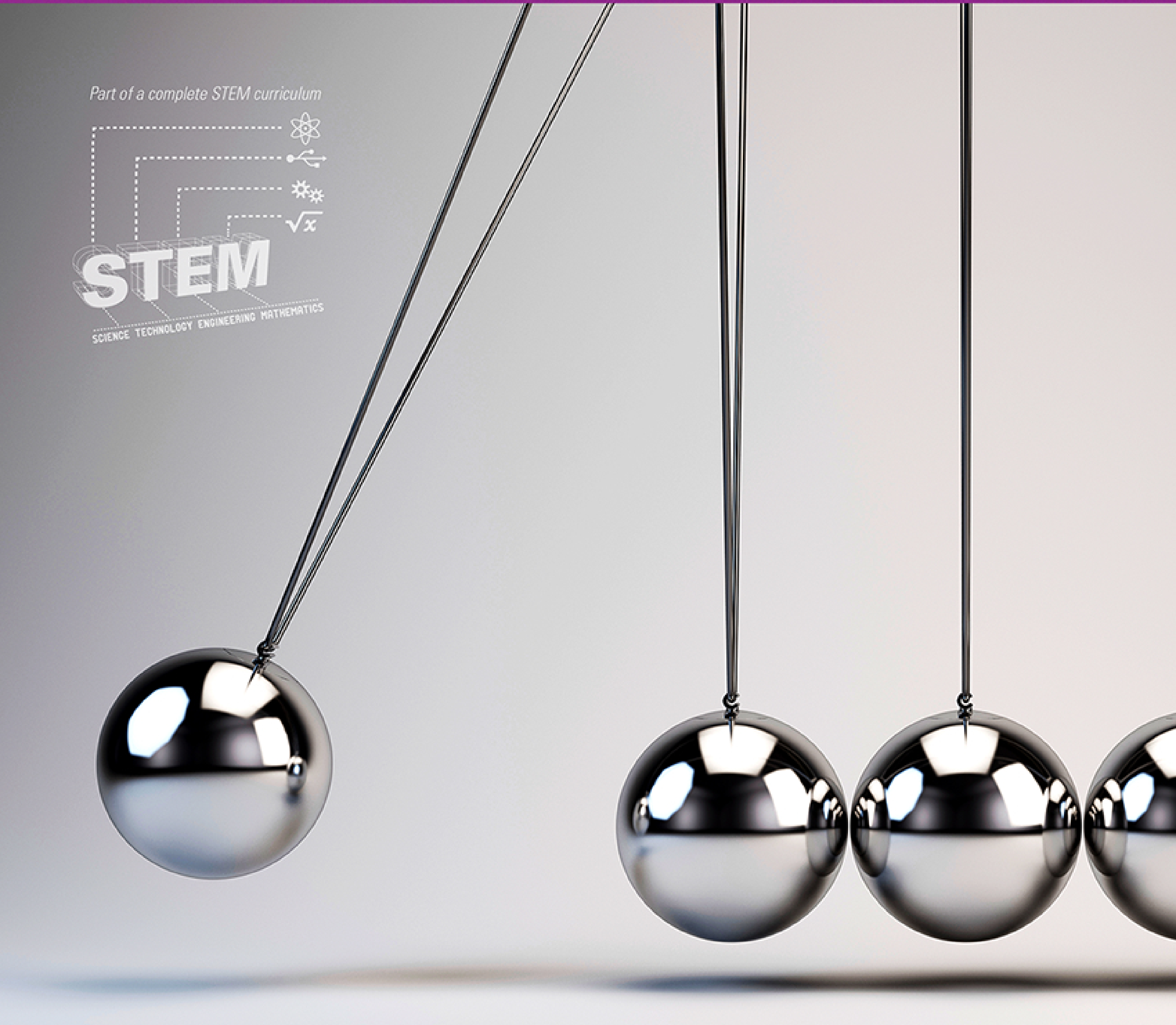
PHYSICAL SCIENCE
MIDDLE SCHOOL

PASCO®
21st CENTURY SCIENCE



Part of a complete STEM curriculum

STEM
SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS

TEACHER GUIDE | PS-3852

Middle School Physical Science
Teacher Guide

PASCO®

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Middle School Physical Science

Teacher Guide
21st Century Science

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Published by
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Roseville, CA 95747-7100
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916-786-3800
916-786-8905 (fax)
www.pasco.com

ISBN 978-1-886998-97-1
Printed in the United States of America
Catalog Number: PS-3852

Contents

Introduction

PASCO scientific's probeware and laboratory investigations move students from the low-level task of memorization of science facts to higher-level tasks of data analysis, concept construction, and application. For science to be learned at a deep level, it is essential to combine the teaching of abstract science concepts with "real-world" science investigations. Hands-on, technology-based, laboratory experiences serve to bridge the gap between the theoretical and the concrete, driving students toward a greater understanding of natural phenomenon. Students also gain important science process skills that include: developing and using models, carrying out investigations, interpreting data, and using mathematics.

At the foundation of teaching science are a set of science standards that clearly define the science content and concepts, the instructional approach, and connections among the science disciplines. The Next Generation Science Standards (2012)© are a good example of a robust set of science standards.

The Next Generation Science Standards (NGSS) position student inquiry at the forefront. The standards integrate and enhance science, technology, engineering, and math (STEM) concepts and teaching practices. Three components comprise these standards: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The lab activities in PASCO's 21st Century Science Guides are all correlated to the NGSS (see http://pasco.com).

- The *Science and Engineering Practices* help students to develop a systematic approach to problem solving that builds in complexity from kindergarten to their final year in high school. The practices integrate organization, mathematics and interpretive skills so that students can make data-based arguments and decisions.
- *Disciplinary Core Ideas* are for the physical sciences, life sciences, and earth and space sciences. The standards are focused on a limited set of core ideas to allow for deep exploration of important concepts. The core ideas are an organizing structure to support acquiring new knowledge over time and to help students build capacity to develop a more flexible and coherent understanding of science.
- *Crosscutting Concepts* are the themes that connect all of the sciences, mathematics and engineering. As students advance through school, rather than experiencing science as discrete, disconnected topics, they are challenged to identify and practice concepts that cut across disciplines, such as "cause and effect". Practice with these concepts that have broad application helps enrich students' understanding of discipline-specific concepts.

PASCO's lab activities are designed so that students complete guided investigations that help them learn the scientific process and explore a core topic of science, and then are able to design and conduct extended inquiry investigations. The use of electronic sensors reduces the time for data collection, and increases the accuracy of results, providing more time in the classroom for independent investigations.

In addition to supporting the scientific inquiry process, the lab activities fulfill STEM education requirements by bringing together science, technology, engineering, and math. An integration of these areas promotes student understanding of each of these fields and develops their abilities to become self-reliant researchers and innovators. When faced with an idea or problem, students learn to develop, analyze, and evaluate possible solutions. Then collaborate with others to construct and test a procedure or product.

Information and computer tools are essential to modern lab activities and meeting the challenge of rigorous science standards, such as NGSS. The use of sensors, data analysis and graphing tools, models and simulations, and work with instruments, all support the science and engineering practices as implemented in a STEM-focused curriculum, and are explicitly cited in NGSS. PASCO's lab activities provide students with hands-on and minds-on learning experiences, making it possible for them to master the scientific process and the tools to conduct extended scientific investigations.

About the PASCO 21st Century Science Guides

This manual presents teacher-developed laboratory activities using current technologies to help you and your students explore topics, develop scientific inquiry skills, and prepare for state level standardized exams. Using electronic-sensor data collection, display and analysis devices in your classroom fulfills STEM requirements and provides several benefits. Sensor data collection allows students to:

- observe phenomena that occur too quickly or are too small, occur over too long a time span, or are beyond the range of observation by unaided human senses
- perform measurements with equipment that can be used repeatedly over the years
- collect accurate data with time and/or location stamps
- rapidly collect, graphically display, and analyze data so classroom time is used effectively
- practice using equipment and interpreting data produced by equipment that is similar to what they might use in their college courses and adult careers

The Data Collection System

"Data collection system" refers to PASCO's DataStudio®, the Xplorer GLX™, SPARKvue™, and SPARK Science Learning System™ and PASCO Capstone™. Each of these can be used to collect, display, and analyze data in the various lab activities.

Activities are designed so that any PASCO data collection system can be used to carry out the procedure. The DataStudio, Xplorer GLX, SPARKvue, or SPARK Science Learning System Tech Tips provide the steps on how to use the data collection system and are available on the storage device that came with your manual. For assistance in using PASCO Capstone, refer to its help system.

Getting Started with Your Data Collection System

To help you and your students become familiar with the many features of your data collection system, start with the tutorials and instructional videos that are available on PASCO's website (www.pasco.com).

Included on the storage device accompanying your manual is a Scientific Inquiry activity that acts as a tutorial for your data collection system. Each data collection system (except for PASCO Capstone) has its own custom Scientific Inquiry activity. The activity introduces students to the process of conducting science investigations, the scientific method, and introduces teachers and students to the commonly used features of their data collection system. Start with this activity to become familiar with the data collection system.

Teacher and Student Guide Contents

All the teacher and student materials are included on the storage device accompanying the Teacher Guide.

Lab Activity Components

Each activity has two components: Teacher Information and Student Inquiry Worksheets.

Teacher Information is in the Teacher Guide. It contains information on selecting, planning, and implementing a lab, as well as the complete student version with answer keys. Teacher Information includes all sections of a lab activity, including objectives, procedural overview, time requirements, and materials and equipment at-a-glance.

Student Inquiry Worksheets begin with a driving question, providing students with a consistent scientific format that starts with formulating a question to be answered in the process of conducting a scientific investigation.

This table identifies the sections in each of these two activity components.

TEACHER INFORMATION	STUDENT INQUIRY WORKSHEET
Objectives	Driving Questions
Procedural Overview	
Time Requirement	
Materials and Equipment	Materials and Equipment
For teacher demonstrations	
For each student or group	For each student or group
Concepts Students Should Already Know	
Related Labs in This Guide	
Using Your Data Collection System	
Background	
Pre-Lab Discussion and Activity	
Preparation and Tips	
Safety	Safety
Driving Question	
Thinking about the Question	Thinking about the Question
Sequencing Challenge	Sequencing Challenge
Investigating the Question	Investigating the Question
Part 1 – Making predictions	Part 1 – Making predictions
Part 2 or more – procedure	Part 2 or more – procedure
Sample Data	
Answering the Question	Answering the Question
Analysis Questions	Analysis Questions
Multiple Choice Questions	Multiple Choice Questions
True/False Questions	True/False Questions
Key Term Challenge	Key Term Challenge
Further Investigations	

Electronic Materials

The storage device accompanying this manual contains the following:

- Complete Teacher Guide and Student Guide with Student Inquiry Worksheets in PDF format.
- The Scientific Inquiry activity for SPARK™, SPARKvue™, Xplorer GLX®, and DataStudio® and the Student Inquiry Worksheets for the laboratory activities are in an editable Microsoft™ Word format. PASCO provides editable files of the student lab activities so that teachers can customize activities to their needs.
- Tech Tips for the SPARK, SPARKvue, Xplorer GLX, DataStudio, and individual sensor technologies in PDF format.
- User guides for SPARKvue and GLX.
- DataStudio and PASCO Capstone® Help is available in the software application itself.

International Baccalaureate Organization (IBO*) Support

IBO Diploma Program

The International Baccalaureate Organization (IBO) uses a specific science curriculum model that includes both theory and practical investigative work. While this lab guide was not produced by the IBO and does not include references to the internal assessment rubrics, it does provide a wealth of information that can be adapted easily to the IB classroom.

By the end of the IB Diploma Program students are expected to have completed a specified number of practical investigative hours and are assessed using the specified internal assessment criteria. Students should be able to design a lab based on an original idea, carry out the procedure, draw conclusions, and evaluate their own results. These scientific processes require an understanding of laboratory techniques and equipment as well as a high level of thinking.

Using these Labs with the IBO Programs

The student versions of the labs are provided in Microsoft Word and are fully editable. Teachers can modify the labs easily to fit a problem-based format.

For IB students, pick one part of the internal assessments rubrics to go over with the students. For example, review the design of the experiment and have students explain what the independent, dependent, and controlled variables are in the experiment. Ask students to design a similar experiment, but change the independent variable.

Delete certain sections. As students become familiar with the skills and processes needed to design their own labs, start deleting certain sections of the labs and have students complete those parts on their own. For example, when teaching students to write their own procedures, have the students complete one lab as it is in the lab guide. In the next lab, keep the Sequencing Challenge, but have students write a more elaborate procedure. Finally, remove both the Sequencing Challenge and the Procedure sections and have students write the entire procedure.

Encourage students to make their own data tables. Leave the procedure, but remove the data tables and require the students to create them on their own. In another lab, leave the driving question and procedure, but remove the analysis questions and have students write their own analysis, conclusion, and evaluation.

Use only the driving question. As students' progress through their understanding of the structure of an experiment, provide them with just the driving question and let them do the rest. Some of the driving questions are too specific (they give the students the independent variable), so revise them appropriately.

Extended inquiry. After students complete an activity in the lab guide, use the extended inquiry suggestions to have the students design their own procedure, or the data collection and processing, or both.

About Correlations to Science Standards

The lab activities in this manual are correlated to a number of standards, including United States National Science Education Standards, the Next Generation Science Standards, and all State Science Standards. See http://pasco.com for the correlations.

Global Number Formats and Standard Units

Throughout this guide, the International System of Units (SI) or metric units is used unless specific measurements, such as air pressure, are conventionally expressed otherwise. In some instances, such as weather parameters, it may be necessary to alter the units used to adapt the material to conventions typically used and widely understood by the students.

Reference

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

Master Materials and Equipment List

Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group. NOTE: Some activities also require protective gear for each student (for example, safety goggles, gloves, apron, or lab coat).

Teachers can conduct some lab activities with sensors other than those listed here. For assistance with substituting compatible sensors for a lab activity, contact PASCO Teacher Support (800-772-8700 inside the United States or http://www.pasco.com/support).

Act	Title	Materials and Equipment	Qty
1	**Archimedes' Principle** Use a force sensor to measure the change in gravitational force on an object in the air and on that same object immersed in water.	Date collection system PASPORT Force Sensor with hook *Objects to be suspended in water* *Water, enough to fill bucket or tub* Balance *String (10 to 20 cm per object)* *Bucket or tub*	1 1 2 1 per class 2 1
2	**Boyle's Law** Use an absolute pressure sensor to investigate the effect of changes in the volume of a confined gas on pressure at constant temperature.		
	Teacher Demonstration	Data Collection System PASPORT Absolute Pressure Sensor Quick-release connector *Syringe (20 ml or 20 cc)* Plastic tubing *Plastic soda bottle, 1-L* Eyedropper *Tap water* *Glass or beaker, 100-mL or tall enough to hold the eyedropper ("diver")*	1 1 1 1 1 1 1 10 mL 1
	Student or Group	Data Collection System PASPORT Absolute Pressure Sensor Quick-release connector PASPORT Sensor Extension Cable *Syringe (20 ml or 20 cc)* Plastic tubing *Clean toilet plunger*	1 1 1 1 1 1 1

Act	Title	Materials and Equipment	Qty
3	**Conservation of Matter** Use a temperature sensor and absolute pressure sensor to measure the change in temperature and pressure of an oxidation reaction.		
	Teacher Demonstration	Balance or scale with 0.1g sensitivity *2-liter clear plastic soda bottle, with cap* *Alka-Seltzer tablets* *Tap water, warm*	1 per class 1 2 200 mL
	Student or Group	Data Collection System PASPORT Temperature Sensor* PASPORT Absolute Pressure Sensor Quick-release connector *Erlenmeyer flasks, 250- mL* Balance or scale with 0.1g sensitivity Tubing *Disposable plastic cup* *Vinegar* *2-hole rubber stopper* *Rubber stopper (no holes)* *Steel wool* *Paper towel (to dry steel wool)* *Glycerin*	1 1 1 1 2 1 per class 1 to 2 cm 1 ~100 mL 1 1 ~2 g 1 1 to 2 drops
4	**Energy Transfer** Use a stainless steel temperature sensor to measure the transfer of heat energy of a candle flame through convection and conduction.	Data Collection System PASPORT Stainless Steel Temperature Sensors Ring stands *Clamps* *Matches*	1 2 2 3 1 or 2
5	**Exploring Velocity and Inertia** Use a motion sensor to measure the velocity of a cart as it travels down an inclined track and collides with an obstacle.	Data Collection System PASPORT Motion Sensor Dynamics track PASCar *Marble* *Small bean bag* Meter stick	1 1 1 1 1 1 1
6	**Heat Transfer in Fluids** Use a fast response temperature sensor to investigate what happens to the temperature of a solution when two substances of different temperatures are mixed.	Data Collection System PASPORT Fast Response Temperature Sensor *Graduated cylinder, 250-mL* *Beakers or cups, 150-mL* *Insulated container* *Hot water* *Cold water* *Red and blue food dyes (optional)* *Stirring rod*	1 1 1 2 1 125 mL 125 mL 2 to 4 drops 1

* Either the PASPORT Fast Response Temperature Sensor or the PASPORT Stainless Steel Temperature Sensor can be used for this activity.

Act	Title	Materials and Equipment	Qty
7	**Investigating Evaporative Cooling** Use a fast response temperature sensor to measure the change in water temperature as it cools.	Data Collection System PASPORT Fast Response Temperature Sensors *Graduated cylinder, 25 to 50 mL* *Warm tap water (not over 40 °C)* *Small fan* *Petri dishes* *Aluminum foil*	1 2 1 ~ 100 mL 1 2 ~ 0.5 m
8	**Investigating Solar Energy** Use a temperature sensor to measure the change in temperature of black coffee as it is warmed by sunlight.		
	Teacher Demonstration	Data Collection System PASPORT Temperature Sensor* *Graduated cylinder, 25- or 50-mL* *Small, polystyrene foam coffee cups that nest within each other* *Black coffee, cold* *Rubber bands* *Clear plastic wrap, 6 in. x 6 in.* *Small metric ruler or tape measure* *Large insulated container or Thermos™ bottle (optional)*	1 1 1 2 20 mL 2 2 1 1
	Student or Group	Data Collection System PASPORT Temperature Sensor* *Graduated cylinder, 25- or 50-mL* *Black coffee, cold* *Rubber bands* *Small, polystyrene foam coffee cups that nest within each other* *Clear plastic wrap, 12 in. x 18 in.*	1 1 1 15 mL 2 2 1
9	**Measuring Light Intensity** Use a light sensor to investigate how light intensity changes as it gets further from the source.		
	Teacher Demonstration	Data Collection System PASPORT Light Sensor PASPORT Sensor Extension Cable *Lamp, with incandescent light bulb without a shade* *Sheet of white paper* Meter stick *Clear and frosted incandescent light bulbs (optional)*	1 1 1 1 1 1 1
	Student or Group	Data Collection System PASPORT Light Sensor PASPORT Sensor Extension Cable *Lamp, with incandescent light bulb without a shade* Meter stick *Clear and frosted incandescent light bulbs (optional)*	1 1 1 1 1 1

* Either the PASPORT Fast Response Temperature Sensor or the PASPORT Stainless Steel Temperature Sensor can be used for this activity.

Act	Title	Materials and Equipment	Qty
10	**Measuring the Voltage of Elements in Series** Use a voltage sensor to investigate the voltage drop across a varying number of elements in series in a circuit.		1
	Teacher Demonstration	Data Collection System PASPORT Voltage Sensor, with leads *Holiday "mini" light* *Wire strippers* *Fresh 9-volt battery*	1 10 1 1 1
	Student or Group	Data Collection System PASPORT Voltage Sensor, with leads *Holiday "mini" lights* *Wire strippers* *Fresh 9-volt battery*	1 1 10 1 1
11	**Motion Graphs** Use a motion sensor to measure the position of a moving object.		
	Teacher Demonstration	Data Collection System PASPORT Motion Sensor Reflector (optional)	1 1 1
	Student or Group	Data Collection System PASPORT Motion Sensor Reflector (optional)	1 1 1
12	**Neutralizing an Acid and a Base** Use a pH sensor to measure change in pH and to determine the endpoint of a titration.		
	Teacher Demonstration	Data Collection System PASPORT pH Sensor *Erlenmeyer flask, 250-mL* Balance *Graduated cylinder, 100-mL* Pipet or eyedropper *Vinegar* *Baking soda* *Sample paper* Buffer solution pH 4 Buffer solution pH 10 *Water*	1 1 2 1 per class 1 1 50 mL ~2 g 1 25 mL 25 mL 100 mL
	Student or Group	Data Collection System PASPORT pH Sensor *Erlenmeyer flasks, 250-mL* Balance *Graduated cylinder, 100-mL* *Beaker, 200 mL* Pipet or eyedropper *Vinegar* *Baking soda* *Sample paper* *Water* *Distilled water in wash bottle*	1 1 2 1 per class 1 1 1 50 mL ~2 g 1 100 mL 200 mL

Act	Title	Materials and Equipment	Qty
13	**Newton's First Law** Use a motion sensor and force sensor to determine how the change in an object's motion is related to the force (push or pull) applied to the object.		
	Teacher Demonstration	Data Collection System PASPORT Motion Sensor PASPORT Force Sensor with hook and rubber bumper *Chair with wheels*	1 1 1 1
	Student or Group	Data Collection System PASPORT Force Sensor with hook and rubber bumper PASPORT Motion Sensor GOcar or other dynamics cart or toy car *Duct tape or packing tape* Metric ruler or meter stick	1 1 1 1 Several strips 1
14	**Newton's Third Law** Use two force sensors to measure a pair of oppositely directed forces.		
	Teacher Demonstration	Data Collection System PASPORT Force Sensors with hooks *Balloons, empty* *Strong rubber band*	1 2 1 or 2 1
	Student or Group	Data Collection System PASPORT Force Sensors with hooks *Strong rubber band* *Towel*	1 2 1 1
15	**Observing Freezing Point Depression** Use a temperature sensor to investigate the effect of solid-liquid transitions on the temperature of ice water solutions.	Data Collection System PASPORT Temperature Sensor* *Graduated cylinder or measuring cups* *Small beaker or cup* *Measuring spoons* *Spoon or stirring stick* Balance *Ice cube tray* *Plastic food wrap, 30 cm. x 30 cm.* *Common kitchen ingredients (salt, sugar, juice, food dye, et cetera)* *Distilled water*	1 1 1 1 1 set 1 1 per class 1 1 ~ 2 g each of several samples 200 mL

* Either the PASPORT Fast Response Temperature Sensor or the PASPORT Stainless Steel Temperature Sensor can be used for this activity.

Act	Title	Materials and Equipment	Qty
16	**Observing Phase Changes** Use a temperature sensor to measure the change in temperature during the heating of two different mixes of ice and water – one with distilled water only and one with salt dissolved in distilled water.		
	Teacher Demonstration	Data Collection System PASPORT Temperature Sensor* *Erlenmeyer flask, 250-mL* *Ice cubes* *Distilled water* *One-hole stopper*	1 1 1 at least 5 200 mL 1
	Student or Group	Data Collection System PASPORT Temperature Sensor* *Erlenmeyer flask, 250-mL* *Graduated cylinder, 50- or 100-mL* *Distilled water* Balance *Ice cubes* *Hot plate* *Measuring spoons* *One-hole stopper* *Table salt* *Towel*	1 1 1 1 200 mL 1 per class at least 5 1 1 set 1 ~2 g 1
17	**Simple Harmonic Motion** Use a motion sensor to measure the period of a simple pendulum.		
	Teacher Demonstration	*2-liter soda bottle with cap* *String, non-stretch, ~2 m* *Food coloring (optional)*	1 ~2 m 3 to 4 drops
	Student or Group	Data Collection System PASPORT Motion Sensor *2-liter soda bottle with cap* Meter stick *String, non-stretch, ~2 m* *Food dye (optional)* *Funnel* *Container of tap water (~500 mL)*	1 1 1 1 ~2 m 2 to 4 drops 1 1

* Either the PASPORT Fast Response Temperature Sensor or the PASPORT Stainless Steel Temperature Sensor can be used for this activity.

