14. Newton's Third Law

Equal and Opposite

Objectives

In this activity, students are introduced to Newton's third law of motion and learn about equal and opposite forces.

Students will investigate the equal and opposite nature of forces while they:

- Recognize that a force is a push or a pull
- Recognize that forces have magnitudes (strengths) and directions
- Relate the sign of the force to the direction, and the magnitude of the force to its strength
- State Newton's third law of motion in their own words
- Gain skills in using scientific measurement tools, the force sensor, as well as the graphing capability of a computer to represent and analyze data
- Design and conduct a scientific investigation

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure a pair of oppositely directed forces
- Measuring the forces exerted on a pair of force sensors connected together and pulled in opposite directions

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	30 minutes
Lab activity, Part 2 – Investigating the force sensor	25 minutes
Lab activity, Part 3 – Equal and opposite forces	25 minutes
Analysis	30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ Force sensors with hooks (2)
- ☐ Balloons, empty (1 or 2)
- ☐ Strong rubber band

For each student or group:

- ☐ Data collection system
- ☐ Force sensors with hooks (2)
- ☐ Strong rubber band

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- A force is a push or a pull.
- How to read and interpret a coordinate graph
- The SI unit of measure for force (newtons)
- The basics of using the data collection system.

Related Labs in This Guide

Labs conceptually related to this one include:

- Simple Machines and Force
- Work and Mechanical Advantage

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them are in the appendix that corresponds to your PASCO data collection system (identified by the number following the symbol: "�"). Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Recording a run of data �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple data runs on a graph �(7.1.10)
- Saving your experiment �(11.1)

Background

Newton's third law of motion is the one that many students in grades 5 to 8 have the most difficulty grasping, because it is difficult to observe in daily life. Newton proposed that whenever objects interact, they exert an equal amount of force on each other and that the forces are in opposing directions. Of course, the consequence of the force of one object acting on another object depends on the amount of force applied AND the amount of mass of the object (as described in Newton's second law – force is equal to the product of the mass multiplied by the acceleration).

For example, consider a tennis racket hitting a tennis ball. Do the forces of these two objects acting on each other cancel each other out? In a way, they do. The force of the tennis racket against the ball is equal and opposite to the force of the other object. The racket compresses the ball and the ball stretches the racket strings. However, since each force is acting on objects that have different masses, action can occur. The mass of the tennis ball is much less than the total mass of the tennis racket and the tennis player who is holding the racket. Therefore, the ball has much more acceleration (change in motion) than the racket. The more massive racket is exerting a force on the less massive ball, which results in the lighter ball flying away from the heavier racket.

The essential idea then, is that forces act in pairs; or, for every action (force), there is an equal and opposite reaction (force). The consequences of each force depend on the amount of force applied and the amount of mass involved.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Direct students to "Thinking About the Question." Instruct students to use various sports as a starting point, but encourage them to think of other examples as well. Not all students are interested or participate in sports, so be mindful of including all students in this discussion.

If students have difficulty coming up with "non-sports" examples, prompt them by blowing up a balloon and letting it go flying across the room. Challenge them to identify the action force (your breath shooting out the open balloon) and the reaction force (the balloon flying across the room in the opposite direction). If you have any toys available such as an "air cannon" or toy rockets and launchers, display them to help prompt students' brainstorming. List some of the students' sports and non-sports examples on the board.

For a particularly specific example, post the following quote on the board:

"I think Isaac Newton is doing most of the driving now."

(This was said by Bill Anders, who was the commander of the Apollo 8 mission to the Moon. He had been asked—by an inquisitive child—who was "driving" the space capsule as they returned to Earth from the Moon, in December, 1968.)

Ask students what they think the astronaut meant by this comment. Accept any contributions that make sense to you.

Model for the students the "tug-of-war" type pulling they will be doing with the two force sensors hooked together with the rubber band. A rubber band is used to smooth out the data; if the sensors are hooked together with just their hooks, the data will appear "choppy" with no smooth curves.

Now direct students to "Investigating the Question."

Preparation and Tips

These are the materials and equipment to set up prior to the lab:

- Install hooks on each of the force sensors ahead of time. Since the hooks and bumpers are small parts that easily get lost, put the bumpers away so students do not have access to them. Remind students not to push or pull the force sensor hooks past 50 newtons.

- Students may need help in setting up the force sensors so that one records a *pull as positive* while the second one records a *push as positive*. If time is a critical factor, you may want to have this portion of the activity set up in advance. This activity often represents a discrepant event for students in grades 5 to 8. The "mirror image" result is usually quite surprising to many students. Encourage students to work in pairs for the pulling of the force sensors, as this makes the counterintuitive results even more surprising. Allow students the time, as much as possible, to make multiple trials. Some students may have a difficult time believing what they are seeing.

