

## 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.

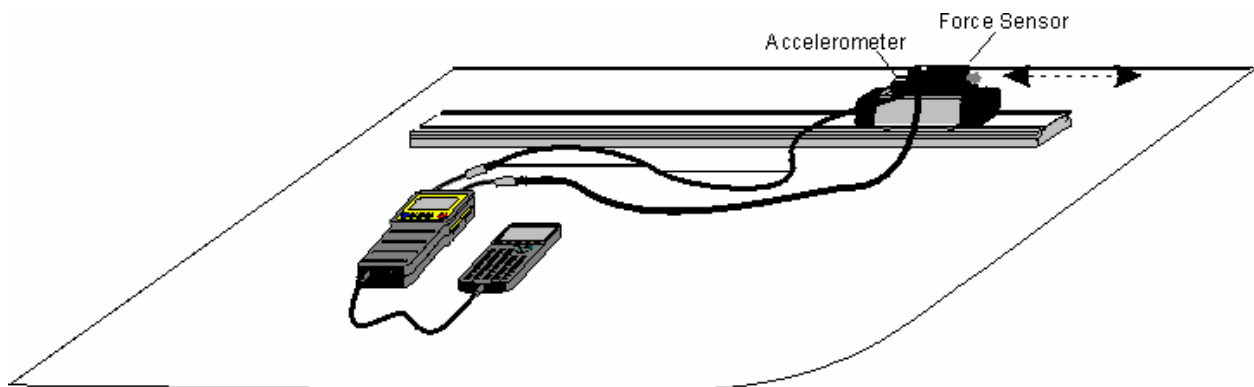


Figure 1

### 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

TI-82, 83, 86, 89, 92, or 92 Plus  
CBL System  
Vernier Force Sensor  
Vernier Low-g Accelerometer

PHYSICS program loaded in calculator  
low-friction dynamics cart  
0.50-kg mass  
Vernier adapter cables (2)

### 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?

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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  $2m$ , would you expect the resulting acceleration to be twice as large or half as large? Is this a direct or inverse relationship?

## Procedure

1. Connect the Low-g Accelerometer using the adapter cable to CH1 of the CBL System. Connect a Student Force Sensor (this is the one we use at UVA) or Dual-Range Force Sensor using the adapter cable to CH2 of the CBL System. If you are using a Dual-Range Force Sensor, set the range switch to 10N (5N on older units). Use the black link cable to connect the CBL System to the TI Graphing Calculator. Firmly press in the cable ends.
2. 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.
3. Turn on the CBL unit and the calculator. Start the PHYSICS program and proceed to the MAIN MENU.
4. Set up the calculator and CBL for the Force Sensor and the Accelerometer.
  - Select SET UP PROBES from the MAIN MENU.
  - Select TWO as the number of probes.
  - Select ACCELEROMETER from the SELECT PROBE menu.
  - Confirm that the Accelerometer is connected to CH 1, and press **ENTER**.
  - Select USE STORED from the CALIBRATION menu.
  - Select LOW-G from the ACCELEROMETER menu.
  - Select FORCE from the SELECT PROBE menu.
  - Select DUAL RANGE 5N, DUAL RANGE 10N, or STUDENT FORCE as appropriate for your sensor.
  - Confirm that the Force Sensor is connected to CH 2, and press **ENTER**.
  - Select USE STORED from the CALIBRATION menu.
5. Next you will zero the sensors. To do this, place the cart on a level surface.
  - Select ZERO PROBES from the MAIN MENU.
  - Select ALL CHANNELS from the SELECT CHANNEL menu.
  - With the cart stationary and no force applied to the Force Sensor, wait for the reading on the CBL to stabilize, and then press **TRIGGER** on the CBL.
6. Set up the calculator and CBL for data collection.
  - Select COLLECT DATA from the MAIN MENU.
  - Select TIME GRAPH from the DATA COLLECTION menu.
  - Enter "0.1" as the time between samples, in seconds.
  - Enter "50" as the number of samples (the CBL will collect data for about 5 seconds).
  - Press **ENTER**, then select USE TIME SETUP to continue. If you want to change the sample time or sample number, select MODIFY SETUP instead.

**Trial 1**

7. You are now ready to collect force and acceleration data. Grasp the Force Sensor hook. Press  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.
8. Press  and select CH1 to see the first graph of acceleration *vs.* time and sketch the graph in your notes. Press  and select CH2 to see the force *vs.* time graph, sketching it the same way. How are the graphs similar? How are they different?
9. 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.
  - Press  and select NEXT, then select NO to return to the MAIN MENU.
  - Select ANALYZE from the MAIN MENU.
  - Select CURVE FIT from the ANALYZE MENU.
  - Select LINEAR L2 , L3 from the CURVE FIT menu.
  - Record the parameters of the fitted equation your Data Table.
  - Press  to see your force *vs.* acceleration plot with the fitted equation.
  - Print or sketch your graph.
  - Press  to return to the MAIN MENU.
10. 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.
11. Repeat Step 10 using a force of  $-1.0$  N.

**Trial 2**

12. Attach the 0.50-kg mass to the cart. Record the mass of the cart, sensors, and additional mass in the Data Table.
13. Repeat Steps 6 – 11.

**Data Table****Trial 1**

Mass of cart with sensors (kg)	
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Fitted equation for force <i>vs.</i> acceleration data

Force pulling cart (N)	Acceleration ( $\text{m/s}^2$ )
1.0 N	
$-1.0$ N	

**Trial 2**

Mass of cart with sensors (kg)	
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Fitted equation for force vs. acceleration data

Force pulling cart (N)	Acceleration ( $\text{m/s}^2$ )
1.0 N	
-1.0 N	

**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.