Name__________________________ Date_________________

PRE-LAB PREPARATION SHEET FOR LAB 4: FORCE AND MOTION

(*Due at the beginning of Lab* 4)

Directions:

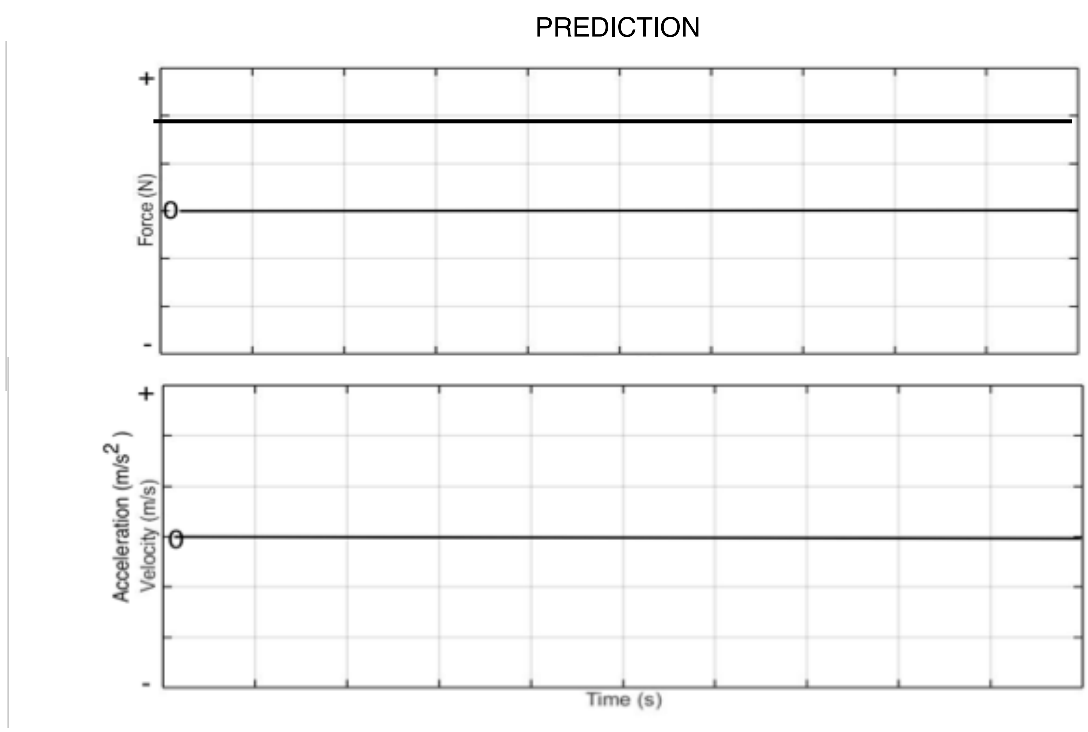
Read over Lab 3 and then answer the following questions about the procedures.

1. What is the purpose of the rubber bands in Activity 1-1?

2. What is the difference between a *linear* and a *proportional* relationship?

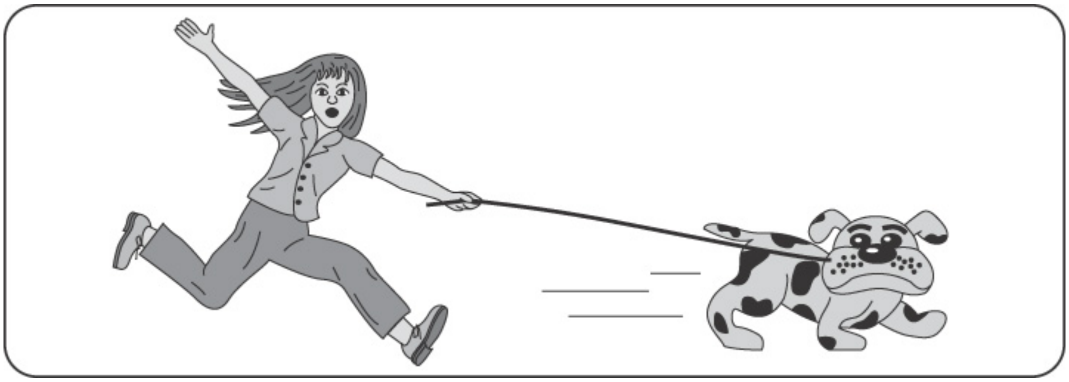
3. Why is it necessary that a force sensor be calibrated?

4. Sketch your Prediction 2-2 below.



Name______________ Date____________________ Partners______________

LAB 4: FORCE AND MOTION



A vulgar Mechanik can practice what he has been taught or seen done, but if he is in an error he knows not how to find it out and correct it, and if you put him out of his road, he is at a stand; whereas he that is able to reason nimbly and judiciously about figure, force and motion, is never at rest til he gets over every rub.

—Isaac Newton

OBJECTIVES

- To learn how to use a force sensor to measure force and to set up a force scale.
- To explore how the motion of an object is related to the forces applied to it.
- To find a mathematical relationship between the force applied to an object and its acceleration.

OVERVIEW

In the previous labs, you have examined position–time, velocity–time, and acceleration–time graphs of different motions of the IOLab using the **Wheel** displays. You were not concerned about how you got the IOLab to move, i.e., what forces (pushes or pulls) acted on it. From your own experiences, you know that force and motion are related in some way. To start your bicycle moving, you must apply a force to the pedal. To start up your car, you must step on the accelerator to get the engine to apply a force to the road through the tires.

