D. Draw the velocity–time graph when given the position–time graph and the reverse.

E. Determine the velocity of an object from data taken from the position–time graph.

II. Overview

The motion of an object can be described in words, as a graph, or in the form of a mathematical equation. In this lab you will learn how to describe the motion of an object that is traveling at constant velocity both verbally and with graphs. You will also learn to translate the description from one form to the other. A motion detector will be used to plot position–time graphs of your motion, or your lab partner's motion, as you move in a straight line either towards or away the detector at a steady rate. You will first concentrate on making and drawing graphs and verbal descriptions of the motion.

III. Investigation 1: Position–Time Graphs

A. Activity 2-1: **Producing Position–Time Graphs as You Move a Cart**

1. The purpose of this activity is to learn how to relate graphs of position vs. time to the motions they represent.
2. You will need Pasco's *Capstone* software, CI-850 interface and a motion detector. You will also need a cart on the track.

Measuring Position: Assume the track is a section of a coordinate system that extends forever in both directions. The motion sensor is at the origin of this coordinate system and at some instant in time other objects may occupy various "positions" on that axis. Unless otherwise stated, units on all axes will be in meters.

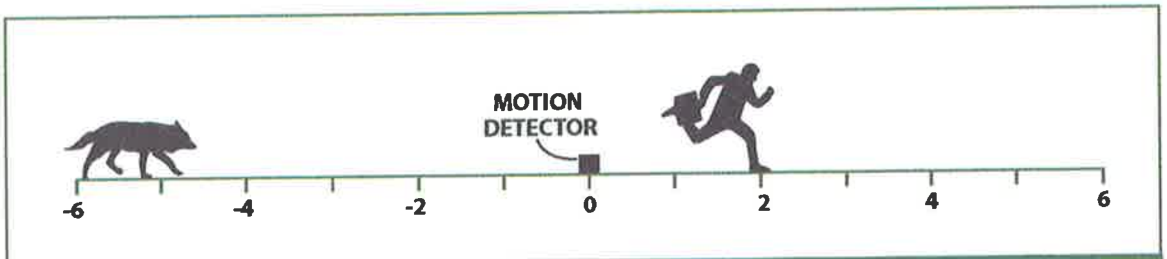


Figure 2-1

So in Figure 2-1, using the symbol x for the position we would say $x = +2$ m for a Marshall Prof. and $x = -5$ m for the wolf. The motion detector is the "origin" from which the position is measured. Note that the motion detector cannot see behind it (unlike the professor), so that in experiments done in the lab you will not encounter negative positions. You may encounter them in homework questions, however. As you push the cart (or pull it, or whatever), the graph on the computer screen displays your position at each instant in time, measured from the origin.

***Note:** Be aware that the motion detector gives the position of the nearest object, so it will give the position of your hand if it crosses the straight-line path between the cart and the detector. It will not correctly measure anything closer than ½ meter, so when making your graphs don't let the cart get closer than ½ meter from the motion detector.*

Procedure

1. Double-click the **PHY202Capstone** folder icon on the desktop. Double-click the Lab 2 Capstone file. Capstone should open and be ready for *Activity 2-1*, which is on the first tab of the experiment window. When you are ready to start graphing distance, click on the **[RECORD]** button in the bottom left-hand corner of the experiment window.

2. Check that the motion detector measures the cart's position correctly by placing it 0.75 m from the detector. Note the shape of the position–time graph you obtain. Make sure the detector is measuring the cart's position correctly before you continue.

3. Now move the cart away and towards the motion detector at different speeds until you understand how different shaped position–time graphs are obtained. For example, how does a distance–time graph look when you move the cart slowly? Quickly? Speed up or slow down? What happens when you move it toward the motion detector? Away? Note it is better to use the terms **away** and **towards**, not forward and backward, since the latter usually refers to your orientation as you move. So, it could be moving either forwards or backwards while moving **away** from the detector, and both would produce the same position–time graph. After completing this activity 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. The next step is to give you some practice in doing this.

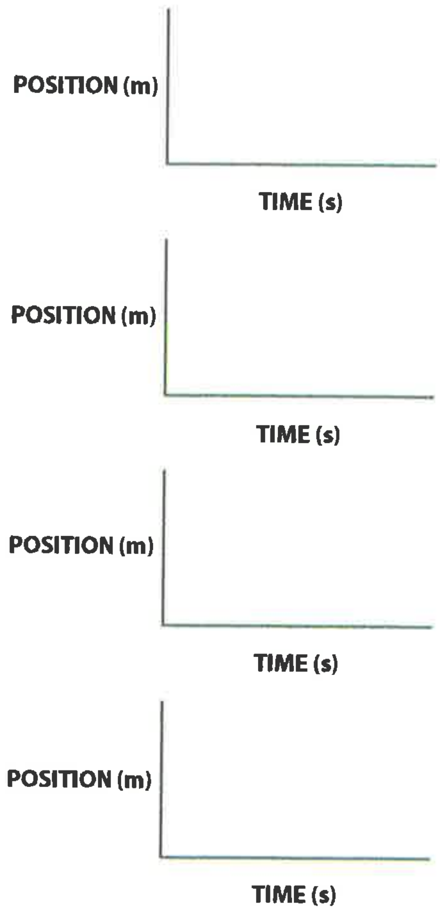


Figure 2-2

4. On the axes Figure 2-2, predict the shape of the position–time graphs for each of the described motions with a dashed line. Then check your predictions by moving in the described way and draw the actual curve with a solid line.

