Name____________________________ Date_________________

PRE-LAB PREPARATION SHEET FOR LAB 3: CHANGING MOTION

(Due at the beginning of Lab 3)

Directions:

Read over Lab 2 and then answer the following questions about the procedures.

1. In Activity 1-1, how do you expect that the position–time graph of the IOLab will differ from those you observed in Lab 1, where the IOLab was moving with a constant velocity?

2. Show how you would add the two vectors shown below:

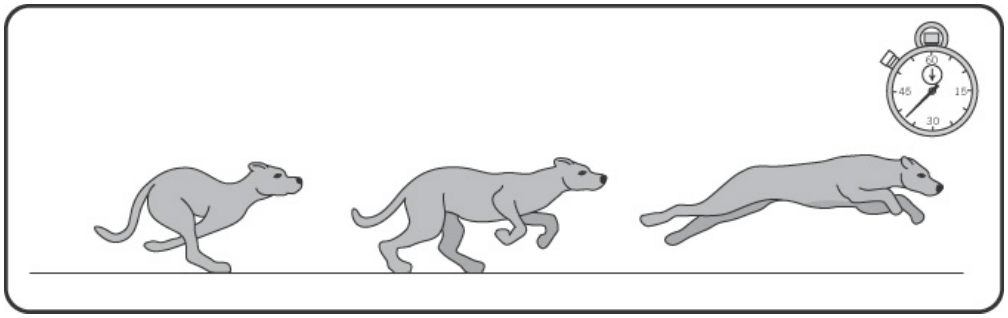
3. Show below how you would subtract the second vector from the first.

4. In words, write down definitions for average velocity and instantaneous velocity.

5. What do you predict the direction (sign) of acceleration will be for the experiment in Activity 2-2: Speeding Up Moving in the Negative Direction?

Name________________________ Date___________ Partners____________________

LAB 3: CHANGING MOTION



A cheetah can accelerate from 0 to 50 miles per hour in 6.4 seconds.

—Encyclopedia of the Animal World

A Jaguar can accelerate from 0 to 50 miles per hour in 6.1 seconds.

—World Cars

OBJECTIVES

- To discover how and when objects accelerate.
- To understand the meaning of acceleration, its magnitude, and its direction.
- To discover the relationship between velocity and acceleration graphs.
- To learn how to represent velocity and acceleration using vectors.

OVERVIEW

In the previous lab, you looked at position–time and velocity–time graphs of the motion of the IOLab. The data for the graphs were collected using the **Wheel** on the IOLab. Your goal in this lab is to learn how to describe various kinds of motion in more detail.

You have probably realized that a velocity–time graph is easier to use than a position–time graph when you want to know how fast and in what direction an object is moving at each instant in time (even though you can calculate this information from a position–time graph).

It is not enough when studying motion in physics to simply say that "the object is moving toward the right" or "it is standing still." When the velocity of an object is changing, it is also important to describe how it is changing. The rate of change of velocity with respect to time is known as the *acceleration.*

To get a feeling for acceleration, it is helpful to create and learn to interpret velocity–time and acceleration–time graphs for some relatively simple motions of the IOLab on a smooth ramp or other level surface. You will be observing the IOLab as it moves with its velocity changing at a constant rate.

INVESTIGATION 1: VELOCITY AND ACCELERATION GRAPHS

In this investigation you will be asked to predict and observe the shapes of velocity–time and acceleration–time graphs of the IOLab moving along a smooth ramp or other level surface. You will focus on motions with a steadily increasing velocity.

You will need the following materials:

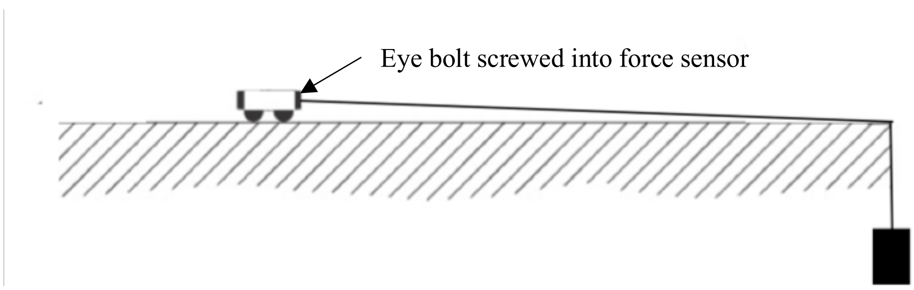
- IOLab with eye bolt screwed into the force sensor
- computer and IOLab software
- smooth tabletop or other flat surface at least 0.5 m long
- string, a little longer than the flat surface (~0.75 m)
- variety of hanging masses (or a pop can and a number of coins)

Activity 1-1: Speeding Up

In this activity you will look at velocity–time and acceleration–time graphs of the motion of the IOLab, and you will be able to see how these two representations of the motion are related to each other when the IOLab is speeding up.

This could be done by moving the cart with your hand, but it is difficult to get a steadily changing velocity in this way. Instead you will use a mass hung over the edge of the ramp to accelerate the IOLab.

Prediction 1-1: Sketch on the PREDICTION axes on the next page your predictions for the position-time, velocity-time and acceleration-time graphs for the situation shown below as the mass falls and pulls the IOLab across the ramp.



1. Set up the IOLab on the ramp, with the string attached to the eye bolt of the IOLab, and a mass attached to the other end of the string. *Be sure that the surface the IOLab rolls on is level.*
2. Set up the IOLab to collect data with the **Wheel** for **position**, **velocity** and **acceleration**.
3. Click the box **Reverse y-axis**.

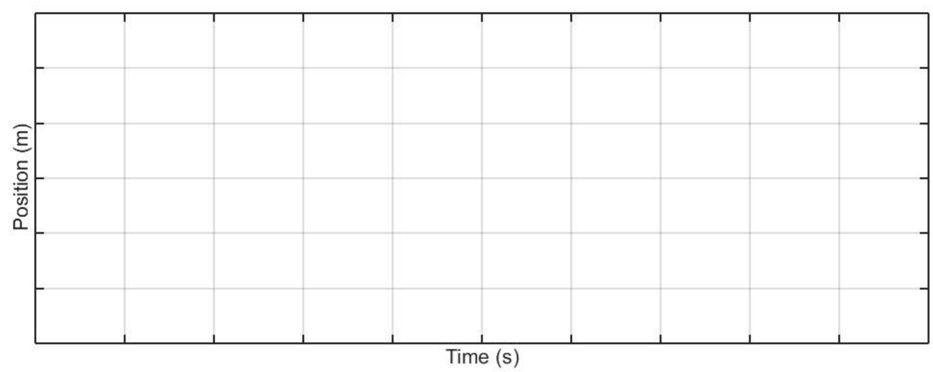
> **NOTE:** Remember that because of the design of the IOLab, it will be necessary to click this box for each set of "wheel" or "force" measurements that you do. This will be explained in more detail in future labs. For now, please remember to see that the **Reverse y-axis** box is checked before each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

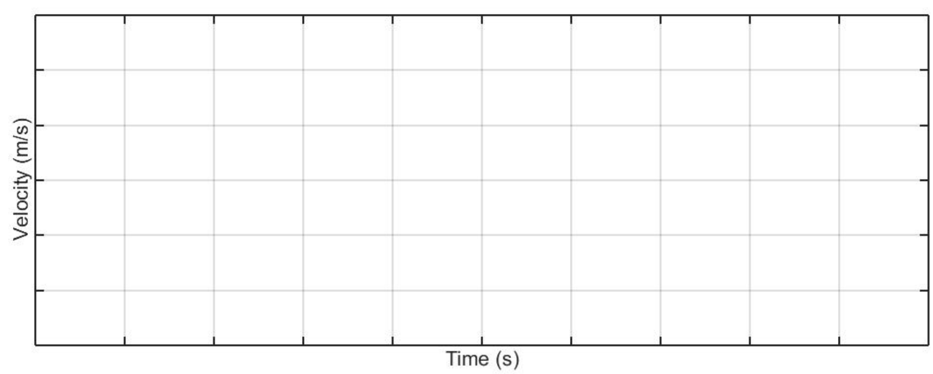
4. Hold the IOLab still and make sure the weight is not swinging. Release the IOLab, making sure you do not cause the weight to start swinging. Collect graphs for the motion of the IOLab along the surface as the mass falls and pulls the IOLab across the surface.

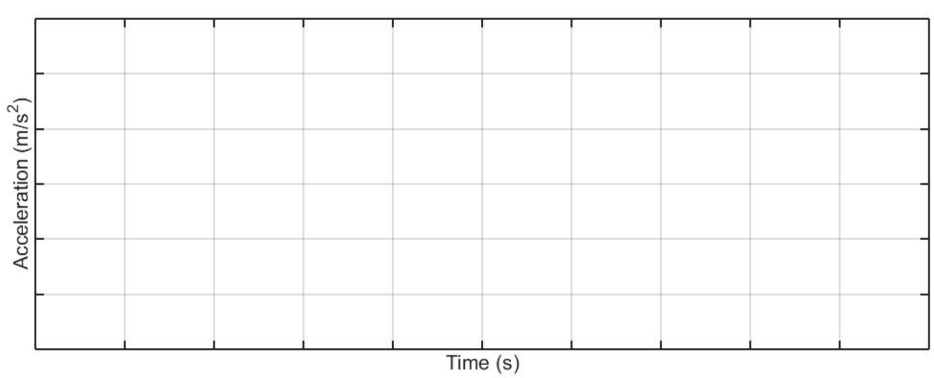
5. Repeat the experiment a couple of times, to make sure you captured a good example of speeding up to the right.