But exactly how is force related to the quantities you used in the Labs 1 and 2 to describe motion—position, velocity, and acceleration? In this lab you will pay attention to forces and how they affect motion. You will learn how to measure forces. By applying forces to the IOLab and observing the nature of its resulting motion graphically, you will come to understand the effects of forces on motion.

INVESTIGATION 1: MEASURING FORCES

In this investigation you will explore the concept of a constant force and the combination of forces in one dimension. You can use these concepts to learn how to set up a force scale and measure forces with a force sensor. You will need the following materials:

- IOLab with force sensor hook
- computer with IOLab software
- five identical rubber bands

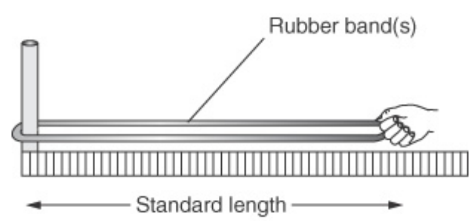
Activity 1-1: How Large Is a Pull?

If you pull on a rubber band attached at one end, you know it will stretch. The more you pull, the more it stretches. Try it.

1. Attach one end of the rubber band to something on the table that can't move. Also attach the meter stick to the table. Now stretch the rubber band so it is several centimeters longer than its relaxed length. Does it always seem to exert the *same* pull on you each time it is stretched to the *same* length? (Most people agree that this is obvious.)
2. Write down the length you have chosen in the space below. This will be your standard length for measurements.

   Standard length of rubber band = ______cm

3. Attach one end of each of two identical rubber bands to something that can't move and stretch them together side-by-side to the standard length.



Question 1-1: How does the combined force of two rubber bands compare to what you felt when only one rubber band was used?

4. Repeat this comparison of how strong the forces feel with three, four, and five rubber bands stretched together to the same standard length.

Question 1-2: Suppose you stretched a rubber band to your standard length by pulling on it. Now you want to create a force six times as large. How could you create such a force?

Question 1-3: Suppose you applied a force with a stretched rubber band one day, and several days later you wanted to feel the same force or apply it to something. How could you assure that the forces were the same? Explain.

Question 1-4: Do side-by-side rubber bands provide a convenient way of accurately reproducing forces of many different sizes? Explain.

Pulling more rubber bands to the same length requires a larger pull. To be more precise about the pulls and pushes you are applying, you need a device to measure forces accurately. The electronic force sensor that is part of the IOLab is designed to do this.

Activity 1-2: Measuring Forces with a Force Sensor

In this activity you will explore the capability of the IOLab's electronic force sensor as a force-measuring device.

1. Screw the hook into the IOLab force sensor until it is tight.
2. Plug the IOLab dongle into a USB port on your computer. Open the IOLab software, and turn on the IOLab.
3. Select **Calibrate**  from the menu, and follow the directions to **Calibrate** (set up) the IOLab force sensor.
4. Select **Force** in the **Sensor** menu to display force vs. time axes.
5. Screw the hook into the force sensor, and attach three rubber bands to the hook.
6. Place the IOLab on a horizontal table with its wheels pointing upwards, and the rubber bands lying on the table (not pulling on the hook).

> **Note:** Since forces are detected by the computer system as *changes* in an electronic signal, it is important to first have the computer "read" the signal when the force sensor has no force pushing or pulling on it. This process is called "zeroing." Also, the electronic signal from the force sensor can change slightly as the temperature changes.

7. Click **Record** and immediately click the **Rezero Sensor** button. Then—while holding the IOLab in place—pull the rubber bands to the standard length from Activity 1-1, and **hold**. Click **Stop**. Make sure you understand what part of the graph represents when the data were taken.
8. Read the average force sensor reading from the graph while the rubber bands are stretched. Use the **analysis feature** of the software to get accurate force readings. Average reading: _______

> **Note:** The force sensor is set up to read a pull on the hook as a negative force. This is the way the sensor is set up. You will adjust for this in later activities.

9. Click **Reset**.

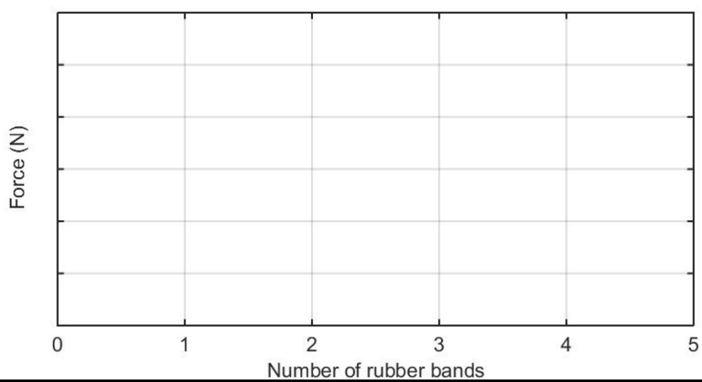
10. Remove one rubber band from the hook. You will still have two rubber bands connected to the hook. With the rubber bands loose, click **Record** and immediately click the **Rezero Sensor** button. Then—while holding the IOLab in place—pull the rubber bands to the standard length and **hold**, and read the average force sensor reading from the graph: ______

11. Repeat the process with one rubber band stretched to your standard length, and read the average force sensor reading from the graph: ______

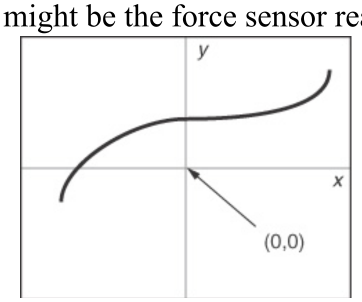
12. Record the force sensor reading for each number of rubber bands in the table below.