Act	Title	Materials and Equipment	Qty
18	**Simple Machines and Force** Use a force sensor to measure the force required to lift a mass with varying configurations of fixed and moveable pulleys.		
	Teacher Demonstration	*Tinker Toys™ or other suitable building materials* Pulley *String*	1 set 1 1
	Student or Group	Data Collection System PASPORT Force Sensor with hook Pulleys *String* 0.2 to 0 .5 kg mass Balance *Tinker Toys™ or other suitable building materials*	1 1 2 1 1 1 per class 1 set
19	**Speed and Velocity** Use a motion sensor to measure the position and velocity of a moving object.		
	Teacher Demonstration	*Watch with second hand, or stopwatch*	1
	Student or Group	Data Collection System PASPORT Motion Sensor Reflector (optional)	1 1 1
20	**Transfer of Energy in Chemical Reactions** Use a fast response temperature sensor and an absolute pressure sensor to measure the change in temperature of an endothermic reaction and the temperature and pressure change of an exothermic reaction.	Data Collection System PASPORT Fast Response Temperature Sensor PASPORT Absolute Pressure Sensor *Erlenmeyer flask, 250 mL* *Graduated cylinder, 100 mL* Quick-release connector Tubing, 20 to 30 cm *1-hole stopper for Erlenmeyer* *Beaker or clear plastic cup, 250 mL* *Instant hot-pack (disposable type)* *Alka-Seltzer® tablets* *Distilled water*	1 1 1 1 1 1 1 1 1 1 2 100 mL

Act	Title	Materials and Equipment	Qty
21	**Varying Reaction Rates** Use a fast response temperature sensor to measure the change in temperature over time during four trials of Alka-Seltzer® tablets as they react and produce bubbles in a container of water.		
	Teacher Demonstration	*Alka-Seltzer® tablet* *Water, room temperature* *Clear plastic cup or beaker, 300 mL (10 oz)*	1 ~200 mL 1
	Student or Group	Data Collection System PASPORT Fast Response Temperature Sensor *Graduated cylinder, 100-mL* *Alka-Seltzer® tablets* *Stopwatch* *Clear plastic cups or beakers, 300-mL (10 oz)* *Spoon or stirring stick* *Warm water* *Ice water*	1 1 1 1 3 1 ~500 mL ~500 mL
22	**Voltage Time** Use a voltage sensor to measure the energy conversions that take place as the battery supplying energy for a miniature motor becomes exhausted.		
	Teacher Demonstration	*Collection of different batteries for display* *Battery, D-cell, in holder* *Magnets, small disk or rectangular* *Electrical lead wires with alligator clips* *20-gauge copper wire* Wire strippers or scissors (for insulated wire) *Sandpaper (for enameled wire)* *Large paper clips* *Cup, plastic, paper, or foam* *Small rubber band* *Masking tape* *Marking pen, permanent, dark color*	Several 1 5 2 ~ 60 cm 1 1 2 1 1 ~20 cm 1
	Student or Group	Data Collection System PASPORT Voltage Sensor *Battery, D-cell, in holder1* *Magnets, small disk or rectangular* *Electrical lead wires with alligator clips* *20-gauge copper wire* Wire strippers or scissors (for insulated wire) *Sandpaper (for enameled wire)* Alligator clip (optional) *Large paper clips* *Cup, plastic, paper, or foam* *Small rubber band* *Masking tape* *Marking pen, permanent, dark color*	1 1 1 5 2 ~ 60 cm 1 1 1 2 1 1 1 1

Act	Title	Materials and Equipment	Qty
23	**Work and Mechanical Advantage** Use a force sensor to measure the force required to lift a mass with varying configurations of fixed and moveable pulleys, in combination with an inclined plane (a ramp).		
	Teacher Demonstration	*Tinker Toys™ or other building materials* Cart or toy car Pulleys *String*	1 set 1 2 to 4 1
	Student or Group	Data Collection System PASPORT Force Sensor with hook Meter stick or ruler Balance *Tinker Toys™ or other building materials* Cart or toy car Pulleys *String*	1 1 1 1 per class 1 set 1 2 1

Calibration materials

If you want to calibrate various sensors, you will need the following:

pH Sensor

Item	Quantity	Where Used
Buffer solution, pH 4 Buffer solution, pH 10 Beaker, small Wash bottle with deionized or distilled water	25 mL 25 mL 3 1	11, 26, 30, 45

Activity by PASCO Sensors

This list shows the sensors and other PASCO equipment used in the lab activities.

Items Available from PASCO	Qty	Activity Where Used
Data Collection System	1	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23
PASPORT Absolute Pressure Sensor	1	2, 3, 20
PASPORT Fast Response Temperature Sensor	1	6, 20, 21
PASPORT Fast Response Temperature Sensor	2	7
PASPORT Force Sensor	1	1, 13, 18, 23
PASPORT Force Sensor	2	14
PASPORT Light Sensor	1	9
PASPORT Motion Sensor	1	5, 11, 13, 17, 19
PASPORT pH Sensor	1	12
PASPORT Stainless Steel Temperature Sensor	2	4
PASPORT Temperature Sensor*	1	3, 8, 15, 16
PASPORT Voltage Sensor	1	10, 22
PASPORT Sensor Extension Cable	1	2, 9

* Either the PASPORT Fast Response Temperature Sensor or the PASPORT Stainless Steel Temperature Sensor can be used for this activity.

Normal Laboratory Safety Procedures

Overview

PASCO is concerned with your safety and because of that, we are providing a few guidelines and precautions to use when exploring the labs in our Middle School Science guide. This is a list of general guidelines only; it is by no means all-inclusive or exhaustive. Of course, common sense and standard laboratory safety practices should be followed.

Regarding chemical safety, some of the substances and chemicals referred to in this manual are regulated under various safety laws (local, state, national, or international). Always read and comply with the safety information available for each substance or chemical to determine its proper storage, use and disposal.

Since handling and disposal procedures vary, our safety precautions and disposal comments are generic. Depending on your lab, instruct students on proper disposal methods. Each of the lab activities also has a Safety section for procedures necessary for that activity.

General Lab Safety Procedures and Precautions

- Follow all standard laboratory procedures
- Absolutely no food, drink, or chewing gum is allowed in the lab.
- Wear protective equipment (for example, safety glasses, gloves, apron) when appropriate.
- Do not touch your face with gloved hands. If you need to sneeze or scratch, take off your gloves, wash your hands, and then take care of the situation.
- Wash your hands after handling samples, glassware, and equipment.
- Know the safety features of your lab such as eye-wash stations, first-aid equipment or emergency phone use.
- Insure that loose hair and clothing are secure when in the lab.
- Handle glassware with care.
- Insure you have adequate clear space around your lab equipment before starting an activity.
- Do not wear open-toe shoes in the laboratory.
- Allow heated objects and liquids to return to room temperature before moving.
- Never run or joke around in the laboratory.
- Do not perform unauthorized experiments.
- Students should work in teams of 2 or more in case of trouble and help is needed.
- Keep the work area neat and free from any unnecessary objects.

Water Related Safety Precautions and Procedures

- Keep water away from electrical outlets.
- Keep water away from all electronic equipment.

Chemical Related Safety Precautions and Procedures

- Consult the manufacturer's Material Safety Data Sheets (MSDS) for instructions on handling, storage, and disposing of chemicals. Your teacher should provide the MSDS documents of the chemicals you are using. Keep these instructions available in case of accidents.
- Many chemicals are hazardous to the environment and should not be disposed of down the drain. Always follow your teacher’s instructions for disposing of chemicals.
- Sodium hydroxide, hydrochloric acid, and acetic acid are corrosive irritants. Avoid contact with your eyes and wash your hands after handling. In case of skin exposure, wash it off with plenty of water.
- Always add acids and bases to water, not the other way around, as the solutions may boil vigorously.
- Diluting acids and bases creates heat; be extra careful when handling freshly prepared solutions and glassware, as they may be very hot.
- Handle concentrated acids and bases in a fume hood; the fumes are caustic and toxic.
- Wear eye protection, lab apron, and protective gloves when handling acids. Splash-proof goggles are recommended. Either latex or nitrile gloves are suitable. Use nitrile gloves if you have latex allergy.
- Read labels on all chemicals and pay particular attention to hazard icons and safety warnings.
- When handling any bacterial species, follow aseptic techniques.
- Wash your hands before and after a laboratory session.
- If any solution comes in contact with skin or eyes, rinse immediately with a copious amount of running water for a minimum of 15 minutes.
- Follow the teacher’s instructions for disposing of chemicals, handling substances.
- Check the label to verify it is the correct substance before using it.
- Never point the open end of a test tube containing a substance at yourself or others.
- Use a wafting motion when smelling chemicals.
- Do not return unused chemicals to their original container.
- Keep flammable chemicals from open flame.

Dangerous or Harmful Substance Related Lab Safety Precautions

- When handling any bacterial species, follow aseptic techniques.
- Always flame inoculating loops and spreaders before setting them down on the lab bench.
- Pipetting suspension cultures can create an aerosol. Keep your nose and mouth away from the tip of the pipet to avoid inhaling any aerosol
- Use caution when working with acids.
- Use appropriate caution with the matches, burning splint and foods, and other hot materials.
- Be careful using a knife or scalpel.

Outdoor Safety Precautions

- Practice appropriate caution around water bodies, steep terrain, and harmful plants or animals.
- Treat plants, animals and the environment with respect.
- Inspect all equipment for damage (cracks, defects, etc.).
- Require students to use a buddy system and specify the procedure to use in case of trouble.

Other Safety Precautions

- If water is boiled for an experiment involving heat, make sure it is never left unattended. Remember, too, that the hot plate will stay hot well after it is unplugged or turned off.
- Any injury must be reported immediately to the instructor, an accident report has to be completed by the student or a witness.
- If you are suffering from any allergy, illness, or are taking any medication, you must inform the instructor. This information could be very important in an emergency.
- Try to avoid wearing contact lenses. If a solution spills in your eye, the presence of a contact lens makes first aid difficult and can result in permanent damage. Also, organic solvents tend to dissolve in soft contact lenses, causing eye irritation. If contact lenses must be worn, use a style of goggles called "eye cup."

Additional Resources

- Flinn Scientific
- The Laboratory Safety Institute (LSI)
- National Science Education Leadership Association (NSELA)/Safe Science Series

Rubric

Use this rubric for scoring students' accomplishments and performance in the different sections of this laboratory activity.

Category	4 points	3 points	2 points	1 point
Pre-Lab Preparation	Excellent participation in pre-lab discussion. All vocabulary terms, and equations, if applicable, are used correctly.	Good participation in pre-lab discussion. Most vocabulary terms, and equations, if applicable, are used correctly.	Good participation in pre-lab discussion. Some vocabulary terms, and equations, if applicable, are used correctly.	Limited participation in pre-lab discussion. Few vocabulary terms, and equations, if applicable, are used correctly.
Activity Set-up	All instructions are read, by all lab group members, prior to beginning set-up. Set-up reflects lab group needs and safety rules.	All instructions are read, by some lab group members, prior to beginning set-up. Set-up reflects lab group needs and safety rules.	Some instructions are read, by some lab group members, prior to beginning set-up. Set-up reflects lab group needs and safety rules.	Activity instructions can't be verified by any lab group members, prior to beginning set-up. Set-up does not reflect lab group needs and/or safety rules.
Data Collection	Data is collected for the specified amount of time in a reliable manner.	Data is collected for almost the specified amount of time, in a reliable manner.	Data is collected in a manner lacking reliability, safety, or specified amount of time.	Data is collected in such a way that it cannot be analyzed.
Lab Notebook or Record	Lab notebook includes a complete record of the activity, including properly drawn and labeled diagrams, data, observations, modifications, reasons for modifications, and some reflection about the strategies used and the results.	Lab notebook includes a nearly complete record of the activity, including properly drawn and labeled diagrams, data, observations, modifications, reasons for modifications, and some reflection about the strategies used and the results.	Lab notebook includes all but two records of the activity: properly drawn and labeled diagram(s), data, observations, modifications, reasons for modifications, and some reflection about the strategies used and the results.	Lab notebook lacks more than two records of the activity: properly drawn and labeled diagram(s), data, observations, modifications, reasons for modifications, and some reflection about the strategies used and the results.
Safety	Great care taken during activity to ensure that all lab members follow all safety rules.	One safety violation during the activity.	Two safety violations during the activity.	More than two safety violations during the activity.
Activity Clean-up	All members of lab group collaborate to complete all clean-up instructions in time allotted.	All clean-up is accomplished in time allotted, by majority of lab group members.	All clean-up is accomplished in time allotted, by minority of lab group members, OR all lab group members collaborate but exceed time limit.	Clean-up is not accomplished.

Lab Activities

1. Archimedes' Principle

Eureka! It's Buoyancy.

Objectives

In this activity, students are introduced to Archimedes' principle and the nature of buoyant forces. Students learn that gravity exerts a pulling force on objects that is greater in air than it is in water and investigate how the water exerts a force of its own on objects immersed in it.

Students will investigate the buoyant force of water while they:

- Recognize that a force is a push or a pull
- Recognize that forces have magnitudes (strengths) and directions
- State Archimedes' principle in their own words
- Formulate explanations and predictions from evidence and then draw logical conclusions
- Identify variables that can affect the outcome of an experiment; in addition, they learn to identify other variables in an experimental design that must be controlled in order to isolate the effect of one variable
- Gain skills and confidence 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 the change in gravitational force on an object in the air and on that same object immersed in water

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	30 minutes
■ Lab activity, Part 2 – Gravity in air	25 minutes
■ Lab activity, Part 3 – Buoyancy	25 minutes
■ Analysis	30 minutes

Materials and Equipment

For each student or group:

- ☐ Date collection system
- ☐ Force sensor with hook
- ☐ Objects to be suspended in water
- ☐ Water
- ☐ Balance
- ☐ String (10 to 20 cm per object)
- ☐ Bucket or tub
- ☐ Towel

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Mass is the amount of matter in an object while weight is a measure of the gravitational force on the object
- How to find the mass of an object with a balance
- Water has a mass of 1 gram for every milliliter of volume – so a known volume of water has a known mass
- Have heard the term *buoyancy* before, even if not familiar with its meaning
- How to read and interpret a coordinate graph, as well as be familiar with 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:

- Newton's First Law of Motion
- 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 a sensor to the data collection system �(2.1)
- Recording a run of data �(6.2)

- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)

Background

Buoyancy was first articulated by Archimedes, a Greek mathematician living in the Roman city of Syracuse in the third century BC. He realized that an object partially or entirely submersed in water has an upward force exerted on it by the water. Furthermore, that upward buoyant force is equal to the weight of the water it displaces.

The legends about Archimedes say that he was sitting in his bath pondering a problem related to the density (and therefore the purity) of the gold metal comprising the king's crown, when his realization of buoyancy dawned upon him. In his excitement at his discovery, he is said to have jumped up out of the bath and run outside (quite naked) shouting, "I have found it! I have figured it out!" Since Archimedes spoke Greek, this came out as, "Eureka! Eureka!"

One common and familiar example of the buoyant force in action is seen in boats and ships, which are made of steel and other metals that are denser than water. Why do they not sink? Because they were designed to displace an amount of water whose weight is greater than their own. The designers and builders of ships take advantage of the fact that displaced water pushes back against the object that displaces it.

In terms of objects that float or sink in a fluid such as water, we are interested in looking at two forces – the downward pull of gravity, and the upward push of the buoyant force. When these two forces are in equilibrium, the object does not move up or down (neglecting any "bobbing" on the water waves or currents).

According to Newton's second law of motion, force is equal to the product of mass multiplied by acceleration. If an object's mass is known, and it is subjected only to the downward pull of gravity, then its weight may be calculated as follows:

Weight = (mass) x (acceleration due to gravity)

Weight is a force — it is the downward force of gravity pulling on an object near a planet's surface. The larger the planet, the greater the force of gravity.

For example, a person whose mass is 20 kilograms has a weight of (20 kg) x (9.8 m/s^2) = 196 N on earth, while the same person on the moon has a weight of (20 kg) x (1.6 m/s^2) = 32 N. The difference is in the acceleration due to gravity, which is 9.8 m/s^2 on earth and 1.6 m/s^2 on the moon; the person's mass never changes.

Archimedes' principle is very general, and applies to objects floating or submerged in any fluid, including other types of liquids and gases, including air. For example, a hot-air balloon has a buoyant force exerted on it by the surrounding denser, cool air. When the buoyant force of the cool air on the balloon is greater than the weight of the balloon, the forces are unbalanced and the balloon gains altitude (rises up). When the buoyant force of the surrounding cool air is less than the weight of the balloon, the forces are also unbalanced and the balloon loses altitude (descends). A hot-air balloon pilot manipulates the balance of these forces, deciding when to ascend, descend, or remain at a constant altitude.

Pre-Lab Discussion and Activity

Engage the students in the following discussion or activity:

Ask students why the Moon's gravity is less than that on Earth. If necessary, suggest that the Moon is much smaller than Earth, so it exerts less gravity. Help students to remember or understand that weight is the force of gravity pulling on an object with mass. If some force were to counteract the pull of gravity on an object, it would then seem like the object weighed less.

Direct students to "Thinking About the Question." After a few minutes, have the lab groups share their ideas. List several of their contributions on the board.

Direct student 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 (as often as you know will be necessary) not to push or pull the force sensor hooks past 50 newtons. Doing so can damage the sensor.

- You may want to cut lengths of string ahead of time, or even tie the objects to be tested to the hooks of the force sensors, to save time. Use non-elastic string, fishing line, or even fine-gauge electrical wire.

- Be certain that the test objects have some way of attaching to the hook of the force sensor. If you cannot find suitable objects, empty soda cans are ideal because they have a metal loop that can be used to attach them to the hook and they can be filled with a known volume of water to change their mass. Possible objects to use include hooked masses blocks of wood, film canisters filled with marbles or small rocks.

- If possible, mount the force sensors on ring support stands, as this provides a much steadier platform from which to hang the objects than having students hold the sensors. If support stands are not available, just encourage students to hold the force sensors as still and steady as they can.

- Advise students to bring the bucket of water up to the object, rather than lowering the object into the water. This method allows the student holding the force sensor to keep it steady, while another student moves the water. Also, it is helpful for students to see the water moving up and then exerting an upward force on the object. This is a good visual reinforcement of the phenomenon of buoyancy.

- Provide students with towels in case of spills or overflows of displaced water.

Safety

Add this important safety precaution to your normal laboratory procedures:

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

Driving Question

What is the buoyant force?

Thinking about the Question

Gravity pulls on everything on Earth, from the smallest particle of dust to the largest jumbo jet flying over the earth's surface. Gravity even does its best to keep the space shuttle from launching at Cape Canaveral and escaping into orbit. Whales however, despite their enormous size, do not feel the pull of gravity quite so strongly – at least not as much as they would if they lived on land.

Have you ever been in a swimming pool and dove below the water? Have you ever tried to pick someone up in the swimming pool? You can easily carry people in water that you would not be able to lift on land. Water makes the creatures swimming in it seem lighter.

Discuss with your lab group members whether a whale (or a person) can really get lighter in water. What is meant by "getting lighter?" What is the difference between weight and mass? What do you think water has to do with this phenomenon? Discuss within your group the meaning of the term buoyancy.

> Answers will vary. Students may say that the whale does not actually lose any mass in the water. When we say that it gets lighter, we mean that its apparent weight has decreased. This is because the gravitational force pulling on the whale near the earth's surface is being opposed by the buoyant force on the whale from the weight of the water it displaces. Weight is a force acting on the whale's mass, while mass is a property of matter.
>
> Water has a particular density, with sea or saltwater being denser than fresh water. Since density is mass per unit of volume, the greater the density of a fluid, the greater its buoyant force. For example, a liter of sea water has more mass than a liter of fresh water, which has more mass than a liter of air. This explains why a whale can float in the ocean, but not in the air.

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	1	4	2, 3	3, 2
Attach object to be submersed to the hook of the force sensor. Submerge and measure the force.	Make sure each lab group member is aware of safety rules and procedures for this lab.	Zero the force sensor by pushing the "zero" button on the side.	Find the mass of each object.	Fill container with enough water to submerse objects.

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:

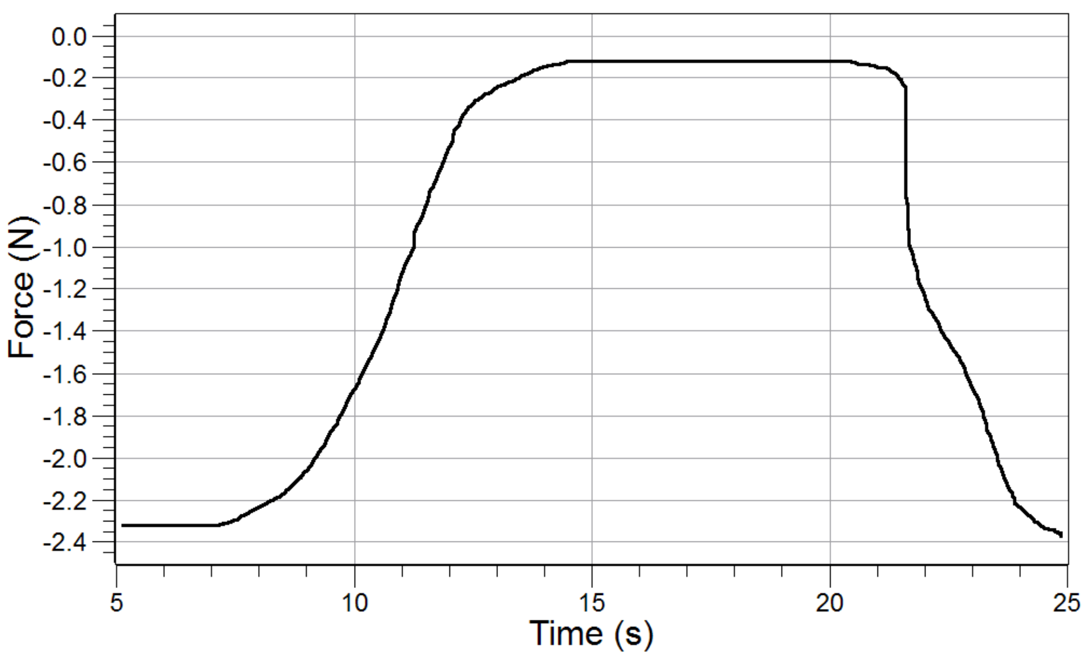
   a. How will a graph of force versus time look when you hang an object from the hook of the force sensor and hold it steady for a few seconds?

   b. How will a graph of force versus time look when you put a heavier object than the first one on the hook of the force sensor and hold it steady for a few seconds?

   c. What will happen to the graphs of both objects when you suspend each object in water?

   When we put a light object on the hook, the force graph will decrease a little. When we put on a heavier object, the graph will decrease more. When we put them in water, the force graphs will increase, showing that gravity is not pulling on them with the same force.

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



Part 2 – Investigating the pull of gravity on objects in air

3. ☐ Find the mass in grams of each of your two objects, and record that mass below.

   Mass of Object 1 __260___ grams

   Mass of Object 2 __310___ grams

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

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

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

7. ☐ Begin data recording. �(6.2)

8. ☐ Hold the force sensor with its hook down, and press the "zero" button. Why do you think this is important?

   If the sensor is not zeroed, the force readings will be inaccurate.

9. ☐ Gently attach the first object to the hook of the force sensor, and hold the entire system steady until the force reading stabilizes. Why do you think that moving the force sensor, even a little bit, results in variations in the force data?

   Every time the force sensor or any part of our system moves, the reading changes. It is because the force sensor is sensitive and gravity is pulling on it a little differently whenever it moves.

10. ☐ Stop data recording. �(6.2) Remove the first object from the force sensor's hook.

11. ☐ Start data recording for a new run of data. �(6.2)

12. ☐ Gently attach the second object to the hook of the force sensor and hold the entire system steady until the force reading stabilizes.

13. ☐ Stop data recording. �(6.2) How can you tell by looking at your data which object was the heavier one? How is the force of each object related to its mass?

    We can tell if we were testing the heavier or lighter object because the heavier the object, the more gravity is pulling it down, and the more newtons of force on the graph. The 310 g object is pulled with more negative newtons than the 260 g object.

    The heavier the object, the more gravity pulls on it. So in this example, the graph shows that the 310 g object is pulled with more negative newtons than the 260 g object.

Part 3 – Investigating the buoyant force

14. ☐ Fill your bucket or other container with water. Fill it with enough water so that you can fully immerse the objects without causing the water to overflow. How is the amount of water displaced or pushed aside related to the size and mass of your object?

    The larger object will displace more water than the smaller one.

15. ☐ Start a new experiment on the data collection system. �(1.2) Display force (push positive) versus time on a graph. �(7.1.1)

16. ☐ Hold the force sensor with its hook down, and press the "zero" button.

17. ☐ Attach the first object gently to the force sensor's hook.

18. ☐ Begin data recording. �(6.2)

19. ☐ Holding the container of water underneath the object, raise it until the object is either floating or is submerged in the water. Allow the force reading to stabilize. Observe the graph and record your observations.

Answers will vary. One student group answered as follows: The graph went up, and stayed level. It went up from –2.6 newtons to zero newtons (and a little above because we moved it too much). Our cans actually floated in the water, they did not sink or submerge all the way.

20. ☐ Stop data recording �(6.2) and set the bucket of water down. Remove the first object from the force sensor's hook.

21. ☐ Attach the second object gently to the force sensor's hook.

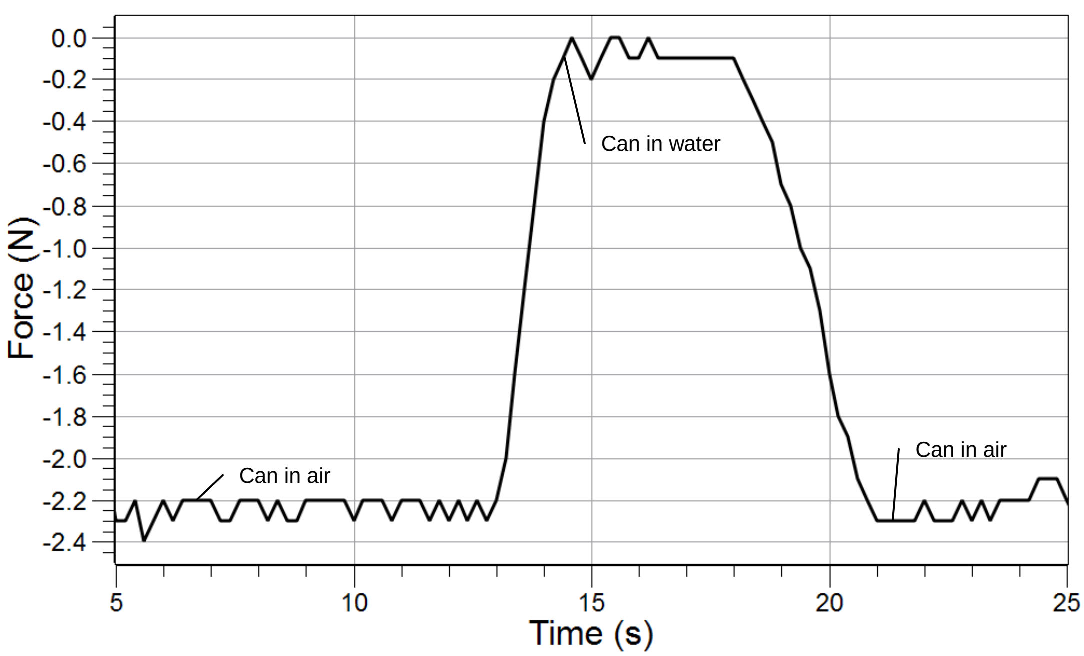
22. ☐ Begin data recording. �(6.2)

23. ☐ Holding the container of water underneath the object, raise it until the object is either floating or is submerged in the water. Allow the force reading to stabilize. Observe the graph and record your observations.

