Name_________________________ **Date**__________________

PRE-LAB PREPARATION SHEET FOR LAB 2: INTRODUCTION TO MOTION

(Due at the beginning of Lab 2)

Directions:

Read over Lab 1 and then answer the following questions about the procedures.

1. In Activity 1-1, how do you think graph **a** will differ from graph **b**?

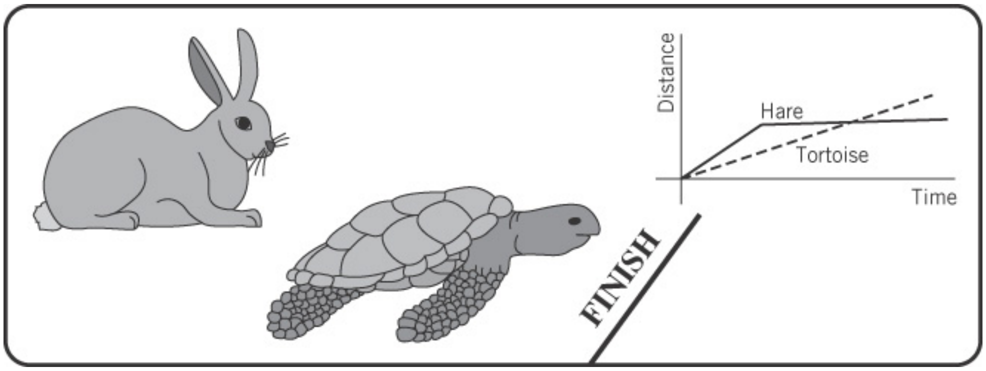
2. What can you say in general about velocity versus time for the graphs a, b, and c in Activity 1-3, part 3?

3. For Prediction 2-1, how will the velocities compare between moving slowly to the right and moving about twice as fast to the left?

4. What is a vector? What vector quantities are studied in this lab?

Name______________________ **Date**______________ **Partners**_____________________

LAB 2: INTRODUCTION TO MOTION



Slow and steady wins the race.

—Aesop's fable: The Hare and the Tortoise

OBJECTIVES

- To discover how to use an IOLab and its software
- To explore how various motions are represented on a distance (position)–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

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 an IOLab to plot 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*.

IOLAB SOFTWARE AND CALIBRATION

If you have done LAB 0 then you can skip this section. If not, here is a quick guide to get you taking data with the IOLab.

If you are using your own computer, then you will need to install software and calibrate the IOLab before you collect any data.

1. Go to http://www.iolab.science/
2. Watch a video and follow the instructions for software installation on your computer (best viewed in full screen):
    a. Windows: https://www.youtube.com/watch?v=H0f3RfRPGOE
    b. Macintosh: https://www.youtube.com/watch?v=Vyq-sSKBxVw

If this is your first time using the IOLab and its software, then use the following videos to learn how to use it.

3. Using the IOLab to gather data:
   https://www.youtube.com/watch?v=XAhnYkMvFxg
4. Saving your data for later use (or analysis on Excel):
   https://www.youtube.com/watch?v=H8JO0EOeSGU

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

The purpose of this investigation is to learn how to relate graphs of the distance as a function of time to the motions they represent. You will need the following materials:

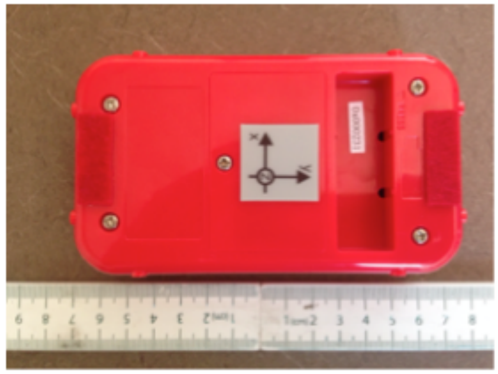
- Calibrated IOLab
- Flat, level, smooth surface like a smooth tabletop
- Computer with IOLab software
- 2 meter sticks or tape measures

How does the distance–time graph look when you move the IOLab slowly? Quickly? What happens when you move the IOLab to the right? To the left? 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.

Activity 1-1: Making and Interpreting Distance–Time Graphs

1. Insert the dongle (the object that looks like a flash drive) into a USB port on your computer.
2. Turn on your IOLab by pressing and holding the right button: .
3. Place the IOLab on a flat, smooth surface such as a table so that the wheels are down and the +y axis points to your right. Place the two meter sticks as shown below.
4. Open the IOLab software (by double-clicking on the file "IOLab CEF").

Reverse y-axis



5. Under sensor, select "Wheel". On the graph, de-select Vy and Ay. Leave the box next to Ry checked. This means that the IOLab will measure position as a function of time.
6. Click the box **Reverse y-axis**.

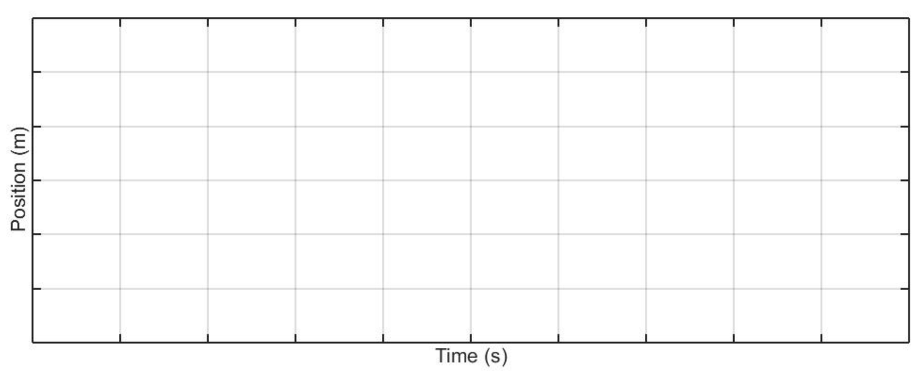
> **NOTE:** Because of the design of the IOLab, it will be necessary to click this box for each set of "wheel" or "force" measurements that you do. This will be explained in more detail in future labs. For now, please remember to see that the **Reverse y-axis** box is checked before each measurement.

7. Click the "Record" button and immediately move the IOLab at a slow, constant speed to the right (in the +y direction). Then click "Stop". Repeat the experiment a couple of times, to make sure you captured a good example of moving at a constant speed to the right.

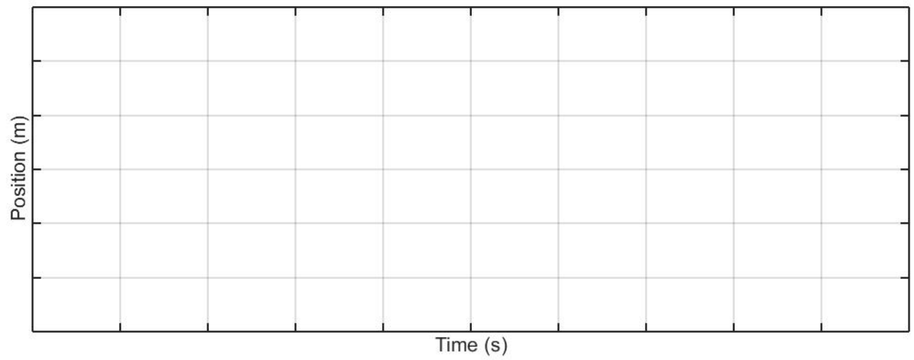
> **NOTE:** The IOLab and software afford you the opportunity to repeat measurements very quickly. Get into the habit of repeating your measurements until you get a clear representation of what you are exploring.