Number of rubber bands	0	1	2	3
Force sensor reading (N)				

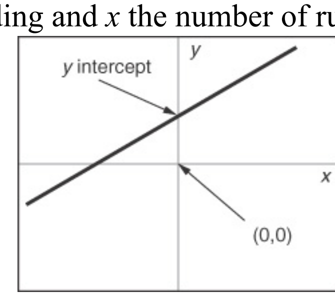
13. On paper, or with graphing software, plot a graph of Force sensor reading vs. Number of rubber bands pulled to your standard length.



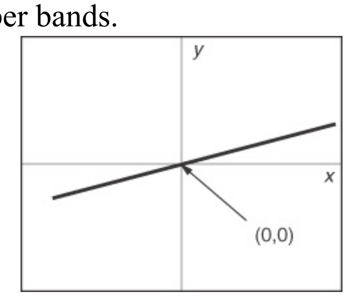
Comment: We are interested in the nature of the mathematical relationship between the reading of the force sensor and force (in rubber band units). This can be determined from the graph by drawing a smooth curve that fits the plotted data points. Some definitions of possible mathematical relationships are shown below. In these examples, y might be the force sensor reading and x the number of rubber bands.



y is a function of x, which increases as x increases.



y is a *linear* function of x, which increases as x increases according to the mathematical relationship $y = mx + b$, where b is a constant



y is *proportional* to x. This is a special case of a linear relationship where $y = mx$, and b, the y *intercept,* is zero.

called the *y intercept*.

These graphs show the differences between these three types of mathematical relationship. *y* can increase as *x* increases, and the relationship doesn't have to be *linear* or *proportional. Proportionality refers only to the special linear relationship where the y intercept is zero, as shown in the example graph on the right.*

Question 1-5: How are force sensor readings related to the size of the pull exerted on the force sensor hook by the rubber bands? Describe the mathematical relationship in words.

Question 1-6: Based on your graph, what force sensor reading corresponds to the pull of one rubber band when stretched to your standard length? How did you determine this?

Comment: You can use your measurements to define a quantitative force scale. You might call it the "rubber band scale," or give it yours or your partner's name. Whenever the force sensor has the reading corresponding to the pull of one rubber band stretched the standard length, the force is equivalent to one "rubber band," or one "Mary" or one "Sam." Other forces can be measured as some number of these units.

Your graph relates two different ways of measuring force, one with standard stretches of different numbers of rubber bands (rubber band units) and the other with a force sensor. This is called a *calibration curve* and is used to compare measurements of quantities made with two different measuring instruments. You could use it to convert forces measured in force sensor units to rubber band units, and vice versa.

Physicists have defined a standard unit of force called the *newton,* abbreviated N. For the rest of your work on forces and the motions they cause, it will be more convenient to use the force sensor readings directly in newtons. Then the forces you measure can be compared to forces anyone else measures.

INVESTIGATION 2: MOTION AND FORCE

Now you can use the IOLab to explore the effects of forces applied to it by using the measurements of the **Wheel** and **Force Sensor** together. You will be able to explore the relationship between motion and force.

You will need the following materials:

- IOLab and hook
- computer with IOLab software
- smooth tabletop or other flat surface at least 0.5 m long

Activity 2-1: Pushing and Pulling a Cart

In this activity you will move the low friction IOLab by pushing and pulling it with your hand. You will measure the **force**, **velocity**, and **acceleration** vs. time. Then you will be able to look for mathematical relationships between the applied force and the velocity and/or acceleration, to see whether either velocity or acceleration (or neither) is related to the force.

1. **Set** up the IOLab and force sensor hook on a smooth level surface as shown below.

Prediction 2-1: Suppose you grasp the force sensor hook and move the IOLab forward and backward. Do you think that either the velocity or the acceleration graph will look like the force graph? Is either of these motion quantities related to force? (That is to say, if you apply a changing force to the IOLab, will the velocity or acceleration change in the same way as the force?) Explain.

Test your prediction.

2. If you haven't closed the IOLab software, your force sensor should already be calibrated from Investigation 1. If it isn't, close and re-open in the IOLab software, select **Calibrate**  from the menu, and follow the directions.

3. Now, select **Wheel** and **Force** to display **velocity** and **acceleration**, and **force** axes. (Click on **R_y** so that **position** is <u>not</u> displayed.) Set the **Data smoothing** to **7 points** for each set of axes. Try your best to get both sets of axes displayed on the screen.

4. Click the **Reverse y-axis box for both the Wheel and Force graphs**.

> **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.