Answers will vary. One student group answered as follows: The same thing happened as with our lighter can. When we immersed it in the water, the graph went up from –3.1 newtons to about zero newtons, and floated without totally sinking.

24. ☐ Stop data recording. �(6.2)

Sample Data



Answering the Question

Analysis

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

   Answers will vary. Students should find that the heavier objects pulled with a greater force than the lighter objects, and that the force on the objects decreased as they were immersed in the water.

2. Archimedes' principle of buoyancy states that an object immersed in a fluid such as water is acted upon by an upward force equal to the weight of the fluid that is displaced. This upward force is called *buoyancy*. How does your data from Part 3 provide evidence for buoyancy? Explain your reasoning.

   Answers will vary. One student group said: We noticed on our graphs that the newtons of force pulling on the objects is not a coincidence. We think this because the amount of newtons is almost the same as the number of grams of each object. For example, our 260 gram object pulled on the force sensor with about –2.6 newtons, and our 310 gram object pulled on the force sensor with about –3.1 newtons. This happened in the air only. Once we put our cans in the water, they lost all their pull. Since we learned that weight is a pulling force, we think the water gives a pushing force.

3. How could you re-state or paraphrase Archimedes' principle in your own words?

   Answers will vary. One student group said the following: When you put an object in water, it loses weight but not mass by the amount of water it pushes aside. If it pushes aside an amount of water that weighs more than it does, it floats.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. What is the force that determines an object's weight on Earth?

   A. Mass
   B. Gravity
   C. Volume

2. Which force pushes on an object in an upward direction, opposite the pull of gravity?

   A. Buoyancy
   B. Volume
   C. Weight

3. Weight is measured with a force sensor while mass is measured with

   A. A gravitational sensor.
   B. A graduated cylinder.
   C. A balance.

4. If you were on the Moon, which quantity would be less than it is on Earth?

   A. Your mass
   B. Your weight
   C. Your volume

5. Which of the following is a pull of Earth's gravity on objects close to the earth's surface?

   A. Weight
   B. Buoyancy
   C. Mass

6. An object fully under water is said to be:

   A. Balanced
   B. Less massive
   C. Submerged

7. Which term describes the amount of space an object takes up?

   A. Volume
   B. Buoyancy
   C. Weight

8. The buoyant force on an object acts in which direction?

   A. Opposite the force of gravity
   B. In the same direction as gravity
   C. At a right angle to the force of gravity

9. In order for an object to experience a buoyant force, it must:

   A. Have a very large mass
   B. Have a very large volume
   C. Displace some type of fluid

10. What fluid is displaced by a helium balloon tied to a child's wrist by a string?

    A. Air
    B. Helium
    C. No fluid is displaced

Further Investigations

Foil boats: Use your understanding of Archimedes' principle of buoyancy to design and construct an aluminum foil boat that can carry the most mass. Challenge your classmates to see whose design take the best advantage of buoyancy. Who can float the most pennies or marbles on the smallest sheet of foil?

Test the buoyant force of very salty water. Use your discovery to discuss why ships float higher in the ocean than they do in fresh-water rivers, and why bathers can rest on their backs and read a newspaper while floating in the Dead Sea.

Test the buoyant force of different liquids such as oil.

Rubric

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

2. Boyle's Law

How Does a Trapped Gas Behave?

Objective

Students investigate the effect of changes in the volume of a confined gas on pressure at constant temperature. Using the pressure sensor, students observe simple tables or graphs and compare the change of pressure with varying volume.

Students measure the change in pressure by varying the volume of trapped air in a syringe while:

- Understanding that substances have characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample
- Realizing that energy is a property of many gases and is associated with heat and mechanical motion
- Observing the relationship between volume of a gas and the resulting pressure in a container
- Gaining skills and confidence in using a scientific measurement tool, the pressure sensor, as well as the spreadsheet and graphing capacity of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the change in pressure in a syringe as the volume is changed
- Measure the pressure in a syringe while decreasing and then increasing the volume in 2-mL increments
- Using math skills to obtain a linear relationship between pressure and volume by computing the inverse of pressure and plotting the resulting values versus volume

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	25 minutes
■ Part 2 – Decreasing the volume of trapped gas	15 minutes
■ Part 3 – Increasing the volume of trapped gas	15 minutes
■ Analysis	25 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Absolute pressure sensor
- ☐ Quick-release connector[1]
- ☐ Syringe (20 ml or 20 cc)
- ☐ Plastic tubing[1]
- ☐ Plastic soda bottle, 1-L
- ☐ Eyedropper
- ☐ Tap water, 10 mL
- ☐ Glass or beaker, 100-mL or tall enough to hold the eyedropper ("diver")
- ☐ Clean toilet plunger

[1] Included with PASPORT Absolute Pressure Sensor

For each student or group:

- ☐ Data collection system
- ☐ Absolute pressure sensor
- ☐ Quick-release connector[1]
- ☐ Sensor extension cable
- ☐ Syringe, 20-ml or 20-cc
- ☐ Plastic tubing[1]
- ☐ Clean toilet plunger

[1] Included with PASPORT Absolute Pressure Sensor

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Forces exerted by air result in pressure
- Because air pressure is largely invisible to our senses, it can be more difficult to comprehend than temperature, light intensity, or other more tangible phenomena occurring around us
- How to calculate the slope of a line
- The meaning of the inverse of a value, in this case the inverse of pressure
- How to find the inverse of a value
- The general form of inverse variation is the equation $y = k/x$. The product of x and y is always k
- How to plot data on a set of coordinate axes using graph paper, ruler, and pencil

Related Labs in This Guide

Labs conceptually related to this one include:

- Conservation of Matter
- Yeast Growth

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 a sensor to the data collection system �(2.1)
- Putting the data collection system into manual sampling mode with manually entered data. �(5.2.1)
- Recording a run of data �(6.2)
- Starting a new manually sampled data set �(6.3.1)
- Recording a data point �(6.3.2)
- Stopping a manually sampled data set �(6.3.3)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Boyle's Law states that for a given amount of a gas at a fixed temperature the pressure of the gas is inversely proportional to the volume. A pressure versus volume graph of a gas at a fixed temperature will yield a negatively sloping curve. It is often helpful for the students to plot a graph of "volume versus (1/pressure)" to obtain a linear relationship. By doing this, they can calculate the slope (change in y/change in x) of the line to show that pressure times volume is a constant value.

The effect of Boyle's law is demonstrated by deep sea divers who experience decompression sickness. Commonly known as the "bends," this condition is caused by bubbles of nitrogen gas forming in the blood and tissues of the body after breathing gas at a high pressure when at great depths and then rising too quickly to the lower pressure at the surface. Just as a balloon filled with air at the surface shrinks in size when it is taken under water, due to the compressibility of the air and the pressure of the water, the air in the lungs also compresses at greater depths.

When the same balloon is returned to the surface, the balloon expands to its original volume. If a diver goes underwater, where the pressure is greater, the diver's blood can hold more nitrogen than it did before. As the diver breathes from the tank, more nitrogen gets into the blood, which becomes saturated at high-pressure levels. If the diver returns to the surface too quickly, then the air pressure is lowered quickly, and the extra nitrogen expands and comes out of the blood as bubbles.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity.

Show the class the simple Cartesian diver (refer to the "Preparation and Tips" section). Have one student apply pressure to the sides of the bottle, hold it for a few seconds, and then release the pressure.

Ask students to work in groups to discuss what happened to the eyedropper. Allow each group to operate the diver. Have students examine closely the air trapped in the eyedropper. What happens to the amount of air in the eyedropper when they press the sides of the bottle? What happens to the amount of air in the eyedropper when they release the pressure? After a few minutes, ask the students to share their thoughts with the class.

> Students should observe that pressure on the sides of the bottle causes the "diver" to sink, while releasing the pressure allows the diver to rise again. The volume of air trapped inside the eyedropper decreases when pressure is applied to the bottle and increases when the pressure is released.

Share with the class that applying pressure to the sides of the bottle increases the pressure on the water, forcing it into the dropper and reducing the volume of air in the dropper. The eyedropper becomes heavier and sinks. Releasing the pressure allows the volume to increase, forcing out some of the water. Since the eyedropper weighs less it will once again float.

Ask students to describe the relationship between the volume of the air in the eyedropper and the pressure applied on the bottle.

> Students should say that as the pressure applied to the bottle increases, the volume of air in the eyedropper decreases. As the pressure decreases, the volume of air increases.

Direct students to “Thinking about the Question.” After a few minutes, ask the groups to share some of their ideas with the class.

Demonstrate the effect of pushing the air out of a plunger. Ask students to describe the relationship between the volume of the trapped air in the plunger and the pressure needed to release it from the floor.

> Students should say that the smaller the volume of trapped air, the greater the pressure needed to release the plunger from the floor.

Share with the students that in science and mathematics we describe the relationship between two variables, like pressure and volume, as either “direct” or “inverse.” In a direct relationship, if one variable increases in value, the other variable also increases. In an inverse relationship, if one variable increases, the other variable decreases. Ask the students if both the Cartesian diver and the toilet plunger show a direct or inverse relationship.

Demonstrate how to prepare the absolute pressure sensor by pressing one end of the plastic tubing onto the syringe and twisting the other end of the tubing to connect to the quick-connect port of the pressure sensor (by twisting, this connection should snap into place). Direct the students to “Investigating the Question.”

Preparation and Tips

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

- Insert the quick-release connector into one end of the tubing for each lab group.

- Build a simple Cartesian diver with a liter plastic bottle and an eyedropper, as follows:

  a. Prepare the diver: Fill the glass or beaker with water and put the eyedropper in it. Fill the dropper so that it just barely floats – just the tip of the rubber bulb should be above water. This is the diver, which now has neutral buoyancy (it will not float up or sink down on its own). By testing for neutral buoyancy in the glass, you avoid having to retrieve the diver from the bottom of the plastic bottle if it should happen to sink.

  b. Now fill the plastic soda bottle all the way to the top with water. Avoid leaving any air between the water and the cap. Place the eyedropper into it and screw the cap on tightly. Test the Cartesian "diver" by squeezing the sides of the bottle with your hands. The diver should sink while you squeeze the bottle and float back up when you release the pressure.

  c. As you increase the pressure by squeezing the bottle, the air inside the eyedropper is compressed. This allows room for more water to enter the dropper, which you can observe as you squeeze the bottle. As more water enters, the dropper becomes heavier and sinks. Practice applying just the right amount of pressure so you can hold the diver steady in the middle of the bottle.

- Syringes often are marked in cubic centimeters (cc). These are equivalent to milliliters (mL).

Safety

Add this important safety precaution to your normal laboratory procedures:

- Wear protective goggles for this activity.

Driving Question

How does a change in volume of a confined gas affect its pressure?

Thinking about the Question

Observe a clean toilet plunger pressed against a smooth surface like the floor. It may be necessary to lightly wet the rim with a wet towel so that no more air can get under the rim once you press down on the plunger. Propose an explanation about why the plunger sticks to the floor when you gently pull it away.

Discuss with the members of your group whether the volume of the pocket of trapped air changes when you pull on the plunger. Record your thoughts below. Be prepared to share your thoughts with the class.

Air will be trapped inside the toilet plunger. As students push on the plunger, they decrease the volume of the space that the air can fill. Decreasing the volume will increase the pressure of the trapped air. It should be harder to remove the toilet plunger from the floor.

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	1	3	4	2
Calculate the inverse pressure and graph inverse pressure versus volume. What is the relationship?	Make certain each lab group member is aware of safety rules and procedures for this lab.	Obtain absolute pressure data points as you decrease the volume, then begin again and increase volume.	Make a table of the pressure and volume data when decreasing the volume and when increasing the volume.	Set the initial volume of the syringe and then connect it to the pressure sensor (connected to the data collection system).

Investigating the Question

Part 1 – Making predictions

1. ☐ Predict the effect of decreasing the volume on the pressure in the syringe (as volumes go from 20 mL to 18 mL, 16 mL, 14 mL, 12 mL, 10 mL, 8 mL, and 6 mL) of the syringe. Describe and explain your prediction.

   Air will be trapped inside the syringe like the air trapped inside the toilet plunger. The pressure inside the syringe will increase as the volume decreases, because the number of air molecules will stay the same but will be squeezed more tightly together.

2. ☐ Predict the effect on pressure in the syringe of increasing the volume (from 6 mL to 8 mL, 10 mL, 12 mL, 14 mL, 16 mL, 18 mL, 20 mL) of the syringe. Describe and explain your prediction.

   Air will be trapped inside the syringe like the air trapped inside the toilet plunger. The pressure inside the syringe will decrease as the volume increases, because the number of air molecules will stay the same but the amount of space available to them will increase, and they will have to travel farther before having collisions with each other or with the walls of the syringe.

Part 2 – Decreasing the volume of trapped gas

3. ☐ Start a new experiment on the data collection system. �[(1.2)]

4. ☐ Put the data collection system into manual sampling mode with manually entered data. �[(5.2.1)]

   Note: Enter "Absolute pressure" with the units of "kPa" and "Distance" with the units of "cm", with two digits past the decimal point displayed.

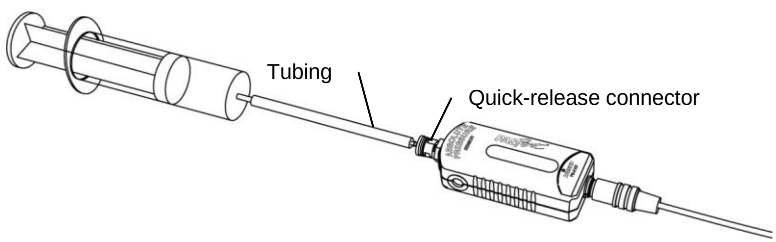
5. ☐ Use the sensor extension cable to connect an absolute pressure sensor to the data collection system. �(2.1)

   Note: The syringe should not yet be connected to the sensor.

6. ☐ Display Pressure on the y-axis of a graph with Volume on the x-axis. �(7.1.1)

7. ☐ Move the plunger of the syringe to the 20 mL mark.

8. ☐ Connect one end of the plastic tube to the syringe. Attach the other end of the tube (with the quick-release connector) to the pressure sensor by twisting until it clicks into place. Check with your teacher if you have any questions about how to connect this system properly.



9. ☐ Start a new manually sampled data set. �(6.3.1)

10. ☐ Move the plunger to the 18 mL mark. Record this data point. �(6.3.2)

11. ☐ Move the plunger to the 16 mL mark. Record this data point (both pressure and volume). �(6.3.2).

12. ☐ Move the plunger to the 14 mL mark. Record this data point �(6.3.2)

13. ☐ Move the plunger to the 12 mL mark. Record this data point �(6.3.2)

14. ☐ Continue recording data points as you decrease the volume in the syringe by 2 mL increments, until you reach a volume of 6 mL.

15. ☐ When you have recorded all of your data, stop the data set. �(6.3.3)

Part 3 – Increasing the volume of trapped gas

16. ☐ Disconnect the tube from the pressure sensor.

17. ☐ Move the plunger of the syringe to the 2 mL mark.

18. ☐ Display a new graph with Pressure on the y-axis and Time on the x-axis. �(7.1.1)

19. ☐ Reconnect the tube to the pressure sensor.

20. ☐ Start a new manually sampled data set. �(6.3.1)

21. ☐ With the plunger at 2 mL, record this data point �(6.3.2)

22. ☐ Move the plunger to the 4 mL mark. Record this data point �(6.3.2)

23. ☐ Move the plunger to the 6 mL mark. Record this data point �(6.3.2)

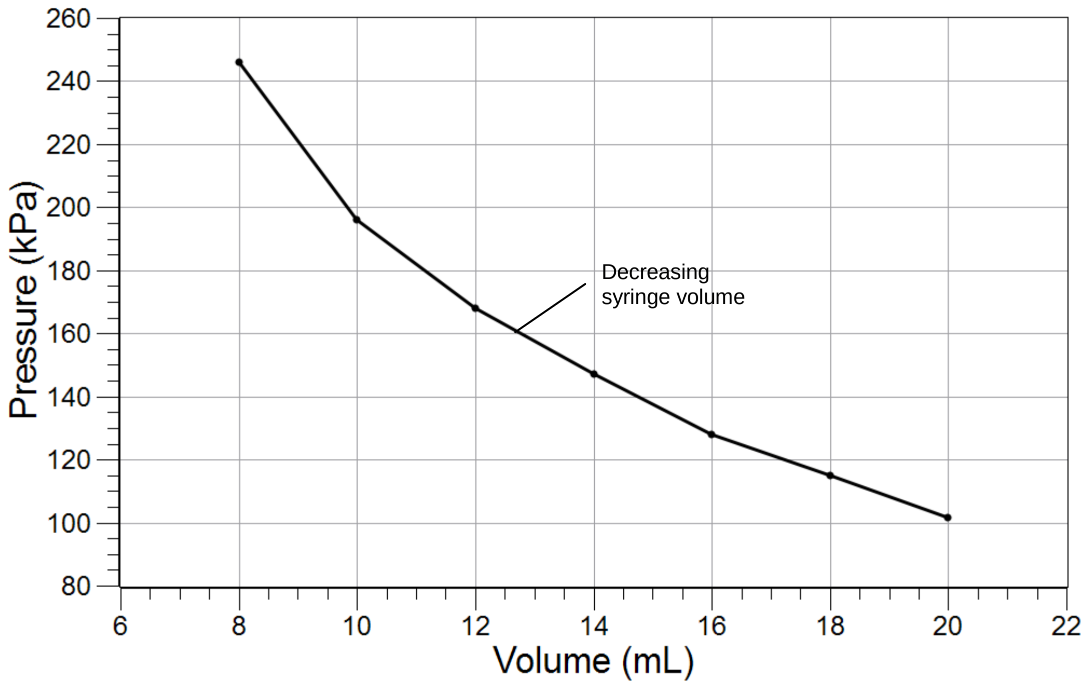
24. ☐ Move the plunger to the 8 mL mark. Record this data point �(6.3.2)

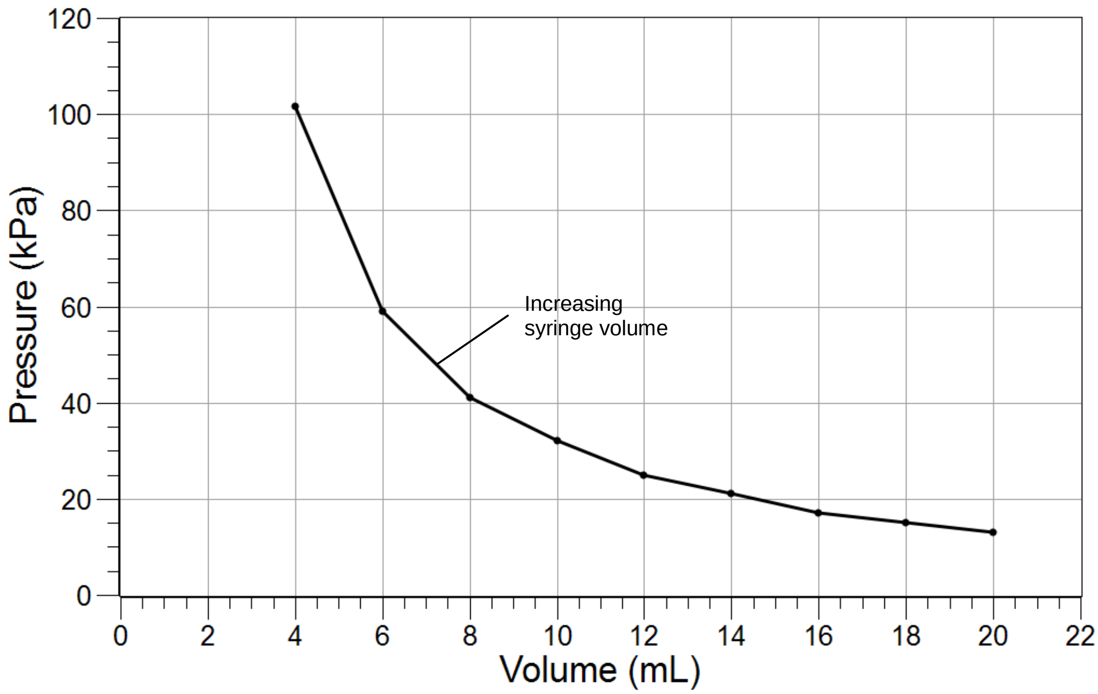
25. ☐ Continue recording data points as you increase the volume in the syringe by 2 mL increments, until you reach a volume of 20 mL.

26. ☐ Stop data recording. �(6.3.3)

27. ☐ Save your experiment �(11.1) and clean up according to your teacher's instructions.

Sample Data





Answering the Question

1. What type of relationship did you see when you decreased the volume of trapped air?

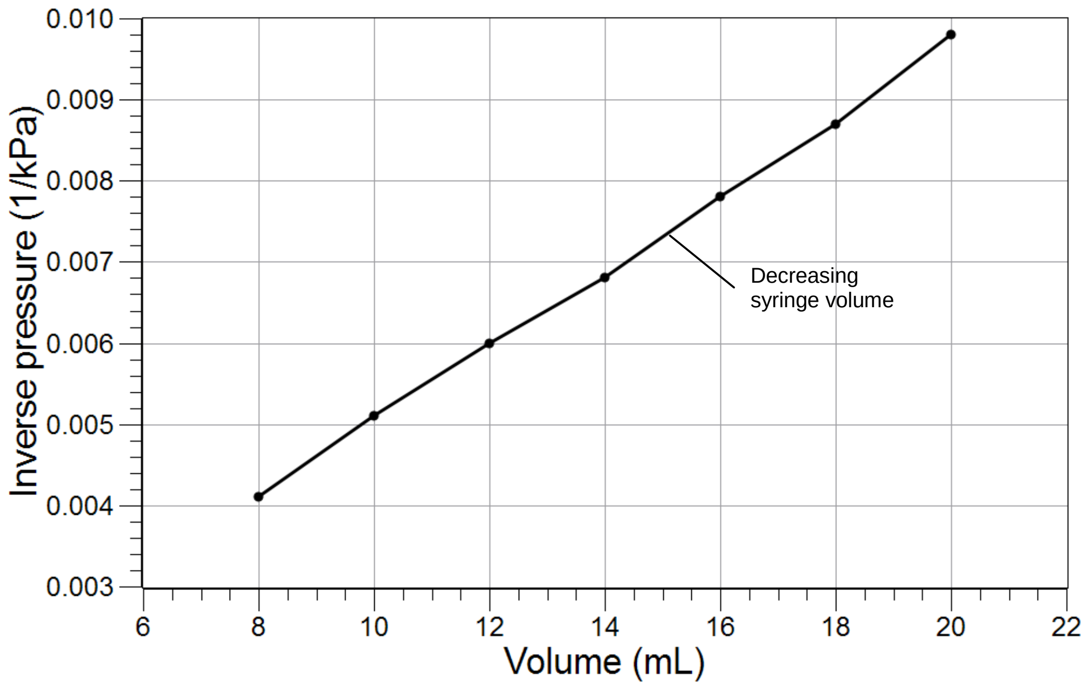
   As the volume decreased, the pressure increased. The graph of pressure versus volume is a curve sloping downward.

2. Using data from the first data run when decreasing the volume of trapped gas, complete Table 1. Calculate the value of 1/Pressure for each volume.

Table 1: Pressure with decreasing volume

Decreasing Volume (mL)	Pressure (kPa)	1/Pressure (kPa^{-1})
20	101.7	0.0098
18	115	0.0087
16	128	0.0078
14	147	0.0068
12	168	0.0060
10	196	0.0051
8	246	0.0041

3. Graph 1/Pressure versus Volume using the data in Table 1.



4. Does the graph show a direct or an inverse relationship? Explain your reasoning.

   The graph shows an inverse relationship, since the 1/Pressure versus Volume graph results in a straight line sloping upward.

5. What type of relationship did you see when you increased the volume of trapped air?

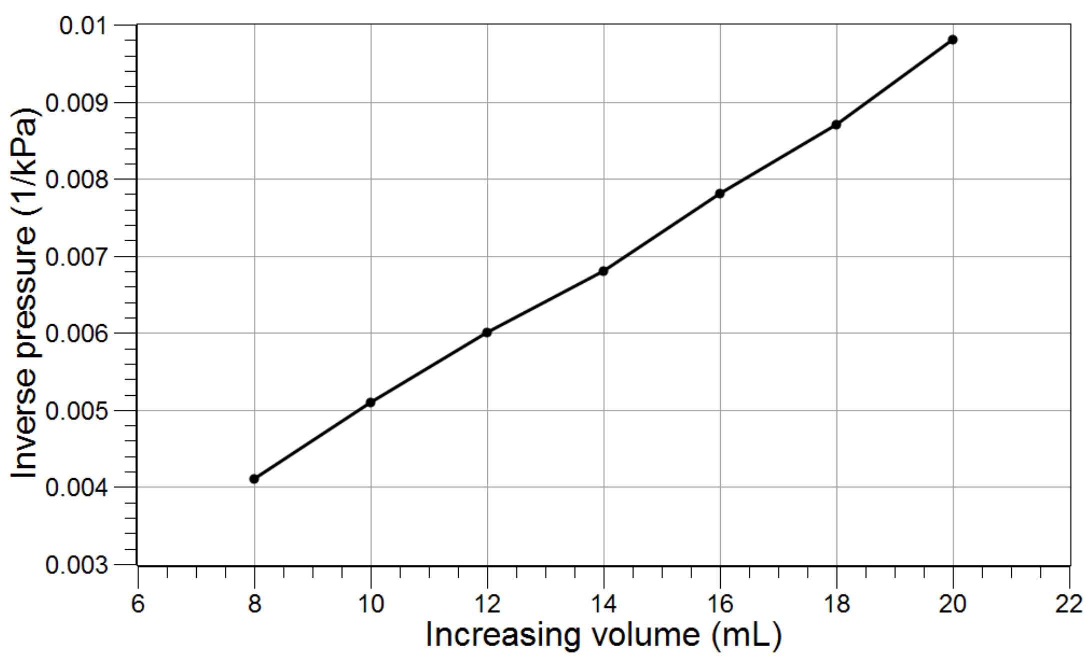
   As the volume increased the pressure decreased. The graph of pressure versus volume is a curve sloping downward.