8. When you have a good graph, keep a copy of it (save it or print it). Sketch what you see in the graph on the axes (a) below . . Then click on the **Reset** button just once. (<u>Each time you click the **Reset** button, you will need to click</u> **Reverse y-axis** again.)
9. Repeat this process with different speeds and directions, keep a copy of each graph, and sketch on the appropriate axes below. Indicate the scales on both axes.

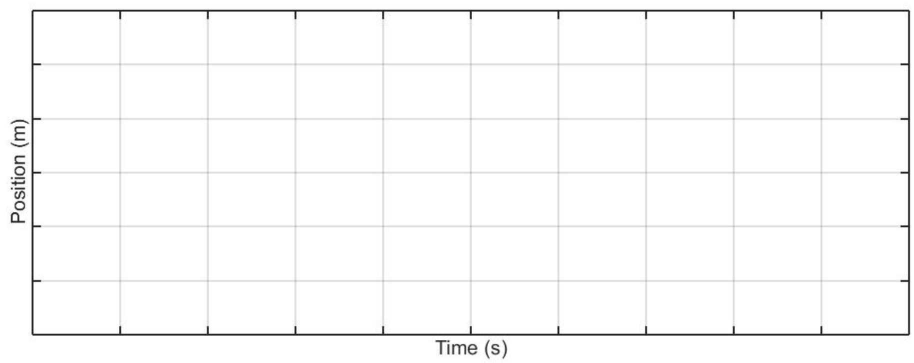
   a. Slow motion to the right



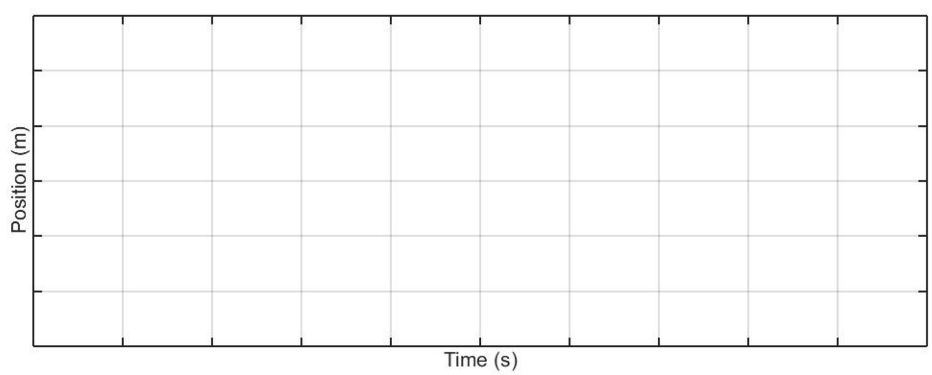
   b. Faster motion to the right



c. Slow motion to the left



d. Faster motion to the left

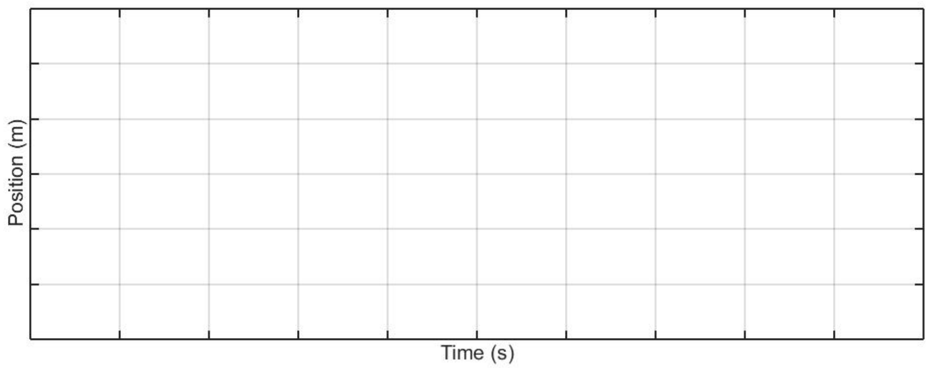


Question 1-1: Describe the difference between a graph made by moving the IOLab slowly to the right and one made by moving it quickly to the right.

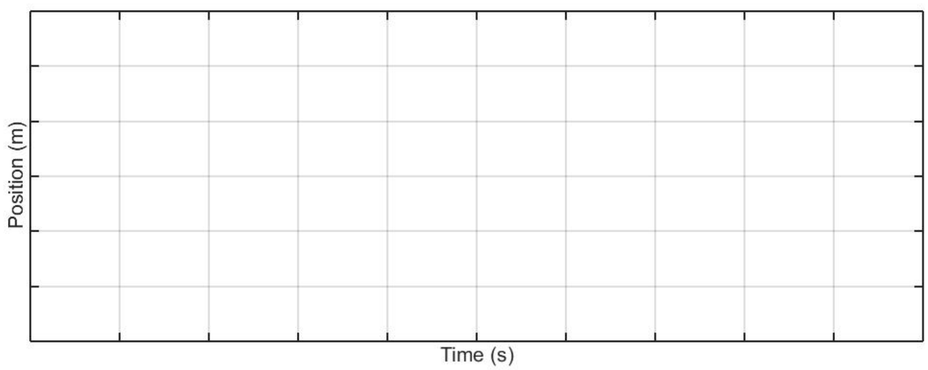
Question 1-2: Describe the difference between a graph made by moving the IOLab to the left and one made by moving it to the right.

Prediction 1-1: Predict the position–time graph produced when you start the IOLab at the origin, move it slowly and steadily to the right for 5 s, stop for 5 s, and then move it back to the origin twice as fast. Sketch your prediction on the axes below. Compare your predictions with those made by others in your group. Indicate the scales on both axes.

Prediction



Final Result



Test your prediction.