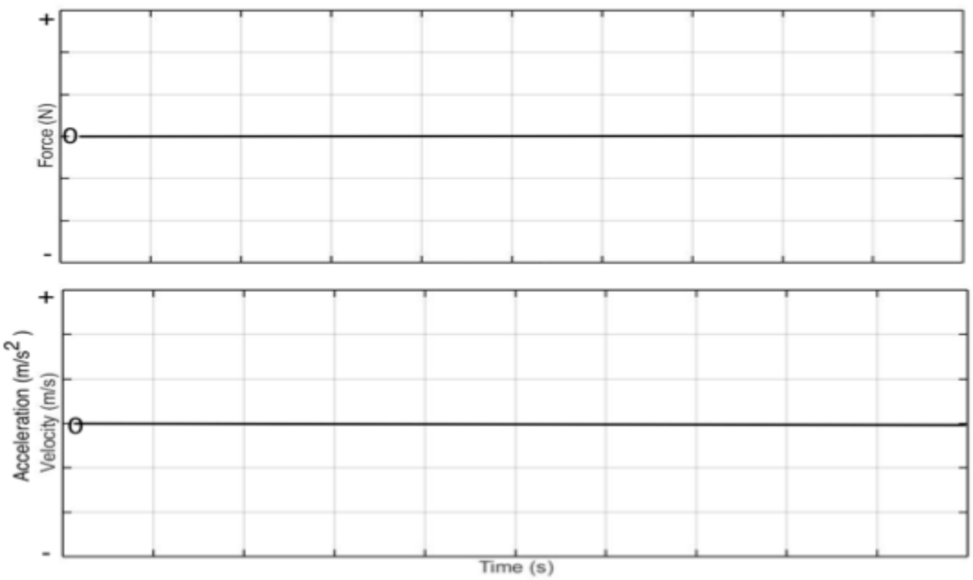
5. **Click Record**, and immediately click **Rezero sensor** to zero the force sensor. Then grasp the force sensor hook and pull the cart quickly towards you and then stop it quickly. Wait a second and then push it quickly away from you and again stop it quickly. **Note: Try to get sudden starts and stops, and to pull and push the force sensor hook along a straight line without lifting the IOLab off the tabletop.**

6. Repeat both of these motions one more time, and then click **Stop**.

7. Identify and label on the graphs what the times are at which the actions listed above happen. If necessary, repeat this set of motions several times until you are clear what happens at what moment.

8. Keep a copy of your graphs (print or save) , and carefully sketch your graphs on the RESULTS axes below. Make sure you indicate what the numerical scale is on the horizontal and vertical axes.

RESULT



Question 2-1: Does either graph—velocity or acceleration—resemble the force graph? Which one? Explain how you reached this conclusion.

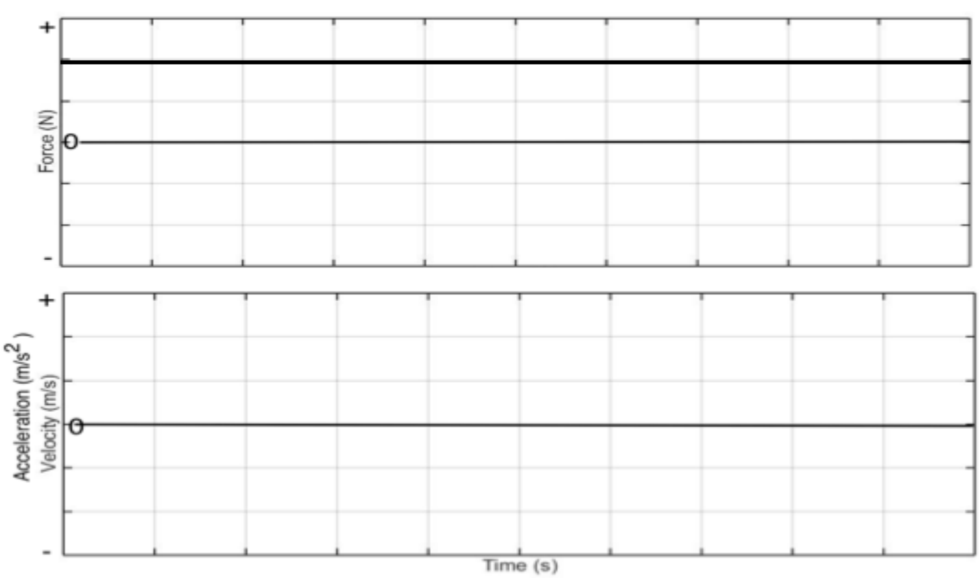
Question 2-2: Based on your observations, does it appear that there is a mathematical relationship between either (1) applied force and velocity, (2) applied force and acceleration, (3) both, or (4) neither? Explain based on your graphs.

Activity 2-2: Speeding Up Again

You have seen in the previous activity that force and acceleration seem to be related. But just what is the relationship between force and acceleration?

Prediction 2-2: Suppose that you have a cart with very little friction and you pull it with a constant force as shown on the force–time graph below. Sketch on the PREDICTION axes your predictions of the velocity–time and acceleration–time graphs of the cart's motion.

PREDICTION



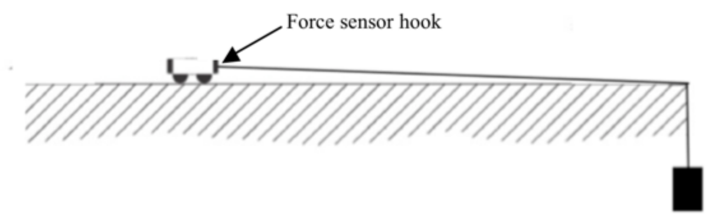
Describe in words the predicted shape of the velocity vs. time and acceleration vs. time graphs that you sketched.

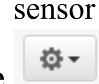
To test your predictions, you will need the following:

- IOLab and hook
- IOLab software
- smooth tabletop or other flat surface at least 0.5 m long
- string
- variety of hanging masses roughly 20, 40 and 60 g (or a pop can and coins)

Test your predictions.

1. Set up the IOLab on the tabletop or ramp as shown below, with the string attached to the hook and hung over the edge of the table with a mass of about 20 g hanging from it. The mass should have around 0.75 m to fall to the floor.