6. Using data from your second graph, when increasing the syringe volume, complete Table 2. Calculate the value of 1/Pressure for each volume.

Table 2: Pressure with increasing volume

Increasing Volume (mL)	Pressure (kPa)	1/Pressure (kPa^{-1})
4	101.7	0.0098
6	59	0.017
8	41	0.024
10	32	0.031
12	25	0.040
14	21	0.048
16	17	0.059
18	15	0.067
20	13	0.077

7. Graph 1/Pressure versus Volume using the data in Table 2.



8. Did the graph show a direct or an inverse relationship? Explain your reasoning.

The relationship is inverse based on the 1/P versus V graph resulting in a straight line.

9. Describe the similarities and differences for both 1/Pressure versus Volume graphs.

Both graphs show straight lines with a positive slope, indicating there is an inverse relationship between pressure and volume.

10. Explain how the graphs display Boyle's Law. Be prepared to share your thoughts with the class.

Boyle's Law states that for a given amount of a gas at a fixed temperature the pressure of the gas is inversely proportional to the volume. By plotting a 1/Pressure versus Volume graph, a linear relationship results. The slope (the change of y compared to the change in x) of the line shows that Pressure times Volume is a constant value.

True or False

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

___T___ 1. Collisions between air molecules and the walls of their container create pressure.

___F___ 2. There is a direct relationship between the volume of a gas and its pressure, when the gas is held at a constant temperature.

___F___ 3. In the SI system, pressure is measured in units called newtons.

___F___ 4. The graph of increasing volume versus increasing pressure is a straight line.

___T___ 5. The inverse of a number is equal to one divided by the number.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. Which is the best way to characterize an inverse relationship?

   A. As one quantity decreases, the other quantity decreases at the same rate.
   B. As one quantity increases, the other quantity decreases proportionally.
   C. As one quantity increases, the other quantity undergoes a random change.

2. Air molecules confined in a closed volume undergo more collisions when that volume:

   A. Decreases
   B. Increases
   C. Is chilled by at least 10 degrees Celsius

3. The inverse of 4.0 is equal to:

   A. 40.0
   B. 1.0
   C. 0.25

4. Suppose you are given a closed air-tight container that holds a particular gas at room temperature. You then squeeze the container and put a big dent in it. Which of the following is *not* true about the gas inside the dented container?

   A. There is less room for the gas molecules that are sealed inside the container.
   B. There are exactly as many gas molecules now as there were before you dented the container.
   C. The pressure of the gas has remained the same as it was before you dented the container.

5. The relationship between the volume of a gas and its pressure can be seen in which example?

   A. The adhesive used to glue labels onto containers
   B. A suction cup used to attach something to a wall
   C. An empty balloon waiting to be inflated with helium gas

Further Investigations

Does multiplying pressure times volume in the data collected result in a constant? What could be the cause of any variation?

Marshmallows are mostly sugar and water wrapped around a bunch of air bubbles. Place several miniature marshmallows inside a syringe. Predict the affect on the marshmallows as the volume of trapped gas in the syringe is changed. Test your prediction.

Often when you are given bags of chips and snacks on airplanes, the bags are fully inflated. Design and perform an investigation that will use the pressure sensor to show changes of volumes of trapped gases at different altitudes

Rubric

Rubric focuses on successfully performing the scientific process, collecting and displaying data, understanding the concepts, and communicating conclusions.

3. Conservation of Matter

Never Created, Never Destroyed

Objectives

Students investigate a chemical change and confirm the Law of Conservation of Matter. Using the temperature and pressure sensors, students measure changes during a synthesis reaction.

Students investigate and observe the conservation of matter during a chemical change while they:

- Achieve a familiarity with chemical and physical reactions and with the ways substances can behave or change in the process
- Measure a reaction that results in heat transfer
- Gain skills and confidence in using scientific measurement tools, the temperature and pressure sensors, as well as the graphing capability of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the change in temperature and pressure of an oxidation reaction
- Measuring the mass of a closed system before and after an oxidation reaction
- Measuring the change in temperature and pressure during the oxidation reaction of steel wool that has been soaked in vinegar

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	50 minutes
■ Lab activity, Part 2 – Measuring the mass of the reaction	25 minutes
■ Lab activity, Part 3 – Reaction temperature and pressure changes	25 minutes
■ Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Balance or scale with 0.1g sensitivity
- ☐ 2-liter clear plastic soda bottle, with cap
- ☐ Alka-Seltzer© tablets (2)
- ☐ Tap water, warm, 200 mL

For each student or group:

- ☐ Data collection system
- ☐ Temperature sensor
- ☐ Absolute Pressure sensor
- ☐ Quick-release connector[1]
- ☐ Erlenmeyer flasks (2), 250-mL
- ☐ Balance or scale with 0.1 g sensitivity
- ☐ Tubing, 1 to 2 cm[1]
- ☐ Disposable plastic cup
- ☐ Vinegar ~100 mL
- ☐ 2-hole rubber stopper
- ☐ Rubber stopper (no holes)
- ☐ Steel wool ~2 g
- ☐ Paper towel (to dry steel wool)
- ☐ Glycerin, 1 to 2 drops

[1]Included with PASPORT Absolute Pressure Sensor

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Recognize, list, compare, and contrast physical and chemical changes
- Classifying reactions as endothermic or exothermic
- Recognize and be able to interpret simple chemical formulas, including H_2O and NaCl
- Pressure in a gas is the result of the collisions of the air molecules with the walls of its container
- Use of the balance to find the mass of objects
- Reading and interpreting a coordinate graph
- Familiar with the SI units of measure for temperature (degrees Celsius) and pressure (Pascals)
- Basic use of the data collection system

Related Labs in This Guide

Labs conceptually related to this one include:

- Boyle's Law
- Endothermic or Exothermic?

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 �(2.1)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple graphs simultaneously �(7.1.11)

Background

A physical change occurs when new kinds of matter are formed. The composition of the matter changes, and new kinds of matter have different properties from the old matter. Evidence of a chemical change may include the production or use of energy, such as heat being given off or absorbed, the production of a gas or solid, or a change of color. If the composition of the matter changes chemically during a phase change, it is a chemical change (for example, a raw egg is changed to a hard-boiled egg). This type of evidence is called an indicator.

The law of conservation of matter states that the mass of an isolated or closed system will always remain constant, regardless of the processes acting inside the system. The matter cannot be created or destroyed, it only changes form. In many textbooks, the law of conservation of matter is referred to as "conservation of mass." Because matter is anything that has mass and takes up space, if mass is conserved, then matter is conserved. In other words, in a closed system, the mass of the reactants is equal to the mass or the products.

Steel wool may have oils or another protective coating on it to prevent rusting. When steel wool is soaked in a weak acid such as vinegar, the protective coating is removed by the acid. The weak acid speeds up the rate of the oxidation reaction of iron with oxygen in the atmosphere, resulting in rust appearing.

Steel wool reacts with oxygen to form reddish-brown iron (III) oxide (rust) in a chemical reaction. The iron in steel wool is oxidized by oxygen:

$$2Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3\,(s)$$

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask students what the difference is between a physical and chemical change. Is matter conserved in both? Ask the students how they could test their hypotheses. List their methods on the board.

> Answers will vary. One class discussion produced the following: In a physical change, the substances may change forms but no new substances are created. In a chemical reaction new substances are produced with properties that are different from the properties of the original substances. In a physical change such as dissolving salt in water, the mass of the original water plus the mass of the original salt is equal to the mass

of the salt water solution, so matter is conserved. In a chemical reaction such as vinegar reacting with baking soda, a gas is produced. If we carried out this reaction in a closed system and found the mass of the reactants before the reaction, then the mass of the products after the reaction, we could tell if matter was conserved.

Demonstrate the conservation of matter to the students by placing a clean 2-liter plastic soda bottle, with its cap, on a balance or scale sensitive to better than 0.1 gram. Record the mass in grams of the bottle. Remove the bottle and record the mass of an Alka-Seltzer© tablet. Keeping in mind that every mL of water has a mass of 1 gram, add 100 mL of warm tap water to the 2-liter soda bottle. Sum the mass of the bottle, cap, Alka-Seltzer tablet, and 100 mL of water. This is the mass of the entire closed system.

Break the Alka-Seltzer tablet in half and add both halves of the tablet to the water in the bottle. Cap the bottle immediately. Record the mass of the bottle system. Is there a change in mass from the sum of the ingredients added to the 2-liter bottle?

There is no change in mass.

Ask the students if the same mass reading would occur if the cap was not on the 2-liter bottle.

With the cap off the bottle, the final mass would be less, due to the escaping of some of the gas that was produced in the reaction. Many students may have misconceptions about this because they do not think that gases have mass.

Repeat the chemical reaction without the cap. How is the mass conserved when the cap is present?

The mass changed by 0.2 grams when the tablet dissolved in the bottle without the cap; however when the tablet dissolved in the bottle with the cap on, the mass did not change. When the cap was on during the reaction, mass was conserved, because none of the reactants can escape the bottle.

Direct the students to "Thinking About the Question." If students have difficulty thinking of examples of chemical changes, prompt them with one or two examples such as the burning of wood or paper, the tarnishing of metals like silver or copper, or the production of carbon dioxide gas from mixing vinegar and baking soda. After a few minutes, ask the student lab groups to share some of their ideas with the class.

It is appropriate at this time to discuss the limitations of balances. It is not uncommon for students to believe that balances have unlimited precision. Depending on the type of balance used, there should be an uncertainty of at least + or – 0.1 gram.

Preparation and Tips

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

1. Prepare ahead of time for the Alka-Seltzer tablet and soda bottle demonstration. Wash, rinse, and dry a plastic 2-liter soda bottle. Remove its label. It is always advisable to rehearse teacher demonstrations ahead of time, so you know what to expect.

2. You may also want to place the temperature sensor and pressure sensor tubing into the holes of the stopper ahead of time rather than having students do this. Be sure that the temperature sensor fits tightly; if necessary make a plastic tubing "collar" to improve the fit. This is to make sure the system is air-tight so pressure changes are accurate. If necessary, you can lubricate the tubes with glycerin or dish detergent to get them through the holes more easily.

3. Obtain steel wool that is free of pre-applied detergent or soap which can interfere with the rate of the reaction (and add mess); usually the local hardware store has plain steel wool

without soap. You may wish to pre-tear or pre-cut the steel wool into sample portions ahead of time for students.

4. Provide a liquid waste receptacle for students to dispose of their used vinegar. This may be poured down the sink drain if a sink is available. Steel wool samples may be safely discarded in the trash.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear safety goggles for the duration of this activity.
- Use gloves if you have a cut or break in your skin.
- Wash your hands with soap and water after this activity.

Driving Question

Is matter conserved during a chemical reaction?

Thinking about the Question

In science, a substance or quantity is said to be “conserved” if it can be changed in form but cannot be created or destroyed. During a chemical reaction new kinds of matter are formed, and those new kinds of matter have different compositions and properties from the old matter. Matter is not created or destroyed; it is conserved.

Your intuition tells you a lot about this idea already, based on experiences you may have had in the past. If you have ever used LEGO™ products to build a model or structure, then you are familiar with the “conservation” of LEGOs. What happens if you take apart an old model you no longer want, so that you can use the LEGO™ pieces to build something new? Is the total number of LEGOs any different now than when you built the original model? After you have assembled your next masterpiece, how many pieces will you have to work with? Of course you know that no matter how many times and ways you rearrange your LEGO building blocks, you will always have the same number and type of pieces to work with. Whether you build a replica of the Eiffel tower or a model of a 747 or a horse, you begin and end with the same set of LEGOs. In other words, those LEGO pieces are conserved.

Discuss with your lab group members how you can tell that a chemical reaction has taken place rather than a physical reaction. Be sure to think of several examples of chemical changes and describe how the substances formed are different from the original substances.

Answers will vary. One class answered as follows: Chemical changes include the rusting of iron, milk turning sour, vinegar reacting with baking soda, and hydrochloric acid reacting with zinc metal. When iron rusts, the iron oxide, or brown rust, does not have the same properties as iron. It is now powdery and dull, not shiny and strong; the rust is brittle instead of malleable like the iron. When milk turns sour, it no longer looks, tastes, or smells like milk. Sour milk is used in some recipes for cooking or baking, but it is not drunk as a beverage. When vinegar reacts with baking soda, a gas, carbon dioxide, is produced. When hydrochloric acid reacts with zinc metal, a black granular substance is produced along with a flammable gas, hydrogen, What do you know about the amount of matter produced during a chemical reaction? Does it increase or decrease? Does it stay the same?

In a chemical reaction, the amount of products after the reaction must be the same as the amount of reactants before the reaction. It can be shown with a chemical equation that every atom of reactant must be accounted for in the products of the reaction. A chemical reaction "rearranges" the matter but does not add or delete any matter.

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.

2	1	3	4	5
Soak steel wool samples in vinegar.	Make sure each lab group member is aware of safety rules and procedures for this lab.	Place steel wool samples into flasks.	Find the mass of the flask + steel wool + stopper system.	Observe the reaction of steel wool and vinegar for 30 minutes.

Investigating the Question

Part 1 – Making predictions

1. ☐ What will happen to the mass of the steel wool when you add vinegar to it?

   When we add vinegar, the mass of the steel wool will increase.

2. ☐ Will a chemical reaction occur between the steel wool and the oxygen in the air? How will you know?

   There will be a chemical reaction, which we will recognize by either a color change, the production of gas, or heat being given off or absorbed.

3. ☐ If a chemical reaction does occur, what will the new substances or products be?

   We predict that the chemical reaction will produce rust.

4. ☐ How will the temperature change if the steel wool reacts?

   The temperature will increase.

5. ☐ How would this change appear on a graph of temperature versus time?

   On the graph, the curve will slope up from left to right (it will have a positive slope).

6. ☐ How will the pressure change if the steel wool reacts?

The pressure will decrease.

7. ☐ How would this change appear on a graph of pressure versus time?

On the graph, the curve will slope down from left to right (it will have a negative slope).

Part 2 – Measuring the mass of the reaction

8. ☐ Roll each sample of steel wool into a spherical shape, but do not compress them too tightly. Why do you think it is important not to compress the steel wool too tightly?

It is important not to compress the wool too tightly so that the vinegar is able to penetrate into the wool to clean it. Loosely packed steel wool has a larger surface area.

9. ☐ Place the samples of steel wool into the plastic cup and add vinegar until the samples are completely immersed. Soak the steel wool for 5 minutes.

10. ☐ Remove one sample of steel wool from the cup. Squeeze it gently to remove excess vinegar, then dry the steel wool with a paper towel.

11. ☐ Place the dried steel wool sample into a 250-mL Erlenmeyer flask and cover the opening with the rubber stopper (no holes). Why do you think the system you have just set up is referred to as a "closed system?"

This would be a closed system once the stopper is in place because no products or reactants can escape the flask. Also, no other materials or substances can enter. The inside of the flask is totally isolated.

12. ☐ Measure the mass of the entire closed system of flask + steel wool + stopper, and record it here.

Mass = 141.7 grams

13. ☐ Set the closed system flask aside and observe it every two minutes for the next 30 minutes while you work on Part 3 of the activity.

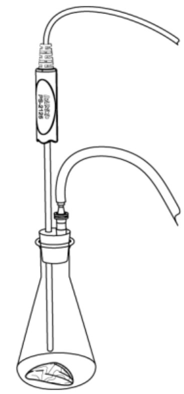
14. ☐ After 30 minutes have elapsed, measure the mass of the entire closed system of flask + steel wool + stopper, and record it here.

Mass = 141.7 grams

15. ☐ After the 30 minutes elapsed, what did you observe inside the flask? Write your observations.

Student answers will vary. One group answered as follows: We observed that the steel wool began to rust and that condensation formed on the inside of the flask. The steel wool changed color slowly, from its original gray-silver color to a more brownish color. Also, the stopper seemed to be sucked into the opening of the flask more tightly.

Part 3 – Reaction temperature and pressure changes



16. ☐ While you are observing the closed system of flask + steel wool + stopper from Part 2, prepare the 2-hole stopper for use with the second Erlenmeyer flask:

    a. Insert the stainless steel temperature sensor into one of the holes in the 2-hole stopper. In order to have an air-tight seal, you may need to use the plastic collar (insert the temperature sensor into the plastic collar first, then insert the collar into the hole of the stopper). Use a drop of glycerin to lubricate the sensor.

    b. Insert the tubing of the pressure sensor into the other hole in the 2-hole stopper.

    c. Connect the tubing to the pressure sensor using the quick-release connector.

17. ☐ Remove the second sample of steel wool from the cup. Squeeze it gently to remove excess vinegar, then dry the steel wool with a paper towel.

18. ☐ Place the second piece of steel wool into a 250-mL Erlenmeyer flask and cover the opening with the rubber stopper that contains the pressure and temperature probes.

19. ☐ Discard the used vinegar according to your teacher's instructions.

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

21. ☐ Connect the pressure sensor and the temperature sensor to the data collection system. �(2.2)

22. ☐ Display two graphs simultaneously. On one graph, display Temperature on the y-axis with Time on the x-axis. On the second graph, display Pressure on the y-axis with Time on the x-axis. �(7.1.11)

23. ☐ Begin data recording. �(6.2)

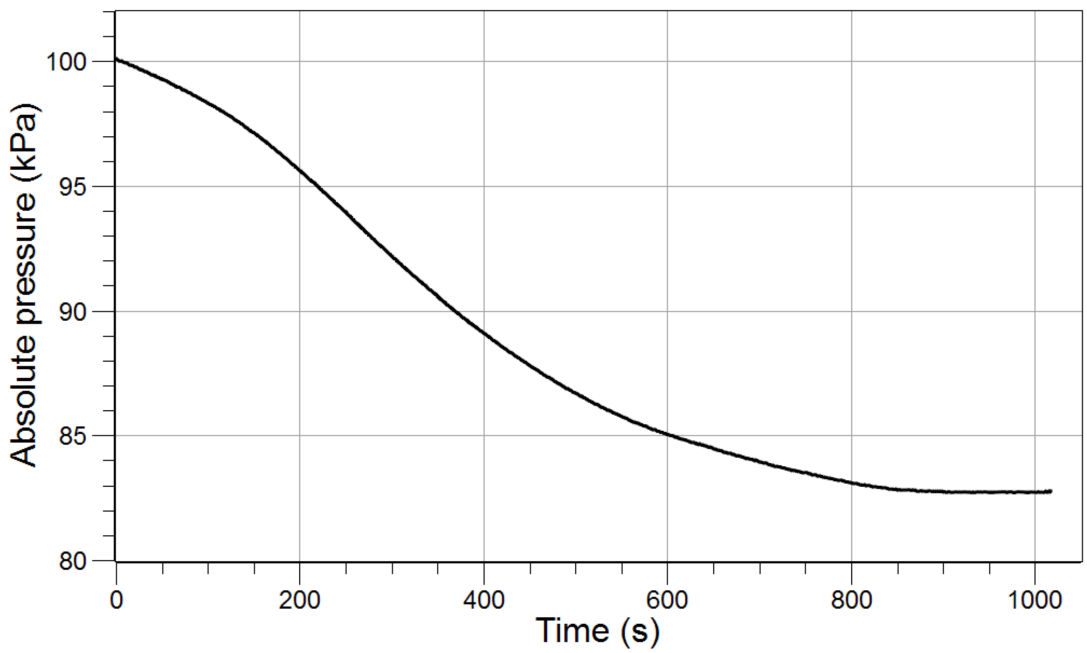
24. ☐ Record pressure and temperature data until the 30 minutes have passed for Part 2 of this activity, then stop data recording. �(6.2)

25. ☐ At the end of the 30 minutes, observe the Temperature and Pressure graphs and note any trends or patterns you see. Write your observations here.

Based on our graphs, the temperature inside the flask went up and the pressure went down.

26. ☐ Discard the steel wool according to your teacher's instructions.

Sample Data



Answering the Question:

Analysis

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

The temperature went up during this time, and a chemical reaction occurred.

2. Compare the mass of the system in Part 2 before and after the reaction. What evidence supports matter being conserved in the closed system?

The mass stayed the same before and after the reaction. Matter was conserved in the closed system because no mass was lost or gained during the reaction.

3. How can you explain the formation of rust (iron oxide) on the steel wool, without any increase in mass? Where did the rust come from?

Answers will vary. One student group answered as follows: The rust, which is iron oxide, needed oxygen to form. The source of the oxygen inside the closed flask was the air, which contains oxygen. The reason there was no increase in the mass was because the same amount of oxygen that went into forming the rust, came out of the air. It just moved around, but it was there all along.

4. For Part 3, how did your predictions compare to the results? What happened to the temperature and the pressure inside the flask?

The temperature increased, while the pressure decreased, as predicted.

5. Was the steel wool and oxygen reaction endothermic or exothermic? Explain your reasoning.

This was an exothermic reaction, because heat energy was given off during the reaction. We could tell this by the increase in temperature.

6. How can you explain the change in the pressure?

The pressure dropped in the flask because the rust used up some of the oxygen in the air. The air gave up oxygen to form the rust, which meant there were less oxygen molecules in gas form in the flask.

7. How might your experimental results have been different if you had not carried out the reaction in a closed system? Would you be able to use the results from such an experimental setup as evidence for conservation of matter? Explain your reasoning.

Answers will vary. One student group answered as follows: In an open system, without the stopper in place, the temperature change might not have been as great, because some of the heat would have escaped out the top of the flask. Also, there would be more air and oxygen available to form rust, so possibly there would have been an increase in mass. If the mass increased during the reaction, then matter was gained from the outside. In addition, you may not be able to detect a noticeable pressure change.

8. In your own words, state what is meant by "conservation of matter."

Answers will vary. One student group answered as follows: When a chemical change or reaction takes place in a closed container, the mass of the container and all the parts of the reaction is the same at the beginning of the experiment as it is at the end of the experiment. No new matter is created; the matter that was already present just gets rearranged.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. The measure of the amount of matter in a substance is:

   A. Volume
   B. Mass
   C. Pressure

2. The process of rusting involves iron or steel taking ________ from the air and undergoing a chemical reaction.

   A. Oxygen
   B. Nitrogen
   C. Heat energy

3. Beginning and ending a chemical change with the same amount of mass is known as:

   A. A closed system
   B. Conservation of matter
   C. An exothermic reaction

4. A certain chemical reaction involves 6.0 x 10^{23} molecules of table salt, or sodium chloride (NaCl). If this reaction has taken place in a closed system, at the end of the reaction, how many atoms of chlorine (Cl) will be present?

   A. Less than 6.0 x 10^{23} atoms
   B. More than 6.0 x 10^{23} atoms
   C. Exactly 6.0 x 10^{23} atoms

5. Pressure is measured in SI units known as:

   A. Newtons
   B. Pascals
   C. Joules

True or False

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

___T___ 1. Matter cannot be created during a chemical reaction; it can only change forms.

___F___ 2. Rusting is an endothermic reaction.

___T___ 3. To demonstrate conservation of matter during a chemical reaction, the reaction must be carried out in a closed container.

___T___ 4. If fifty water (H_2O) molecules are present at the beginning of a reaction in a closed system, by the end of the reaction there will still be fifty oxygen and one hundred hydrogen atoms in the system.

___F___ 5. Boiling vinegar and iron shavings in a lidless pan on the stove could help demonstrate conservation of matter.

Further Investigations:

Try using lemon juice, cranberry juice, and orange juice with the steel wool. Was matter still conserved?

Heat an open Erlenmeyer flask with the steel wool, and let it cool back down. This will increase the rate of reaction, and also allow air into the flask. Why should you expect the mass of the steel wool + flask to increase when heated in air?

Rubric

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

4. Energy Transfer

Radiation, Conduction, Convection

Objective

In this activity, students explore temperature changes that result from the energy transfer methods of conduction and convection.

Students will be able to:

- Explain what heat is
- Describe the conduction and convection energy transfer methods

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up materials and equipment to test transfer of heat energy of a candle flame through convection and conduction
- Measuring the change in temperature at two locations, above a candle flame and at the end of a metal cylinder
- Using math skills to analyze graphical data and determine the difference in rates of change of temperature

Time Requirement

Introductory discussion and lab activity, Parts 1 and 2 – Making predictions	30 minutes
Lab activity, Part 3 – Measuring energy transfer	30 minutes
Analysis	25 minutes

Materials and Equipment

For each student or group:

- ☐ Data collection system
- ☐ Stainless steel temperature sensors (2)
- ☐ Ring stands (2)
- ☐ Clamps (3)
- ☐ Matches

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Heat is the transfer of energy between objects that are at different temperatures.
- Heat energy is transferred from areas of higher temperature to areas of lower temperature.