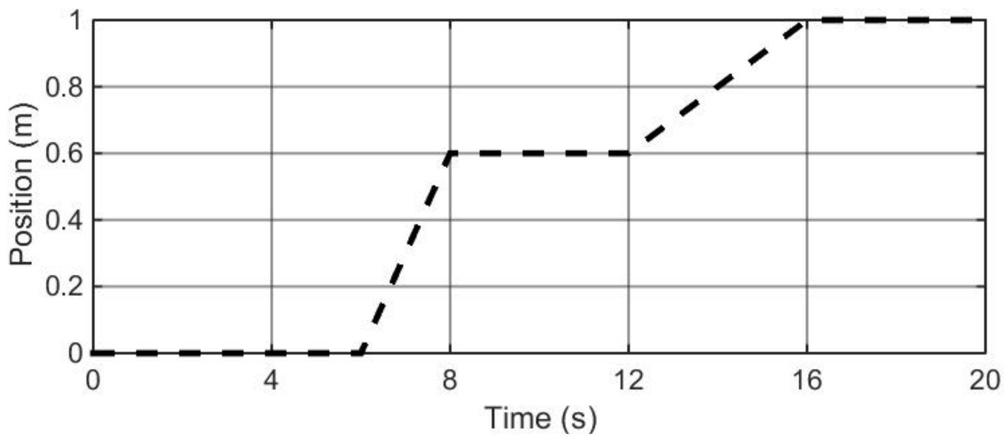
1. Move the IOLab in the way described in Prediction 1-1, and graph your motion.
2. Repeat the experiment until you are satisfied with your graph. Keep a copy and and sketch your final result on the axes above. Indicate the scales on both axes.

Question 1-3: Is your prediction the same as the final result? If not, then describe how you would move the IOLab to make a graph that looks like your *prediction*.

Activity 1-2: Matching a Position–Time Graph

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

1. Move the IOLab to try to match the graph shown below as closely as possible. Repeat as many times as needed in order to get it right (times, positions, slopes).

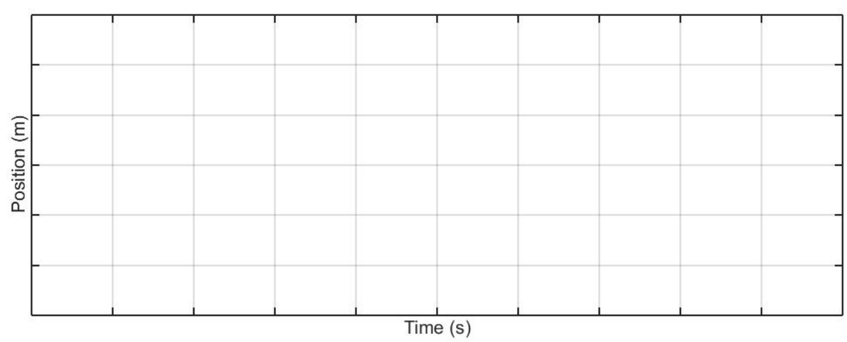


Question 1-4: What was the difference in the way you moved the IOLab to produce the two differently sloped parts of the graph you just matched?

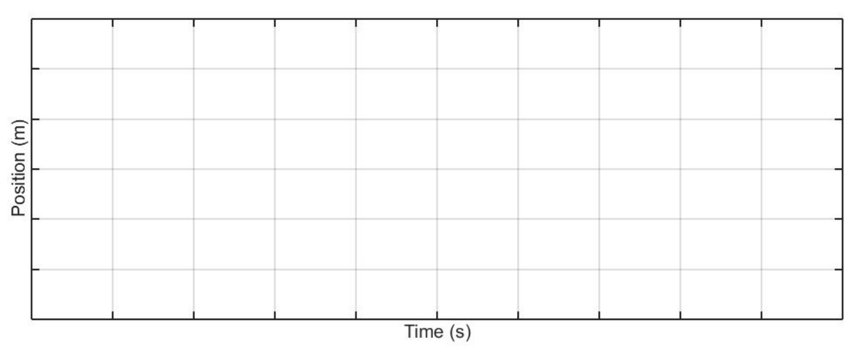
Activity 1-3: Other Position–Time Graphs

1. Create your own position–time graph and sketch it on the Prediction axes below. Use straight lines, no curves. Indicate the scales on both axes.

Prediction

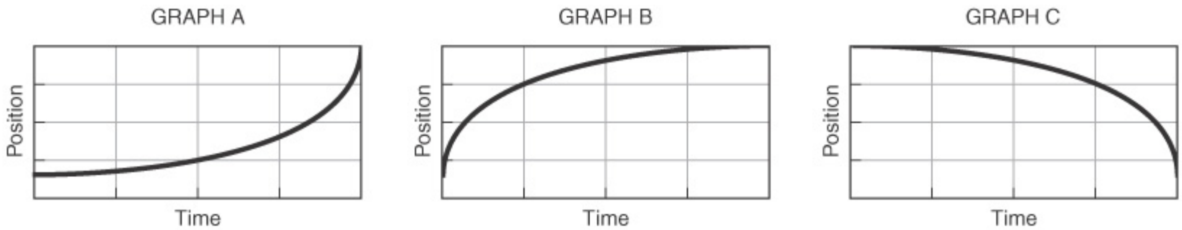


Best Attempt



2. Now see how well you can duplicate this graph by moving the IOLab. Keep a copy and sketch your best attempt with the IOLab to match your position–time graph. Indicate the scales on both axes.

3. Can you make a curved position–time graph? Use the IOLab to try to make each of the graphs shown below.



4. Describe how you must move the IOLab 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 that result in a *straight-line* position–time graph and those that result in a *curved-line* position–time graph?

INVESTIGATION 2: VELOCITY–TIME GRAPHS OF MOTION

You have already plotted the position of the IOLab as a function of time. Another way to represent the motion of the IOLab is with a graph that describes how fast and in what direction it is 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 the speed (how fast the IOLab is moving) and also the direction it is moving. Thus, when you examine the motion of an object moving along a line, the direction the object is moving is indicated by the sign (positive or negative) of the velocity.

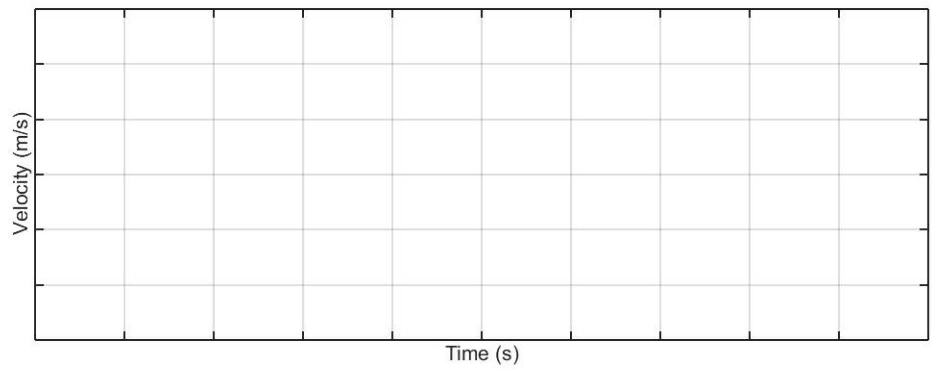
Graphs of velocity over time are more challenging to create and interpret than those for position. A good way to learn to interpret them is to create and examine velocity–time graphs of the IOLab, as you will do in this investigation.