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

PREDICTION

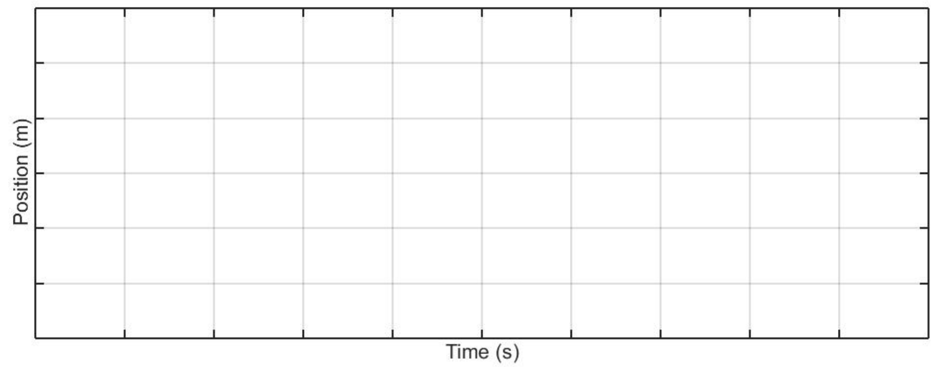


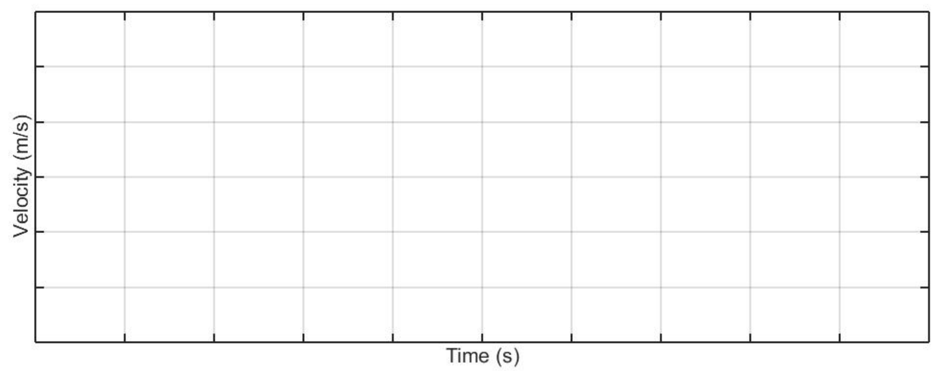


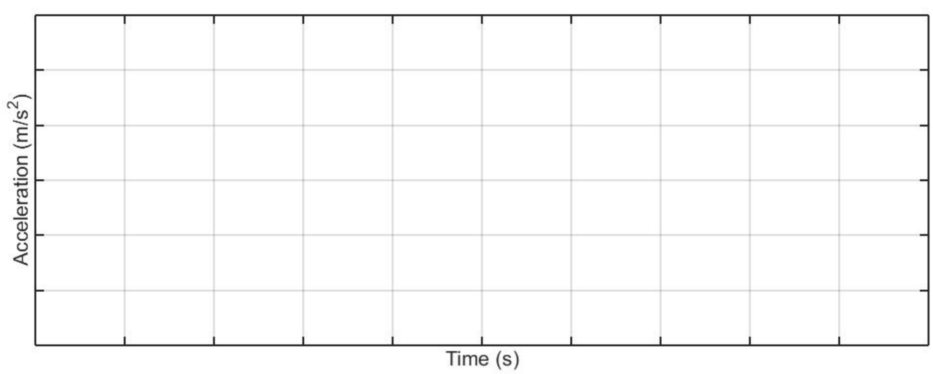


6. When you have good graphs, keep a copy of them (save or print). Sketch your position-time and velocity-time graphs neatly on the RESULTS axes below. Label the graphs "Speeding *Up 1*." (Ignore the acceleration axes for now.) Indicate the scales on both axes.

RESULTS







Question 1-1: How does this position-time graph of the IOLab differ from the position graphs for steady (constant velocity) motion that you observed in Lab 1: Introduction to Motion?

Question 1-2: What feature of your velocity graph signifies that the motion was *in the positive direction*?

Question 1-3: What feature of your velocity graph signifies that the cart was *speeding up?* How would a graph of motion with a constant velocity differ?

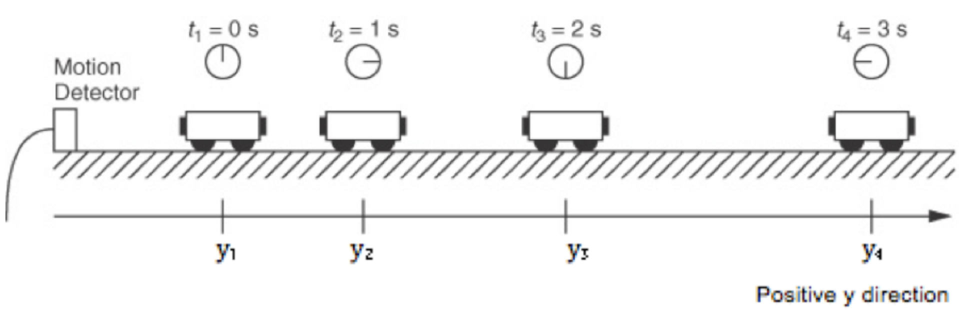
7. Adjust the acceleration graph so that it fills the axes. Sketch your graph on the acceleration axes above, and label it "*Speeding Up 1*."

Question 1-4: During the time that the IOLab is speeding up, is the acceleration positive or negative? How does *speeding up* while moving *in the positive direction* result in this sign of acceleration? (Hint: Remember that acceleration is the *rate of change* of velocity. Look at how the velocity is changing. It takes two points on the velocity–time graph to calculate the rate of change of velocity.)

Question 1-5: How does the velocity vary in time as the IOLab speeds up? Does it increase at a steady (constant) rate or in some other way?

Question 1-6: How does the acceleration vary in time as the IOLab speeds up? Is this what you expect based on the velocity graph? Explain.

Question 1-7: The diagram below shows the positions of an IOLab at equal time intervals as it speeds up. Assume that the IOLab is already moving at t_1.



At each indicated time, sketch a vector above the IOLab that might represent the velocity of the IOLab at that time while it is moving in the positive direction and speeding up.

Question 1-8: Show below how you would find the vector representing the change in velocity between the times t_3 and t_4 (at 2 and 3 s) in the diagram above. (Hint: Remember that the change in velocity is the final velocity minus the initial velocity, and the vector difference is the same as the sum of one vector and the negative of the other vector.)

Based on the direction of this vector and the direction of the positive y axis, what is the sign of the acceleration? Does this agree with your answer to Question 1-4? Explain.

Activity 1-2: Speeding Up More

Prediction 1-2: Suppose that you accelerate the IOLab at a faster rate. How would your velocity and acceleration graphs be different than those above? Sketch your predictions with dashed or different color lines on the previous set of PREDICTION axes.

1. Test your predictions. Make velocity-time and acceleration-time graphs. This time accelerate the cart with a significantly larger hanging mass. Repeat if necessary to get nice graphs.

2. Keep a copy of your graphs (print or save) and sketch your velocity and acceleration graphs with solid or different color lines on the previous set of RESULTS axes. Be sure that the graphs are labeled "*Speeding Up 1*" and "*Speeding Up 2*."

Question 1-9: Did the shapes of your velocity and acceleration graphs agree with your predictions? How is the magnitude (size) of acceleration represented on a velocity–time graph?

Question 1-10: How is the magnitude (size) of acceleration represented on an acceleration–time graph?

INVESTIGATION 2: SLOWING DOWN AND SPEEDING UP

In this investigation you will look at the IOLab moving along a ramp or other level surface *and slowing down*. A car being driven down a road and brought to rest when the brakes are applied is a good example of this type of motion.

Later you will examine the motion of the IOLab in the negative direction and *speeding up*.

In both cases, we are interested in how velocity and acceleration change over time. That is, we are interested in the shapes of the velocity–time and acceleration–time graphs (and their relationship to each other), as well as the vectors representing velocity and acceleration.

You will need the following materials:

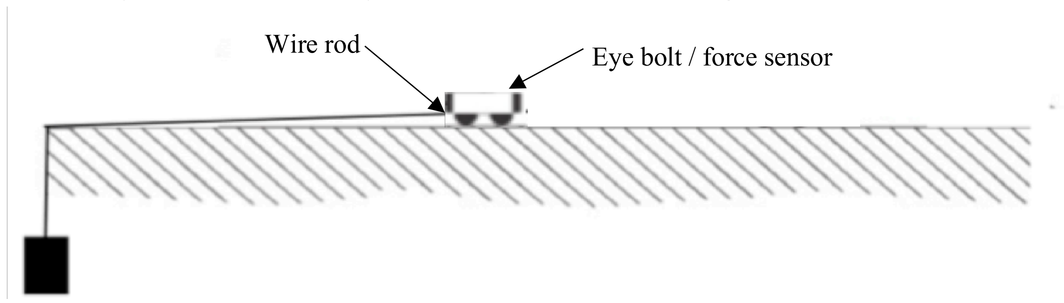
• IOLab with eye bolt screwed into force sensor

• computer and IOLab software
• smooth tabletop or other flat surface at least 0.5 m long
• string
• variety of hanging masses (or a pop can and a number of coins)

Activity 2-1: Slowing Down

In this activity you will look at the velocity and acceleration graphs of the IOLab moving *in the positive direction* and *slowing down*.