- You may want to suggest that it is difficult to observe *truly* equal and opposite events of forces in daily life, because most often objects that exert forces on one another are not the same mass. One example that some students may be familiar with is from football. It is possible to observe two opposing players of the same mass (weight here on Earth for this discussion) who are running toward each other at the same speed collide and both stop in their tracks. Their forces have cancelled one another and summed to zero. Since they are experiencing a net force of zero in that moment, their motion does not change. Most objects that interact, however, do not have equal masses nor come at one another at equal speeds.

- Action-reaction force pairs can also be difficult for students to understand because of the fact that students must identify the two objects that are interacting. Sports provide many examples. Some include: a baseball being caught by a glove (the ball acts on the glove, the glove then acts on the ball); a bowling ball and bowling pins (the ball acts on one or more pins, the pins then act on the ball). Encourage students to describe in their own words what is pushing on what, and in what direction.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not over-stretch the rubber band.

- Do not apply a pushing or pulling force greater than 50 newtons to the force sensors (doing so will damage the sensors).

Driving Question

What is meant by equal and opposite forces, and what does this have to do with Newton's third law of motion?

Thinking about the Question

A force is a push or a pull. Objects can interact with one another by applying forces to each other.

If you have ever watched or participated in any sport, you have seen and experienced forces. Soccer players know that applying a large force to the ball, in the direction of the opponent's goal, is one good way to score. They hope that an opponent is not able to apply a similar large force to the ball—but in the opposite direction—before the ball enters the goal. Likewise, basketball players can apply a small, upward force to the ball just under the hoop or a large force from beyond the three-point line, in the hope of getting the ball to its target.

Occasionally, in some sports, large forces are exchanged between the players themselves, without the involvement of a ball. Football players are experts at applying pushing forces to one another. In fact, they are so good at using force to their advantage, that their progress down the field is often measured not in yards but in inches!

Discuss with your lab group members some examples of forces applied in opposite directions. Try to think of several additional examples that have to do with sports, and several that do not have to do with sports. Next, discuss with your group some examples of forces that are equal in size. Again, come up with some ideas from sports as well as some ideas that have nothing to do with sports.

Sequencing Challenge

Note: This is an optional ancillary activity.

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

5	3	1	2	4
Collect additional data so you have multiple trials of the same experiment.	Record force data.	Make sure each lab group member is aware of safety rules and procedures for this lab.	Use a rubber band to connect the hooks of two force sensors together.	Apply a series of pulling forces to a pair of force sensors connected together.

Investigating the Question

Note: When students see the symbol "�" with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please make copies of these instructions available for your students.

Part 1 – Making predictions

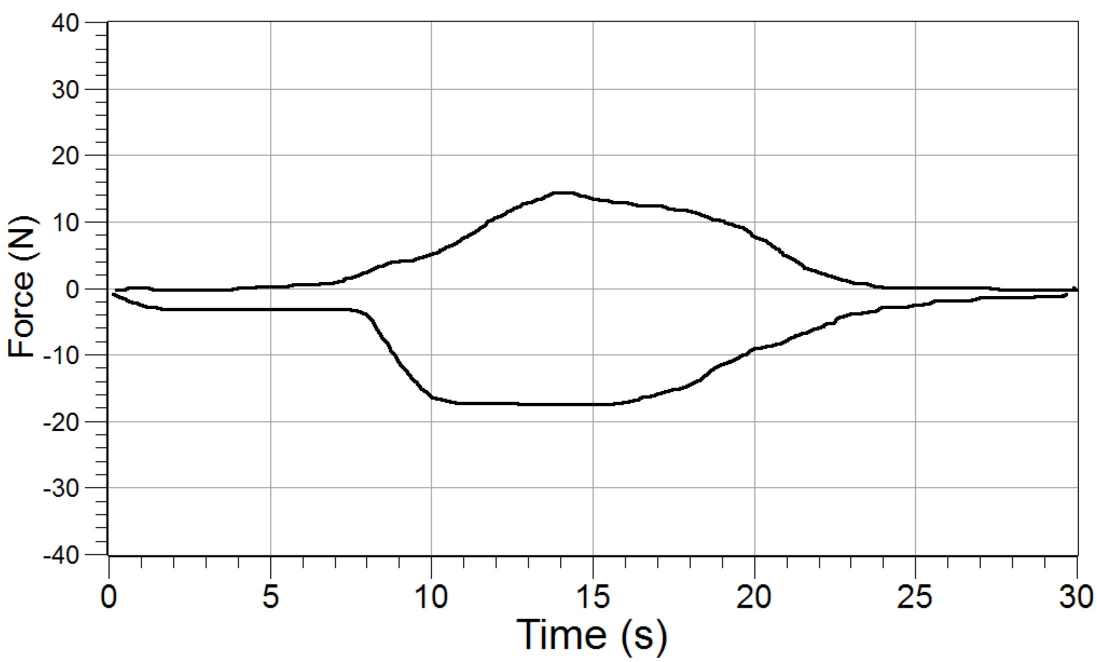
1. ☐ Write your predictions for the following:

   a. How will the graph of force (pull = positive) look when you pull on the hook of the force sensor for a few seconds and then let go?

   b. How will the graph of force (push = positive) look when you pull on the hook of the force sensor and then let go?