Activity 2-1: Making Velocity Graphs

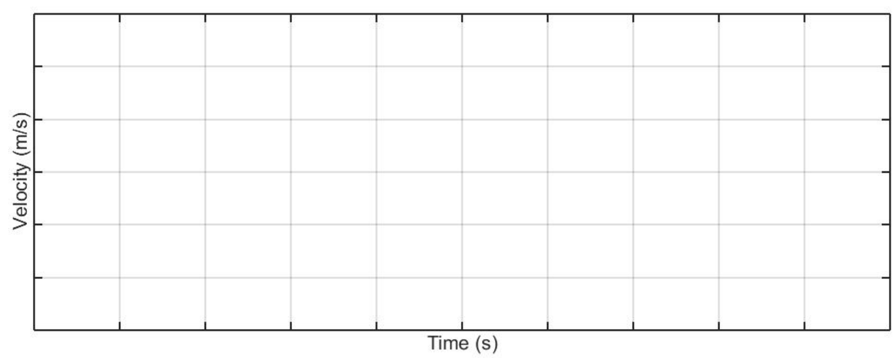
1. Now you will record velocity. Click on the box next to Vy in the IOLab software. Be sure that the **Reverse y-axis** box is checked.

2. Graph the velocity of the IOLab for different speeds and directions as described in (a)–(d) below, keep copies and sketch your graphs on the axes. *(Just sketch smooth patterns; leave out smaller bumps that are mostly due to unevenness in motion.)*

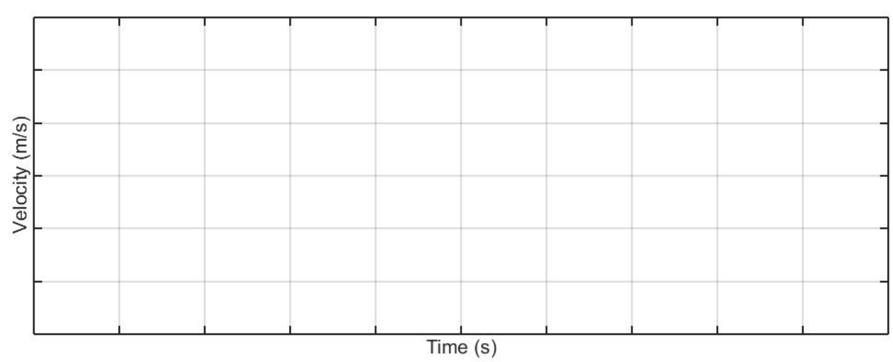
a. **Begin graphing** and make a velocity graph by moving the IOLab to the right (in the +y direction) *slowly and steadily.* Sketch your graph on the axes below. Indicate the scales on both axes.



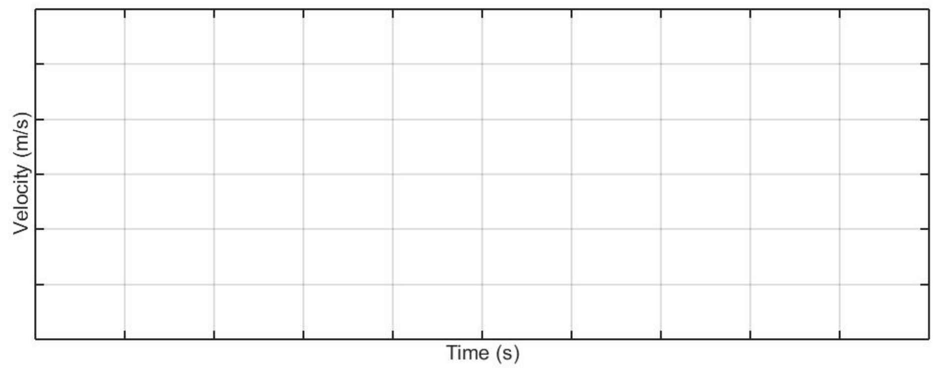
b. Make a velocity graph, moving the IOLab to the right *medium fast and steadily.*



c. Make a velocity graph, moving the IOLab to the left slowly (don't pick up and turn around the IOLab and hence keeping the +y direction the same as before).



d. Make a velocity graph, moving the IOLab to the left *medium fast and steadily*.

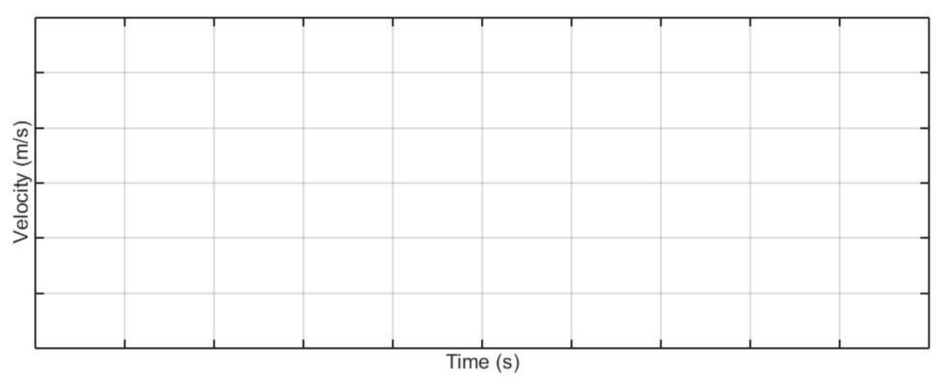


Question 2-1: What is the most important difference between the graph made by moving the IOLab to the right *slowly* and the one made by moving it to the right *more quickly*?

Question 2-2: How are the velocity–time graphs different for motion *to the right* and motion *to the left*?

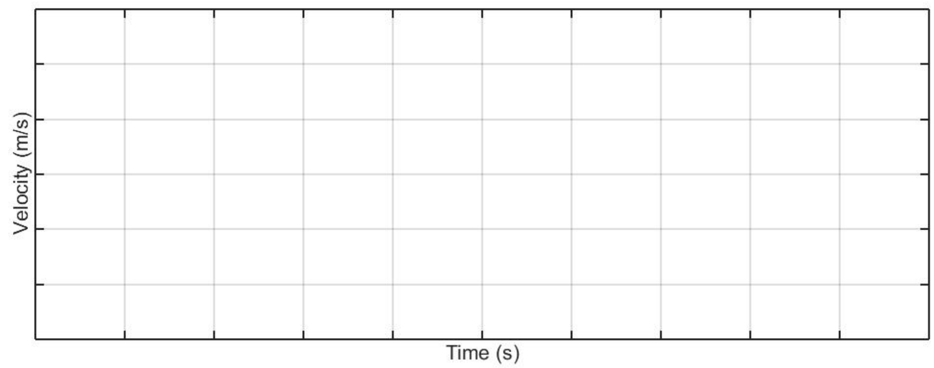
Prediction 2-1: Predict a velocity–time graph for a more complicated motion of the IOLab and check your prediction. Sketch below, your *prediction* of the velocity–time graph produced if you

- move the IOLab to the right slowly and steadily for about 4 s;
- hold the IOLab still for about 4 s;
- move the IOLab to the left steadily about twice as fast as before for about 2 s



3. Test your prediction. **Begin graphing** and repeat the motion of the IOLab until you think it matches the description. Do not pick up the IOLab and turn it around and hence keep the +y direction of the IOLab as before.
4. Sketch the best graph on the axes below. *Be sure the 4 seconds you hold the IOLab still shows clearly.* Label the different parts of the graph. Indicate the

scales on both axes.