   a. Using a dashed line, predict the distance-time graph produced by moving the cart away from the detector (origin) *slowly and steadily*. Now check your prediction and draw it with a solid line.

   b. Using a dashed line, predict the distance-time graph produced by moving the cart away from the detector (origin) *medium fast and steadily*. Now check your prediction and draw it with a solid line.

   c. Using a dashed line, predict the distance-time graph produced by moving the cart toward the detector (origin) *slowly and steadily*. Now check your prediction and draw it with a solid line.

d. Using a dashed line, predict the distance-time graph produced by moving the cart away from the detector (origin) *starting off medium fast and slowing down to a stop.* Now check your prediction and draw it with a solid line.

Question 2-1

What is the difference between the graph made the cart moving away from the detector *slowly* and steadily and the one made by it moving away *quickly* and steadily?

Question 2-2

What is the difference between the graph made by the cart moving steadily *toward* the motion detector and one made by it moving *steadily away* from the motion detector?

Question 2-3

What is the difference between the graph made by the cart moving away from the detector at constant speed and one where it moves away but slows down?

B. Activity 2-2: Describing and Matching Position–Time Graphs of Your Motion

By now you may be pretty good at predicting the shape of a graph of the cart's movements. Can you do things the other way around? Can you read a position–time graph on the computer screen and figure out how to move the cart so as to reproduce the graph? You will describe the motion from the position–time graph, and then confirm your description by moving the cart in such a way as to match the computer graph.

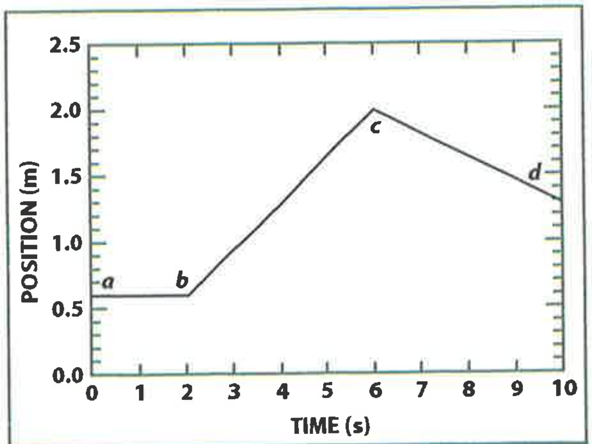


Figure 2-3

Procedure

1. Select the next tab, labeled **A2-2a.** A position graph like that shown in Figure 2-3 will appear on the screen.

2. Describe how you would move the cart to produce this graph.

3. Now move the cart in front of the motion sensor so as to match the graph on the computer screen. Try it a number of times. Get the times right. Get the positions right.

Question 2-4

Describe in words the speed in each of the differently sloped parts of the graph, a–b, b–c, and c–d:

Question 2-5

What was the difference in the direction in the differently sloped parts of the graph, b–c and c–d?

IV. Investigation 2: Measuring Displacement & Velocity

The velocity of an object is defined as the *rate of change* of position, so it is important to understand how *change* in position is measured. The change of position is given by the difference in the final and initial coordinates, or $x_f - x_i$, and is called the *displacement*. You will see that displacement is a quantity that has both magnitude, or size, and direction. Such quantities are common in physics, and are called vector quantities. Vector quantities are often given bold type.

Measuring Displacement: Let's revisit the wolf and the professor, both of whom have since undergone a displacement since we last looked. An arrow drawn from the initial position to the final position can be used to represent the displacement of each.

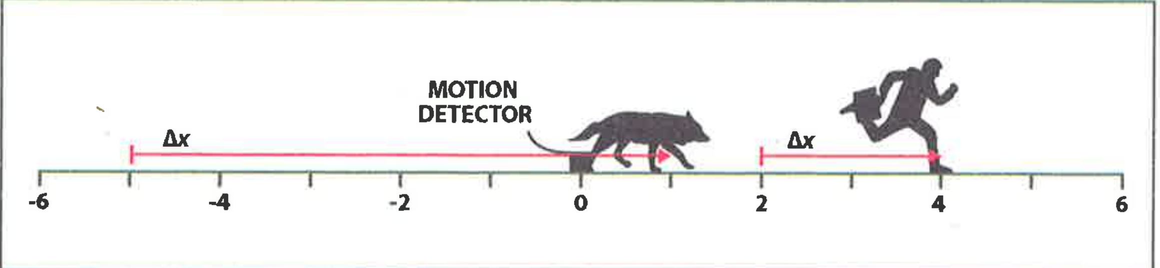


Figure 2-4

The symbol delta, Δ, is frequently used to denote change, so the displacements are