Related Labs in This Guide

- Investigating Solar Energy
- Exploring Environmental Temperatures
- Monitoring Weather
- Water's Role in Climate

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 a sensor to the data collection system �(2.2)
- Starting and stopping data recording �(6.2)
- Displaying data in a �(7.3.1)
- Saving your experiment �(11.1)

Background

Convection

Convection is the transfer of thermal energy by the movement of a substance from one place to another. Convection takes place only in liquids and gases. For example, the lower layers of the atmosphere absorb infrared energy emitted by the Earth's surface. The warmed gas expands, rises, and transfers thermal energy to higher layers of the atmosphere. Convection in the atmosphere is responsible for the redistribution of thermal energy from the equatorial regions to the polar regions as well as from the surface upward.

Convection is generally used to describe vertical motion. Advection is sometimes used to describe horizontal motion, such as winds.

Convection also occurs in Earth's oceans. In water warmed at the bottom, the motion of the warmed water is from the bottom toward the top. As the surface water becomes cooler, it sinks toward the bottom due to density differences.

Conduction

Conduction is the transfer of thermal energy through matter by molecular activity. Molecules transfer the energy through collisions from one to the next. The thermal energy tends to move from a region of higher temperature to a region of lower temperature.

Some substances conduct thermal energy much better than others. Metals tend to be good conductors of thermal energy. Because of the space between particles, air is a poor conductor. Conduction is the least important method of energy transfer for the atmosphere as a whole.

Radiation

Radiation is the transfer of thermal energy by the emitting of electromagnetic waves, which carry the energy away from the object that emitted them. For temperatures that are less than glowing red hot, the radiation emitted is in the infrared region of the electromagnetic spectrum.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity.

Ask the students, "What is heat?"

Heat is the transfer of energy between objects that are at different temperatures.

Ask the students, "How does heat energy flow when being transferred?"

Heat energy is transferred from areas of higher temperature to areas of lower temperature.

Ask the students, "What are three methods of heat energy transfer?"

Conduction, Convection and Radiation are three methods of heat energy transfer.

Direct the students to "Thinking About the Question." Discuss the answers to these questions as a whole group and come to a consensus.

Now direct the students to "Investigating the Question."

Preparation and Tips

Although this lab requires no specific lab preparation, allow 10 minutes to assemble the equipment needed to conduct the lab.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear eye protection and aprons.
- Follow proper fire safety precautions when working with the candle.
- Be very careful when handling heated materials.

Driving Question

Which method of energy transfer, convection or conduction, will heat the temperature sensor faster?

Thinking About the Question

Radiation does not require material in order to transfer energy; solar radiation travels through the vacuum of space. Convection and conduction both occur in matter.

Is convection possible in outer space?

Convection requires matter so it would not be able to occur in the vacuum of outer space.

How are the three methods of energy transfer involved in warming the lower level of Earth's atmosphere?

The surface absorbs solar radiation and becomes warmer. Air in contact with the surface is warmed by direct contact - conduction. The warmed air is less dense so it rises and transfers energy to the air above - convection.

If conduction and convection both occur in matter, what is the difference between them?

They occur in different states of matter. Conduction occurs in solids, convection occurs in both liquids and gases.

Sequencing Challenge

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.

2	1	3	5/4	4/5
Measure the length of the metal cylinder which is to be heated.	Make sure each lab group member is aware of the safety rules and procedures for this lab.	Position the tip of a temperature sensor the same distance from the candle flame as the metal cylinder is long.	Record temperature data from the two temperature sensors simultaneously.	Use a match to light the candle.

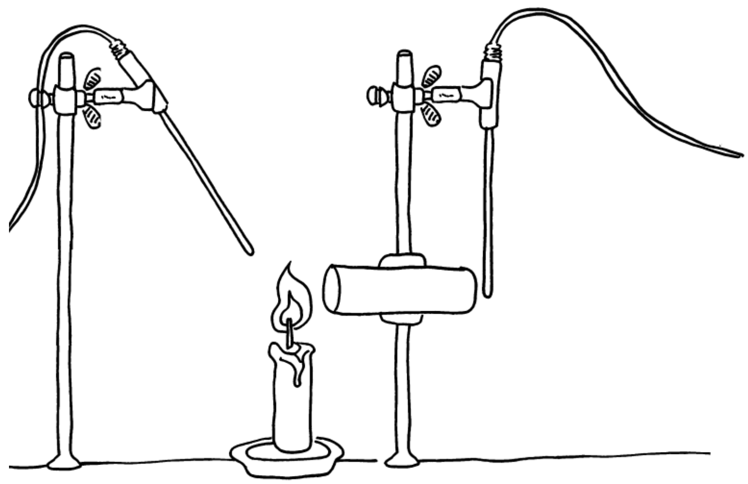
Investigating the Question

Part 1 – Equipment setup

1. ☐ Use a clamp and support rod to hold the metal cylinder horizontally.

2. ☐ Use a second clamp to support the temperature sensor so that the tip of the sensor touches one end of the metal cylinder.

3. ☐ Position the candle 2 cm from the other end of the metal cylinder so when the candle is burning, the flame will heat the end of the cylinder.



4. ☐ Use a third clamp and a second support rod to hold a second temperature sensor so that the tip of the sensor is above the flame the same distance as the length of the metal cylinder. Why would the second temperature sensor need to be the same distance above the flame as the length of the metal cylinder?

The second temperature sensor would need to be the same distance above the flame as the length of the metal cylinder in order to have a valid experiment. By using the same distance for each sensor, energy will have to be transferred through the same length of air as through metal. If these two distances were different, we would have introduced an additional variable into the experiment.

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

6. ☐ Connect both temperature sensors to the data collection system. �(2.2)

Part 2 – Making a prediction

7. ☐ Record your prediction for which energy transfer method, conduction or convection, will heat faster.

Answers will vary. One student group answered as follows: We predict that convection will transfer heat energy faster than conduction.

Part 3 – Measuring energy transfer

8. ☐ Display the temperature against the metal cylinder and the temperature above the unlit candle in a digits display �(7.3.1).

9. ☐ Start data recording �(6.2).

10. ☐ Carefully light the candle and place it at one end of the metal cylinder.

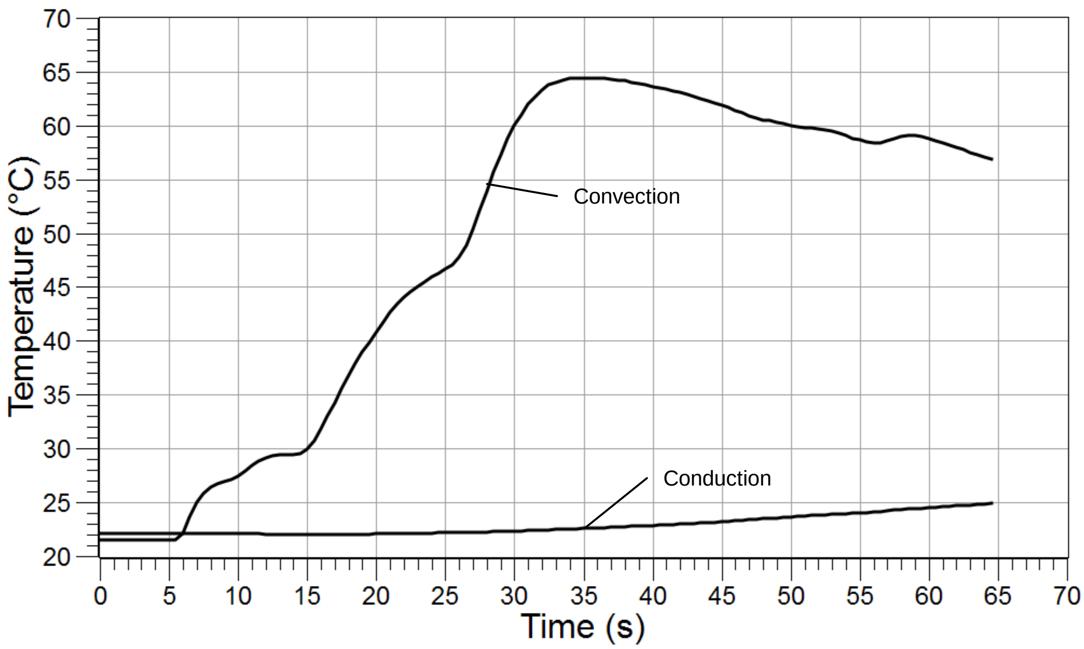
11. ☐ Extinguish the candle when either temperature reaches 70 to 75 °C. Although the temperature sensor is made to withstand temperatures up to 130 °C, what are some reasons you need to extinguish the candle before the sensor reaches that temperature?

Answers will vary. One group answered as follows: We need to blow out the candle before the temperature sensor gets to 70 degrees because even though it wouldn't damage the sensor, metal at that temperature is still hot enough to burn a person. It would be better not to have the sensors any warmer than we could touch without burning ourselves. Also, water boils at 100 degrees C, so we do not want the sensor to be even that hot.

12. ☐ Wait until the metal cylinder cools before removing it.

13. ☐ Save your experiment �(11.1) and clean up according to your teacher's instructions.

Sample Data



Answering the Question

Analysis

1. What are the starting temperatures for the sensor touching the metal cylinder and the sensor above the candle?

Answers will vary. One student group reported the following data: Our starting temperatures for both sensors were 21 degrees Celsius.

2. What are the ending temperatures for the probe touching the metal cylinder and the probe above the candle?

   Answers will vary. One student group reported the following data: Our ending temperature for the sensor touching the metal cylinder was 25 degrees Celsius, and for the sensor above the candle was 57 degrees Celsius.

3. Looking at your prediction, were you correct? Why or why not.

   Answers will vary. One group answered as follows: We predicted that conduction would heat the metal the fastest, and according to our temperature data, this is what happened in our experiment.

4. Describe how energy is transferred by conduction.

   Conduction is the transfer of thermal energy through matter by molecular activity. Molecules transfer the energy through collisions from one molecule to the next. The thermal energy tends to move from a region of higher temperature to a region of lower temperature.

5. Describe how energy is transferred by convection.

   Convection is the transfer of thermal energy by the movement of a substance from one place to another. Convection takes place only in liquids and gases.

6. Based on your results, which would heat faster from room temperature, food inside an oven or food on the stove top? Explain your reasoning.

   Answers will vary. One student group answered as follows: Based on our results we think that food in the oven would heat up faster than food in a pan on the stove. The air inside an oven heats by convection, because the heating element is on the bottom where it heats the air and the air then rises to the top of the oven where the food is. Food in a pan on the stove has to have heat conducted from the burner through the metal of the pan and through the bottom of the food.

Key Term Challenge

Fill in the blanks from the randomly ordered words below. Words may be used more than once:

radiation	thermal	convection	conduction

1. The transfer of thermal energy caused by density differences in a fluid is called __convection__.

2. When a warm object is touching a cool object, heat moves by __conduction__.

3. Molecules transfer thermal energy through collisions from one to the next in __conduction__.

4. The energy transfer that does not require a medium is called __radiation__.

5. The transfer of thermal energy by the movement of a substance from one place to another is called __convection__.

6. The transfer of thermal energy through matter by molecular activity is called __conduction__.

7. The least important method of energy transfer method for the atmosphere as a whole is __conduction__.

8. __Thermal__ energy tends to move from a region of higher temperature to a region of lower temperature.

Further Investigations

Have students design an experiment to measure the transfer of energy by convection in water.

Have students research global warming and ask them to explain the process in terms of energy transfer methods such as radiation and convection.

Rubric

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

5. Exploring Velocity and Inertia

Crash Test

Objectives

In this activity students explore Newton's laws of motion. Students will use a motion sensor to measure the velocity of an object on a PASCar. This PASCar comes to a sudden stop and the object continues its motion.

Students will:

- Investigate the relationship between velocity and the distance an object is thrown after collision
- Explain how Newton's laws of motion are involved in this investigation
- Design and conduct a scientific investigation

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the work area and equipment to measure the velocity of a cart as it travels down an inclined track and collides with an obstacle
- Measuring the distance traveled by a "crash test dummy" after each collision
- Using math skills to relate the velocity of the cart to the distance traveled by the dummy

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	40 minutes
■ Lab activity, Parts 2 and 3	40 minutes
■ Analysis	30 minutes

Materials and Equipment

For each student or group:

- ☐ Data collection system
- ☐ Motion sensor
- ☐ Dynamics track
- ☐ PASCar or other cart or toy car
- ☐ Marble
- ☐ Small bean bag
- ☐ Meter stick

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The difference between speed and velocity.
- Newton's laws of motion.
- Use of measuring devices such as a meter stick to measure the length of objects or distances from one point to another.
- SI units of measure for length (m) and velocity (m/s).
- Math skills necessary to average a set of data and to graph data points on a set of coordinate axes (on graph paper).
- The basics of using the data collection system.

Related Labs in the Guide

Labs conceptually related to this one include:

- Motion Graphs
- Speed and Velocity

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 a sensor to the data collection system �(2.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Viewing statistics of data �(9.4)

Background

"Speed" is the rate at which an object travels a certain distance. "Velocity" is the rate of change in the position of an object as it moves in a particular direction. "Position" requires a frame of reference from which motion or a location can be described. So, imagine you are listening to the weather report and you hear a storm is moving at 40 kilometers per hour (40 km/hr). That would be the *speed* of the storm. If the weather reporter said the storm was moving at 40 km/hr east, that would be describing the storm's *velocity*. Now if the weather reporter mentioned the storm was moving at 40 km/hr east from Medina. This gives the velocity of the storm as well as its current *position*, Medina, which is used as a *frame of reference* for the storm's motion from there.

Sometimes, the direction component of velocity is not stated but is understood. For example, a paintball gun may state the maximum velocity of a fired paintball is 91 meters per second (91 m/s). The direction of the paintball is not stated, but is understood to be out from the barrel of the gun.

Newton's first law of motion states that an object in motion will continue that motion with constant speed in a straight line unless a force acts on it. This resistance to a change in motion is referred to as "inertia." A person riding in a car is traveling at the same rate as the car. If the car suddenly stopped due to an outside force acting on it, such as from a tree, the person would continue moving forward due to their inertia, until a force is applied to him or her. Hopefully, it is a seatbelt and not the dashboard that applies a force to the person! Inertia is why someone who is not wearing a seat belt gets ejected from the vehicle since there is no force acting to prevent the forward motion of the person.

Newton's second law of motion states force equals mass times acceleration ($F = m \times a$). So the greater the acceleration, the more force acting on an object. In the case of the person riding in the car, the faster the acceleration of the person, the greater would be the resulting force of impact on someone who is not wearing a seatbelt.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Investigate the movement of the PASCar. Try rolling the car around while keeping your hand on it. Try pushing the car gently and releasing it. Why does the PASCar move when you are pushing it with your hand?

> You are applying a force to it.

Why does the PASCar keep moving even after you push it and let it go?

> The car's inertia keeps it in motion.

Why does the PASCar slow down and then stop?

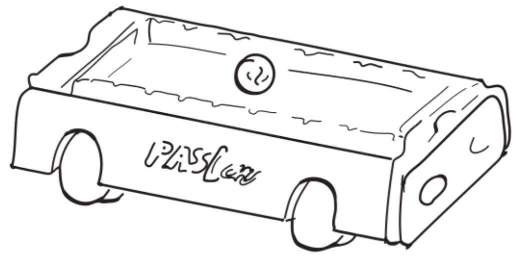
> Friction from the surface the car is traveling on and the air causes the car to slow down and stop.

Place a marble on the car as shown. Gently push the car. What happens to the marble when the PASCar is pushed?

> The marble appears to move backwards.

Why do you think this happens?

> The marble's inertia keeps it from moving since there is no force acting on it while the PASCar accelerates out from under the marble.



Direct the students to "Thinking About the Question." Discuss the answers to these questions as a whole group and come to a consensus.

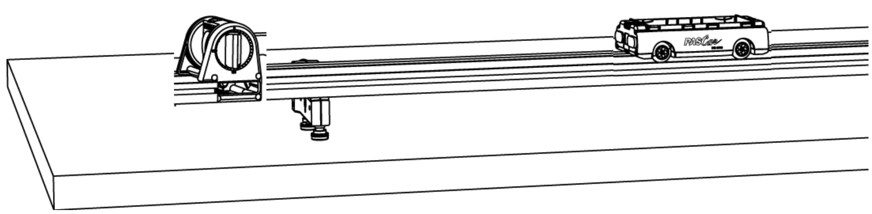
Now direct the students to "Investigating the Question."

Preparation and Tips

These are the material s and equipment to set up prior to the lab.

- Refresh the students on how the motion sensor works. This lab should be done after the students have had a chance to explore motion with the motion sensor.

- Attach the motion sensors to the dynamics track with the round gold screen perpendicular to the surface of the motion track prior to the start of the lab activity. The selector switch on the top of each motion sensor should be set to the "cart" icon instead of the "person" icon.



- To avoid spikes in the graph, have the student who is releasing the PASCar move it as little as possible. This can best be done by resting their hand on the motion track and holding the PASCar in place with a finger, then lift the finger off the PASCar during the run, leaving the hand in the same position.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Make sure the students set up their materials so that they have a safe, clear area to work.

Driving Question

How does velocity affect the distance a moving object, the "crash test dummy", is thrown after a collision?

Thinking About the Question

Why does an object keep moving after a collision such as a car crash?

> Any object with mass has inertia, which is the property that resists a change in motion.

What is velocity?

> Velocity is speed in a given direction.

How could you test to see how velocity affects the distance an object is thrown after a collision?

> We could model car crashes at different velocities and measure the distances that an object flew after impact.

What materials would you need in order to do this?

> We would need a dynamics cart and track, and an object like a bean bag to model the passenger, To cause the cart to crash, we would need a way of stopping it, such as a heavy book.

What are the characteristics of a good experiment?

> In a good experiment, all of the variables are controlled except the one we want to test. Also, the results of a good experiment should be able to be replicated by another group.

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.

2	4	5	3	1
Incline a track to make a ramp for your PAScar and "crash test dummy" to accelerate down.	Record the velocity of the PAScar as it rolls along the motion track.	Measure the distance the "crash test dummy" flew after the collision.	Place a bean bag on the PAScar to model a person during the collision.	Make sure each member of your lab group is aware of safety rules and procedures for this lab.

Investigating the Question

Note: When students see this 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 prediction on how velocity affects the distance a crash test dummy is thrown after a collision? Explain your reasoning.

   We think that the higher the velocity of the PASCar, the farther the crash test dummy will be thrown. It will be thrown farther because due to its inertia, it will continue to travel along at the higher velocity.

2. ☐ You will arrange the dynamics track so that it is inclined at three different angles, or heights. Your lab group members will decide whether to work from steepest incline to least steep, or least steep incline to steepest. Predict how the steepness, or slope of the incline, will be related to the velocity of the PASCar.

   The steeper the ramp is inclined, the higher the velocity the PASCar will be traveling when it hits the bottom and collides.

Part 2 – Equipment set up

3. ☐ Set up the motion track on the floor ensuring there is enough clear area for the crash test dummy to be thrown without hitting anything.

4. ☐ Incline the motion track using books or the adjustable feet on one end of the track.

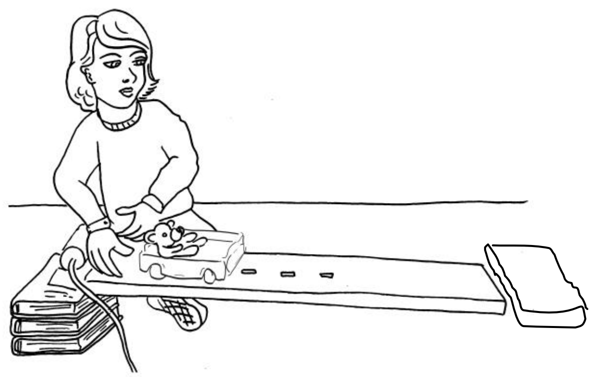
5. ☐ Using the meter stick, determine the height of the track at the inclined end. This height will be used for Velocity 1. Record this as Height 1 in Table 1 at the bottom of this section.

6. ☐ Place a textbook at the end of the motion track so the cart will collide with its bound side.

7. ☐ Make sure the motion sensor is attached to the motion track and the gold disk is perpendicular to the track. Why should the disk be positioned perpendicular to the track?

   The screen should be perpendicular to the track so that the motion sensor can "see" down the track. If it does not, the position data will not be accurate.

8. ☐ Place the crash test dummy (bean bag) at the front of the PASCar, sitting as if it were driving.



9. ☐ If the collision spot (the point where the cart will hit the book) is not already marked with tape, place a small strip of tape on the floor to mark it. Why is this tape needed?

This tape will help us measure from exactly the same point each time, even when we move the book. It prevents the initial position from being a variable in our experiment.

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

11. ☐ Connect the motion sensor to the data collection system. �(2.1)

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

Part 3 – Testing with the motion sensor and track

13. ☐ After the PASCar is in position, begin data recording �(6.2) and release the PASCar.

14. ☐ When the PASCar's motion stops, stop data recording �(6.2).

15. ☐ Measure the distance to the nearest 0.1 cm from the collision spot (marked with tape) to the middle of the crash test dummy. Record this distance in Table 2.

16. ☐ From your velocity graph, determine the maximum velocity of the PASCar. �(9.4) Record this velocity in Table 2.

17. ☐ Repeat the testing for a total of three trials for this height of the track. Record all results in Table 1.

18. ☐ After completing three trials for the first height of the motion track, change the height of the track.

19. ☐ Using the meter stick, determine the new height of the track at the inclined end. This height will be used for Velocity 2. Record this as Height 2 in Table 1.

20. ☐ Carry out three collisions at this height of the inclined motion track. Record all results (distance traveled and maximum velocity) in Table 2.

21. ☐ After completing three trials for Height 2 of the motion track, change the height of the track.

22. ☐ Using the meter stick, determine the new height of the track at the inclined end. This height will be used for Velocity 3. Record this as Height 3 in Table 1.

23. ☐ Carry out three collisions at this third height of the inclined motion track. Record all results in Table 2. Why do you think you were asked to complete three trials for each height rather than just one? Explain your reasoning.

We were supposed to do three trials so that we can average our results. An average of three results would minimize the effect of any errors we made during our experiment. If we had just one trial, and those measurements had errors, we would not necessarily know it because we would have no other data to compare it to.

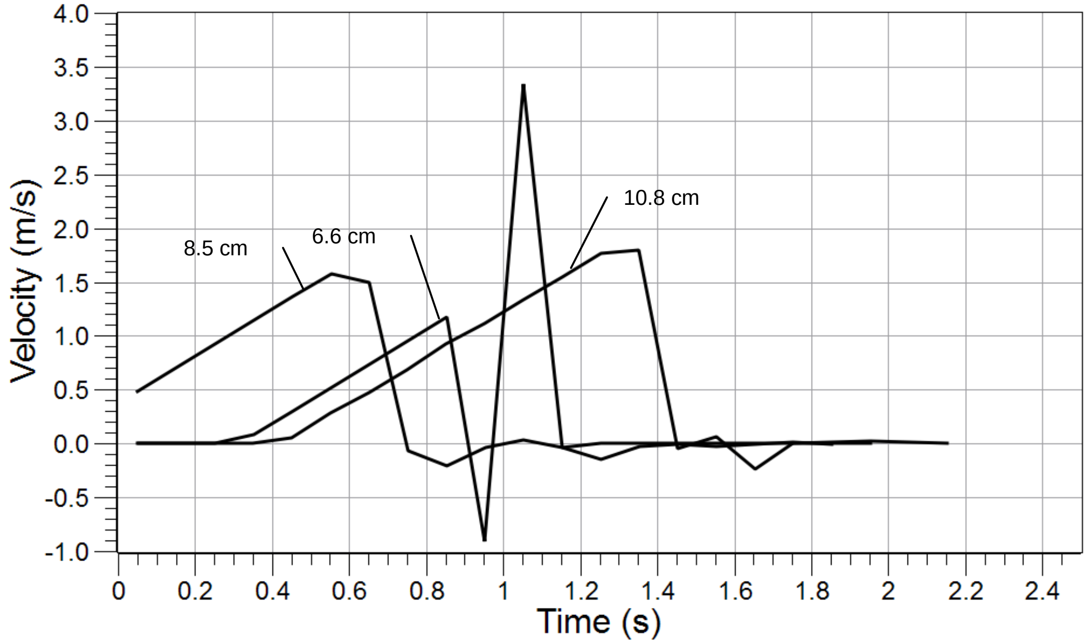
Table 1: Height

	Height 1: 6.6 cm	Height 2: 8.5 cm	Height 3: 10.8 cm

Table 2: Distance and velocity

	Distance Bean Bag Traveled (cm)	Distance Bean Bag Traveled (cm)	Distance Bean Bag Traveled (cm)
Trial 1	15.1	21.6	27.2
Trial 2	15.3	19.4	28.4
Trial 3	14.4	20.1	27.6
	Maximum Velocity of Cart: Height 1 (m/s)	**Maximum Velocity of Cart: Height 2 (m/s)**	**Maximum Velocity Cart: Height 3 (m/s)**
Trial 1	0.74	0.91	1.13
Trial 2	0.74	0.92	1.11
Trial 3	0.73	0.91	1.12

Sample Data



Answering the Question

Analysis

1. Look over Table 2 containing your experimental results. Do your results agree with your predictions from Part 1? Why or why not? Explain your thinking.