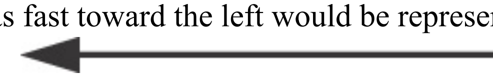
Comment: Velocity implies both speed and *direction*. How fast you move the IOLab is its speed: the rate of change of position with respect to time. As you have seen, for motion along a line (e.g., the positive y axis) the sign (+ or −) of the velocity indicates the direction. If you move the IOLab to the right, its velocity is positive, and if you move it to the left, its velocity is negative.

The faster you move the IOLab to the right, the larger positive number its velocity is. The faster you move the IOLab *to the left*, the "larger" negative number your velocity is. That is −4 m/s is twice as fast as −2 m/s, and both motions are to the left.

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 the IOLab toward the right, its velocity vector can be represented by

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

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



Note that the choice of right as positive and left as negative is an arbitrary (but commonly used) convention. We could have chosen left as positive and right as negative if we had initially placed the IOLab in a different orientation.

Question 2-3: Sketch below velocity vectors representing the three parts of the motion described in Prediction 2-1.

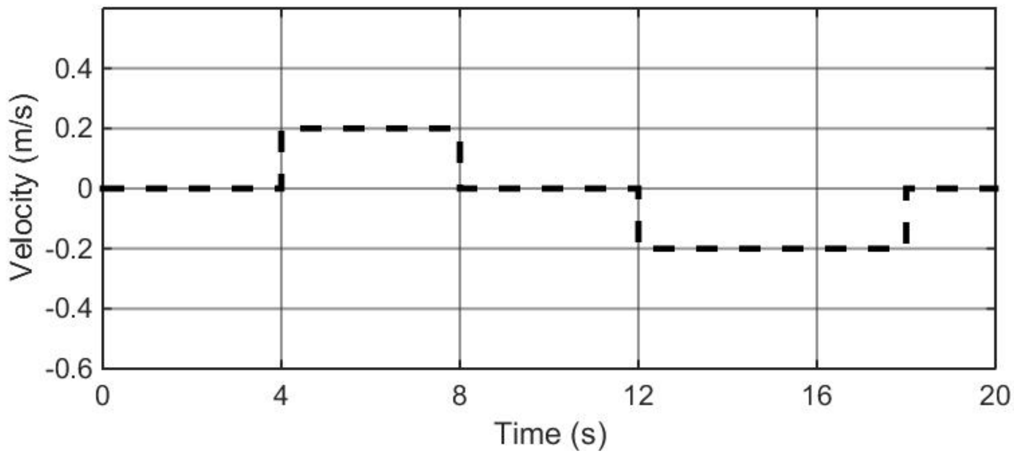
Moving slowly to the right:

Remaining still (Hint: How long is the velocity vector?):

Moving rapidly to the left:

Activity 2-2: Matching a Velocity Graph

In this activity, you will try to move the IOLab to match a velocity–time graph shown below. This is often much harder than matching a position graph as you did in the Activity 1-2. Most people find it quite a challenge to move the IOLab so as to match a velocity graph. In fact, some velocity graphs that can be invented cannot be matched!



Prediction 2-2: Describe in words how you would move the IOLab so that its 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. Begin graphing, and move the IOLab so as to imitate this graph. You may try a number of times. Get the times right. Get the velocities right.

Save a copy and sketch in your best match on the axes above.

Question 2-3: Describe how you moved the IOLab to match each part of the graph. Did this agree with your predictions?

Question 2-4: Is it possible for an object to move so that it produces an absolutely vertical line on a velocity–time graph? Explain.

Question 2-5: Did the IOLab pass through the origin on your return trip? If so, why did this happen?

Question 2-6: Does a velocity graph tell you where to start? Explain.

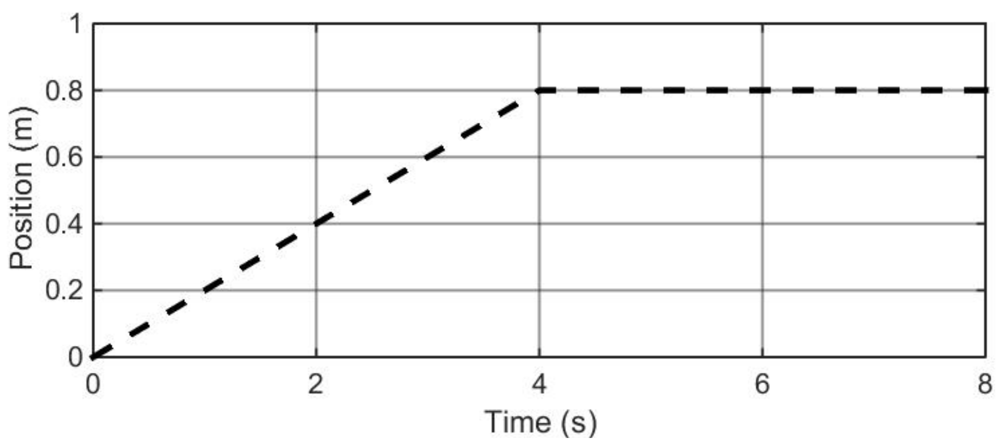
INVESTIGATION 3: RELATING POSITION AND VELOCITY GRAPHS

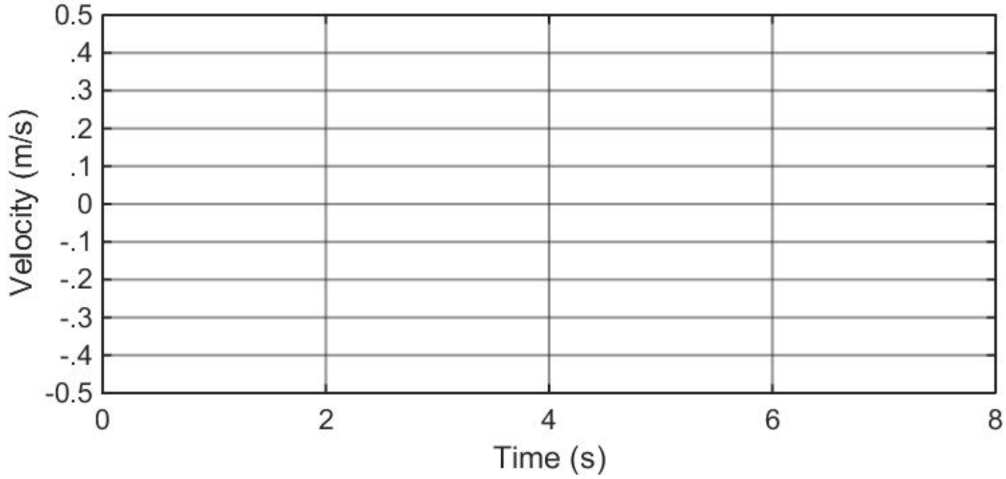
You have looked at position–time and velocity–time graphs separately. Since position–time and velocity–time graphs are different ways to represent the same motion, it is possible to figure out the velocity at which the IOLab is moving by examining its position–time graph. Conversely, you can also figure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

Activity 3-1: Predicting Velocity Graphs from Position Graphs

1. Select both Ry and Vy in the IOLab software. Be sure that the **Reverse y-axis** box is clicked.

Prediction 3-1: Predict a 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. Using a *dashed line,* sketch your *prediction* of the corresponding velocity–time graph on the velocity axes.