$$\Delta x_{\text{prof}} = x_f - x_i = (4) - (2) = +2 \text{ m.}$$

$\Delta x_{\text{wolf}} = x_f - x_i =$ __________________

Because of the choice of positive and negative x values, $x_f > x_i$ for both the professor and the wolf, both displacements are positive. Note that the wolf first moves towards the origin (motion detector) and then away, but it has a positive velocity throughout! Since the motion detector detects objects on the positive x-axis only, detector motion away from the detector is always positive and moving towards is always negative. For an object or person on the negative x-axis this is not the case. For example the wolf in the above diagram, moves towards and then away from the origin, but is moving in the positive x-direction throughout. Examine the diagram to confirm this statement. Now figure out how you could move towards then away from the origin and be moving in the $-x$-direction throughout.

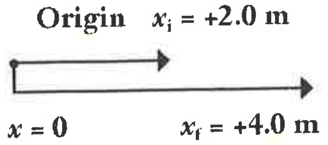
A. Activity 2-3: **Vector Representation and Vector Diagrams**

The change in position of the professor can be illustrated in a *vector diagram* where "arrows" drawn to scale represent the initial and final positions, and also the change in position. Adding the change in position vector to the initial position vector gives the final position vector. Mathematically:

$$x_i + \Delta x = x_f \quad \text{so} \quad \Delta x = x_f - x_i \qquad \textbf{(1)}$$

Procedure

1. **Vector Diagram.** Examine the vector representation of the initial, x_i, and final, x_f, positions of the professor relative to the origin in the diagram below. Note that *vector arrows* that start at the origin are used to represent the initial and final positions in a vector diagram. A point on the x-axis is not sufficient.



2. In a vector diagram where there is a change in position, there must also be a displacement vector arrow Δx which when added "head-to-tail" to the initial position vector, x_i, must give the final position vector, x_f. In the vector diagram above, draw the change in position vector. It should agree with Δx drawn in the diagram of the professor on the previous page.

   Does the displacement vector you have drawn above, Δx, agree with the displacement vector of the professor drawn in the above diagram of the professor and the wolf?

3. The situation for the displacement of the wolf is a little more complicated, since its initial position is in the negative direction, but once again x_i and Δx added head-to-tail give x_f.

   Vector Diagram. Add a displacement vector arrow Δx to the initial position vector so that it gives the final position of the wolf.

   Does it agree with displacement vector of the wolf drawn in the above diagram of the wolf chasing the professor?

4. From this it is clear that the direction of the *change* in position for both the Prof. and the wolf are both in the positive x-direction. For that reason both velocities are positive.

5. What if the motion is in the opposite direction? In the situation shown below, calculate the displacement of the lady and her dog in the short time since the leash was pulled out of her hand.

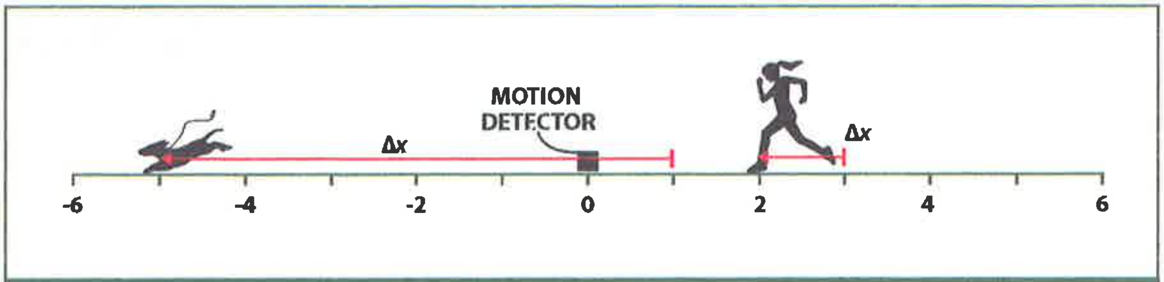


Figure 2-5

Substitute initial and final positions into the equations below to get x.

$\Delta x_{\text{lady}} = x_f - x_i =$ ______________

$\Delta x_{\text{dog}} = x_f - x_i =$ ______________

6. You will notice that both displacement vectors in this case point in the negative x-direction. Does this agree with the sign of the displacements calculated above? Explain.

7. Draw vector diagrams for the lady to obtain the displacement vector. First draw the initial and final position vectors, and then draw the displacement vector. Make sure your result corresponds to the x_{lady} in the diagram above. Do the same for the lady's dog.