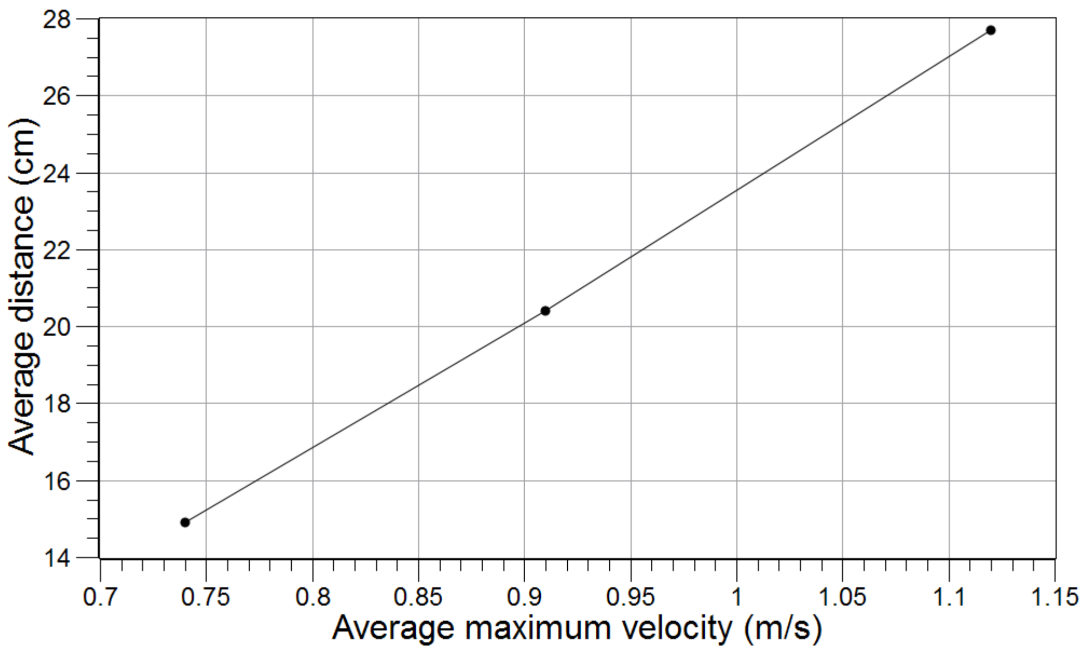
   According to our results, the data supports our prediction. We predicted the crash test dummy would go farther when it crashed at higher velocities than when it crashed at lower velocities. This was true for each trial we did.

2. Average your results for each trial. Record the results of these calculations in Table 3 below:

Table 3: Average velocity and distance

	Average Maximum Velocity for All Trials (m/s)	Average Maximum Distance for All Trials (cm)
Height 1	0.74	14.9
Height 2	0.91	20.4
Height 3	1.12	27.7

3. On graph paper, plot the data you have averaged. Which is the independent variable, the velocity of the PASCar or the distance the dummy was thrown? On which axis of your graph should you display the independent variable?



The independent variable is the velocity of the cart, because that is the thing we varied intentionally. It should be plotted on the x-axis of our graph. The distance that the crash test dummy flew after the collision depends on the velocity, so the distance is the dependent variable. It should be plotted on the y-axis of our graph.

4. The bean bag and PASCar are models that represent a real-life situation. Explain what these models represent, including a description of what the collision represents.

The bean bag represents a person riding in a car. The PASCar represents the car the person is riding in. In this model, the person is not wearing a seatbelt, so the collision represents a real car crash in which the person is ejected from the car.

5. What property of matter is responsible for the crash test dummy (the bean bag) continuing to travel on for a distance after the PASCar has stopped?

Inertia is responsible for the dummy continuing to travel a certain distance.

6. Predict what would happen in a collision if there were two crash test dummies riding on the PASCar, one twice as heavy as the other. Use Newton's laws of motion to support your statements.

The heavy dummy would not fly as far as the lighter one because the collision gives the same force to each dummy. Since the heavier dummy has twice the mass, it should fly half the distance. The law of inertia explains why the dummies keep traveling after the cart has stopped. The 2nd law of motion states that force is equal to mass times acceleration. This means that the more mass an object has, the less it can accelerate with the same amount of force.

7. What role do seatbelts play in your safety in a car?

If you are a body in motion, you will stay in motion as long as no outside force acts upon you. The reason seatbelts are important for your safety is because they apply a force to the rider preventing them from staying in motion when the car stops suddenly.

8. If you were not wearing a seatbelt and your car did not have airbags, why would you suffer a more serious injury from a higher velocity crash?

    If you are in a crash with no seatbelt on and your car stops suddenly, you will continue to move in the same direction you were traveling before the collision. The faster the car is traveling before the crash, the faster you will continue moving once the car stops. This would cause more serious injuries. Newton's second law is force equals mass times acceleration (F = m * a), so the greater the acceleration, the more force acting on an object.

9. What does this lab have to do with inertia?

    Newton's first law states that an object in motion will continue that motion with constant speed in a straight line unless a force acts on it. In this lab, the book exerts a force on the PASCar and the PASCar stops. Since the crash test dummy is not attached to the PASCar, there is no force on it except a small friction force. Due to this, the crash test dummy continues moving with the speed it had when the PASCar reached the book.

Key Term Challenge

Fill in the blanks from the randomly ordered words below. You may use a word more than once if necessary.

speed	velocity	acceleration
momentum	force	friction
inertia	frame of reference	motion

1. The __velocity__ of a car tells how fast it is going in a certain direction.
2. A __force__ is a push or a pull on an object.
3. An object's __momentum__ is the product of its mass and its velocity.
4. __Motion__ is described from a frame of reference.
5. An object's __inertia__ causes it to resist changes in its motion.
6. Saying that a truck is traveling at 30 km/h is an example of __speed__ .
7. The force that opposes the motion of a cart on a track or a car on a road is __friction__ .
8. A __frame of reference__ is a point assumed to be fixed and from which motion can be described.
9. An object's motion changes if it is acted on by some external __force__ .

Further Investigations

Use various sizes of bean bags to see if their mass affects how far they are thrown.

Students could use the Internet or library to research how air bags work, and present their findings to the class in a paper or other form of presentation.

Research Isaac Newton's three laws of motion. Ask students to give examples of Newton's laws of motion in action in their daily lives.

Rubric

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

6. Heat Transfer in Fluids

Mixing Temperatures

Objectives

Students investigate what happens to the temperature of a solution when two substances of different temperatures are mixed.

Students investigate the mixing of substances at different temperatures while they:

- Develop the understanding that energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, and the nature of a chemical
- Recognize that heat can be transferred through a fluid
- Learn that heat moves in predictable ways, flowing from warmer objects to cooler objects, until both reach the same temperature
- Gain skills and confidence in using scientific measurement tools, the temperature and pressure sensors, as well as the graphing capability of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the temperature of three samples of water
- Measuring the temperature of a sample of cold water
- Measuring the temperature of a sample of hot water
- Measuring the temperature of a mixture of equal volumes of cold and hot water after mixing them
- Using math skills to average temperatures

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	25 minutes
Lab activity, Part 2 – Measuring temperatures of solutions, Part 3 – Observing the temperature changes of the water mixture	40 minutes
Analysis	25 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor, fast response
- Graduated cylinder, 250-mL
- Beakers or cups (2), 150-mL
- Insulated container
- Hot water, 125 mL
- Cold water, 125 mL
- Red and blue food dyes (optional)
- Stirring rod

Concepts Students Should Already Know

Students should be familiar with the following concepts or skills:

- Use of a graduated cylinder to measure liquid volume, as well as the meaning of the term *volume*
- The arithmetic necessary to set up and compute averages
- How to read and interpret a coordinate graph, as well as be familiar with the SI unit of measure for temperature (degrees Celsius)
- Basics of using the data collection system

Related Labs in This Guide

Labs conceptually related to this one include:

- Transfer of Energy in Chemical Reactions
- Exploring Environmental Temperatures

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 a sensor to the data collections system �(2.1)
- Monitoring live data �(6.1)
- Displaying data in a digits display �(7.3.1)
- Saving your experiment �(11.1)

Background

When cold and warm items come into contact, the cooler item gets warmer while the warmer item gets cooler, until eventually both are the same temperature. With unequal starting amounts, the final temperature of a mixture is closer to the temperature of the largest quantity. For example, if you begin with more hot water than cold water, the temperature of the mixture of the hot and cold water will be warmer than the average of the two temperatures. In general, the final temperature is the mass-weighted average of the starting temperatures. Expressed as an equation, this is:

$$T_{\text{final}} = \frac{(m_{\text{hot}} \times T_{\text{hot}}) + (m_{\text{cold}} \times T_{\text{cold}})}{m_{\text{hot}} + m_{\text{cold}}}$$

In the above equation, m stands for the mass, and T stands for the temperature.

Standard temperature scales, such as the Fahrenheit and Celsius scales, are based on a substance's average thermal kinetic energy per atom or molecule. The more kinetic energy each molecule of water for example, has on average, the more frenetic its motion, and the more thermal energy it can transfer to surrounding water molecules it bumps into. It is this "bumping into" or pushing on surrounding molecules that transfers the heat energy, because at the molecular level, the water molecules are doing work.

Pre-Lab Discussion and Activity

Students in grades 5 to 8 can have difficulty understanding the phenomenon known as heat energy and heat transfer. They are not yet able to grasp the abstract molecular or particulate model of matter, nor understand that temperature is a measure of the average kinetic energy of those particles. The goal is to build up students' set of experiences with energy transfer. The big idea is that when cooler things and warmer things come into contact, the cooler things get warmer while the warmer things get cooler until eventually both are the same temperature (have the same amount of heat energy).

Temperatures of Different Objects

Ask the students to look around the room and select areas they think might have different temperatures. Make a list on the board of the areas selected by the students. Many students will be surprised that most things in the room are the same temperature, even surfaces or objects that "feel" cool to the touch. Many students will not list or select the air in the room, because air to them doesn't seem to have any temperature at all.

Heat Flow

Suggest to the students that if some part of the room is hotter than another area, heat will flow from the hotter area to the cooler area until both areas are the same temperature. If it's a cold day outside and the classroom windows or doors are opened, heat will flow towards the colder area (outside) until both areas have reached the same temperature. If the thermostat is turned on, the furnace will continue to furnish heat to the room, and that heat will continue to flow to the colder outdoors. If the thermostat is turned off, the room will quickly become just as cold as the outdoors.

Challenge the students to think of other substances besides air that have different temperatures, and can be observed mixing every day. If students have difficulty coming up with ideas, suggest filling a bathtub with water. Ask them if they ever filled their bathtub and discovered just as they were about to get in, that the water was too hot or cold. Ask students to share their ideas.

Direct students to “Thinking About the Question.” Have the students discuss the material in this section within their lab groups and then share their answers with the class. If necessary, prompt students to suggest that when equal amounts of hot and cold water are used, the resulting temperature of the mixture is exactly halfway between the two starting temperatures. In other words, the final temperature is the average of the two starting temperatures. As an equation, this is:

$$T_{\text{final}} = \frac{T_{\text{hot}} + T_{\text{cold}}}{2}$$

In this equation, T stands for temperature. Standard temperature scales, such as the Fahrenheit and Celsius scales, are based on a substance's average thermal kinetic energy per atom or molecule. The more kinetic energy each molecule of water for example, has on average, the more frenetic its motion, and the more thermal energy it can transfer to surrounding water molecules it bumps into. It is this "bumping into" or pushing on surrounding molecules that transfers the heat energy, because at the molecular level, the water molecules are doing work.

Direct students to Investigating the Question.

Preparation and Tips

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

- An excellent source of insulated containers can be provided by students themselves, if they have access at home to hot beverage “travel mugs” with spill-proof lids. A day or so ahead of the activity, ask students to bring in their travel mugs to share with the class. Make provisions – such as tape and a marker – for students to label their mugs to take them back home.

- If possible, provide students with red and blue food dye for their water samples. The visual reinforcement for hot and cold water can be very helpful for many learners. In addition, as students pour their mixed water solution out of the insulated container, they will observe that the colors have “mixed” as well as the temperatures, resulting in a new color somewhere between the original two, again serving as visual reinforcement.

- Be sure to remind students to measure the temperatures of the hot and cold water samples and then *quickly* pour those samples into the insulated container. Waiting too long will result in heat loss to the surrounding atmosphere that will throw off the students’ results.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear safety goggles for the duration of this activity.

- Do not use water above 40 °C. Painful burns may result.

Driving Question

What is the resulting temperature when you mix equal parts hot and cold water?

Thinking about the Question

Have you ever heated a drink only to discover that it became too hot to drink? You could let the drink sit for a time until it cooled enough to drink, or you could add a cooler substance to the cup to cool it faster.

If you've ever taken a bath, you're probably familiar with bath-water that's too hot to get into comfortably, or water that's not warm enough for your preference. Either way, you know that you can change the temperature of the bath-water by adding more water of the temperature you want. You simply add more cold water to your bath if it's too hot, or you add more hot water if it's not warm enough.

When two liquids of different temperatures are mixed together, the warmer one loses heat energy and the cooler one gains heat energy. The final temperature of the mixture is always somewhere between the two starting temperatures. Discuss with your lab group how the amount of the cooler substance added determines the final temperature.

Answers will vary. Students should suggest that the more cool substance is added to a warm substance, the cooler the final temperature will be.

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.

1	4	2	5	3
Make certain that each member of your lab group is aware of the safety rules and procedures for this activity.	In an insulated container, carefully combine equal volumes of hot and cold water samples of known temperatures.	Obtain equal volumes of hot and cold water.	Determine the final temperature of the mixture of the hot and cold water samples.	Measure the temperature of the hot and the cold water samples.

Investigating the Question

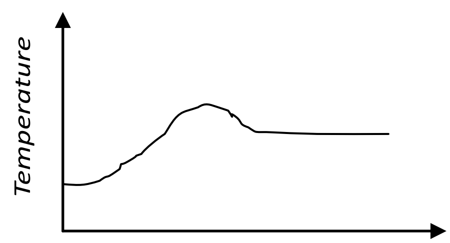
Note: When students see the symbol "�" with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please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

Part 1 – Making predictions

1. ☐ What will happen when equal amounts of hot and cold water are mixed.

   Answers will vary. One student group predicted as follows: We think that when we mix equal amounts of hot and cold water, the mixed water will not be as hot as the original hot water, and also it won't be as cold as the original cold water. It will be about in between.

2. ☐ In the space below, sketch a temperature versus time graph that reflects your prediction.



Part 2 – Measuring temperatures of solutions

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

4. ☐ Connect a temperature sensor to the data collection system. �(2.1)

5. ☐ Display Temperature in a graph display. �(7.1.1)

6. ☐ If you are using food dye, color the hot water red and the cold water blue.

7. ☐ Measure 125 mL of hot water into a 150-mL beaker.

8. ☐ Insert the temperature sensor into the beaker and begin data recording. �(6.2)

9. ☐ When the temperature stabilizes, record it in Table 1. You may need to adjust the scale of the graph to see all of your data. �(7.1.2)

10. ☐ Stop data recording. �(6.2)

11. ☐ Measure 125 mL of cold water into a 150-mL beaker

12. ☐ Insert the temperature sensor into the beaker and begin data recording. �(6.2)

13. ☐ When the temperature stabilizes, record it in Table 1. You may need to adjust the scale of the graph to see all of your data. �(7.1.2)

14. ☐ Stop data recording. �(6.2)

Table 1: Water sample volumes and temperatures

Volume of Water Samples	125 mL
Temperature of Hot Water	39.9 °C
Temperature of Cold Water	25.1 °C

Part 3 – Observing the temperature changes of the water mixture

15. ☐ Mix the equal amounts of hot and cold water in the insulated container.

16. ☐ Place the temperature sensor into the mixture in the insulated container and close the lid as much as possible.

17. ☐ Begin data recording. �(6.2) After the temperature of the mixture stabilizes, record the temperature.

Temperature of mixture: 31.7 °C

18. ☐ a. Why is it important to use the same volume of water for each sample in this part of the activity?

Answers will vary. One student group answered as follows. We think we have to use equal amounts or volumes of water so that the volume is not accidentally a non-controlled variable. If the amounts were different, we would not be comparing the same thing. Also, our equation probably would not work.

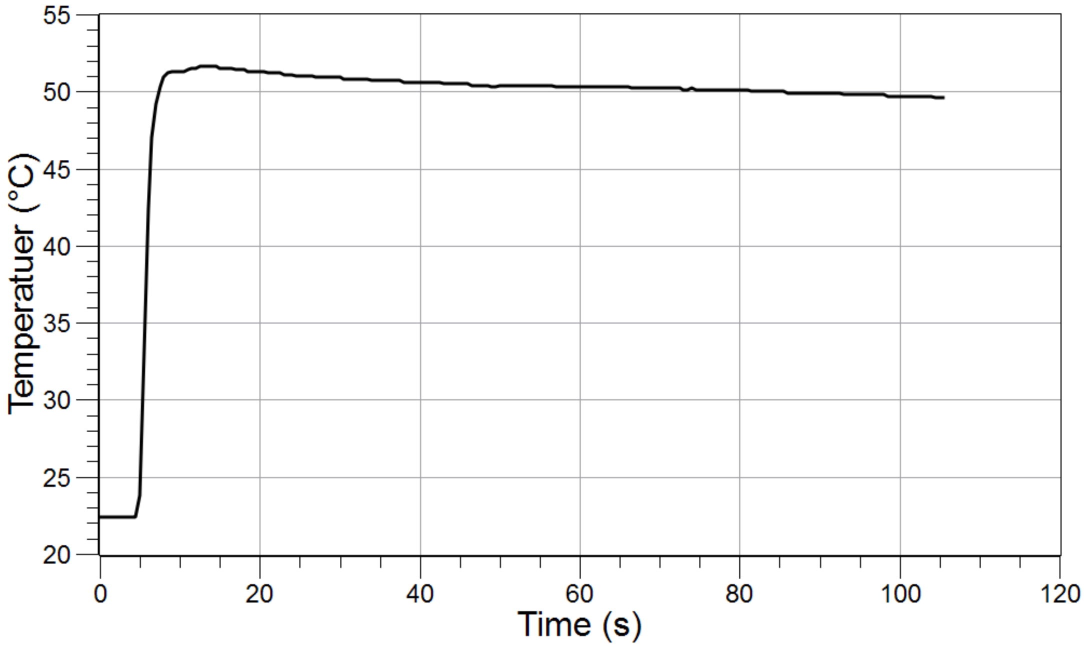
b. If you pour equal volumes of hot and cold water together into one container, what fraction of the mixture is represented by the hot water? Once you have tested your prediction for equal volumes of hot and cold water, what other fractional amounts could you measure and test?

Answers will vary. One student group answered as follows. When we used equal volumes, each was considered a half of the mixture. We could also test 1/4 and 3/4 or maybe tenths. For tenths we could do 100 mL of total water so it would be easier.

19. ☐ Use the equation your class came up with to calculate the final temperature. Is this what your lab group predicted or expected? In the space below, record your calculations and your results.

Answers will vary. One group answered as follows: Our class figured out how to average the temperatures. We would add the two temperatures and divide by 2. If this actually worked perfectly, we should have made the water mixture come out to be 32.5 degrees C, because we did 39.9 + 25.1 = 65. Then we divided 65 ÷2 = 32.5. But our results were a lower temperature, 31.7 degrees C.

Sample Data



Answering the Question

Analysis

1. After reviewing your data, describe the relationship that you see from the beginning and final temperatures of your water mixture.

   The mixture of the hot and cold water had a temperature almost right in between the two original temperatures.

2. How did your predictions from Part 1 compare to the results from Part 3? How closely does your predicted graph match what you actually recorded? How can you explain any difference you saw between the prediction you made and the experimental results?

   Answers will vary. One group answered as follows: Our prediction was that the mixed water would be in between the temperatures of the hot and cold water, which they were. But, our prediction graph did not really match the graph we got. We think that the difference came from maybe losing some heat from the hot water when we poured it, because maybe we let it sit in the glass too long before we poured it into the insulated cup.

3. Where does the heat energy go when two liquids of different temperatures are mixed together?

   Answers will vary. One group answered as follows: The heat energy seems to go toward the colder side of things. The hot liquid's heat goes toward warming up the cold liquid. It is like the hot one is sharing with the cold one so they each have the same amount.

Key Term Challenge

Fill in the blanks from the randomly ordered words below. Note that words may be used more than once:

heat	warm	degrees Celsius	temperature
average	flow	cold	energy

1. By measuring the ___temperature___ of a substance you can get an idea of how much thermal energy its particles contain.

2. ___Heat___ is a form of ___energy___ that is associated with the motion of the molecules of that substance.

3. Thermal or heat ___energy___ tends to ___flow___ from ___warm___ objects or substances to ___cold___ objects or substances.

4. In the SI system ___degrees Celsius___ is the unit of measure for ___temperature___.

5. When equal amounts of a ___warm___ and a ___cold___ substance are mixed, the resulting ___temperature___ is the ___average___ of the two initial temperatures.

6. When ___cool___ things and ___warm___ things come into contact with each other eventually both reach the same ___temperature___, or in other words both have the same amount of ___heat___ ___energy___.

Further Investigations

Investigate what happens if the cold water is a mixture of ice and water.

How could you use the results of this activity to determine the amount of cold water that should be added to a hot bath to bring it to a comfortable temperature?

Rubric

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

7. Investigating Evaporative Cooling

Cooling Curves

Objectives

In this activity, students investigate the transfer of heat and the cooling rate of warm water.

Students investigate and observe changes in water temperature while learning:

- That energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, and the nature of a chemical
- That heat moves in predictable ways, flowing from warmer objects to cooler objects, until both reach the same temperature

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the change in water temperature as it cools
- Designing and making two different-shaped foil containers for water
- Testing the cooling rate for water in each of the containers
- Testing the cooling rate for water in still air and water that is fanned
- Using math skills to find the difference between changes in time and changes in temperature

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	50 minutes
■ Lab activity, Part 2 – Cooling rates of warm water in different-shaped containers	50 minutes
■ Lab activity, Part 3 – Cooling rate of warm water with or without moving air	50 minutes
■ Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ Fast response temperature sensors (2)
- ☐ Graduated cylinder, 25 to 50 mL
- ☐ Warm tap water (not over 40 °C)
- ☐ Small fan
- ☐ Petri dishes (2)
- ☐ Aluminum foil ~ 0.5 meter

For each student or group:

- ☐ Data collection system
- ☐ Fast response temperature sensors (2)
- ☐ Graduated cylinder, 25 to 50 mL
- ☐ Warm tap water (not over 40 °C)
- ☐ Small fan
- ☐ Petri dishes (2)
- ☐ Aluminum foil ~ 0.5 meter

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The term "diameter"
- The use of a graduated cylinder to measure liquid volume
- How to read and interpret a coordinate graph
- The SI unit of measure for temperature (degrees Celsius)
- The basics of using the data collection system and how to collect data from two sensors simultaneously
- Be able to do decimal arithmetic: find sums and differences of decimals, divide decimals to several places, and round a decimal to a specified place

Related Labs in This Guide

- Heat Transfer in Fluids
- Observing Phase Changes
- Observing Freezing Point Depression

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 a sensor to the data collection system. �(2.1)
- Connecting multiple sensors to the data collection system. �(2.2)
- Changing the sampling rate �(5.1)
- Starting and stopping data recording. �(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. �(7.1.3)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

Students in grades 5 to 8 are beginning to understand the phenomenon known as heat energy and energy transfer. Though they may have some awareness of atoms and molecules (the particulate model of matter), generally these concepts are too abstract for students this age. Before they can grasp the molecular or particulate model of matter, they need to have many and varied experiences with the phenomenon of energy transfer. Students who have the opportunity to build experience in this area can expect to make a successful transition to more complex models.

The key idea in this activity is for students to realize that when cooler and warmer substances are allowed to come into contact with each other, the cooler substances become warmer while the warmer substances become cooler. Most students are familiar with home heating in the winter and air conditioning in the summer. They know that they are supposed to keep the doors and windows closed "to keep the heat in" during the winter, or to "keep the hot air out" during the summer.

If some part of the room is hotter than another part, such as the warm hearth near the fireplace or the heating vent from the furnace, that heat will flow from the hotter area to the cooler parts of the room until both areas are the same temperature. Then why does it feel warmer in a certain area of the room? As quickly as the warmth at the hearth is given up to the room, it must be supplied with new heat from the fireplace. If the fire is allowed to burn out, the fireplace and hearth will soon cool down to the same temperature as the rest of the room. Where ever there is heating, heat must be flowing in and where ever there is cooling, heat must be flowing out. Heat, then, can be thought of as thermal energy on the move.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask students if they have ever received an injection at the doctor's office. Have them recall that alcohol is put on their skin to cleanse it before the injection is given. Ask students to think about how the alcohol felt once it was applied. Students who have had injections will recall that the alcohol seems to feel "cold." Explain to students that the alcohol evaporates much more quickly from their skin than does water, carrying heat energy away with it, which causes that area to feel cooler.

Discuss with students that some liquids, such as the type of alcohol used in antiseptics, perfumes, and aftershave products, evaporate at a faster rate than water evaporates. The faster the rate of evaporation, the more rapidly thermal energy is carried away, which leads to a faster rate of cooling.

Ask students to list some ways to increase the rate of cooling by evaporation of a container of liquid.

> Students should suggest that a container of liquid can be made to evaporate more quickly by heating it, by blowing on the surface of the liquid, or by increasing the area exposed to the air.

Direct the students to “Thinking About the Question.”

After a few minutes, ask the student lab groups to share some of their ideas with the class. Record the students’ ideas on the board.

Direct the students to “Investigating the Question.”

Preparation and Tips

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

1. Students are asked in Part 2 to fashion small “bowls” to use as containers for their warm water samples. Provide each group with enough aluminum foil for them to make at least two containers. Provide heavy-duty foil if possible. They may inadvertently tear or puncture one of the containers, so it is helpful to have a “back-up” container just in case. It is important for the containers to have different diameters, so different surface areas can be exposed to the air.

2. Check students’ foil bowls to make sure there is quite a difference in diameters (surface areas). The containers do not need to be perfectly round. Ensure that both containers are the same thickness of foil; for example, if one bowl is made of double-thickness foil, the other bowl should be made the same way. To help visual learners, consider making a few foil bowl examples ahead of time to have ready to show.

3. Provide paper or cloth towels to each lab group, for when spills occur.

4. If you do not have hot tap water available, you can pre-heat water in a microwave. Do not heat the water past 40°C (or comfortable “hot dish water”).

