# Newton's Second Law

How does a cart change its motion when you push and pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart's velocity related to the force you apply? Or does the force just *change* the velocity? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

A Force Sensor and an Accelerometer will let you measure the force on a cart simultaneously with the cart's acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton's second law of motion.
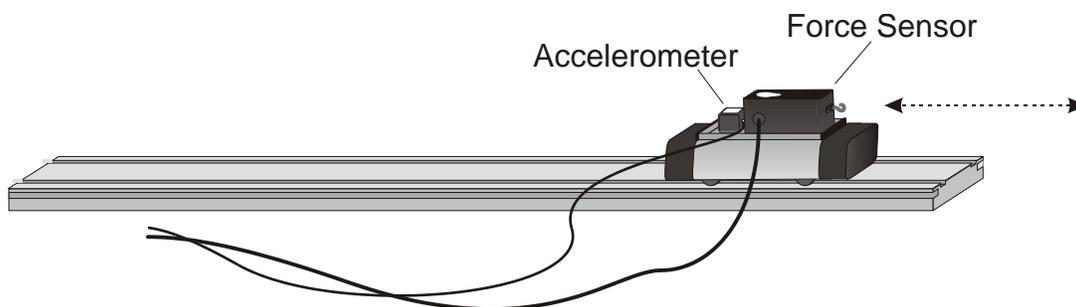


*Figure 1*

## OBJECTIVES

- Collect force and acceleration data for a cart as it is moved back and forth.
- Compare force *vs.* time and acceleration *vs.* time graphs.
- Analyze a graph of force *vs.* acceleration.
- Determine the relationship between force, mass, and acceleration.

## MATERIALS

| | |
|---|---|
| LabQuest | Vernier Force Sensor |
| LabQuest App | low-friction dynamics cart |
| Vernier Low-g Accelerometer | 0.50 kg mass |

## PRELIMINARY QUESTIONS

1. When you push on an object, how does the magnitude of the force affect its motion? If you push harder, is the change in motion smaller or larger? Do you think this is a direct or inverse relationship?

2. Assume that you have a bowling ball and a baseball, each suspended from a different rope. If you hit each of these balls with a full swing of a baseball bat, which ball will change its motion by the greater amount?

3. In the absence of friction and other forces, if you exert a force, *F*, on a mass, *m*, the mass will accelerate. If you exert the same force on a mass of 2*m*, would you expect the resulting acceleration to be twice as large or half as large? Is this a direct or inverse relationship?

## PROCEDURE

1. Attach the Force Sensor to a dynamics cart so you can apply a horizontal force to the hook, directed along the sensitive axis of your particular Force Sensor. Next, attach the Accelerometer so the arrow is horizontal and parallel to the direction that the cart will roll. Orient the arrow so that if you *pull* on the Force Sensor the cart will move in the direction of the arrow. Find the mass of the cart with the Force Sensor and Accelerometer attached. Record the mass in the data table.

2. Set the range switch on the Force Sensor to 10 N. Connect the Force Sensor and the Low-g Accelerometer to LabQuest. Choose New from the File menu. If you have older sensors that do not auto-ID, manually set up the sensors.

3. Next you will zero the sensors. To do this, place the cart on a level surface.

   a. With the cart stationary and no force applied to the Force Sensor, wait for the acceleration and force readings to stabilize.
   b. Choose Zero ► All Sensors from the Sensors menu. The readings for both sensors should be close to zero.

   **Trial I**

4. You are now ready to collect force and acceleration data. Grasp the Force Sensor hook. Start data collection and take several seconds to *gently* move the cart back and forth on the table. Vary the motion so that both small and moderate forces are applied. Make sure that your hand is only touching the hook on the Force Sensor and not the Force Sensor itself or the cart body.

5. Acceleration and force data are displayed on separate graphs. Sketch the graphs in your notes. How are the graphs similar? How are they different?

6. One way to see how similar the acceleration and force data are is to make a new plot of force *vs.* acceleration, with no time axis.

   a. Choose Show Graph ► Graph 1 from the Graph menu to view a single graph.
   b. Choose Graph Options from the Graph menu and deselect Point Protectors and Connect Points. This will remove the point protectors and the line connecting the data points on the subsequent graph.
   c. Select OK.
   d. Change the x-axis to Acceleration and the y-axis to Force.
   e. Sketch this graph in your notes.

7. To fit a line to the graph of force *vs.* acceleration,

   a. Choose Curve Fit from the Analyze menu.
   b. Select Linear as the Fit Equation. The linear-regression statistics for these two data columns are displayed in the form:

$$y = mx + b$$

   where *x* is acceleration, *y* is force, *m* is the slope, and *b* is the y-intercept. What does the

      value of the slope represent?

   c. Select OK.

   d. Print or sketch your graph.

8. Using the regression equation, determine the acceleration of the cart when a force of 1.0 N has acted upon it. Record the force and acceleration in the data table.

9. Repeat Step 8 using a force of –1.0 N.

**Trial 2**

10. Attach the 0.50 kg mass to the cart. Record the mass of the cart, sensors, and additional mass in the data table.

11. Repeat Steps 4–9 for the cart with the additional 0.50 kg mass.

## DATA TABLE

**Trial I**

| Mass of system with sensors (kg) | |
|---|---|

| Regression line for force *vs.* acceleration data |
|---|
| |

**Trial 2**

| Mass of system with sensors and additional mass (kg) | |
|---|---|

| Regression line for force *vs.* acceleration data |
|---|
| |

## ANALYSIS

1. Compare the graphs of force *vs.* time and acceleration *vs.* time for a particular trial.

2. Are the net force on an object and the acceleration of the object directly proportional? Explain, using experimental data to support your answer.

3. What are the units of the slope of the force *vs.* acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).

4. For each trial compare the slope of the regression line to the mass being accelerated. What does the slope represent?

5. Write a general equation that relates all three variables: force, mass, and acceleration.

## EXTENSIONS

1. Use this apparatus as a way to measure mass. Place an unknown mass on the cart. Measure the acceleration for a known force and determine the mass of the unknown. Compare your answer with the actual mass of the cart, as measured using a balance.