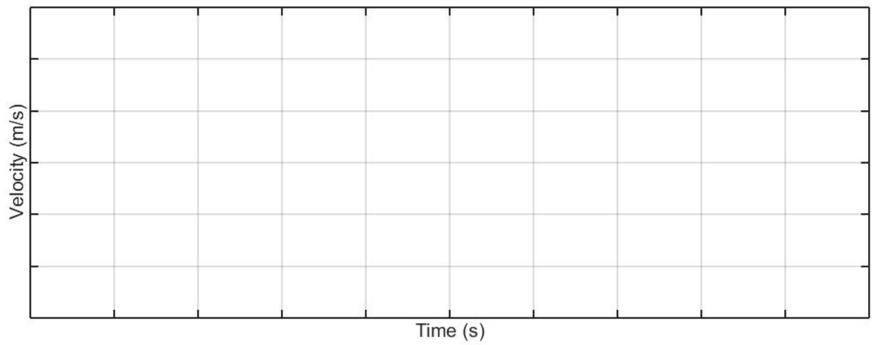
1. The IOLab, ramp, and hanging mass should be set up as shown below. Use the larger mass that you used in Activity 1-2. This time tie the string to the small wire rod.

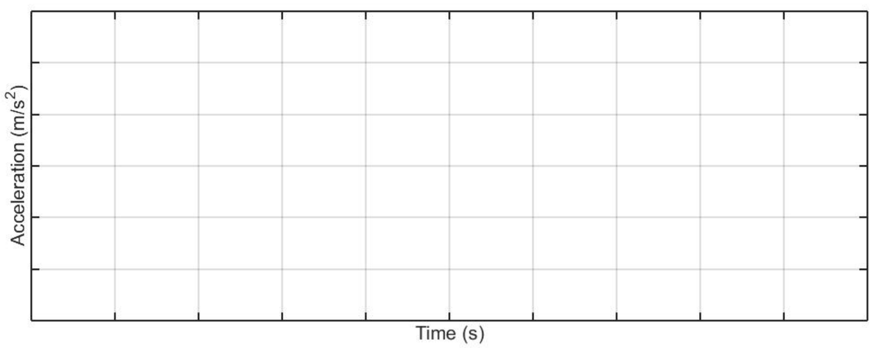


Now, when you give the cart a quick push to the right (in the positive direction) with the mass hanging, it will slow down after it is released.

Prediction 2-1: If you give the IOLab a short push in the positive direction (toward the right) and release it, will the acceleration be positive, negative, or zero (after it is released)? Sketch your predictions for the velocity–time and acceleration–time graphs on the PREDICTION axes below.

PREDICTION





Label your graphs with:
- A at the spot where you started pushing.
- B at the spot where you stopped pushing.
- C the region where only the force of the hanging mass was acting on the IOLab.
- D at the spot where the IOLab came to rest (and you stopped it with your hand).

2. Test your predictions. Set up the IOLab to collect data with the **Wheel** for **velocity** and **acceleration**.

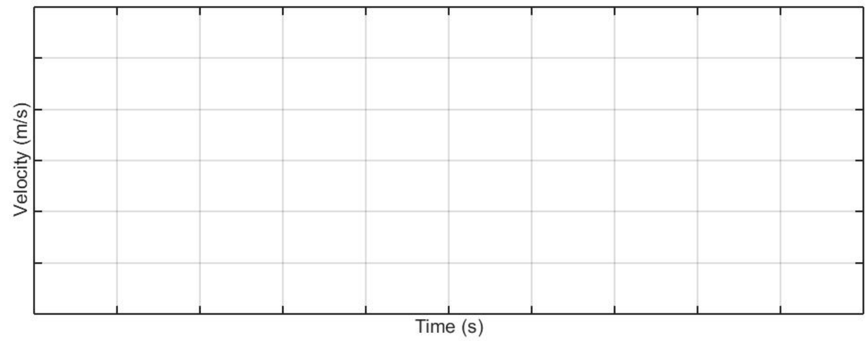
3. Begin graphing, give the IOLab a short push to the right and release it so that it comes to a stop near the right end of the ramp. *Use your hand to prevent it from returning.* You may have to try a few times to get a good run. Don't forget to **adjust the axes** if this will make your graphs easier to read.

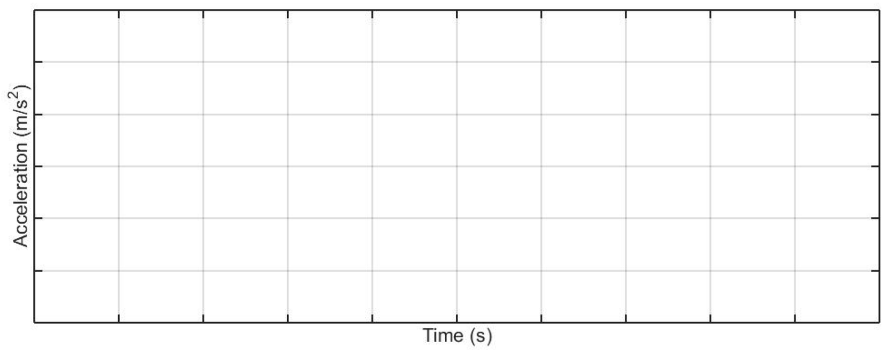
4. Keep a copy of your graphs (print or save) and neatly sketch your results on the RESULTS axes below.

Again label your graphs with:
- A at the spot where you started pushing.
- B at the spot where you stopped pushing.
- C the region where only the force of the hanging mass was acting on the IOLab.
- D at the spot where the IOLab came to rest (and you stopped it with your hand).

In order, to compare to the case of speeding up we studied previously, use the same weights as in Activity 1–1. Also sketch on the same axes with dashed or different color lines the velocity and acceleration graphs for *"Speeding Up 2"* from Activity 1–2.

RESULTS



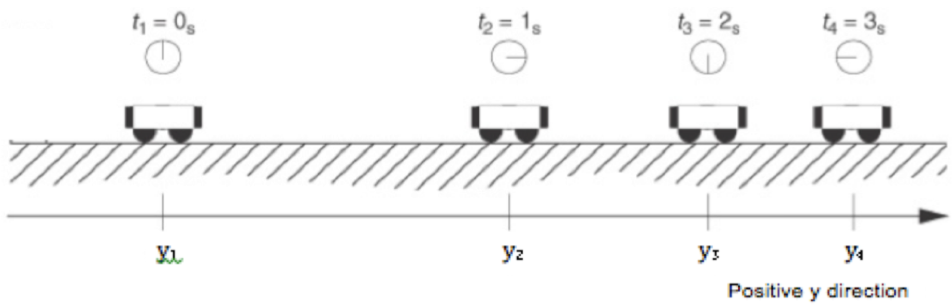


Question 2-1: Did the shapes of your velocity and acceleration graphs agree with your predictions? How can you tell the sign of the acceleration from a velocity–time graph?

Question 2-2: How can you tell the sign of the acceleration from an acceleration–time graph?

Question 2-3: Is the sign of the acceleration (which indicates its direction) what you predicted? How does *slowing down* while moving *in the positive direction* result in this sign of acceleration? (Hint: Remember that acceleration is the *rate of change* of velocity with respect to time. Look at how the velocity is changing.)

Question 2-4: The diagram below shows the positions of the IOLab at equal time intervals. (This is like overlaying snapshots of the IOLab at equal time intervals.) At each



indicated time, sketch a vector above the IOLab that might represent the velocity of the IOLab at that time while it is moving in the positive direction and slowing down. Assume that the IOLab is moving at t_1 and t_4.

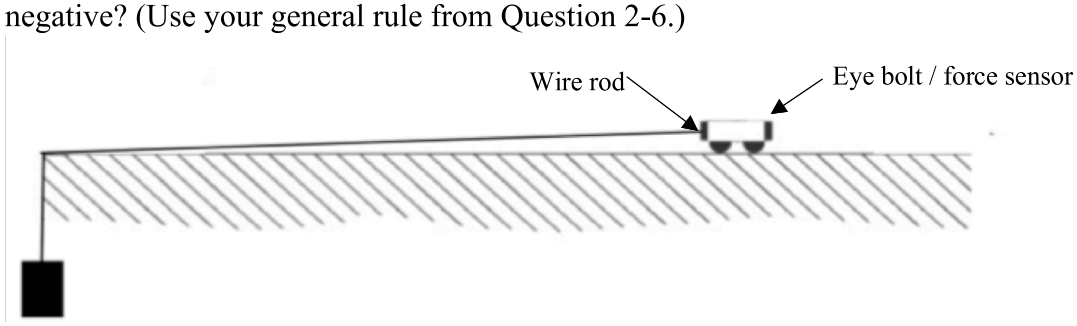
Question 2-5: Show below how you would find the vector representing the change in velocity between the times 2 and 3 s in the diagram above. (Remember that the change in velocity is the final velocity minus the initial velocity.)