5. When supplying Petri dishes, give two bottom halves or two lids to each lab group, rather than one bottom half and one lid. This ensures that each pair of dishes a group uses will be of uniform diameter (surface area). If you have a combination of glass and plastic Petri dishes, make sure that both dishes each group gets are made of the same material.

6. For the fan portion of the activity, be aware that students with long hair should either tie their hair back or not sit next to the fan. Long hair can be caught up into the fan, causing injury to the student.

7. Students may need help with the math computations of the rate of cooling. Lead them through an example or two on the board so they can see that final temperature minus initial temperature gives the change in temperature. Then show them how to divide the change in

temperature by the time it took for the temperature to change. The rate may be considered either the number of degrees of change per second, or the number of seconds per degree.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear safety goggles for the duration of this activity.
- Do not use water above 40 °C. Painful burns may result.

Driving Question

How can you increase the cooling rate of a substance?

Thinking about the Question

In science, a "rate" is the amount of time it takes for a certain action to happen. You are familiar with a person's heart rate, which tells the number of heart beats per minute, and you know that a race car can drive at a higher rate of speed than an ordinary car. You also know that rates can increase or decrease. Exercising increases your heart rate, and stepping on the brakes of a car decreases its rate of speed.

Suppose you are about to sit down and have a delicious bowl of soup, but you cannot even have a taste of it until it cools down or you will burn your tongue. What can you do to increase its rate of cooling? In other words, what can you do to cause it to lose heat energy more quickly? Discuss with your lab group members some different methods that could be used to cool the soup. Which method do you think would be the fastest? Why?

Student answers will vary. Students may suggest cooling the soup by placing ice cubes in it, by blowing on it, by stirring it, by placing it in a shallow, wide bowl instead of a deep bowl, or by placing it in a cooler environment such as the refrigerator, or even outdoors on a cold day. Students may suggest that the fastest method would be to put ice cubes in the soup, but should recognize the disadvantage of diluting the soup's flavor.

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.

4	2	3	5	1
Fill each foil bowl with a sample of warm water.	Decide how to divide your supply of foil so as to construct two bowls of different diameters.	Construct two foil bowls, each with a different diameter.	Record the temperature of each sample of water as it cools.	Make sure each lab group member is aware of safety rules and procedures for this lab.

Investigating the Question

Note: When students see this 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. ☐ Consider two samples of warm water: one 25-mL sample poured into a wide, shallow aluminum bowl and the other 25-mL sample poured into a narrow, deep aluminum bowl. Predict the difference in the cooling rates of these two samples of water.

   Answers will vary. One group answered as follows: We think the water in the wide bowl will cool down faster. We think the water in the narrow bowl will take longer to cool down.

2. ☐ Consider two samples of warm water: one 25-mL sample is poured into a Petri dish and left to sit alone and the other 25-mL sample is poured into a Petri dish and then fanned. Predict the difference in the cooling rates of these two samples of water.

   Students should predict that the fanned water will cool down faster than the water that is not fanned.

Part 2 – Cooling rates of warm water in different-shaped containers

3. ☐ Using the foil provided, design and construct two bowls to hold water samples. Make sure that the bowls are of different diameters; one should be wider than the other.

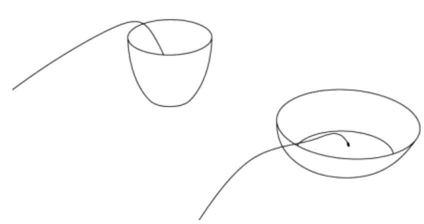
4. ☐ Using the graduated cylinder, pour 25 mL of warm water into each bowl.

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

6. ☐ Connect the fast response temperature sensors to the data collection system. �(2.2)

7. ☐ Display Temperature in a graph �(7.1.1) with the measurements from each sensor on a separate y-axis. �(7.1.11)

8. ☐ Change the sampling rate to take one temperature measurement every 2 seconds. �(5.1)



9. ☐ Place a temperature sensor in each foil bowl of water and start data recording. �(6.2)
Observe and record the initial temperature of both of the water samples. Why do you think it is important to begin this trial with water that is the same temperature in both containers? How would the results be different if you began with water that was 5 °C warmer in one bowl?

Initial temperature of the wider bowl: 31.3 °C

Initial temperature of the narrower bowl: 31.7 °C

Answers will vary. One student group answered as follows: It is important to have the water be the same temperature and not 5 degrees warmer than the other bowl, so that each part of the experiment has the same conditions. We are supposed to control all of the variables except one, and if we let the water start at different temperatures it would be introducing another variable.

10. ☐ Continue collecting data until both temperature readings reach the same temperature and there is no more change. Stop data recording. �(6.2)

Note: The two readings may not reach *exactly* the same temperature, but if they are both changing by less that one-tenth of a degree Celsius every two seconds, you can stop recording.

Note: Data recording for the two temperature sensors cannot be stopped independently.

11. ☐ Observe and record the final temperature of both samples of water, and the time it took for each to complete the cooling. �(9.1) If necessary, adjust the scale of the graph to show all data. �(7.1.2)

Final temperature of the wider bowl: 25.6 °C

Final temperature of the narrower bowl: 25.4 °C

Time for cooling of the wider bowl: 312 sec

Time for cooling of the narrower bowl: 366 sec

12. ☐ Save your experiment. �(11.1)

Part 3 – Cooling rate of warm water with or without moving air

13. ☐ Obtain two Petri dishes that are the same diameter and made from the same type of material. Why do you think diameter is an important variable to control in this part of the experiment? What would happen if one of the Petri dishes was made of plastic, while the other was made of glass?

Answers will vary. One student group answered as follows: We think the diameter determines the amount of water that is exposed to the air. If more water can touch the air in one dish than the other, then that would mean not controlling all the variables except one. That would be considered bad experimental design. The same thing applies if one was made of glass and one was plastic. They should both be made out of the exact same thing so the material does not become another variable.

14. ☐ Fill both Petri dishes to the top with warm water.

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

16. ☐ Display Temperature in a graph �(7.1.1) with the measurements from each sensor on a separate y-axis. �(7.1.11)

17. ☐ Place a temperature sensor in each Petri dish of water and start data recording. �(6.2) Observe and record the initial temperature of the water.

    Initial temperature with fan (moving air) : 31.2 °C

    Initial temperature with no fan (still air): 31.1 °C

18. ☐ Place a small fan next to one of the Petri dishes so the fan can blow on the water. Make sure that the air from the fan blows ONLY on that Petri dish and does NOT blow on the other Petri dish. Why do you think this is such an important part of the experimental design?

Answers may vary. One student group answered as follows: We think it is important to have the fan blow only on the one dish because if it was blowing on both, even a little bit on the second one, then you could not say for sure how long it took for the water to cool in still air. The air would not have been exactly still. This would have introduced an extra variable into the experiment.

19. ☐ Continue data recording until there is no more change, then stop data recording. �(6.2)

20. ☐ Observe and record the final temperature of both samples of water, and the time it took for each to complete the cooling. �(9.1) If necessary, adjust the scale of the graph to show all data. �(7.1.2)

    Final temperature with fan (moving air): 24.7 °C

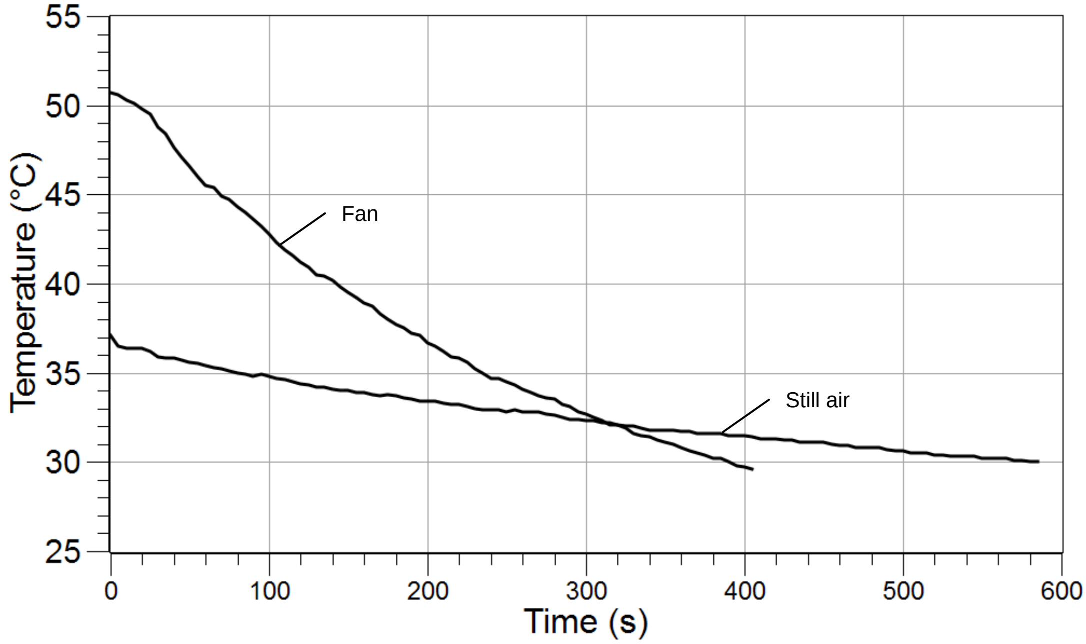
    Final temperature with no fan (still air): 24.9 °C

    Time for cooling with fan (moving air): 163 sec

    Time for cooling with no fan (still air): 612 sec

21. ☐ Save your experiment �(11.1) and clean up according to your teacher's instructions.

Sample Data



Answering the Question:

Analysis

1. Review your data graphs for each part of the activity. You may need to adjust the scale of your graph to see all of your data. �(7.1.2) How did your predictions from Part 1 compare to the results in Part 2?

   We predicted that the water in the wide bowl would cool faster, and it did. We predicted that the narrow bowl of water would take longer to cool, and it did, by 54 seconds.

2. Why was it necessary to use the same amount of water in each sample of water?

   If we had used different volumes of water, we would be introducing another variable to our experiment, and our results would be different.

3. Was it necessary to use containers made of the same material in each trial? Why do you think this is the case?

   We had to use aluminum foil for both of our bowls because if they were made of different things, like foil and a tin can, our results would be totally different. The material for the bowl was one of the controlled variables.

4. For Part 3, how did your predictions compare to the results?

   We predicted that the fanned water would cool much faster. It did. It took the non-fanned bowl 449 seconds longer to cool down to the same temperature. We also thought the fanned water would get colder than the still air water. We did not actually get to find out because once the temperatures stopped changing, we had to stop taking data. We did not have enough time to try again.

5. What sources of error could have caused non-expected results? Explain your reasoning.

Answers will vary. One group answered as follows: We should only test one variable in each trial. By accidentally having more than one variable uncontrolled, we could introduce errors. We could unintentionally have used different amounts of water, or different initial temperatures by pouring one water sample a bit later than the other, giving the first sample time to cool off before we began measuring, or also by making the foil bowls different, such as one thicker than the other. Since we were testing how long it takes to cool water, we only wanted to know what the water was doing and not anything else. If we changed more than one thing at once, it could have been a source of error. Also, any measurements we made, such as the volume of the water in the graduated cylinder, could have been made poorly.

6. What is meant by cooling *rate* in this activity? How can you use the change in temperature compared to the time it took for that temperature to change to find the cooling rate for your different trials? Show your work. Once you have computed the rates, how do you know which water sample cooled the fastest?

Sample calculations:

Part 2, Wider Bowl:

$$\frac{\text{Change in temperature}}{\text{Change in time}} = \frac{5.7°\text{C}}{312\text{ s}} = \frac{5.7}{312} = 0.018\,{}^{°\text{C}}\!/_{\text{s}}$$

Part 2, Narrower Bowl:

$$\frac{\text{Change in temperature}}{\text{Change in time}} = \frac{6.3°\text{C}}{366\text{ s}} = \frac{6.3}{366} = 0.017\,{}^{°\text{C}}\!/_{\text{s}}$$

Part 3, With Fan:

$$\frac{\text{Change in temperature}}{\text{Change in time}} = \frac{6.5°\text{C}}{163\text{ s}} = \frac{6.5}{163} = 0.040\,{}^{°\text{C}}\!/_{\text{s}}$$

Part 3, Without Fan:

$$\frac{\text{Change in temperature}}{\text{Change in time}} = \frac{6.2°\text{C}}{612\text{ s}} = \frac{6.2}{612} = 0.010\,{}^{°\text{C}}\!/_{\text{s}}$$

The cooling rate is how long it takes for the temperature to drop. We found a drop of 5.7 and 6.3 degrees C in the foil bowls of water, in 312 and 366 seconds. So we did our cooling rate in degrees C per second. One cooling rate was 0.018 degrees C per second. The other was 0.017 degrees C per second.

On the fanned and not fanned water, we found a drop of 6.5 degrees C in 163 and 6.2 degrees Celsius in 612 seconds, so their rates are 0.040 degrees C per second and 0.010 degrees C per second. The 0.040 degrees C per second is the fastest rate of cooling. It came from the fanned water.

True or False

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

____T____ 1. The change in temperature divided by the change in time is known as the rate of cooling.

____T____ 2. A graduated cylinder is used to measure 25 mL of warm water.

___T___ 3. Controlling variables is important to good experimental design.

___T___ 4. A cooling curve on a graph of temperature versus time can show the time it took for the temperature to fall by one degree Celsius.

___F___ 5. If a substance is cooling down, then its final temperature will always be higher than its initial temperature.

Key Term Challenge

Fill in the blanks from the randomly ordered words below. You may change the form of a word, for example by making a singular word plural. You may not use every word, and you may use a word more than once:

rate	time	change	x-axis	y-axis
slope	steep	flat	horizontal	

1. A cooling curve on a graph shows the ___rate___ at which the temperature changes.

2. On a graph of temperature versus time, temperature is plotted on the ___y-axis___, while time is plotted on the ___x-axis___.

3. In order to determine the rate, we need to know the ___time___ over which some measurement changes.

4. A cooling curve on a temperature graph is one way of visually understanding the ___change___ in temperature over time.

5. The steeper the ___slope___ of the graph is, the greater the ___rate___ of change___ is.

6. A ___horizontal___ or ___flat___ slope on a temperature versus time graph indicates that there is no ___change___ in the temperature for that portion of the graph.

7. A temperature versus time graph that has a very ___steep___ portion is evidence that at that time in the experiment, the temperature was changing rapidly.

Further Investigations:

Compare the cooling rates of containers made from different materials, such as paper, plastic, ceramic, polystyrene, et cetera.

Investigate how trapping steam in a container changes the cooling rate of the substance in the container.

Compare the cooling curves of different liquids, such as rubbing alcohol, after shave, or nail polish remover.

Design a soup bowl that is good for cooling soup as fast as possible, and one that is good for keeping soup hot for as long as possible.

Rubric

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

8. Investigating Solar Energy

Black Coffee

Objectives

Students analyze the heat that reaches them in the form of light from the sun and identify the sun as the major source of energy for supporting life on the earth.

Procedural Overview

Students gain experience conducting the following procedures:

- Calculating the solar energy that reaches them by using a temperature sensor to measure the change in temperature of coffee as it is warmed by sunlight
- Constructing an insulated cup system to hold a coffee sample for testing
- Using math skills to compute differences in temperatures, times, and rates of warming
- Organizing and comparing their data in simple tables or graphs, and identifying relationships the temperature patterns reveal

Time Requirement

☐ Introductory discussion and lab activity, Part 1 – Making predictions	20 minutes
☐ Lab activity, Part 2 – Setting up	15 minutes
☐ Lab activity, Part 3 – Determining the temperature change	50 minutes
☐ Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Mobile data collection system
- ☐ Stainless steel temperature sensor
- ☐ Polystyrene coffee cups (2), small, that nest within each other
- ☐ Graduated cylinder, 25- or 50-mL
- ☐ Black coffee, cold, 20 mL
- ☐ Rubber bands (2)
- ☐ Clear plastic wrap (2 pieces) ~6 in. × 6 in.

For each student or group:

- ☐ Data collection system
- ☐ Stainless steel temperature sensor
- ☐ Graduated cylinder, 25- or 50-mL
- ☐ Polystyrene coffee cups (2), small, that nest within each other
- ☐ Black coffee, cold, 15 mL
- ☐ Rubber bands (2)
- ☐ Large insulated container or Thermos™ bottle (optional)
- ☐ Clear plastic wrap (2 pieces) ~6 in. × 6 in.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Energy can be measured in joules.
- Temperature is a measure of heat energy, while heat itself is the transfer of thermal energy from a warmer object to a cooler object.

Related Labs in This Guide

Labs conceptually related to this one include:

- Energy Transfer
- Exploring Environmental Temperatures

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. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sampling rate �(5.1)
- Monitoring live data without recording �(6.1)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Displaying data in a digits display �(7.3.1)

Background

The sun is responsible for almost all forms of energy on Earth. Sunlight enters our atmosphere as electromagnetic radiation. By the time sunlight gets to you, this energy is reduced; only about 70% of the sun's radiation reaches the surface. Clouds reflect about 30% of this energy back into space.

Earth's atmosphere protects us from some of the sun's harmful ultraviolet radiation. We are able to see some of the sun's energy—the visible wavelengths of the electromagnetic spectrum. We are able to feel some of the sun's energy also—the infrared wavelengths of the electromagnetic spectrum.

As a source of energy, the sun is essentially limitless and clean. Scientists and engineers are developing ways this unlimited, clean energy can be harnessed to provide the power we need to run our modern world.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Encourage students to determine if electricity, heat, light, and motion have anything in common. Students may know that they are all forms of energy. Ask them to list types of energy that are due to the sun. Have them discuss within their groups and share their answers with the class after a few minutes.

> Energy directly from the sun includes heat (infrared radiation), light (visible radiation), and ultraviolet radiation (powerful enough to damage skin cells, but isn't seen or felt). Energy on earth produced indirectly from the sun includes food that originates from plants that use sunlight; plants that provide energy for animals, which provide energy for other animals; oil, coal, and natural gas; wind power; and electricity generated using solar panels.

Ask students to discuss what color of clothing would be more suitable during different times of the year. Tell them to justify their color selections. Ask them to discuss this within their groups and share their answers with the class after a few minutes. You may feel it is necessary to hint that black appears black because it absorbs all light.

Display a black-coffee-nested-cup arrangement to the students prior to the investigation.

If the students have not used a temperature sensor before, briefly demonstrate how it works in the cold coffee. Demonstrate that the sensor can display small temperature variations (up to 0.10 °C).

Explain that the second plastic cup insulates the coffee so that the room temperature has little effect on it and the main way it can be warmed is from light. Remind students that the cold solution should be quickly moved to its outside location or the cup can be filled at its location from a Thermos® bottle or other insulated container.

Direct the students to "Thinking about the Question." Then have students discuss within their groups where they would like to locate their data collection system and sensor and share these locations with the class. Encourage the students to select different locations with varying amounts of light (for example, shade versus sun).

Have student groups partner with another group that has chosen a location with a different amount of sunlight than they've chosen. Let them know they will share each other's collected data.

Direct the students to “Investigating the Question.” Plan to allow them to share their results with the class after “Part III” to compare the rate of heating at different locations.

Preparation and Tips

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

Prepare the black-coffee-nested-cup apparatus as follows:

a. Nest one polystyrene cup inside another.

b. Pour 15 to 20 mL of cold coffee into the top cup.

c. Cover the top cup with clear plastic wrap and secure the wrap in place with a rubber band.

d. Now cover both cups with another layer of plastic wrap and secure this layer in place with the second rubber band.

e. Poke a small hole in the plastic wrap to insert the temperature sensor.

- Students should partner with another group that has chosen a location with a different amount of sunlight to obtain a second set of data.
- The temperature change is best observed if the cups with the coffee are placed outside at noon, when the sun is directly overhead.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Never look directly at the sun—severe eye damage can result.
- Consider the coffee as chemicals; it is not for drinking.

Driving Question

How much heat is in sunlight?

Thinking about the Question

Almost all the energy on earth arrives as light from the sun. Sunlight striking an object is partly reflected and partly absorbed. The absorbed light hits molecules, making them vibrate faster. We sense this as a rise in temperature.

Discuss with the members of your group how a black liquid is affected by the light that falls on it. Record your thoughts below. Be prepared to share your thoughts with the class.

> The more light an object absorbs, the faster its temperature will rise. Therefore, measuring the rate of the temperature increase of an object is a way of finding out how much energy it is absorbing. A black liquid absorbs almost all the light that falls on it. By measuring how fast the temperature of a black liquid rises, we can determine the rate at which sunlight energy is absorbed.

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.

1	2	3	5	4
Make sure each lab group member is aware of safety rules and procedures for this lab.	Pour 15 mL of cold black coffee into an insulated polystyrene cup, cover it with clear plastic wrap and nest it inside another cup.	Cover the nested cups with a second layer of clear plastic wrap. Place them in your chosen location.	Determine the temperature change and compare it to the temperature change of coffee placed in another location.	Insert the temperature sensor and record the temperature of the coffee in the chosen location for 10 minutes.

Investigating the Question

Part 1 – Making predictions

1. ☐ Predict how fast the temperature of the cold coffee will change when placed outside.

   Student answers will vary based on the location they select for their cups.

2. ☐ Describe and explain your prediction.

   Depending on the location in the sun or shade, students should relate that energy from the sun will be transferred to the cup. The more direct the sunlight, the faster the contents of the cup will heat up.

Part 2 – Setting up

3. ☐ Using the graduated cylinder, measure 15 mL of cold coffee and transfer it into an insulated polystyrene cup. Record the volume V of the coffee in milliliters. The coffee should be colder than the air.

   V_{coffee} = ___15___ ml

4. ☐ Cover the top of the cup with clear plastic wrap, and secure the plastic with a rubber band.

5. ☐ Place the covered cup inside the second cup so they are nested together.

6. ☐ Cover both cups with another layer of plastic wrap, and secure this in place with the second rubber band.

7. ☐ Poke a small hole in the plastic wrap to insert the temperature sensor (don not insert the temperature sensor yet).

8. ☐ Quickly take the cup with the coffee, the temperature sensor, the instructions for using the data collection system if you need them, and the data collection system to your selected location.

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

10. ☐ Connect the temperature sensor to the data collection system. �(2.1)

11. ☐ Display temperature in a digits display. �(7.3.1)

Part 3 – Determining the temperature change

12. ☐ Monitor the temperature without recording. �(6.1)

13. ☐ Set the sampling rate to 1 sample per second. �(5.1)

14. ☐ Push the temperature sensor through the clear plastic wrap covering the cups and down into the coffee, making as small a hole as possible.

15. ☐ Gently swirl the cups so the coffee mixes as you record the initial temperature. Be sure the sensor tip is always covered with coffee.

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

18. ☐ Start data recording. �(6.2)

19. ☐ Record the initial temperature (T_{initial}) of the coffee at your chosen location in Table 1.

20. ☐ After 10 minutes, stop data recording and record the final temperature (T_{final}) in Table 1.

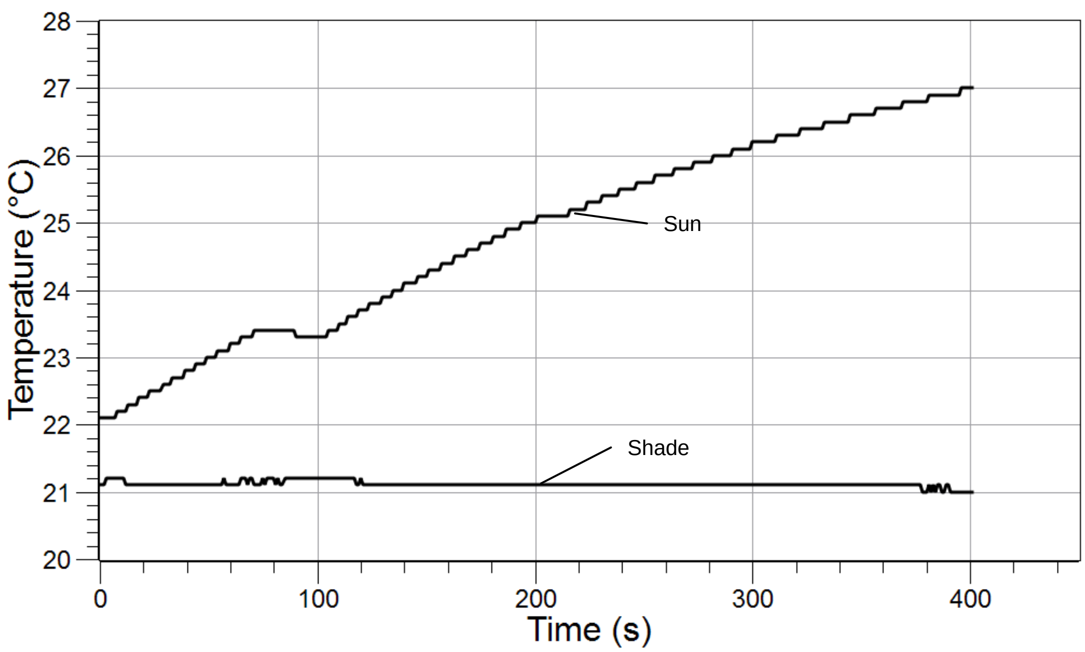
21. ☐ Record the type of sunlight in your selected location and the length of time you recorded data in both Table 1 and Table 2.

22. ☐ Obtain the amount of sunlight, air temperature, time interval, and the initial and final temperatures of the coffee from your partner group and record them as required in Table 1 and Table 2.

Table 1: Temperature change of coffee in varying levels of sunlight (raw data)

Sunlight Condition	Time Interval (s)	Coffee Temperature (°C)	
		Initial	Final
Full sun (our group)	400	22.10	27.00
Shade (partner group)	400	21.12	21.00

Sample Data



Answering the Question

Analysis

1. Determine the rise in temperature. You may need to adjust the scale of the graph �(7.1.2) Show your calculations below and record the answer in Table 2.