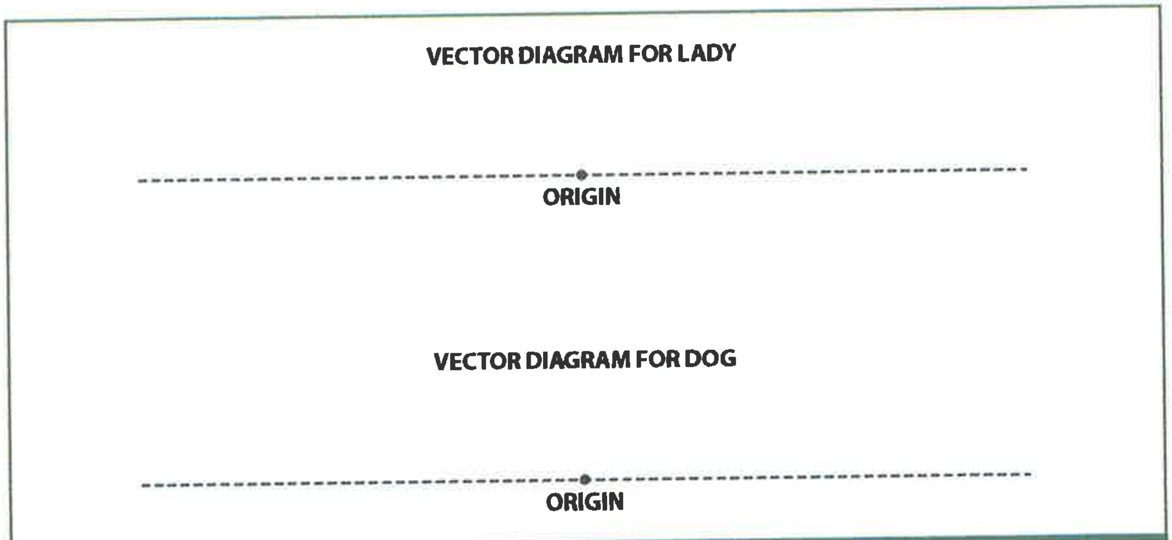


Figure 2-6

Measuring Velocity: Velocity is defined as the change in position, or displacement, divided by the change in time.

$$v = \frac{\Delta x}{\Delta t} = \frac{(x_f - x_i)}{(t_f - t_i)} \tag{2}$$

Just like the displacement, velocity has magnitude and direction and is a vector quantity. Thus, when the displacement is positive, $x_f > x_i$ (and that $t_f > t_i$), the velocity is positive. If $x_f < x_i$ the velocity is negative. You will develop an understanding of velocity–time graphs by first predicting and then producing them as you or lab partner move in front of the motion sensor.

B. Activity 2-4: **Predicting and Generating Velocity–Time Graphs**

Note that when using a motion detector, the position cannot have negative values, since the motion sensor cannot "see" behind it. However, negative velocities occur whenever the magnitude of an object's displacement vector decreases.

Procedure

1. On the velocity–time axes in Figure 2-7, predict the velocity graph you will get by moving the cart in the positive x-direction *slowly and steadily*. Draw the prediction with a dashed line. Assume you move the cart steadily without any sudden changes of speed.