Based on the direction of this vector and the direction of the positive y axis, what is the sign (the direction) of the acceleration? Does this agree with your answer to Question 2-3?

Question 2-6: Based on your observations in this lab, state a general rule to predict the sign (the direction) of the acceleration if you know the sign of the velocity (i.e., the direction of motion) and whether the object is speeding up or slowing down.

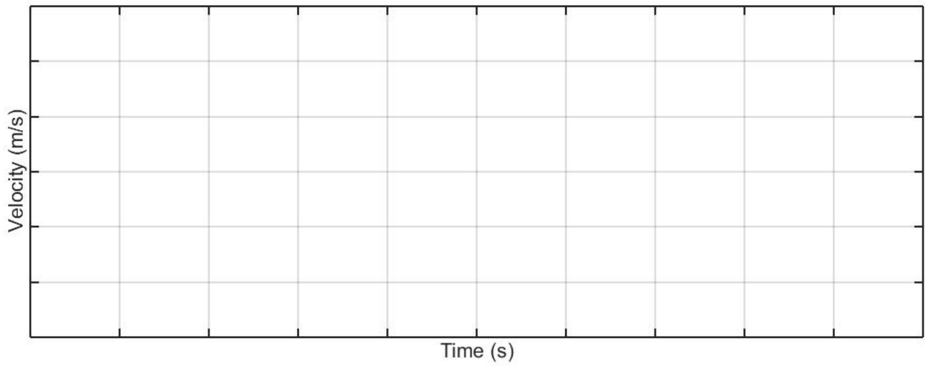
Activity 2-2 Speeding Up While Moving In the Negative Direction

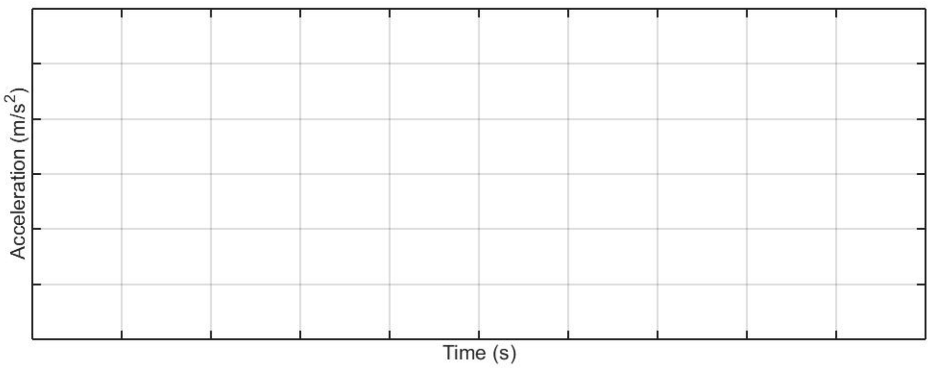
Prediction 2-3: Suppose now that you start with the IOLab at the far right end of the ramp, and let the falling mass pull it in the *negative direction*. See the diagram below. As the IOLab moves toward the left (in the negative direction) and speeds up, predict the direction of the acceleration. Will the sign (direction) of the acceleration be positive or negative? (Use your general rule from Question 2-6.)



Sketch your predictions for the velocity–time and acceleration–time graphs on the PREDICTION axes below.

PREDICTION



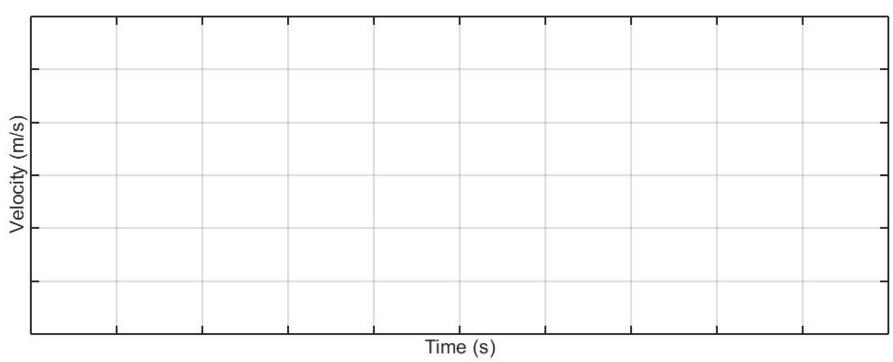


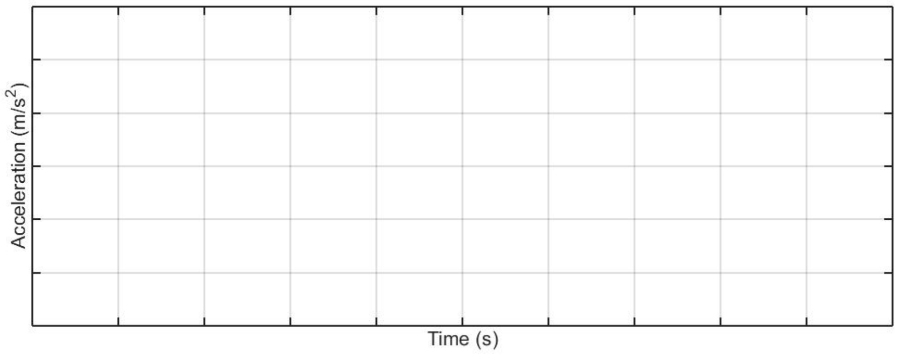
1. Test your predictions. Graph the IOLab moving *in the negative direction* and *speeding up*. **Begin** graphing and release the IOLab from rest from the far right end of the ramp. *Stop the* IOLab *before it reaches the other end of the ramp.*

2. Keep a copy of these graphs (print or save) and sketch on the RESULTS axes below. Label these graphs as "*Speeding Up While Moving in Negative Direction*."

Question 2-7: How does your velocity graph show that the IOLab was moving *in the negative direction*?

RESULTS

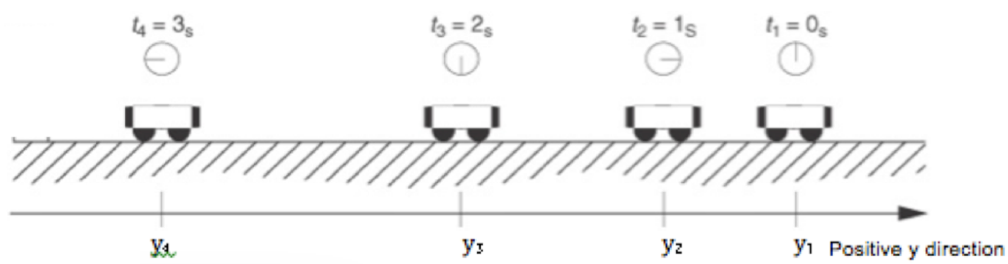




Question 2-8: During the time that the IOLab was speeding up, is the acceleration positive or negative? Does this agree with your prediction? Explain how *speeding up* while moving *in the negative direction* results in this sign of acceleration. (**Hint:** Look at how the velocity is changing.)

Question 2-9: When an object is speeding up, what must be the direction of the acceleration relative to the direction of the object's velocity? Are they in the same or different directions? Explain.

Question 2-10: The diagram below shows the positions of the IOLab at equal time intervals. At each indicated time, sketch a vector above the IOLab that might represent the velocity of the IOLab at that time while it is moving in the negative direction and



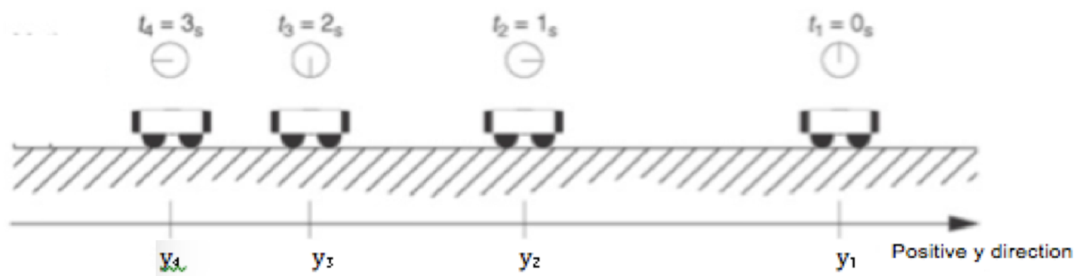
speeding up. Assume that the IOLab is already moving at t_1.

Question 2-11: Show below how you would find the vector representing the change in velocity between the times 2 and 3 s in the diagram above. Based on the direction of this vector and the direction of the positive *y axis*, what is the sign of the acceleration? Does this agree with your answer to Question 2-8?

Question 2-12: Was your general rule in Question 2-6 correct? If not, modify it and restate it here.

Question 2-13: There is one more possible combination of velocity and acceleration directions for the IOLab: moving *in the negative direction and slowing down*. Use your general rule to predict the direction and sign of the acceleration in this case. Explain why the acceleration should have this direction and this sign in terms of the sign of the velocity and how the velocity is changing.

Question 2-14: The diagram below shows the positions of the IOLab at equal time intervals for the motion described in Question 2-13. At each indicated time, sketch a vector above the IOLab that might represent the velocity of the IOLab at that time while it is moving in the negative direction and slowing down. Assume that the IOLab is moving at t_1 and t_4.



Question 2-15: Show how you would find the vector representing the change in velocity between the times 2 and 3 s in the diagram above. Based on the direction of this vector and the direction of the positive *y axis*, what is the sign of the acceleration? Does this agree with your answer to Question 2-13?