We think the pull = positive graph will go up when we pull on the hook. We think the push = positive graph will go below zero when we pull on the hook. When we let go, on either one, the graph will go back to zero.

   c. In the space below, sketch a force versus time graph that reflects your predictions.



Part 2 – Investigating the force sensor

2. ☐ Start a new experiment on the data collection system. �(1.2).

3. ☐ Connect a force sensor to the data collection system. �(2.1)

4. ☐ Display Force on the y-axis of a graph with Time on the x-axis. �(7.1.1).

5. ☐ Zero the force sensor (do this by pressing the small "zero" button near the top front of the sensor).

6. ☐ Begin data recording. �(6.2)

7. ☐ While holding the sensor steady, pull steadily on the hook. (Watch the graph – do not exceed 50 N of force).

8. ☐ How can you tell from the graph whether the hook is being pushed or pulled? What part of the graph display indicates whether the pull or push is positive? According to your data, what is another name for "negative" force? Explain why you think this.

Answers will vary. One student group answered as follows: When we pulled on the hook, the graph dipped below the x-axis. It went negative. When we pushed on the hook the graph went up and got more positive. We saw on the y-axis that it said Force Push Positive (N), so that is how we knew. On our graph, negative force can be considered a pull (and positive force can be considered a push).

9. ☐ Stop data recording �(6.2)

Part 3 – Equal and opposite forces

10. ☐ Connect the hooks of the two force sensors together with the rubber band.

11. ☐ Connect the second force sensor to the data collection system. �(2.2)

12. ☐ Display Force from each sensor on the y-axes of a graph with Time on the x-axis. �(7.1.10) Set one of the force sensors to measure a *push as the positive force*, and the other force sensor to measure a *pull as the positive force*. What about this set-up is described by the term "opposite?" What about this set-up makes it "equal?" Do you think the forces you are about to apply will be balanced? Explain why you think this.

Answers will vary. One student group answered as follows: In this set-up, opposite describes the direction we will be pulling the two force sensors, since we will be pulling them apart and away from each other. Equal is probably describing the two force sensors, which are the same thing. When we pull our force sensors apart in opposite directions, the forces will be equal to each other. We think this because this is what Newton's third law of motion says will happen.

13. ☐ Zero each force sensor.

14. ☐ Begin data recording. �(6.2).

15. ☐ Rest the two force sensors flat on your table and gently pull them apart from each other, stretching the rubber band as you do. Remember not to pull hard enough to break the rubber band.

16. ☐ Record pulling data for 20 to 30 seconds. See how much variety you can produce in your graph.

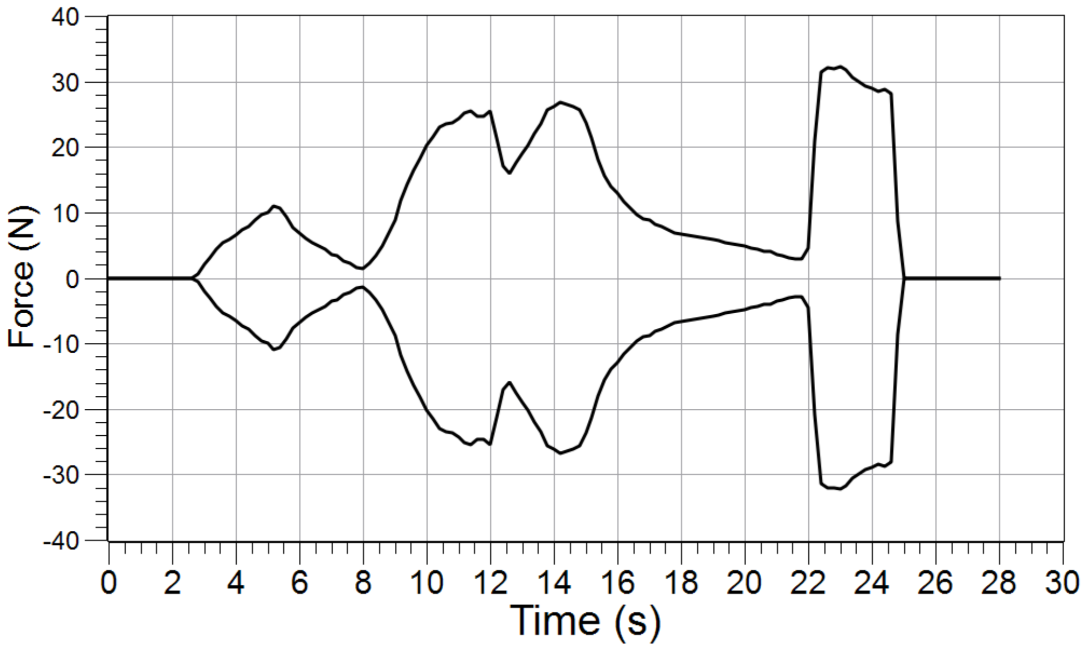
17. ☐ If there is time, have each lab group member take a turn pulling on the force sensors.