2. If you haven't closed the IOLab software, your force sensor should already be calibrated from Investigation 1. If it isn't, select **Calibrate**  from the menu, and follow the directions. Since calibration takes practically no time, it is wise to redo it, to make sure your data are good.

3. Select **Wheel** and **Force** to display **velocity**, **acceleration**, and **force** axes. (Click on **R_y** so that **position** is <u>not</u> displayed.) Set the **Data smoothing** to **7 points** for each set of axes. Try your best to get both sets of axes displayed on the screen.

4. Click the **Reverse y-axis box for bopth the Wheel and Force graphs**.

5. Begin with the mass hung over the edge, but the string held loose by a finger at the edge of the tabletop. That is, initially there is no force applied to the force sensor. Make sure the weight is not swinging.

6. Click **Record**, and immediately click **Rezero sensor** to zero the force sensor. Then release your finger, and let the falling mass pull the IOLab across the table. Stop the IOLab just before it falls off the edge of the tabletop. Then click **Stop**.

7. If necessary, repeat until you get good graphs for the entire motion of the IOLab.

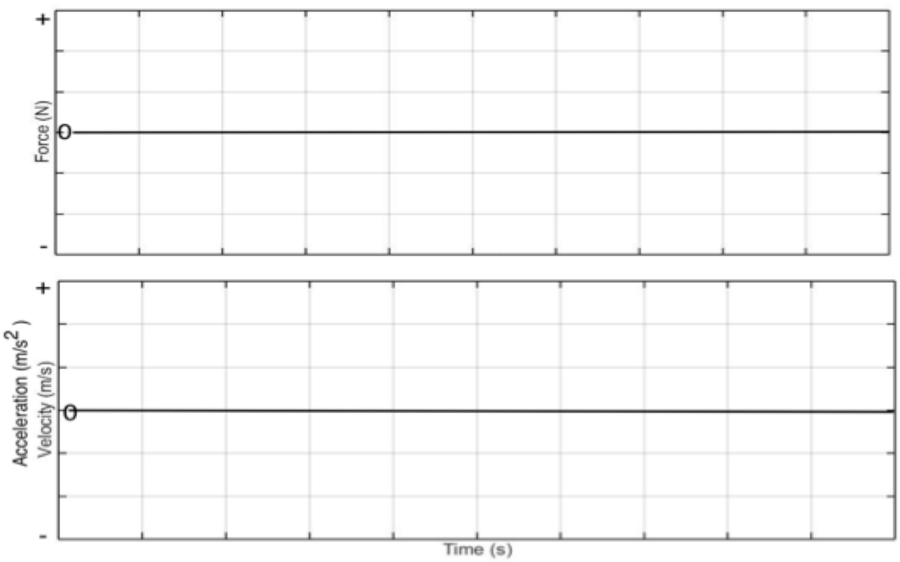
8. If necessary, **adjust the axes** to display the graphs more clearly. Keep copies of the graphs (print or save) and sketch the actual velocity, acceleration, and force graphs on the RESULTS axes below. Draw smooth graphs; don't worry about small bumps.

Identify the time before the mass is released, the moment it is released, and the moment you stop the IOLab at the edge of the table.

9. Measure the average force and average acceleration over the time that the IOLab was being pulled by the falling mass.

Average force 1: _________ N   Average acceleration 1: ____________ m/s^2

RESULTS



Questions 2-3: After the cart is moving, is the force that is applied to the IOLab by the string constant, increasing, or decreasing? Explain based on your graph.

Question 2-4: How does the acceleration vary in time? Does this agree with your prediction? Does a constant applied force produce a constant acceleration?

Question 2-5: How does the velocity vary in time? Does this agree with your prediction? What kind of change in velocity corresponds to a constant applied force?

Activity 2-3: Acceleration from Different Forces

In the previous activity you examined the motion of the IOLab with a constant force applied to it. But what is the relationship between acceleration and force? If you apply a larger force to the same IOLab (while the mass of the IOLab is not changed) how will the acceleration change? In this activity you will try to answer these questions by applying different forces to the IOLab, and measuring the corresponding accelerations.

If you accelerate the same IOLab with two other different forces, you will then have enough data to plot a graph of acceleration vs. force. You can then find the mathematical relationship between acceleration and force (with the mass of the IOLab kept constant).

Prediction 2-3: Suppose you pulled the cart with a force about twice as large as before. What would happen to the acceleration of the cart? Explain.

Test your prediction. Accelerate the cart with a larger force than before. To produce a larger force, hang a mass about two times as large as in the previous activity. Don't forget to follow these steps:

1. If you haven't closed the IOLab software, your force sensor should already be calibrated from Investigation 1. If it isn't, select **Calibrate**  from the menu, and follow the directions.
2. Select **Wheel** and **Force** to display **velocity**, **acceleration**, and **force** axes. (Click on **R**$_y$ so that **position** is <u>not</u> displayed.) Set the **Data smoothing** to **7 points** for each set of axes. Try your best to get both sets of axes displayed on the screen.
3. Begin with the <u>mass of about 40 g</u> hung over the edge, but the string held loose by a finger at the edge of the table, i.e., initially there is no force applied to the force sensor.
4. Click the **Reverse y-axis box for bopth the Wheel and Force graphs**.
5. Click **Record**, and immediately click **Rezero sensor** to zero the force sensor. Then release your finger, and let the falling mass pull the IOLab across the table. Stop the IOLab just before it falls off the edge of the tabletop. Then click **Stop**.
6. If necessary, **adjust the axes** to display the graphs more clearly. Keep copies (print or save) and sketch the actual velocity, acceleration, and force graphs using dashed or different color lines on the same RESULTS axes above. Be sure that any differences between these graphs and the ones for the smaller hanging mass are clearly represented by your graphs.