Activity 2-3: Reversing Direction

In this activity you will look at what happens when the IOLab slows down, reverses its direction, and then speeds up in the opposite direction. How does the velocity change with time? What is the IOLab's acceleration?

The setup should be the same as in Activities 2-1 and 2-2. The larger hanging mass should be used. A good choice would be about 50 grams or about 0.5 N.

Prediction 2-3: You hang the mass and give the IOLab a very short push to the right *(positive direction)*. It moves away, slows down, reverses direction, and then moves back to the left.

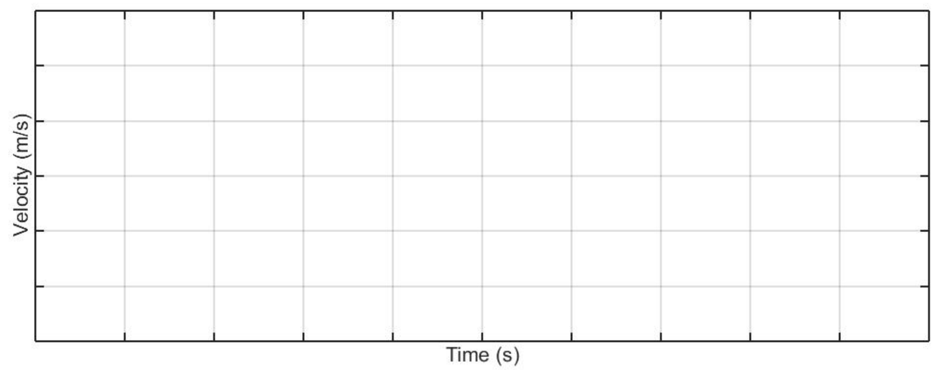
For each part of the motion—*toward the right, at the turning point*, and *back toward the left*—indicate in the table below whether the velocity will be positive, zero, or negative. Also indicate whether the acceleration will be positive, zero, or negative.

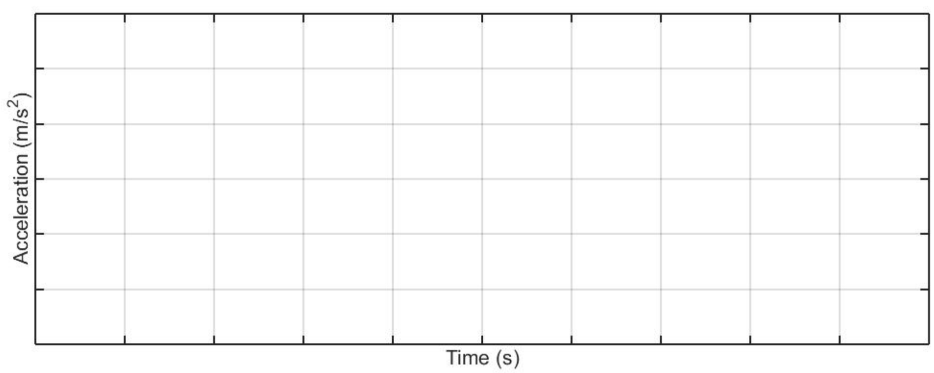
PREDICTION TABLE

	Moving away	At the turning point	Moving toward
Velocity			
Acceleration			

Prediction 2-4: On the PREDICTION axes that follow sketch your predictions of the velocity–time and acceleration–time graphs of this entire motion.

PREDICTION





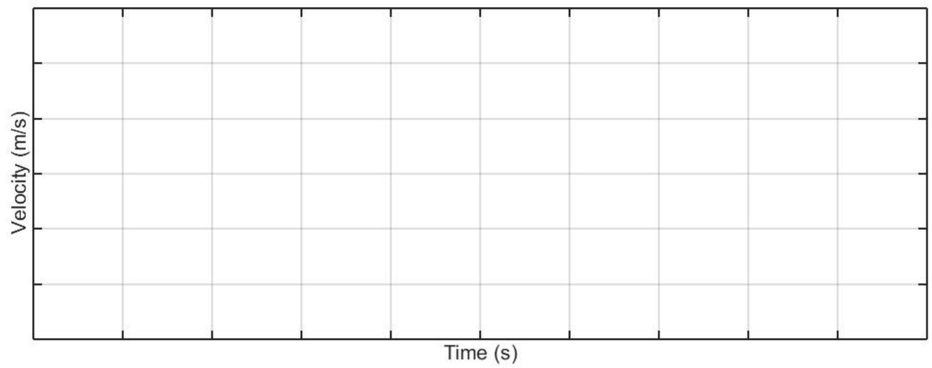
1. Test your predictions. **Begin** graphing with the back of the IOLab near the left end of the ramp, and the mass hanging over the edge. Give the IOLab a short push to the right (positive y direction) and release, so that it travels almost to end of the flat surface. The IOLab will slow down, and then it will reverse its direction and moves toward the left.

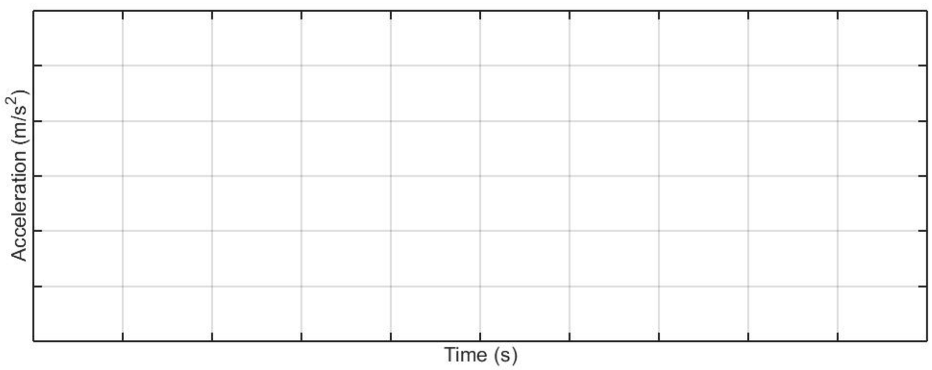
You will want to try a few times to get a good round trip. Don't forget to change the scales if this will make your graphs clearer.

2. When you get a good round trip, keep copies (print or save) and sketch both graphs on the RESULTS axes below. Label both graphs with

- A where the IOLab started being pushed.
- B where the push ended (where your hand left the IOLab).
- C where the IOLab reached its turning point (and was about to reverse direction).
- D where you stopped the IOLab with your hand.

RESULTS





Question 2-17: You labeled *both* graphs with A, B, C, and D. Explain how you know where each of these points is.

Question 2-18: Did the IOLab "stop" at its turning point? (**Hint:** Look at the velocity graph. What was the velocity of the IOLab at its turning point?) Does this agree with your prediction? How much time did it spend at the turning point velocity before it started back toward the detector? Explain.

Question 2-19: According to your acceleration graph, what is the acceleration at the instant the IOLab reaches its turning point? Is it positive, negative, or zero? Is it significantly different from the acceleration during the rest of the motion? Does this agree with your prediction?

Question 2-20: Explain the observed sign of the acceleration at the turning point. (Hint: Remember that acceleration is the *rate of change* of velocity. When the IOLab is at its turning point, what will its velocity be in the next instant? Will it be positive or negative?)

Question 2-21: On the way back, is there any difference between these velocity and acceleration graphs and the ones that were the result of the IOLab starting from rest (Activity 2-2)? Explain.

Activity 2-4: Sign of the Push and Stop

Find on your acceleration graphs for Activity 2-3 the time intervals when you pushed the cart to start it moving and when you stopped it.

Question 2-22: What is the sign of the acceleration during the push and during the stop? Explain why the acceleration has this sign in each case.

Challenge: You throw a ball up into the air. It moves upward, reaches its highest point, and then moves back down toward your hand. Assuming that upward is the positive direction, indicate in the table that follows whether the velocity is positive, zero, or negative during each of the three parts of the motion. Also indicate if the acceleration is positive, zero, or negative. (**Hint:** Remember that to find the acceleration, you must look at the *change* in velocity.)

	Moving up *after release*	At highest point	Moving down
Velocity			
Acceleration			

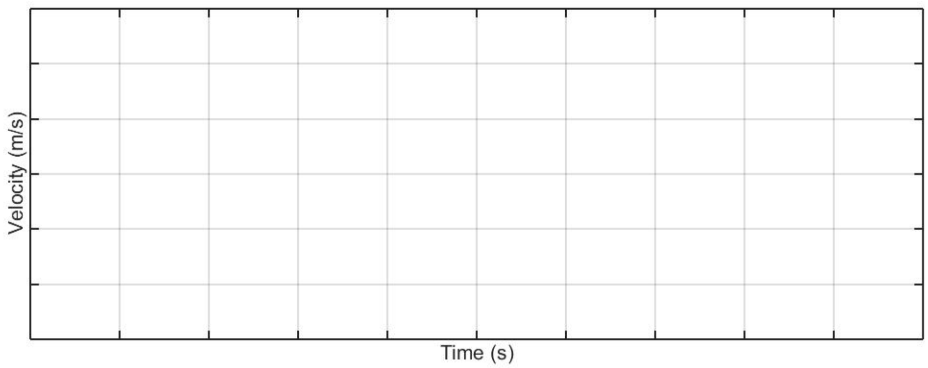
Question 2-23: In what ways is the motion of the ball similar to the motion of the IOLab that you observed in Activity 2-3? What causes the ball to accelerate?

