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.

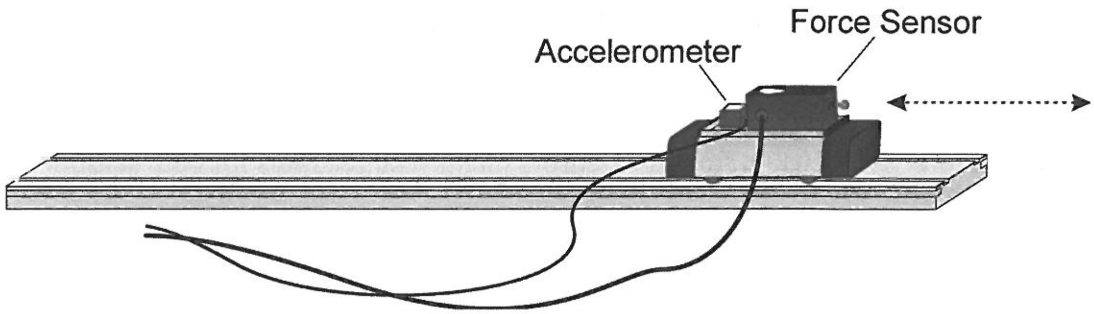

Figure 1

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
LabQuest App
Vernier Low-g Accelerometer
Vernier Force Sensor
low-friction dynamics cart
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?

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.

LabQuest

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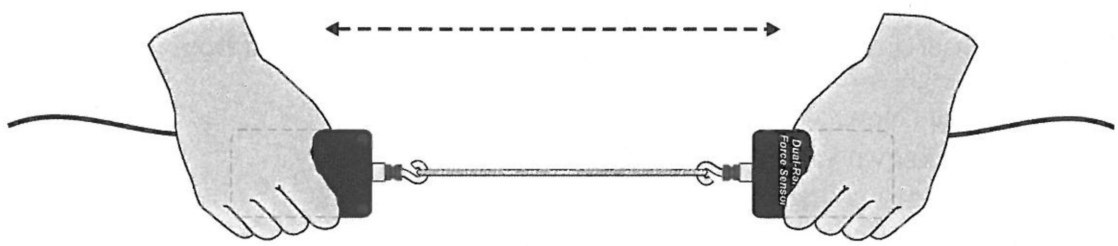
Newton's Third Law

You may have learned this statement of Newton's third law: "To every action there is an equal and opposite reaction." What does this sentence mean?

Unlike Newton's first two laws of motion, which concern only individual objects, the third law describes an interaction between two bodies. For example, what if you pull on your partner's hand with your hand? To study this interaction, you can use two Force Sensors. As one object (your hand) pushes or pulls on another object (your partner's hand) the Force Sensors will record those pushes and pulls. They will be related in a very simple way as predicted by Newton's third law.

The *action* referred to in the phrase above is the force applied by your hand, and the *reaction* is the force that is applied by your partner's hand. Together, they are known as a *force pair*. This short experiment will show how the forces are related.



OBJECTIVES

- Calibrate two Force Sensors.
- Observe the directional relationship between force pairs.
- Observe the time variation of force pairs.
- Explain Newton's third law in simple language.

MATERIALS

LabQuest	0.5 kg mass
LabQuest App	string
two Vernier Force Sensors	rubber band

PRELIMINARY QUESTIONS

1. You are driving down the highway and a bug splatters on your windshield. Which is greater: the force of the bug on the windshield, or the force of the windshield on the bug?

2. Hold a rubber band between your right and left hands. Pull with your left hand. Does your right hand experience a force? Does your right hand apply a force to the rubber band? What direction is that force compared to the force applied by the left hand?

3. Pull harder with your left hand. Does this change any force applied by the right hand?

4. You will be using the sensors in a different orientation than that in which they were calibrated. Next you will zero the sensors. This step makes both sensors read exactly zero when no force is applied. To do this,
   a. Hold both sensors with the measurement axis horizontal and no force applied to the hooks.
   b. When the readings stabilize, choose Zero ▶ All Sensors from the Sensors menu. The readings for the sensors should be close to zero.
5. Make a short loop of string with a circumference of about 30 cm. Use it to attach the hooks of the Force Sensors. Hold one Force Sensor in your hand and have your partner hold the other so you can pull on each other using the string as an intermediary. Be careful to apply force only along the sensitive direction of your particular Force Sensor.
6. Start data collection. *Gently* tug on your partner's Force Sensor with your Force Sensor. Also, have your partner tug on your sensor. You will have 5 seconds to try different pulls.
7. After data collection is complete, the graph of force *vs.* time will be displayed with data from both sensors. If either plot has force peaks with flat tops, you pulled too hard. Try again, pulling with less force. To take more data, start data collection again.
8. Print or sketch your graph. Collect another run of data.
9. What would happen if you used the rubber band instead of the string? Would some of the force get "used up" in stretching the band? Sketch a prediction graph of the two force readings in your notes, and repeat Steps 6–8 using the rubber band instead of the string.

ANALYSIS

1. Examine the graph. To examine the data on the displayed graph, select any data point. As you move the tap each data point, the two force values for a given time are displayed to the right of the graph. What can you conclude about the two forces (your pull on your partner and your partner's pull on you)? How are the magnitudes related? How are the signs related?
2. How does the rubber band change the results—or does it change them at all?
3. Is there any way to pull on your partner's Force Sensor without your partner's Force Sensor pulling back? Try it.
4. While you and your partner are pulling on each other's Force Sensors, do your Force Sensors have the same positive direction? What impact does your answer have on the analysis of the force pair?
5. Reread the statement of the third law given at the beginning of this activity. The phrase *equal and opposite* must be interpreted carefully, since for two vectors to be equal ($\vec{\mathbf{A}} = \vec{\mathbf{B}}$) and opposite ($\vec{\mathbf{A}} = -\vec{\mathbf{B}}$) then we must have $\vec{\mathbf{A}} = \vec{\mathbf{B}} = 0$; that is, both forces are always zero. What is really meant by *equal and opposite*? Restate Newton's third law in your own words, not using the words "action," "reaction," or "equal and opposite."
6. Re-evaluate your answer to the bug-windshield question.