7 Measure the average force and average acceleration over the time that the IOLab was being pulled by the falling mass:

Average force 2: ___________ N Average acceleration 2: ___________ m/s^2

Question 2-6: How did the force applied to the cart compare to that with the smaller force in Activity 2-2?

Question 2-7: How did the acceleration of the cart compare to that caused by the smaller force in Activity 2-2? Did this agree with your prediction? Explain.

8. Repeat steps 1-4 with a mass of about 60 g, three times the mass used in Activity 2-2.

9. Measure the average force and average acceleration over the time that the IOLab was being pulled by the falling mass:

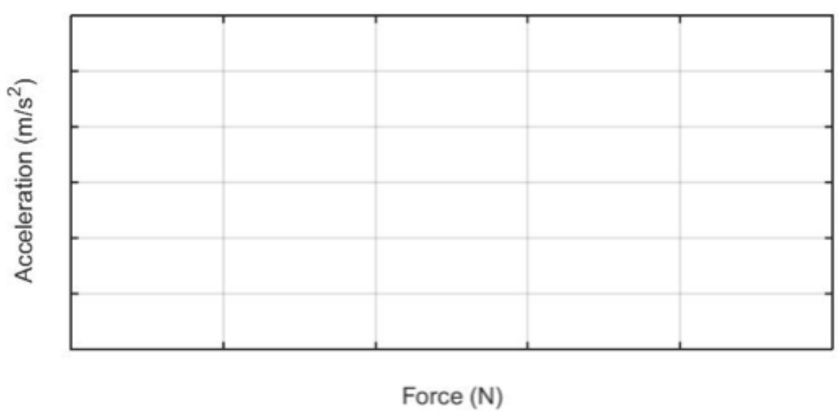
Average force 3: ___________ N Average acceleration 3: ___________ m/s^2

10. Record your measured values in Table 3-1.

Table 3-1

Trial	Average force (N)	Average acceleration (m/s^2)
0	0.0	0.0
20 g mass		
40 g mass		
60 g mass		

11. On paper, or with graphing software, plot a graph of acceleration vs. applied force. Sketch your graph on the axes below (or print or save the graph).



If you have time, carry out the following Extension to get more data for the acceleration vs. force graph you will make in the next activity. **If you don't have time to collect more data, skip to Questions 2-9 and 2-10.**

Extension 2-4: More Acceleration vs. Force Data

Gather data for average acceleration and average force for several other forces applied to the same IOLab. Be sure to follow steps 1-4 in Activity 3-2. Fill in the remaining rows in Table 3-1, and add these data points to your graph or software graphical analysis.

Question 2-8: Does there appear to be a simple mathematical relationship between the acceleration of the IOLab (with fixed mass and small friction) and the force applied to the IOLab (measured by the force sensor)? Write down the equation you found and describe the mathematical relationship in words. (You may want to refer to the **Comment** at the bottom of page 6.)

Question 2-9: If you increased the force applied to the IOLab by a factor of 10, how would you expect the acceleration to change? How would you expect the acceleration–time graph of the IOLab's motion to change? Explain based on your graphs.

Question 2-10: If you increased the force applied to the IOLab by a factor of 10, how would you expect the velocity–time graph of the IOLab's motion to change? Explain based on your graphs.

Comment: The mathematical relationship that you have been examining between the acceleration of the cart and the applied force is known as *Newton's second law.* In words, when there is only one force acting on an object, the force is equal to the mass of the object times its acceleration.

HOMEWORK FOR LAB 4:
FORCE AND MOTION

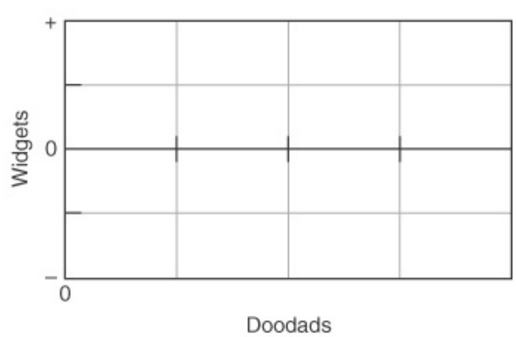
1. You are given 10 identical springs. Describe how you would develop a scale of force (i.e., a means of producing repeatable forces of a variety of sizes) using these springs.

2. Describe how you would use an un-calibrated force sensor and the springs in Question 1 to develop a quantitative scale of force. How could you measure forces that do not correspond to exact numbers of stretched springs?