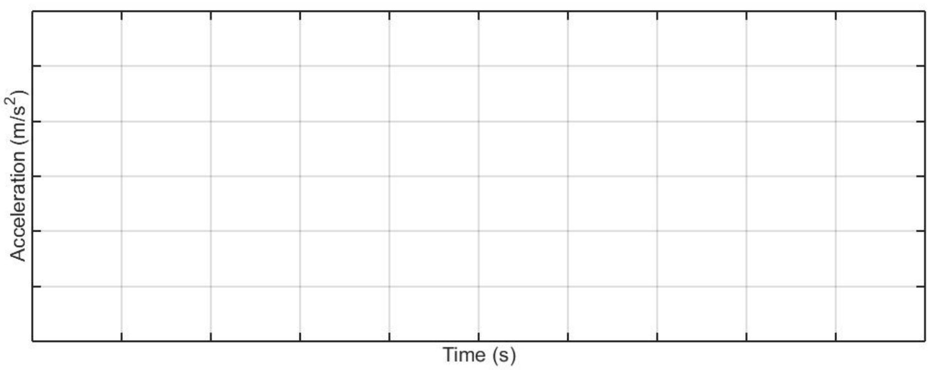
INVESTIGATION 3: MOTION ON AN INCLINED RAMP

Now you will observe the motion of the IOLab along an inclined ramp under the influence of the gravitational force. First a prediction.

Prediction 3-1: The IOLab is given a short push up an inclined ramp and released. On the PREDICTION axes below, sketch your predictions for the velocity-time and acceleration-time graphs for its motion up the ramp and back down again. *Don't include the push or the stop on your graphs.*

PREDICTION



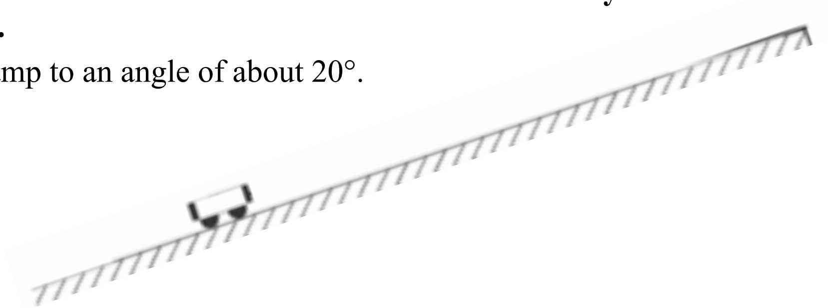


To test your prediction you will need the following:

- IOLab
- computer and IOLab software
- smooth ramp or other flat surface at least 0.5 m long that can be tilted at 20°
- blocks or books to elevate one end of the ramp to an angle 20°

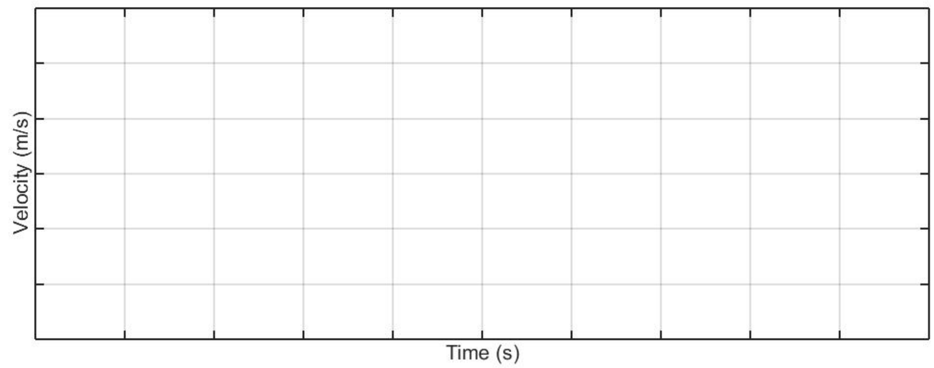
Activity 3-1: The Motion of the IOLab Along an Inclined Ramp

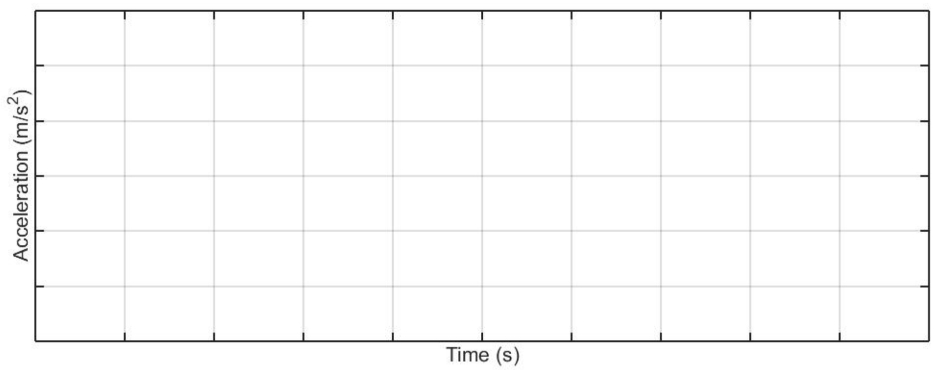
1. Set up the IOLab to collect data with the **Wheel** for **velocity** and **acceleration.**
2. Incline the ramp to an angle of about 20°.



3. Collect graphs of **velocity** and **acceleration** for the motion of the IOLab along the inclined ramp as you give it a short push up the ramp (in the positive y direction), release it and then stop it when it returns to its original position.
4. Keep copies of your graphs (save or print) and sketch them on the RESULTS axes below. (Be sure that the graphs are labeled clearly.) Label the various points as before.

RESULTS





Question 3-1: Describe your graphs. Did they agree with your predictions?

Question 3-2: Would you describe this motion as having constant velocity or constant acceleration? Explain.

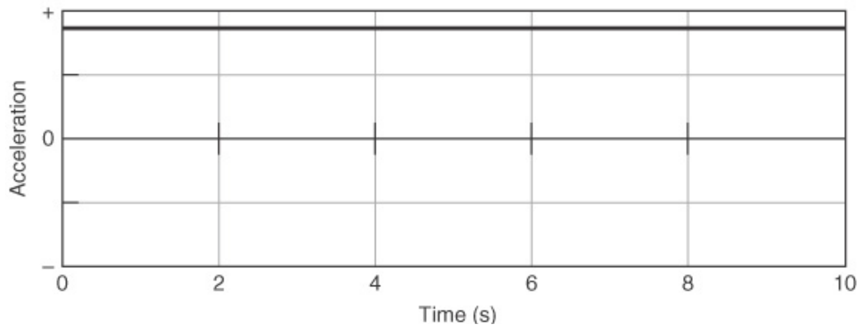
Question 3-3: What was the sign of the acceleration as the IOLab moved up the ramp? What about down the ramp? Explain these by your rule in Question 2-6.

Question 3-4: What was the sign of the acceleration of the IOLab when it was at its highest point along the ramp? Explain this value for acceleration.

Question 3-5: Are your graphs similar to any set of graphs in Investigation 2? Which ones? Explain why these sets of graphs are similar in shape.

HOMEWORK FOR LAB 3: CHANGING MOTION

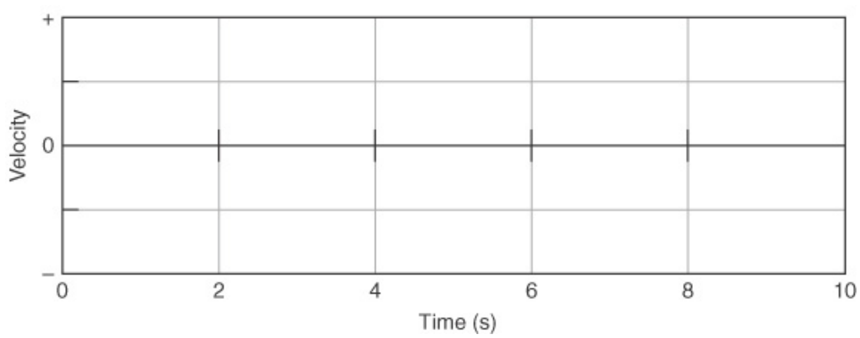
1. An object moving along a line (the + position axis) has the acceleration–time graph on the right.



a. Describe how the object might move to create this graph if it is moving away from the origin.

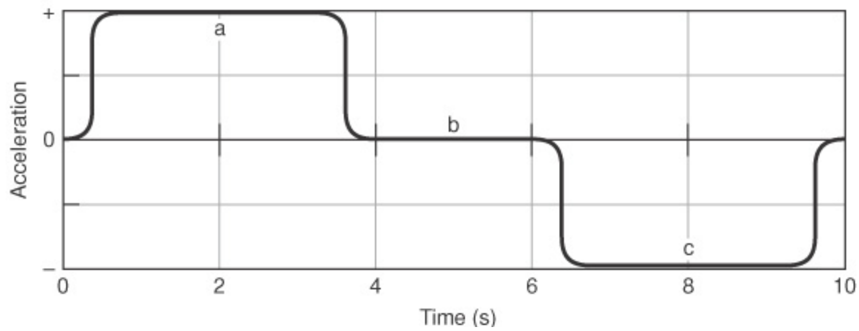
b. Describe how the object might move to create this graph if it is moving toward the origin.

c. Sketch with a solid line on the axes on the right a velocity–time graph that goes with the motion described in (a).



d. Sketch with a dashed line on the axes on the right a velocity–time graph that goes with the motion described in (b).