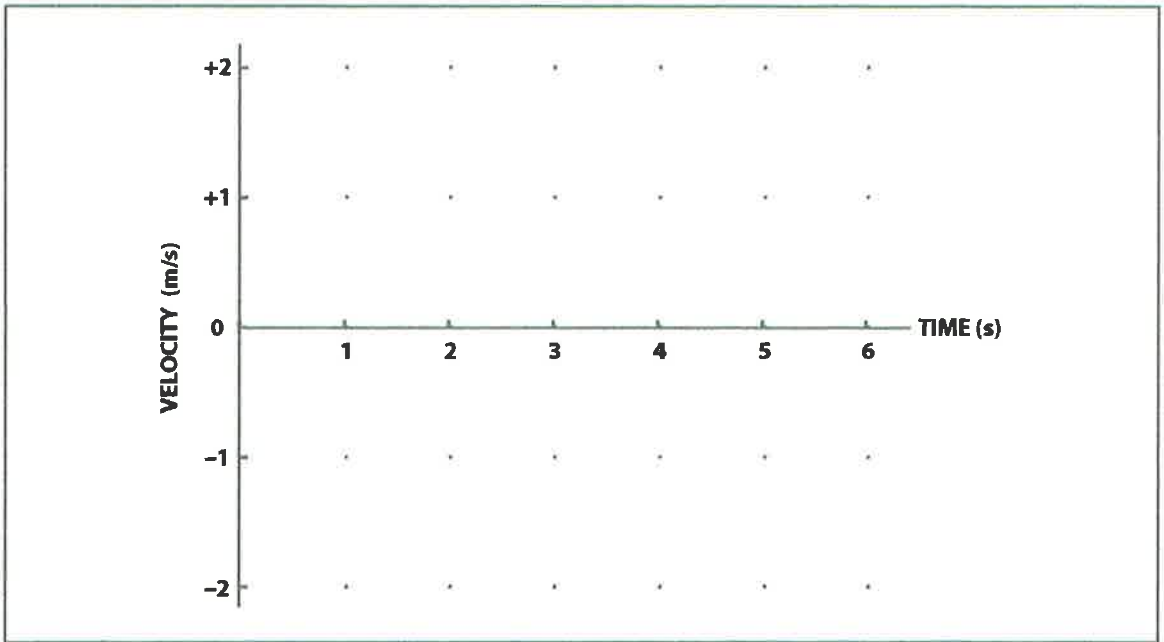


Figure 2-7

2. Check your prediction using the motion detector. Click over to tab **A2-4** and make sure that your axes are scaled to match those above. Make sure the cart is *already moving* slowly and steadily when you start to record so that you don't record the motion as it speeds up from a standing start (we will look at that motion later on). Repeat until you get a graph you're satisfied with. *To delete a run press the "Delete Last Run" button in the bottom center of the experiment window, or use the drop-down arrow on the right of the button to select a run to delete.*

3. On the same set of axes, predict the velocity–time graph you will get moving the cart in the positive x-direction *medium fast and steadily.* Check your prediction.

4. On the same set of axes, predict the velocity–time graph you will get moving the cart in the negative x-direction *medium fast and steadily.* Check your prediction.

Question 2-6

What is the most important difference between the velocity–time graph made by moving the cart *slowly* and one made by moving the cart away *more quickly?*

Question 2-7

How are the velocity–time graphs different for motion in the positive x-direction and the negative x-direction?

Question 2-8

Can you tell, from a velocity–time graph, the cart's position when you started moving it and where you it was when you stopped moving it? Explain.

C. Activity 2-5: **Position–Time and Velocity–Time Graphs of the Same Motion**

Prediction

1. On the first graph in Figure 2-8, using a dashed line, draw the position–time graph you would expect if you were to:
   a. move the cart away from the detector slowly and steadily for about 4 seconds, then
   b. hold it still for about 4 seconds, and then
   c. move it toward the detector steadily twice as fast as before for 2 seconds.
2. Now predict the velocity–time graph for that on the graph located in Figure 2-8.

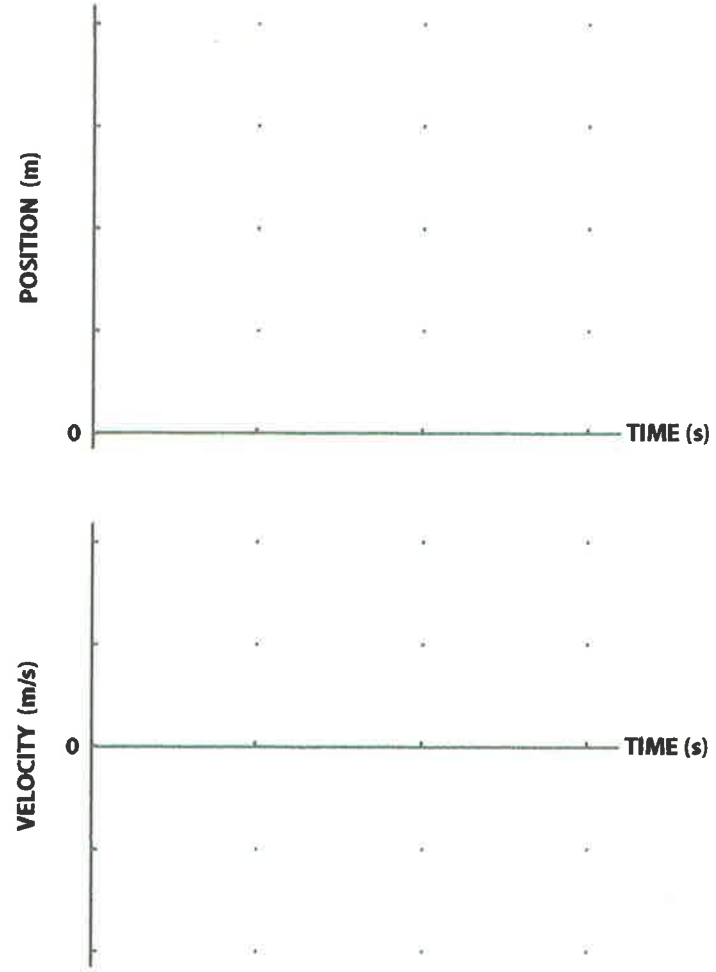


Figure 2-8

Procedure

1. Click on the **A2-5** tab and test your prediction. Draw the best graph on the axes above using a solid line. **Be sure the 4-second stop shows clearly.**

Question 2-9

The velocity is the slope of the position–time graph. Explain how this is demonstrated from your graphs.

Question 2-10

In producing the above velocity–time graph, did it matter where the cart started i.e., its initial position?