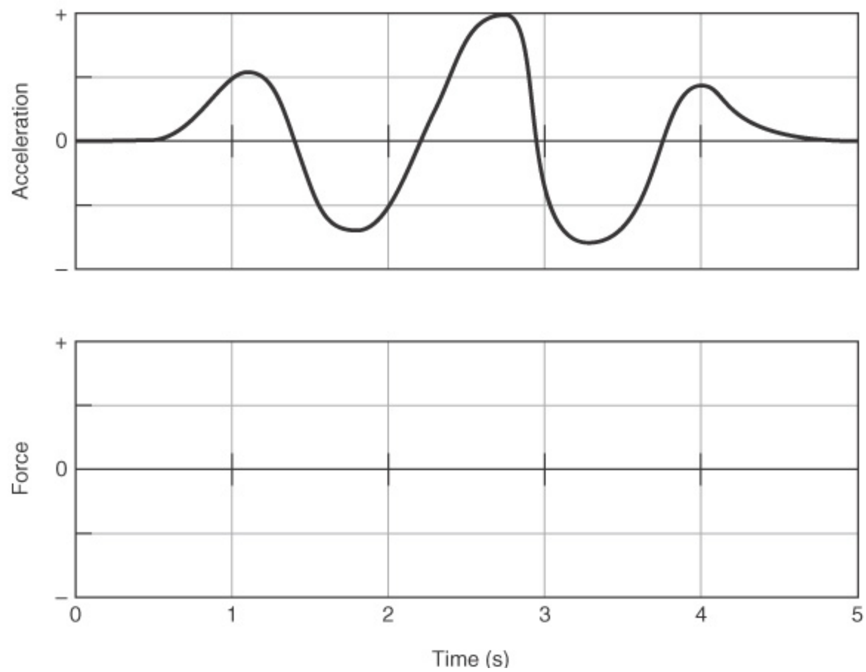
3. What is meant by a proportional relationship? Is this the same as a linear relationship? Explain.

4. Given the table of data below for widgets and doodads, how would you determine if the relationship between widgets and doodads is a proportional one? Sketch on the axes to the right of the table what the graph would look like if widgets are proportional to doodads.

Widgets	Doodads
0.0	0.0
150.5	10.0
305.0	20.0
442.7	30.0
601.3	40.0

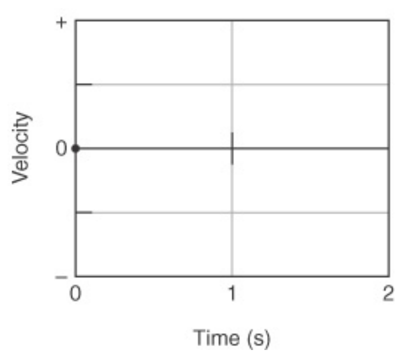


5. A force is applied that makes an object move with the acceleration shown below. Assuming that friction is negligible, sketch a graph of the force on the object as a function of time on the axes below.

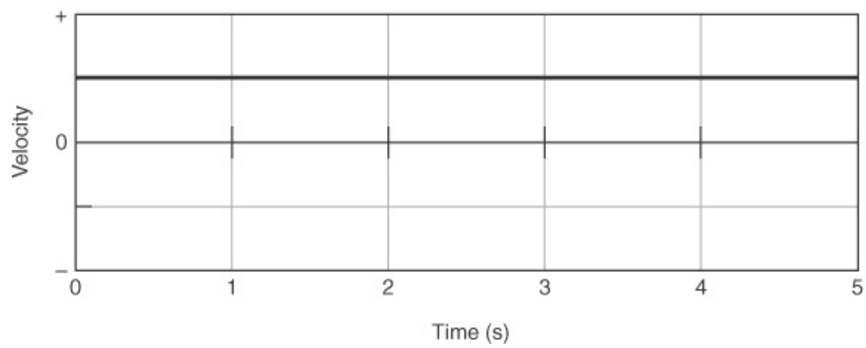


Explain your answer:

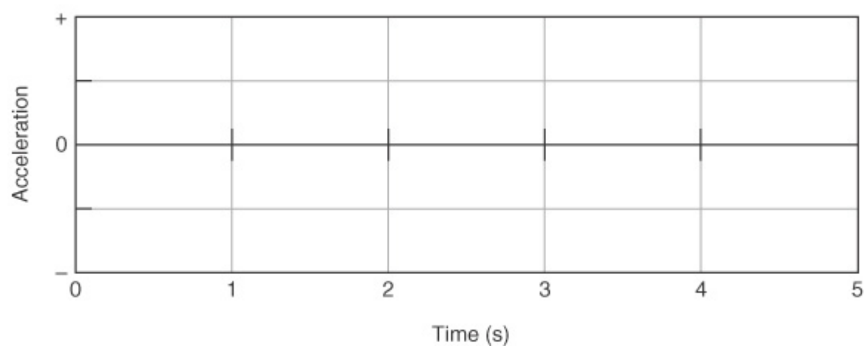
6. Assuming that the object starts at rest, roughly sketch a possible velocity–time graph for the object in Question 5 for the first 2 sec on the axes below.



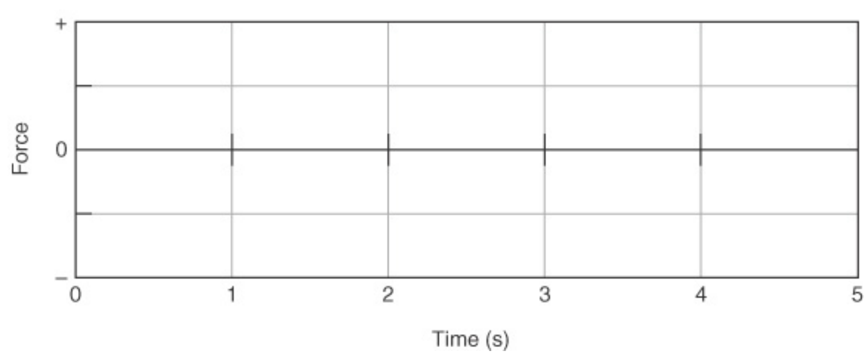
7. A cart can move along a horizontal line (the + position axis). It moves with the velocity shown below.