2. How would an object move to create each of the three labeled parts of the acceleration–time graph shown below?

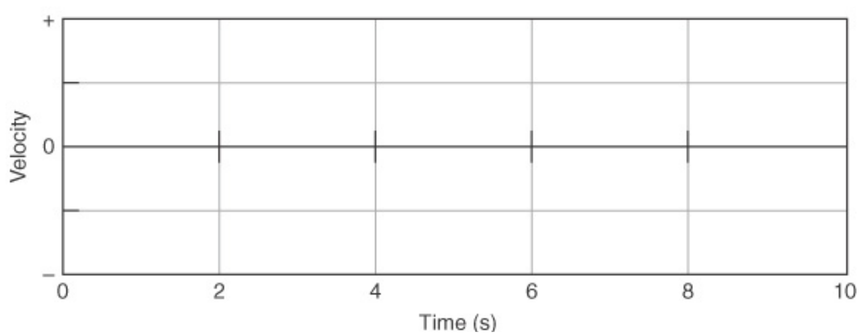


a:

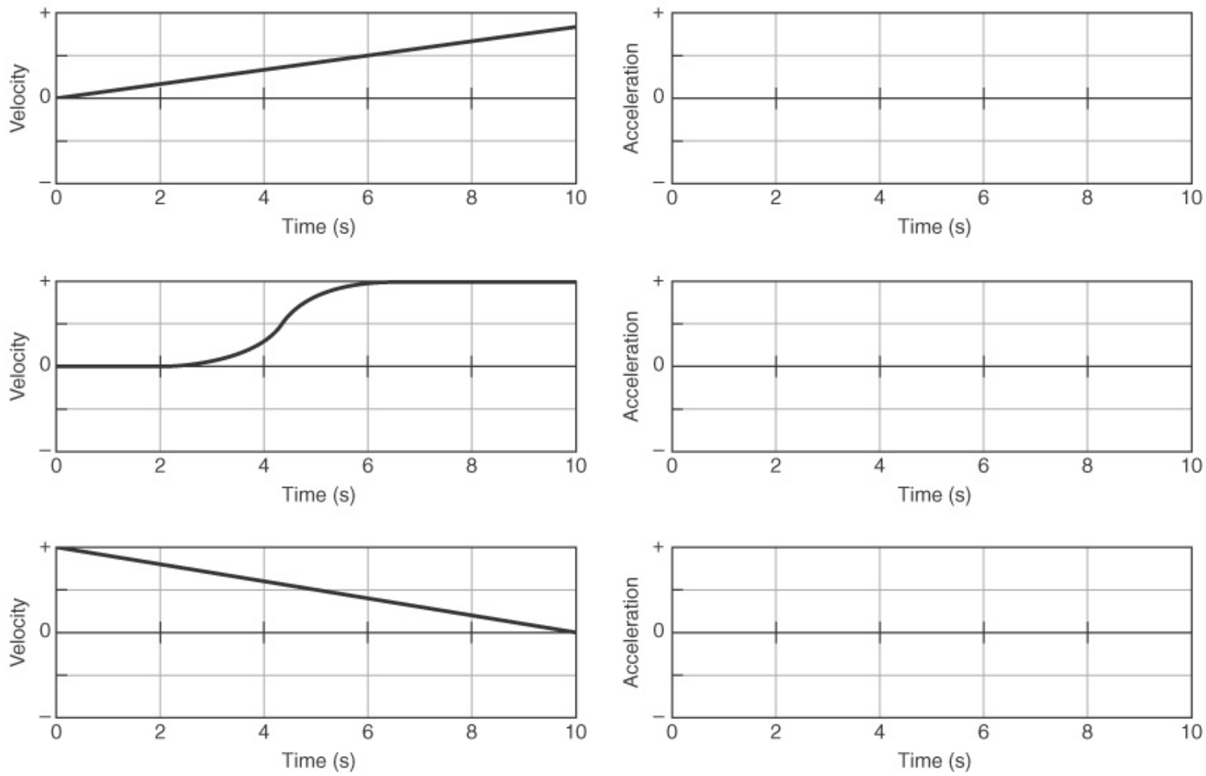
b:

c:

3. Sketch below a velocity–time graph that might go with the acceleration–time graph in Question 2.



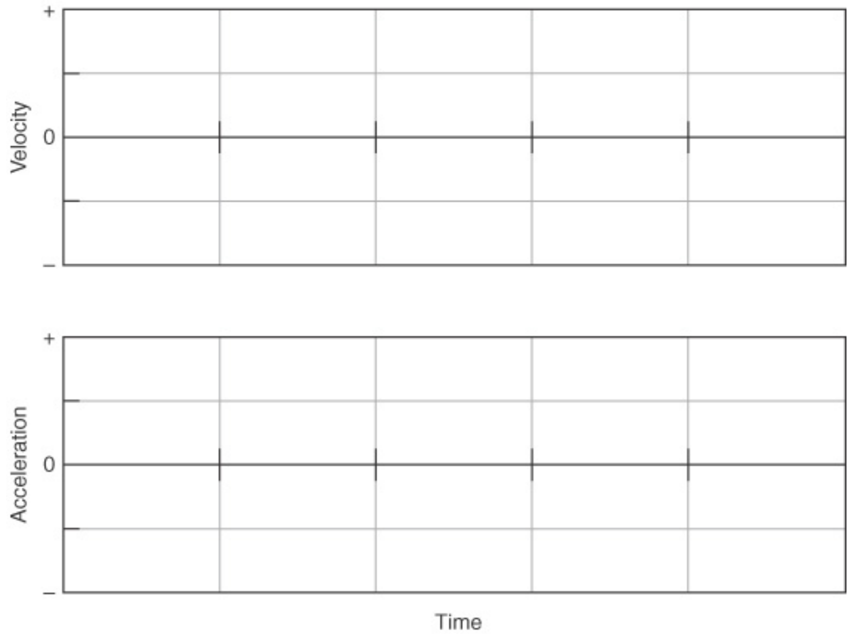
4. For each of the velocity–time graphs that follow, sketch the shape of the acceleration–time graph that goes with it.



5. A car can move along a line (the + position axis). Sketch velocity–time and acceleration–time graphs that correspond to each of the following descriptions of the car's motion.

a. The car starts from rest, and moves away from the origin, increasing its speed at a steady rate.

b. The car is moving away from the origin at a constant velocity.

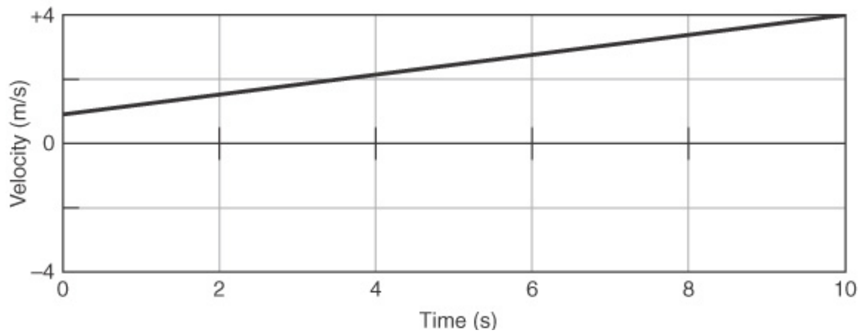


c. The car starts from rest, and moves away from the origin, increasing its speed at a steady rate twice as large as in (a) above.

d. The car starts from rest, and moves toward the origin, increasing its speed at a steady rate.

e. The car is moving toward the origin at a constant velocity.

6. The following is a velocity–time graph for a car.

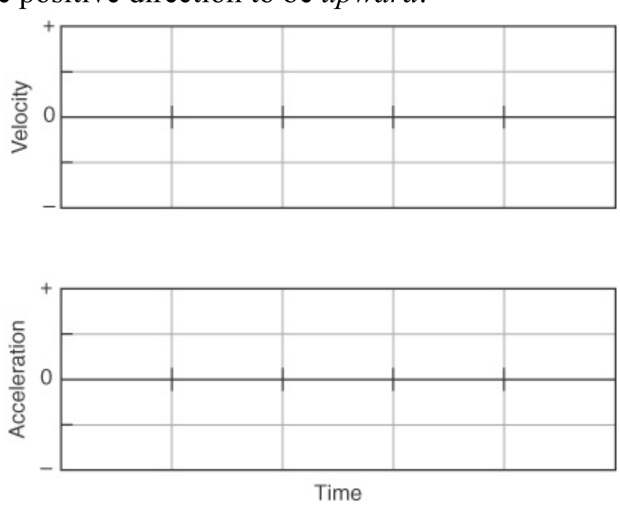


What is the average acceleration of the car? Show your work below.