Test your prediction.

2. When you have made a good duplicate of the position graph for the IOLab, save a copy and sketch the graph over the existing position–time graph.

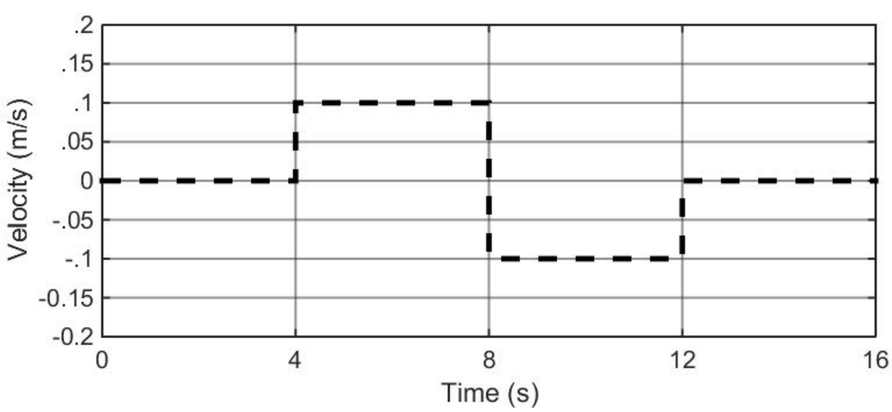
3. Use a *solid line* to sketch the actual velocity–time graph on the same axes with your prediction. (Do not erase your prediction.)

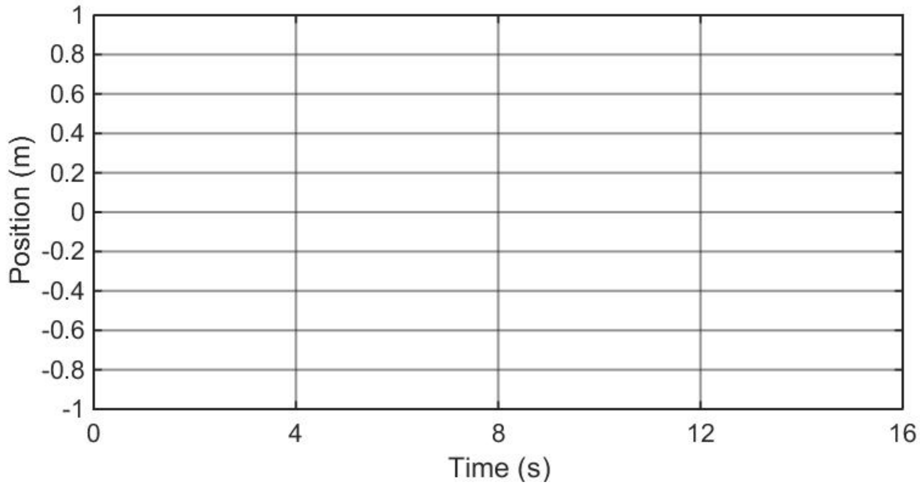
Question 3-1: How would the position graph be different if you moved the IOLab faster? Slower?

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

Activity 3-2: Predicting Position Graphs from Velocity Graphs

Prediction 3-2: 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 the IOLab started at the origin.)





1. Do your best to duplicate the top (velocity–time) graph by moving the IOLab.

2. When you have made a good duplicate of the velocity–time graph, save a copy and sketch your actual result over the existing velocity–time graph.

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

Question 3-8: How can you tell from a *velocity*–time graph that the moving object has changed direction?

Question 3-9: How can you tell from a position–time graph that an object's motion is steady (motion at a constant velocity)?

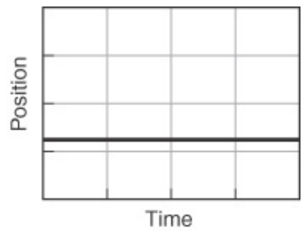
Question 3-10: How can you tell from a velocity–time graph that an object's motion is steady (constant velocity)?

HOMEWORK FOR LAB 2: INTRODUCTION TO MOTION

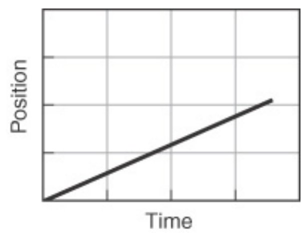
POSITION–TIME GRAPHS

Answer the following questions in the spaces provided.

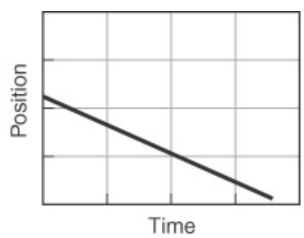
1. What do you do to create a horizontal line on a position–time graph?



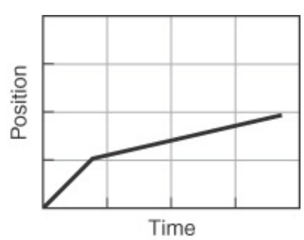
2. How do you move to create a straight line that slopes up?



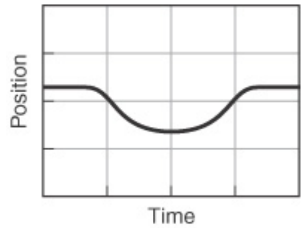
3. How do you move to create a straight line that slopes down?



4. How do you move so the graph goes up steeply at first, and then continues up less steeply?

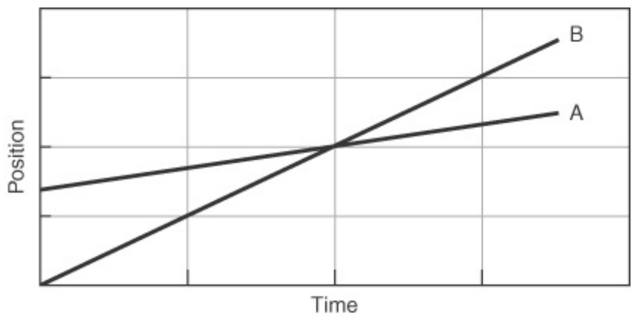


5. How do you move to create a U-shaped graph?



Answer the following about two objects, A and B, whose motions produced the following position–time graphs.