Question 2-11

How does distance traveled relate to larger speed if the time spent traveling remains constant?

Relating a Position–Time Graph to Its Velocity–Time Graph

As you are now aware, the position–time graph for an object traveling at constant velocity is a straight line. And, as you have observed, the faster you move, the more inclined is your position–time graph. The *slope* (rise/run) of a position–time graph is displacement (the change in position, Δx) divided by change in time. The slope is a quantitative measure of this incline, and therefore gives the velocity of the object.

Note that if the graph slopes downward, then $x_2 < x_1$, so that the displacement $x_2 - x_1$ is negative and so is the velocity.

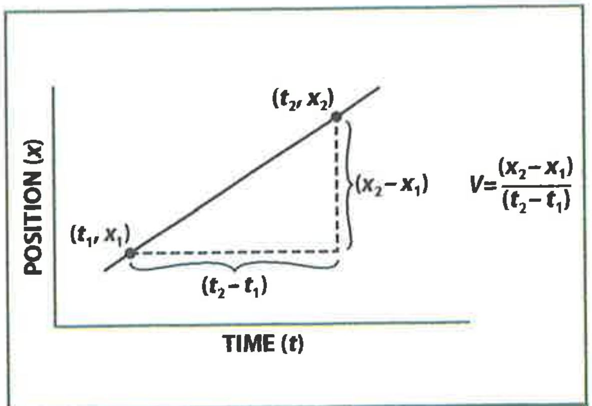


Figure 2-9

D. Activity 2-6: **Measuring Velocity by Direct Measurement and from the Slope of the Position–Time Graph**

Procedure

1. Click on the **A2-6** tab. Using this graph you will generate a position–time graph as you move the cart steadily for several seconds either away or towards the motion detector (your choice).

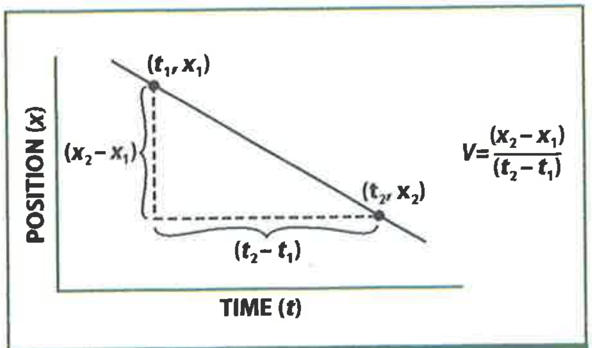


Figure 2-10

2. Now choose two positions along the path of the cart's motion (for example two positions a half meter apart somewhere in the middle). Now, with one hand on the cart and the other on a stop watch, measure the time it takes for the cart to move from the first position, x_1, to the second position, x_2 during the course of graphing the entire path of motion with Capstone. This is basically the same process as measuring the slope of the graph. Repeat the graphing and the measurements until you are satisfied that you have data that represents motion at constant velocity.

Results from Position–Time Graph

Use the Add Coordinates tool, ⌖, to read the position and time coordinates on the graph for two typical points *while you were moving.* Use Multi-Coordinates and then use your arrow keys to move the cursor to the point that you want to measure. For the better accuracy, use two points on the line that are far apart but still typical of the motion. *These need not be the same points used in measuring the velocity directly with a stopwatch*, and $t_1 \neq 0$ s since $t = 0$ when you start recording data with the motion sensor. **Don't forget to put in units!**

Table 2-1

Measurement	Data and Results	Stopwatch Data
Position 1	$x_1 =$	Distance = ____________
Position 2	$x_2 =$	Time = ____________
Displacement	$\Delta x = (x_2 - x_1) =$	Speed = ____________
Time 1	$t_1 =$	
Time 2	$t_2 =$	
Time Interval	$\Delta t = (t_2 - t_1) =$	
Velocity	$\Delta x / \Delta t =$	

Question 2-12

Was your displacement positive or negative? Why? Was the velocity positive or negative? Is this what you expected from the direction of the motion? Why?

Question 2-13

Does the velocity you calculated from the position–time graph agree exactly with the speed you calculated directly using the stopwatch? Do you expect them to agree exactly? Why? How would you account for any differences?

Vector Representation of Velocity

Velocity implies both speed and *direction.* How fast the cart moves is its speed. The rate of change of position with respect to time is velocity which may or may not have the same numerical value as speed. As you have seen, for motion along a line (e.g., the x-axis) the sign (+ or –) of the velocity indicates the direction. If you move the cart in the positive x-direction, both the cart's displacement and its velocity are positive. The faster it moves in the positive x-direction, the larger the positive number. If it moves in the negative x-direction both its displacement and velocity are negative. The faster it moves in the negative x-direction, the "larger" the negative number.