Sketch the acceleration–time graph of the cart's motion on the axes below.



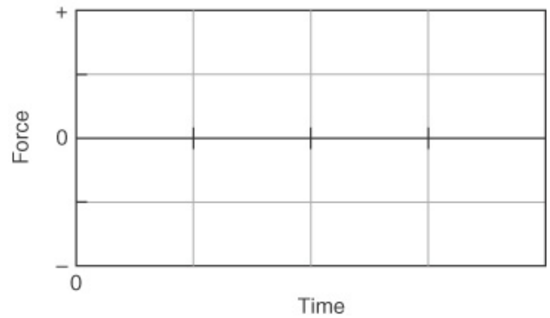
Assuming that friction is so small that it can be neglected, sketch on the axes below the force that must act on the cart vs. time to keep it moving with this velocity and acceleration.



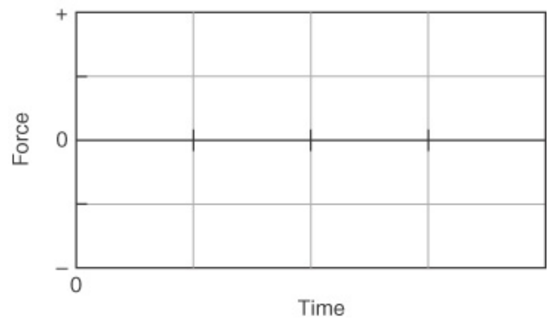
Explain both of your graphs.

Questions 8–10 refer to an object that can move in either direction along a horizontal line (the + position axis). Assume that friction is so small that it can be neglected. Sketch the shape of the graph of the force applied to the object that would cause the motion described to continue.

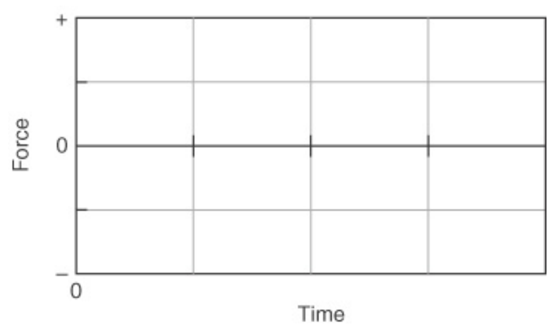
8. The object moves away from the origin with a constant velocity.



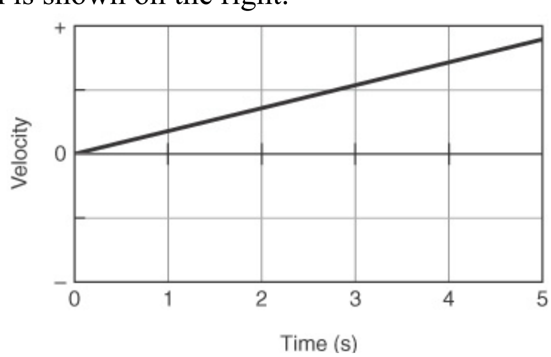
9. The object moves toward the origin with a constant velocity.



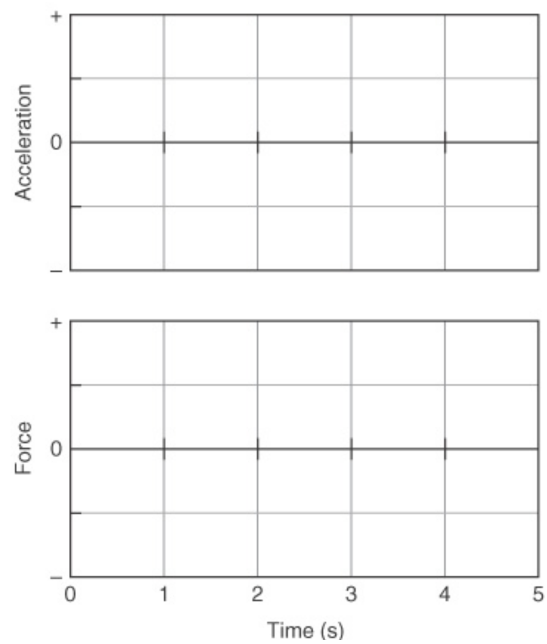
10. The object moves away from the origin with a steadily increasing velocity (a constant acceleration).



Questions 11 and 12 refer to an object that can move along a horizontal line (the + position axis). Assume that friction is so small that it can be ignored. The object's velocity–time graph is shown on the right.

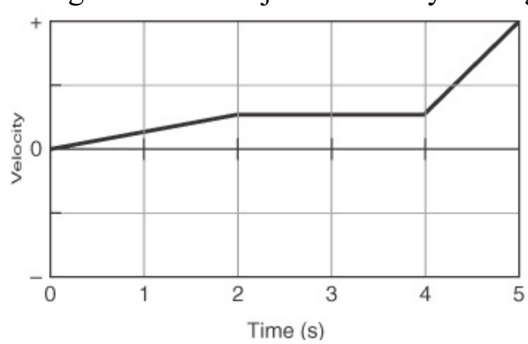


11. Sketch the shapes of the acceleration–time and force–time graphs on the axes below.



12. Suppose that the force applied to the object were twice as large. Sketch with dashed lines on the same axes above the force, acceleration, and velocity vs. time.

13. An object can move along a horizontal line (the + position axis). Assume that friction is so small that it can be ignored. The object's velocity–time graph is shown below.



Sketch the shapes of the acceleration-time and force-time graphs on the axes below.