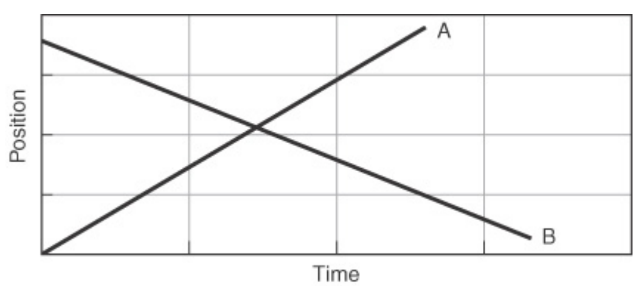
6. a. Which object is moving faster—A or B?



b. Which starts ahead? Define what you mean by "ahead."

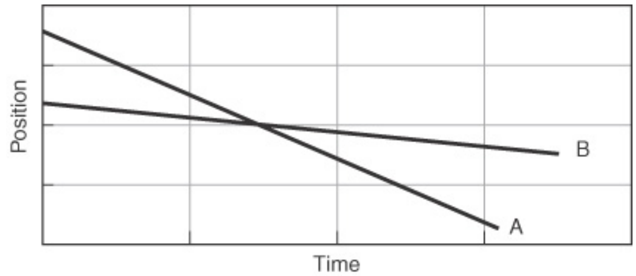
c. What does the intersection mean?

7. a. Which object is moving faster?



b. Which object has a negative velocity according to the convention we have established?

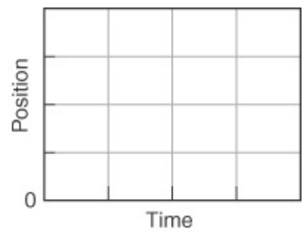
8. a. Which object is moving faster?



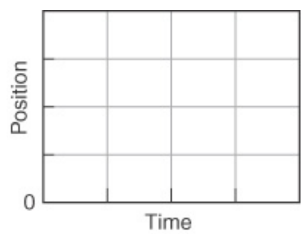
b. Which starts ahead? Explain what you mean by "ahead."

Sketch the position–time graph corresponding to each of the following descriptions of the motion of an object.

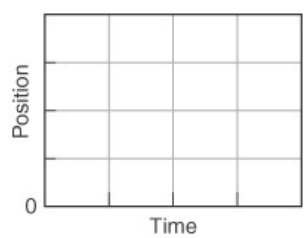
9. The object moves with a steady (constant) velocity away from the origin.



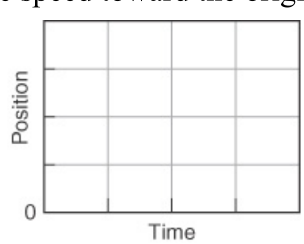
10. The object is standing still.



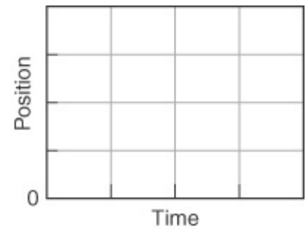
11. The object moves with a steady (constant) velocity toward the origin for 5 s and then stands still for 5 s.



12. The object moves with a steady velocity away from the origin for 5 s, then reverses direction and moves at the same speed toward the origin for 5 s.

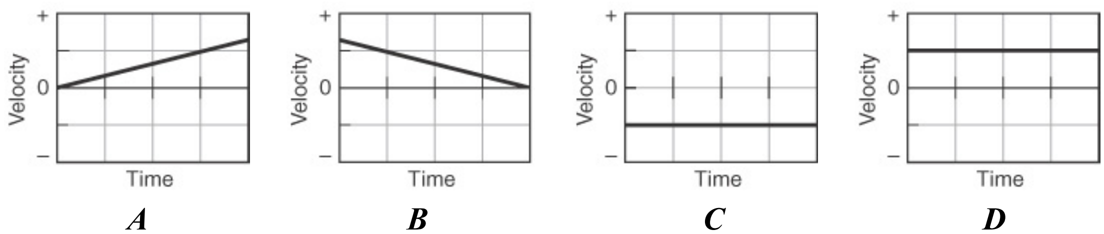


13. The object moves away from the origin, starting slowly and speeding up.



VELOCITY–TIME GRAPHS

After studying the velocity–time graphs you have made, answer the following questions. Use phrases such as “speeding up”, “slowing down” or “constant velocity,” and “away” or “towards” to describe your motion.



1. How do you move to create a horizontal line in the positive part of a velocity–time graph, as shown in one of the graphs (which one?) above?

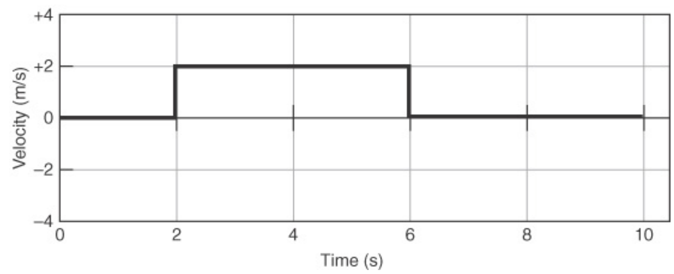
2. How do you move to create a straight-line velocity–time graph that slopes up from zero, as shown in one of the graphs (which one?) above?

3. How do you move to create a straight-line velocity–time graph that slopes down, as shown in one of the graphs (which one?) above?

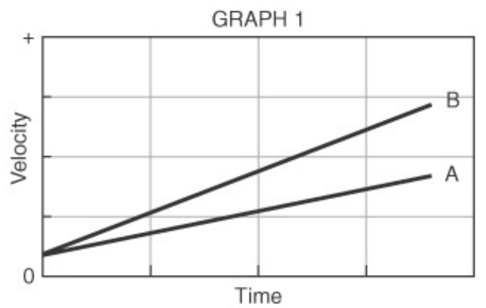
4. How do you move to make a horizontal line in the negative part of a velocity–time graph, as shown in one of the graphs (which one?) above?

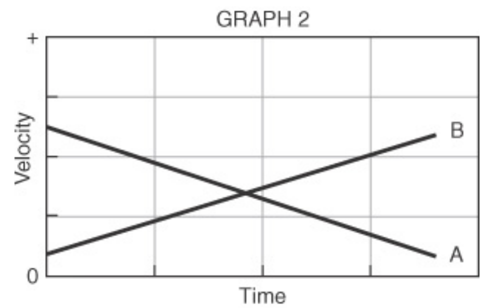
5. The velocity–time graph of an object is shown below. Figure out the total change in position *(displacement)* of the object. Show your work.

   Displacement = ______m



6. Both of the *velocity* graphs below show the motion of two objects, A and B. Answer the following questions separately for 1 and for 2. Explain your answers when necessary.





Graph 1

a. Is one object faster than the other? If so, which one is faster—A or B?

b. What does the intersection mean?

c. Can you tell which object is "ahead"? (Define "ahead.")

d. Does either A or B reverse direction? Explain.

Graph 2

a. Is one object faster than the other? If so, which one is faster—A or B?

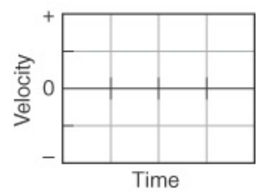
b. What does the intersection mean?

c. Can you tell which object is "ahead"? (Define "ahead.")