These two ideas of direction and speed can be combined and represented by *vectors.* An arrow pointing in the direction of motion represents a velocity vector. In this lab, a single "tick" is used to distinguish it from the displacement vector. (These conventions are convenient, but they are by no means universal!) The velocity vector is usually drawn above the object, and the length of the arrows are drawn in proportional to the velocity at that instant, so the greater the velocity the longer the arrow. This can be illustrated for the case of the wolf and the professor. The wolf moves three times farther than the professor in the same time, so has it three times the velocity.

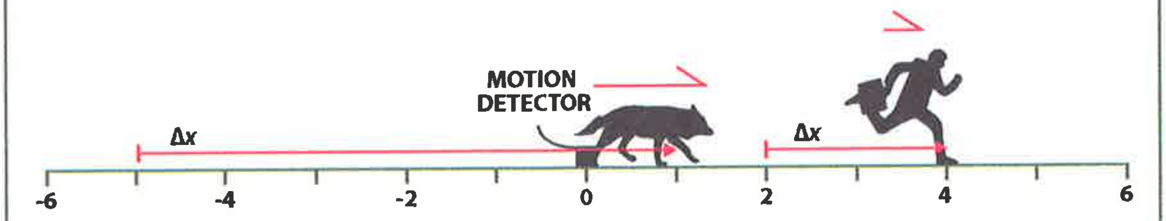


Figure 2-11

Draw the velocity vectors for the lady and her rapidly disappearing dog. You have already calculated the displacement in the same time interval, so you know the relative speeds of the dog and the lady. The length of the vectors should be *approximately* in the same ratio as those speeds.

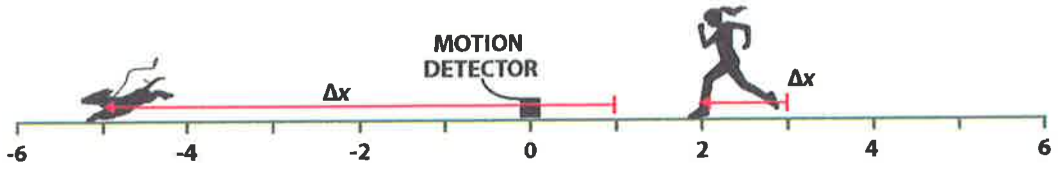


Figure 2-12

V. Conclusions

Write a conclusion on a separate sheet of paper. It should be approximately one page in length and include brief discussions of what you did, your observations, your results, and an analysis of your data, including potential sources of error.

1. In the space provided, describe how you would move the cart to create the following position–time graphs. To distinguish between different shapes and slopes, you must use the terms moving *steadily* when the speed is constant and *faster* or slower where there are different the speeds in a single graph. Also use *towards* or *away* from the detector. Don't use backwards or forwards since that depends on what direction you are facing.

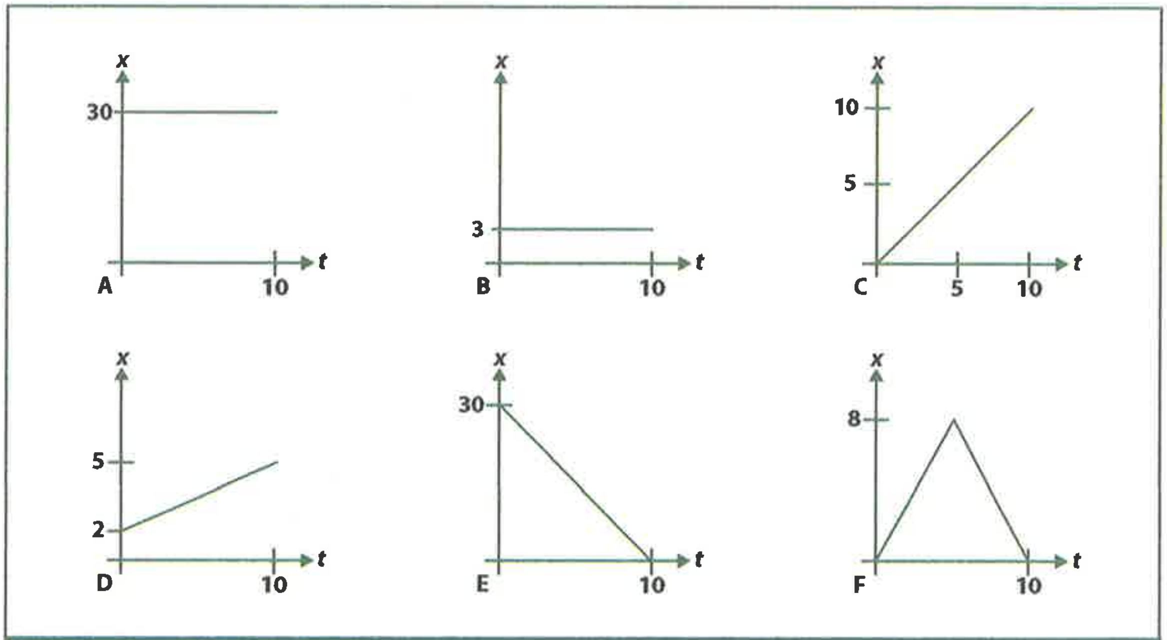


Figure 2-13

2. You are on a boat heading out to sea. The boat is going 5 m/s toward a buoy (the origin in your chosen frame of reference) that is 300 meters away. How long will it take to be 500 meters beyond the buoy?