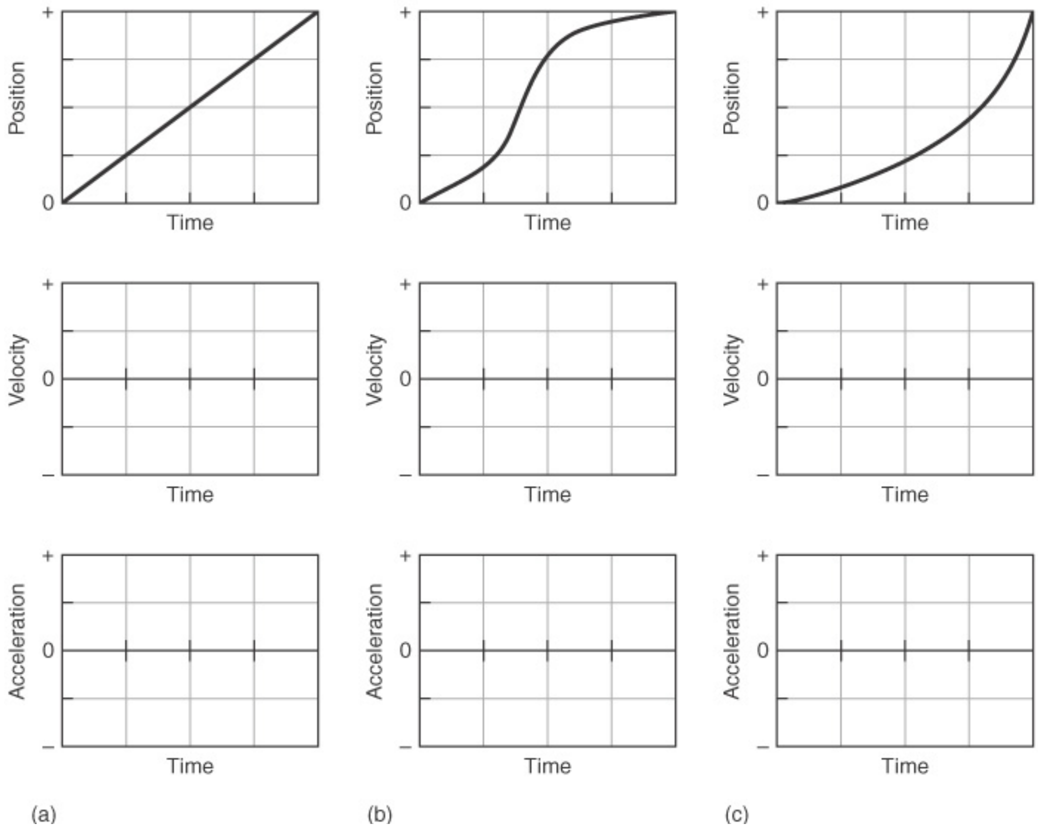
7. A car moves along a line (the + position axis). Fill in the table below with the sign (+ or −) of the velocity and acceleration of the car for each of the motions described.

	Position	Velocity	Acceleration when speeding up	Acceleration when slowing down
Car moves Away from the origin	+			
Car moves toward the origin	+			

8. A ball is tossed in the air. It moves upward, reaches its highest point, and falls back downward. Sketch a velocity–time and an acceleration–time graph for the ball from the moment it leaves the thrower's hand until the moment just before it reaches her hand again. Consider the positive direction to be *upward*.



9. For each of the position–time graphs shown, sketch below it the corresponding velocity–time and acceleration–time graphs.



10. Each of the pictures below represents a car moving down a road. The motion of the car is described. In each case, draw velocity and acceleration vectors above the car that might represent the described motion. Label the vectors. Also specify the sign of the velocity and the sign of the acceleration. (The positive position direction is toward the right.)

a.

Sign of velocity:

The driver has stepped on the accelerator, and the car is just starting to move forward.

Sign of acceleration:

b.

Sign of velocity:

The car is moving forward. The brakes have been applied. The car is slowing down, but has not yet come to rest.

Sign of acceleration:

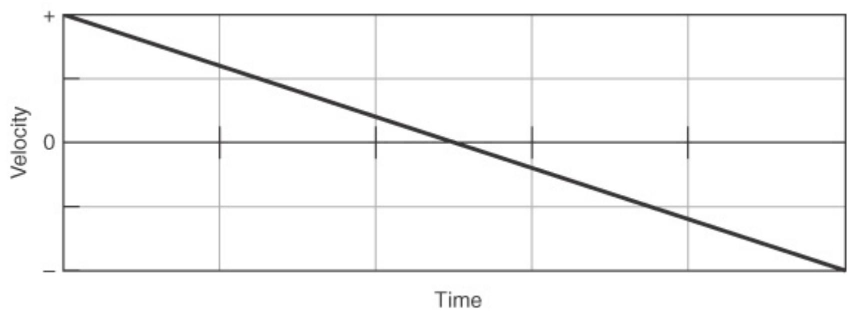
c.

Sign of velocity:

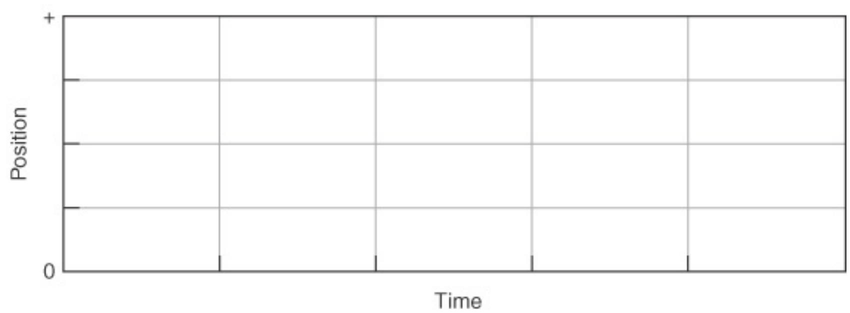
The car is moving backward. The brakes have been applied. The car is slowing down, but has not yet come to rest.

Sign of acceleration:

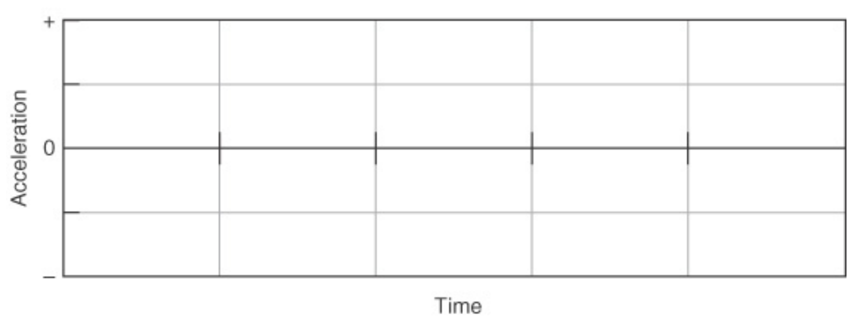
11. a. Describe how you would move to produce the velocity–time graph below.



b. Sketch a position–time graph for this motion on the axes below.

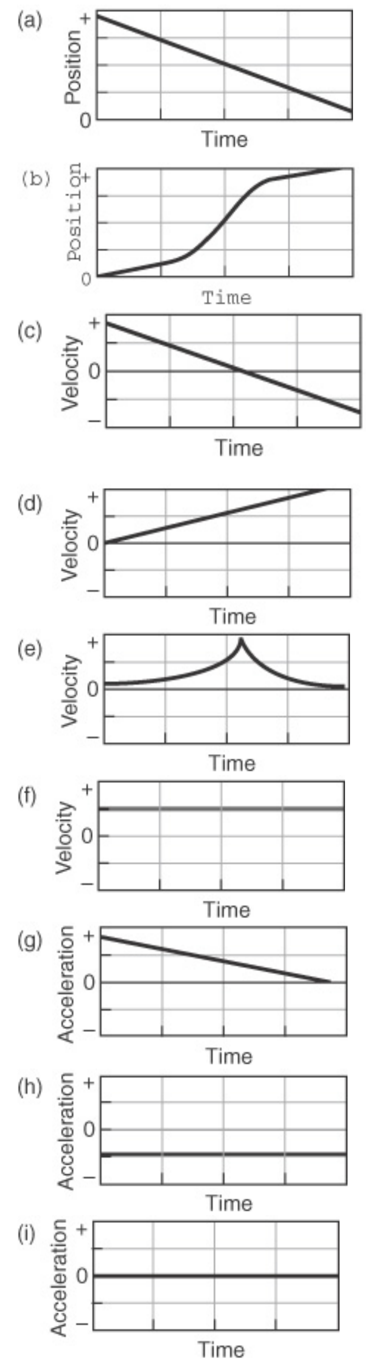


c. Sketch an acceleration–time graph for this motion on the axes below.



The graphs on this page represent the motion of objects along a line that is the positive position axis. Notice that the motion of objects is rep-resented by position, velocity, or acceleration graphs.

Answer the following questions. You may use a graph more than once or not at all, and there may be more correct choices than blanks. If none of the graphs is correct, answer J.



______**12.** Pick one graph that gives enough information to indicate that the velocity is always negative.

Pick three graphs that represent the motion of an object whose velocity is constant (not changing).

______**13.** ______**14.** ______**15.**

______**16.** Pick one graph that definitely indicates an object has reversed direction.

______**17.** Pick one graph that might possibly be that of an object standing still.

Pick 3 graphs that represent the motion of objects whose acceleration is changing.

______**18.** ______**19.** ______**20.**

Pick a velocity graph and an acceleration graph that could describe the motion of the same object during the time shown.

______**21.** Velocity graph.

______**22.** Acceleration graph.