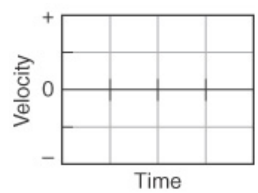
d. Does either A or B reverse direction? Explain.

Sketch the velocity–time graph corresponding to each of the following descriptions of the motion of an object.

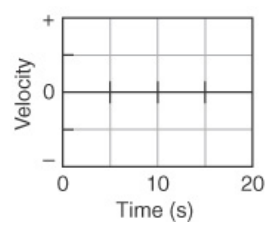
7. The object is moving away from the origin at a steady (constant) velocity.



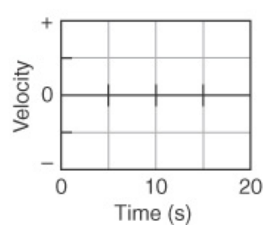
8. The object is standing still.



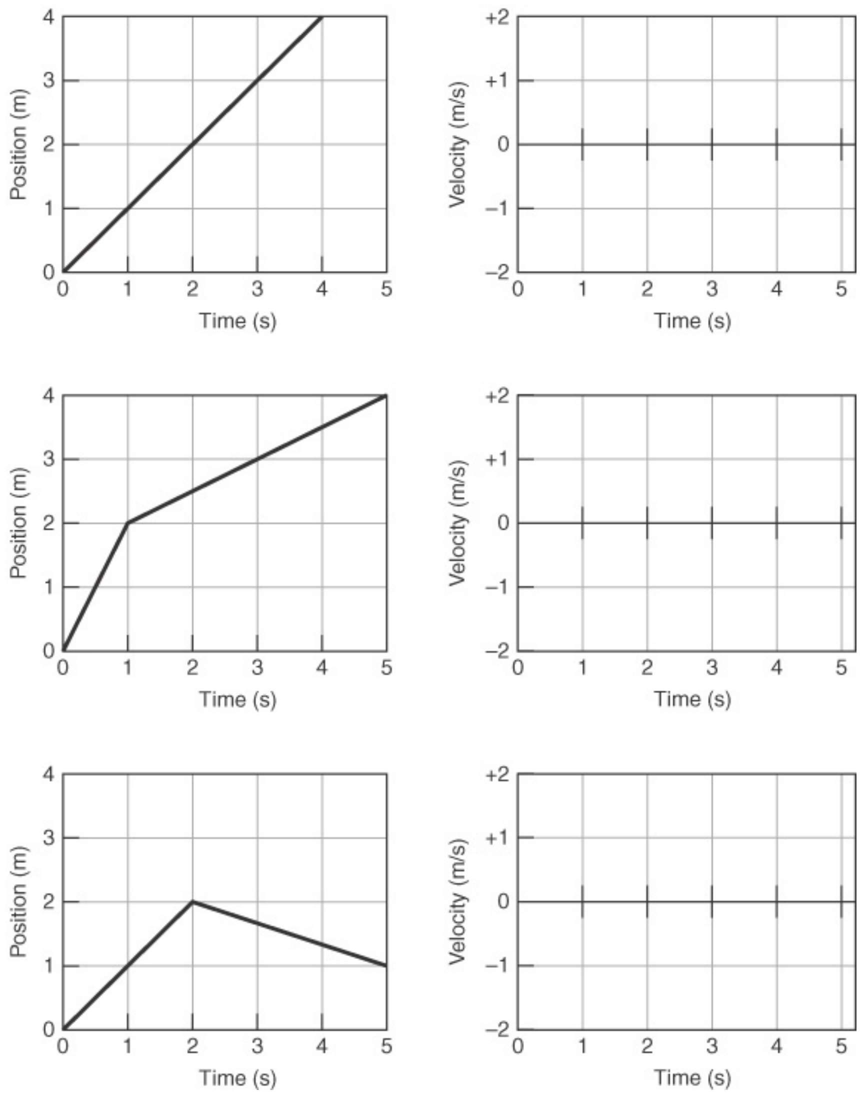
9. The object moves toward the origin at a steady (constant) velocity for 10 s, and then stands still for 10 s.



10. The object moves away from the origin at a steady (constant) velocity for 10 s, reverses direction, and moves back toward the origin at the same speed for 10 s.



11. Sketch the velocity graphs for an object whose motion produced the position–time graphs shown below on the left. Position is in meters (m) and velocity in meters per second (m/s). **(Note:** Unlike most real objects, you can assume that these objects can change velocity so quickly that it looks instantaneous with this time scale.)



12. Sketch careful graphs below of position and velocity for a cart that

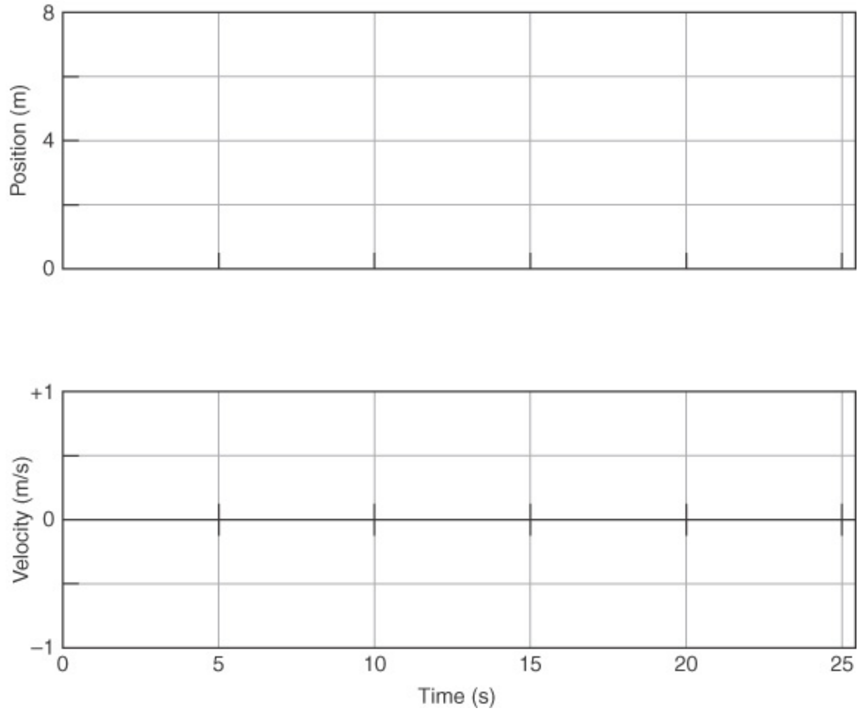
a. moves away from the origin at a slow and *steady* (constant) velocity for the first 5 s.

b. moves away at a medium-fast, *steady* (constant) velocity for the next 5 s.

c. stands still for the next 5 s.

d. moves toward the origin at a slow and *steady* (constant) velocity for the next 5 s.

e. stands still for the last 5 s.


8
4
0
Position (m)
+1
0
−1
Velocity (m/s)
0
5
10
15
20
25
Time (s)