Now from the origin draw vectors to represent both the initial and final positions and a vector that gives the displacement vector.

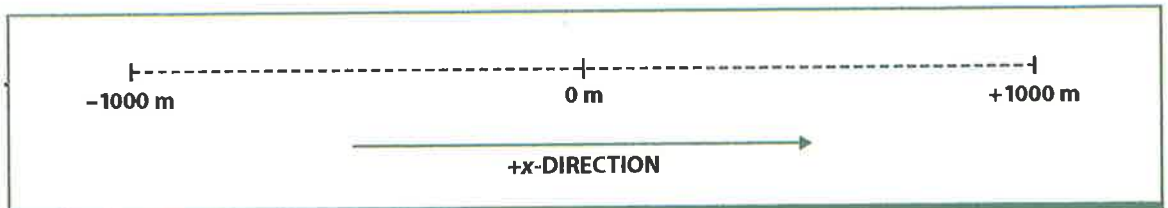


Figure 2-14

Does the direction of the vector arrow Δx agree with the sign of the velocity calculated above? Explain.

3. Use the numerical values on the axes to draw the exact velocity graphs for an object whose motion produced the position–time graphs shown below. Position is in meters and velocity in meters per second.

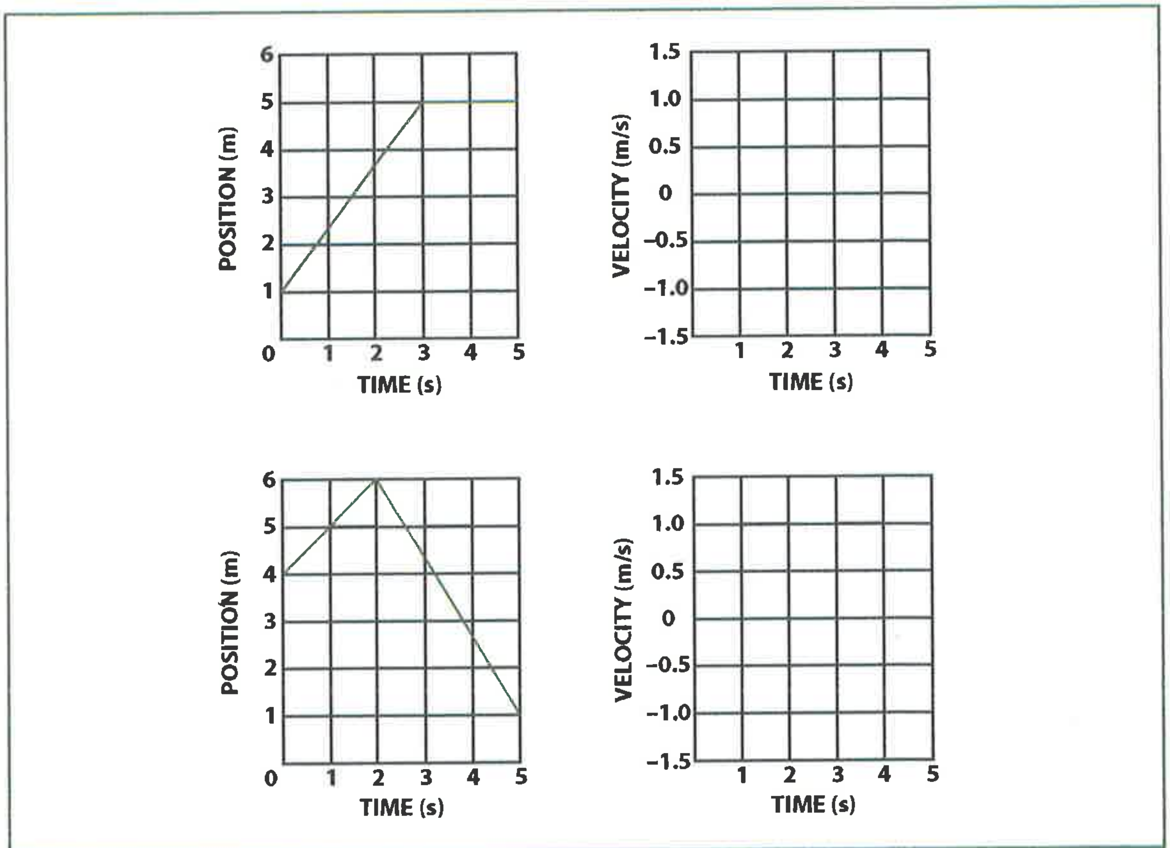


Figure 2-15