18. ☐ Stop data recording. �(6.2)

19. ☐ What did you notice about the two forces, based upon your observations of the graphs? Write your observations.

Answers will vary. One student group answered as follows: The graphs made a mirror image every time, no matter who was pulling on the force sensors. We could not get the two force sensors to make anything but mirror image patterns of data,

Sample Data



Answering the Question

Analysis

1. How did your predictions from Part 1 compare to the results in Part 2?

Answers will vary. One student group answered as follows: We predicted that if the push is set to positive, then the way to get a negative graph is to pull the hook. When the pull is set to positive, you have to push on the hook to get the graph to be negative.

It turned out that depending on how the force sensor is set up, you can get a positive or negative graph for either a push or a pull.

2. Sir Isaac Newton's third law of motion states that if one object applies a force on another object, then the second object applies a force of equal strength and opposite direction back on the first object. How does your data from Part 3 support Newton's third law of motion? Explain your reasoning.

Answers will vary. One student group answered as follows: Newton's 3rd law is supported by our graphs of data because there are two parts to every force graph, and one part is always positive while the other part is always negative. The forces always came in pairs. So this supports the "opposite" part of the 3rd law. Also, our graphs were definitely equal. Ever y graph we made was an exact mirror image, as if we had done a reflection of it over the x-axis. This supports the “equal” part of the 3rd law.

3. How could you re-state or paraphrase Newton’s third law of motion in your own words?

   Answers will vary. One student group answered as follows: For every pull we did on one force sensor, the other force sensor felt the same exact thing, but in the opposite direction. If one pull was a small positive number, the opposite pull was exactly the same number but negative. This is like absolute value that we use in math. Therefore, we think that the 3rd law of motion could be called the absolute value law of motion, since the all the forces are the same distance from zero (or the x-axis on the graph).

True or False

Enter a "T" if the statement is true or an "F" if it is false.

___F___ 1. In physical science, force is measured in units called Kelvins.

___F___ 2. It is common to find forces acting alone.

___F___ 3. Newton's first law of motion is related to forces that act in pairs.

___T___ 4. An example of an action-reaction force pair is a balloon's air pushing out of the opening toward the left and the balloon flying off toward the right..

___T___ 5. If you hit a volleyball during a game, the volleyball will push back against your hand.

___F___ 6. Stretching a rubber band between two force sensors can result in forces that are in opposite directions, but are equal in strength.

Key Term Challenge

Fill in the blanks from the randomly ordered words below. You may not use all the terms, or you may use some terms more than once,

newtons	force	twelve	five
reaction	third	opposite	action

1. Newton's __third__ law of motion tells us that if one object applies a force on another object, then the second object applies a force of equal strength, but in the opposite direction, on the first object.

2. Forces always come in____action____ – ____reaction____ pairs.

3. When the space shuttle is launched, the ______action________ force pushes the rocket's hot exhaust gases downward, and the ____reaction____ force of the hot gases lifts the rocket against the downward ____force_____ of gravity.

4. An action force of twelve __newtons__ pushing on an object from the right would have a reaction force of __twelve________ __newtons______pushing back against that force from the left.

Further Investigations

Use the prediction tool �(7.1.12) to create a positive pattern. Challenge a classmate to "match" your pattern and create its opposite (mirror image) with two force sensors hooked together.

See if you can write your name and its "reflection" with two force sensors hooked together.

Compare and contrast a graph made with two hooked-together force sensors that sit flat on a table and two that are held vertically, so that one force sensor has gravity working "with" it and the other has gravity working "against" it.

Rubric

For scoring students' accomplishments and performance in the different sections of this laboratory activity, refer to the Activity Rubric in the Introduction.