For the sample data for full sun:

$T_{final} - T_{initial} = T_{change}$

27.00 °C – 22.10 °C = 4.90 °C

2. Find the rate of temperature increase by calculating the increase per time. Show your calculations.

For the sample data for full sun:

$T_{increase}$/Time = Rate of temperature increase

4.90 °C/400 s = 0.0122 °C/s

3. Calculate the amount of sunlight energy (J) absorbed by the coffee. The equation for this is:

   mass × energy needed to change 1 g of water 1 °C × temperature change = amount of heat transferred

   The energy needed to change 1 g of water 1 °C is 4.19 J/(g °C), so the equation to use to calculate the amount of sunlight energy absorbed by the coffee is:

   $m \times 4.19\ \mathrm{J/(g\ °C)} \times \Delta T = Q$

   where m is the mass, ΔT is the change in temperature, and Q is the symbol for the amount of heat transferred.

   Note: 1 milliliter of water has a mass of 1 gram. For this calculation, assume that this is the same for the coffee.

   For the sample data for full sun:

   15 g x 4.19 J/(g °C) x 4.90 °C = 308 J

4. Obtain the data from your partner group and enter it in Table 2.

Table 2: Determination of energy from sunlight

Sunlight Condition	Time Interval (s)	Temperature Change (°C)	Amount of Energy Absorbed (J)
Full sun	400	4.90	308
Shade	400	–0.12	–7.5

5. Compare the amount of sunlight energy (J) absorbed by the coffee at your location with the results of your partner group and other students that had different amounts of sunlight heating their coffee. How does the amount of sunlight affect the amount of energy transferred to the coffee?

   The more the coffee is exposed to sunlight, the more energy is transferred.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. A change in the amount of heat energy present in an object can be measured by the change in

   A. Time
   B. Mass
   C. Temperature

2. An insulated cup of cold coffee is taken outdoors on a sunny day. It first spends 15 minutes in the shade, then 15 minutes in full sun, followed by 15 minutes in a partially sunny area. Which temperatures might have been measured at 15 minutes, 30 minutes, and 45 minutes?

   A. 22 °C, 35 °C, 37 °C
   B. 37 °C, 50 °C, 22 °C
   C. 22 °C, 37 °C, 35 °C

3. Which aspect of a temperature versus time graph indicates the rate of change in heat energy?

   A. The label on the y-axis
   B. The slope of the curve
   C. The final temperature recorded

4. Which statement below about the sun's energy is not correct?

   A. Visible light is the only type of energy from the sun that we can use.
   B. The sun's energy is essentially unlimited.
   C. Thermal and light energy from the sun reach the earth's surface.

Key Term Challenge

Fill in the blanks from the randomly ordered words below:

temperature	heat	warm	cold
sunlight	time	Joules	degrees Celsius
increase	energy		

1. Almost all of the______energy______available on Earth comes from the sun.

2. A measure of the average kinetic energy of the particles of a substance is ____temperature____.

3. Heat energy always flows from a ______warm______ object to a ______cold______ object.

4. We see some of the sun's energy as visible light, and we feel part of the sun's energy as ______heat______.

5. Scientists and engineers look for ways to use ______sunlight______ as a renewable and clean source of energy.

6. In the SI system of measurement, energy is measured in units called ______Joules______.

Further Investigations

Predict how the temperature of the coffee changes during different times of the day or under different weather conditions and test your prediction.

How does varying the area of the surface exposed to the sun affect the amount of energy absorbed by a black liquid such as coffee?

Design and perform an investigation that will use clear water or other liquids instead of coffee. How do the results compare?

Rubric

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

9. Measuring Light Intensity

Bright Lights

Objectives

Students investigate how light intensity changes as they alter the distance between themselves and a light bulb. Students investigate light while:

- Observing interactions of light with matter (air) by transmission and scattering
- Learning that energy is associated with heat, light, electricity, mechanical motion, and the nature of a chemical

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the intensity of light
- Using a light sensor to measure the intensity of the light at increasing distances from the light source
- Using math skills to measure distances between a light bulb and sensor and to graph the relationship between light intensity and distance from the light

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Designing a research method and making predictions	50 minutes
■ Lab activity, Part 2 – Measuring the light intensity and Part 3 – Measuring the light intensity at your best study location	30 minutes
■ Analysis	30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ Light sensor
- ☐ Sensor extension cable
- ☐ Lamp with incandescent light bulb, without a shade
- ☐ Sheet of white paper
- ☐ Meter stick
- ☐ Clear and frosted incandescent light bulbs (optional)

For each student or group:

- ☐ Data collection system
- ☐ Light sensor
- ☐ Sensor extension cable
- ☐ Meter stick
- ☐ Lamp with incandescent light bulb, without a shade
- ☐ Clear and frosted incandescent light bulbs (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- "Lux" is the metric unit for light intensity or brightness of a light.
- Light bulbs of all types exist with a wide variety of intensities; students should be familiar with examples of low-intensity light sources such as holiday light bulbs (“mini-lights”), flashlight bulbs, small lamp bulbs, and higher-intensity light sources such as incandescent light bulbs of different wattages.

Related Labs in This Guide

Labs conceptually related to this one include:

- Measuring the Voltage of Elements in Series

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. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system. �(2.1)
- Starting a manually sampled new data set. �(6.3.1)
- Recording a manually sampled data point. �(6.3.2)
- Stopping a manually sampled data set. �(6.3.3)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Displaying data in a digits display �(7.3.1)
- Saving your experiment �(11.1)

Background

Light from a light bulb is considered a "point source," meaning that it spreads out spherically from its point of origin. Geometrically, the formula for calculating surface area of a sphere is $4\pi r^2$, where r is the radius of the sphere. Because the light is spreading spherically, at twice the distance from the source the light has spread over 2^2, or 4 times, the area. At three times the distance from the source the light has spread out over 3^2, or 9 times, the area. In other words, the farther you are from the source of light, the larger the area a given amount of light spreads over. The result is a decrease in the intensity of the light, as this area increases by the square of the distance. The equation relating the distance from the light source to the light intensity is:

$$I = \frac{S}{4\pi r^2}$$

where I is the intensity of the light. This is called the Inverse Square Law. This inverse square law is observed in other physical phenomena also, including gravitation and sound.

In the case of light, the source is generally denoted by a "source strength" S. The variable S doesn't stand for one particular unit, because there are several different ways to describe a light source, including power in watts, power in the visible range of the electromagnetic spectrum, or even power related to the eye's sensitivity. Regardless of the definition of the source, if you determine the amount of light per unit area reaching 1 unit of distance, then it will be one fourth that amount at 2 units from the source.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Turn on an incandescent light bulb (without a shade) at the front of the room. (A 60-watt bulb with the light sensor set to the 0 to 260 lux sensitivity works well for this investigation.) Caution the students not to stare directly at the light bulb. Explain that an incandescent light bulb produces visible light by heating a tungsten wire or filament until it glows. Also explain that electrical energy is being converted within the light bulb into both heat and light energy. Ask students to describe the steps or process electricity goes through to cause visible light to be produced.

To demonstrate the change in light intensity with distance from the light source, hold a sheet of white paper about 20 centimeters (cm) from the light bulb when it is turned on. Suggest to students that they determine a way to indicate brightness. Then move the sheet of white paper about 40 cm from the light bulb and ask if the paper appears brighter or dimmer at the greater distance. They should record the distance and their description of the brightness of the paper. Continue to move the sheet of white paper away from the light bulb in 20-cm intervals and again ask the students to describe if the paper is brighter or dimmer. Have students, within their groups, draw a line graph of brightness of the paper versus distance, based on their observations. After a few minutes, ask them to display their graphs to the class. Continue the discussion with the students until they grasp that light spreads out, and therefore is less bright, as it travels away from the light bulb.

The above exercise provides you an opportunity to review line graphs. If students displayed a straight line, ask them what this implies, and how it corresponds to the x-axis and y-axis definitions. Using the graph, help them relate an increase in brightness to a decrease in distance or a decrease in brightness to an increase in distance.

If they drew a curve, use their graph to see if it showed a larger decrease in brightness with each increase in distance from the light. That is to say, does light intensity decrease by the same amount each time you move 10 cm away (a linear decrease)? Or, does it decrease by a greater amount each time you move 10 cm away (a nonlinear decrease)?

At this point, students should realize that they need a better method of measuring the brightness of the light bulb. Show the students a light sensor. Explain to them that the sensor offers a more exact way to measure the brightness of the light (also referred to as "intensity"). Introduce the light intensity unit called lux (symbol: "lx"). If available, show the students several incandescent light bulbs, some frosted and some not.

Direct students to the "Thinking about the Question" section of this lab. Allow them to work within their groups for a few minutes to determine how to find their ideal distance from a light bulb for studying at night. Ask them to present their designs to the class. Did they consider all of the variables, such as direction from the light bulb, reflective surfaces close to the light bulb, and so on?

This activity prepares the students for their investigations because they will design their own method for determining the amount of light they need for studying and measuring the light intensity at varying distances from an incandescent light bulb. Approve student designs before directing them to the "Investigating the Question" section of the lab.

Preparation and Tips

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

- The light sensor should be set to the 0 to 260 lux sensitivity for light bulbs of 60 watts or less. For higher wattages, it may be necessary to set the sensitivity to the 0 – 26,000 Lux setting on the sensor.
- Students design the procedure for this activity, so you may want to provide them with a variety of materials for measuring distance and angles from the light source.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Do not touch or stare directly at the light bulb while it is lit—extreme burns and damage to the eyes might result! Any metal or plastic directly touching the light bulb might get very hot.

Driving Question

How does the brightness of an incandescent light bulb vary with distance?

Thinking about the Question

When you are studying at night, does it matter how close you sit to the light? What is the light intensity at the position you find best? When the light bulb is turned on, light spreads out as it travels away from the bulb. The farther you are from the source of light, the larger the area a given amount of light covers.

Keeping this in mind, work with your group to design a way to determine the ideal distance you should be from the light bulb while studying at night.

Student answers will vary. Students may say that they can measure the intensity of the light at different distances from the lamp. They may suggest comparing the brightness, or intensity of light, to the distance from the light bulb.

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	2	1	4	3
Analyze the way the light intensity changes with increasing distance from the light bulb. Find the light intensity at the study point.	Design a way to obtain light intensity using the light sensor at different distances from the light bulb.	Make sure that each lab group member is aware of safety rules for this lab.	Determine the best distance from the light bulb for studying.	Connect the light sensor to the data collection system. Record the light intensity at the different distances.

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 – Designing a research method and making predictions

1. ☐ Design a method of measuring light at varying distances (between 20 to 80 cm) from a light source at intervals of 10 cm. Record your investigative procedure by writing a description of your plans or steps in the space below.

   The methods students design will vary. Students might choose to use any clamps, lab apparatus, and support stands available; they might decide to use a plumb bob, to mount a meter stick, attach a wire cage around the light bulb, and so on. Methods suggested by the students will depend on materials they will have available or are allowed to provide themselves, including tape, extra wire, etc.

2. ☐ Predict how the intensity of the light changes as you increase the distance from the light bulb.

   Student answers will vary. Many students will state that light intensity will decrease by the same amount each time they move 10 cm away, but the light intensity actually decreases a greater amount each time they move 10 cm away from the light.

Part 2 – Measuring the light intensity

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

4. ☐ Connect the light sensor to the data collection system. �(2.1)

5. ☐ Display light intensity in a digits display. �(7.3.1)

6. ☐ Put the data collection system into manual sampling mode with manually entered data. �(5.2.1)

   Note: Enter "Light Intensity" with the units of "lx" and "Distance" with the units of "cm", with two digits past the decimal point displayed.

7. ☐ Start a new, manually sampled data set. �(6.3.1)

8. ☐ Using the method of positioning the light sensor your group developed to obtain the light intensity at the different positions from the light bulb, record each data point as follows:

   a. Record the light intensity and enter the distance from the light bulb. �(6.3.2)

   b. Record the light intensity for each distance in Table 1.

9. ☐ When you have recorded all of your data, stop the data set. �(6.3.3)

10. ☐ Display Light Intensity on the y-axis of a graph with Distance on the x-axis. � (7.1.1)

Note: Adjust the scale of the graph as needed. �(7.1.2)

Table 1: Change in light intensity as distance changes

Distance from Light (cm)	Light Intensity (lx)
20	259.10
30	120.15
40	73.40
50	37.10
60	24.41
70	17.83
80	9.26

Part 3 – Measuring the light intensity at your best study location

11. ☐ Determine the distance from the light bulb at the position you find best for studying. Record that distance.

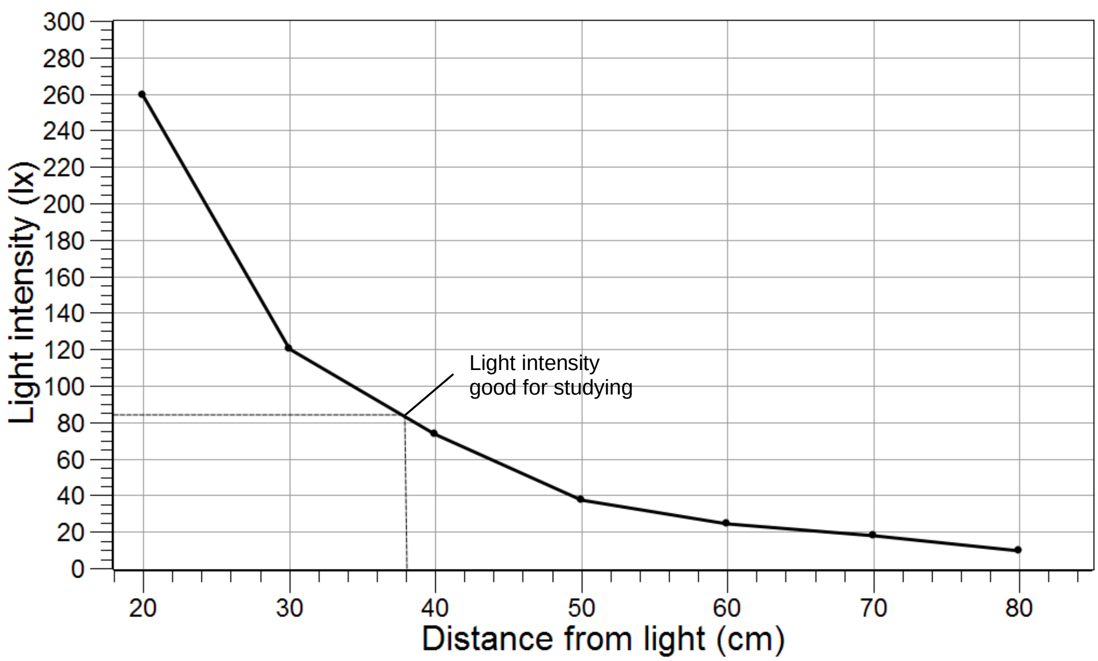
    Distance from the light bulb ___38___ cm

12. ☐ Save your experiment �(11.1) and clean up according to your teacher's instructions.

Answering the Question

Analysis

1. Display data in a graph to show Light Intensity versus Distance. �(7.1.1) Sketch the Light Intensity versus Distance on the graph below.



2. Explain the relationship between distance from the source and the light intensity with the diffuser.

   Light intensity decreased with an increase in distance but not at the same rate.

3. Using the graph, determine the light intensity at the distance you determined in Part 3. Note this distance on the graph.

   Answers will vary. For this example, the light intensity that corresponds to 38 cm is 83 lx.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. In the SI System of measurement, what is the unit for light intensity?

   A. Watts
   B. Lux
   C. Decibels

2. When you are father away from a light source, the intensity of the light is:

   A. Less than when you are closer
   B. Greater than when you are closer
   C. Exactly the same regardless of your distance away

3. A possible set of data recorded by someone backing away from a light source could be:

   A. 5.8 lux, 33.8 lux, 1142.4 lux
   B. 37.5 lux, 7.2 lux, 2.6 lux
   C. 10 lux, 20 lux, 30 lux

4. Light intensity generally varies with:

   A. A person's eyesight
   B. The diameter of the light bulb
   C. The distance from the light source

True or False

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

___T___ 1. A graph of light intensity versus distance from the light source will show a curve that decreases as distance increases.

___F___ 2. The light intensity that is best for studying is the same for everyone.

___T___ 3. If a light bulb is "incandescent," it glows as the result of being heated by a current flowing through it.

Further Investigations

Predict the changes in light intensity at different angles around the light bulb. Design and conduct an investigation to measure light intensity at different angles and at the same and increasing distances from the light bulb.

Have students use several light bulbs with different wattage to find the position that provides the amount of light needed for studying. Compare the intensity of the light at each position for each bulb. Was the light intensity about the same for each light bulb? Was the light intensity the only factor in determining that position?

Is there a difference in illumination between a frosted and non-frosted light bulb? Test your prediction.

Rubric

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

10. Measuring the Voltage of Elements in Series

Varying Lights

Objectives

In this activity, students investigate the voltage drop across a varying number of elements in series in a circuit.

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the voltage across a circuit
- Building a simple circuit with wire, holiday "mini" light bulbs, and batteries
- Systematically measuring the voltage across different numbers of resistors ("mini" light bulbs) in series

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	30 minutes
■ Lab activity, Part 2 – Testing 2 bulbs in series; Part 3 – Testing 3 bulbs in series; Part 4 – Testing 4 bulbs in series	40 minutes
■ Analysis	25 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ Voltage sensor, with leads
- ☐ Holiday "mini" light
- ☐ Wire strippers
- ☐ 9-volt battery, fresh

For each student or group:

- ☐ Data collection system
- ☐ Voltage sensor, with leads
- ☐ Holiday "mini" lights (10)
- ☐ Wire strippers
- ☐ 9-volt battery, fresh

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Electrical terms related to circuits, including "current," "resistance," and "voltage"
- How to build a simple circuit given wires, a resistor such as a light bulb, and a battery
- How to strip the ends of insulated wire to allow for electrical contact in the circuit

Related Labs in This Guide

Labs conceptually related to this one include:

- Measuring Light Intensity
- Voltage Time

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 a sensor to the data collection system �(2.1)
- Monitoring live data without recording �(6.1)
- Adjusting the scale of a graph �(7.1.2)
- Displaying data in a digits display �(7.3.1)

Background

A series circuit has elements connected one after another along a single path. In such a circuit, electrical current can only flow in one path, from high-potential, or the positive terminal, to low-potential, or the negative terminal. An expression for the resistance R found in a *series circuit* is:

In symbols:

$$R_{Total} = R_1 + R_2 + \ldots + R_n$$

In words:

The total resistance in a series circuit is equal to the sum of the individual resistances.

Also, the sum of the voltage measured across each resistor in a series is the voltage of the voltage source. The voltage measured across resistors of equal resistance (in series) is the same.

A parallel circuit has elements connected in a branched path. In such a circuit, electric current can pass through all of the paths, from high-potential or the positive terminal to low-potential or the negative terminal. The expression for the resistance found in a *parallel circuit* is:

In symbols:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\frac{1}{R_n}$$

In words:

The reciprocal of the total resistance in a parallel circuit is equal to the sum of the reciprocals of the individual resistances.

The reason this equation is expressed in terms of reciprocals is because *conductance* and *resistance* are opposites, and in a parallel circuit we are really talking about the conductance of the electricity through the different pathways.

The total parallel resistance is less than the separate pathways' resistances, because parallel resistors resist less together than they do separately. This means then that the total parallel conductance is greater than the separate pathways' conductances because parallel resistors conduct more together than they do separately.

Circuits are often difficult for students to understand; the following analogy may be helpful for class discussion and clarifying misconceptions:

An electrical circuit is similar to water running through a hose from a faucet. In this model, the volume of water represents the current I flowing through the hose that represents the wire. More water flows through a hose with a larger diameter, corresponding to a greater current.

The resistance R to flow is dependent on the length or the narrowness of the hose. If you turn the faucet on full, the pressure needed to push the water through the hose is at maximum. The pressure needed to push the water represents the voltage V. Power P is the rate of flow of the water in the hose.

Similarly, a waterfall can provide another analogy. The height of a waterfall (the distance the water has to fall) corresponds to the voltage (there is more energy in the water falling from a high waterfall than a low one). The current corresponds to the volume of water flowing (there would be an enormous current corresponding to the volume of water of Niagara Falls, but a small current in a waterfall of the same height that had very little water falling).

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask the students what is required to make a complete electrical circuit. The key idea is that a circuit is a closed path and consists of a flow of current through all the circuit elements. The current cannot pile up anywhere, so whatever goes into an element must have a way to flow out.

Make a list of your students' responses. Focus on a source (battery), conductor (wire), and load that offers resistance to the flow of electrons. Students might mention many kinds of loads, including bulbs, resistors, motors, and so on. Depending on their experience with circuits, students might also mention switches. When a switch is inserted into a circuit it can be used to complete a circuit (switch closed) or break the connection (switch open).

Demonstrate a simple circuit with a 9-volt battery connected to a holiday "mini" light. When the circuit is complete, the bulb lights up. Demonstrate how to use the voltage leads by connecting them across the holiday “mini” light (on either side of the bulb) with the leads while the bulb is lit.

Direct students to the "Thinking about the Question" section of this lab. Allow the students to work for a few minutes within groups to create a schematic drawing of the circuit and then ask them to present their drawings to the class.

Next, ask the students to think about adding bulbs to the circuit. To help the students understand the voltage drop created by the addition of the bulbs, refer to the earlier analogy in the Background section. As bulbs are added to the circuit in series, they represent the addition of more length of hose to the model. This additional length of (narrow) hose increases the resistance to the flow of the water. The more bulbs connected in series, the more resistance to the flow of water.

Direct students to the "Investigating the Question" section of this lab.

Preparation and Tips

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

- Depending on the ages of the students, you might cut apart the individual lights, leaving wire leads at each end, in advance of the investigation. Each lead should be stripped of 3 centimeters (cm) of insulation to expose the wire. Each student group will need 10 individual bulbs.
- Use fresh 9-volt batteries to power the holiday “mini” lights.
- Cut the plug off the string of lights so students won't plug in the lights.

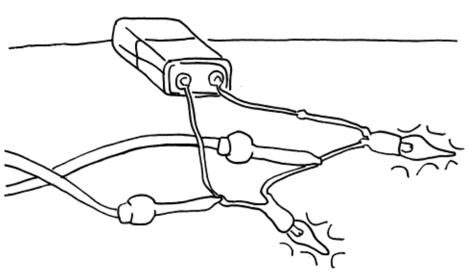
Safety

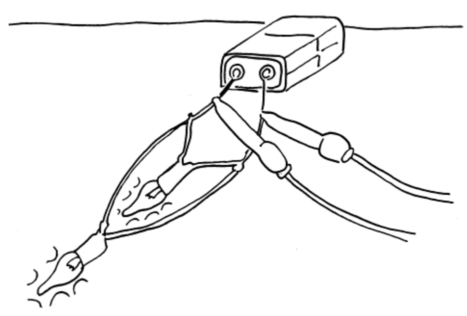
Add this important safety precaution to your normal laboratory procedures:

- Never plug the holiday "mini" lights into a household circuit.

Driving Question

What are the voltages in different chains of light bulbs?





Thinking about the Question

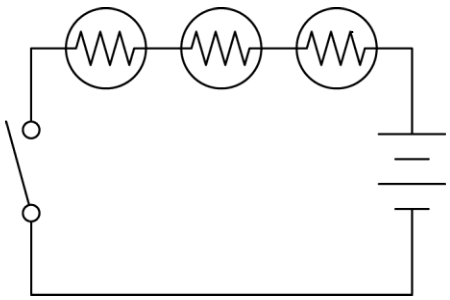
You can use the voltage sensor to detect resistance, indicated by a voltage drop when current flows through the material. Usually you can ignore the resistance of wire and concentrate on the resistance of the circuit elements, such as lamps, which are connected by the wires.

If you were given three holiday "mini" lights how could you chain the lights to make a circuit?

> One group answered as follows: We could connect each side of a light's wire to another wire on another light, so we form a string of wire and lights, with one end of the string connected to one end of the battery, and the other end of the string connected to the other end of the battery.

Work with members of your group to connect the 3 bulbs in series. Sketch your circuit. Be prepared to share your thoughts with the class.

> Student answers will vary. A possible drawing might be:



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.

1	2	5	4	3
Make sure each lab group member is aware of the safety rules and procedures for this lab.	Connect the voltage sensor to your data collection device.	Determine how the voltage drops across the mini-bulbs relates to the number of bulbs in series and the voltage source.	Connect additional mini-bulbs in series; measure and record the voltage drop across each mini-bulb.	Construct a circuit with 2 mini-bulbs in series. Record voltage drop across each mini-bulb.

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. ☐ Predict the voltage drop across each bulb in a circuit that contains 2 or more bulbs in a row. Record your prediction.

   Student answers will vary. They might predict that the voltage will be divided equally across each bulb in series (assuming the bulbs have the same resistance).

Part 2 – Testing 2 bulbs in series

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

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

4. ☐ Monitor live data without recording. �(6.1)

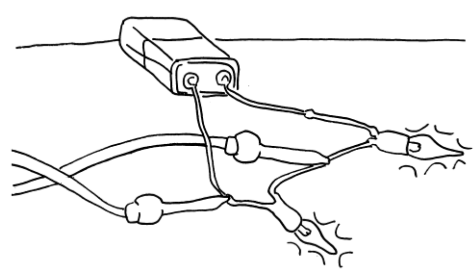
5. ☐ Display voltage in a digits display. �(7.3.1)

6. ☐ Connect 2 bulbs in series to the 9 V battery.

7. ☐ Connect the voltage sensor leads on either side of each bulb and record the voltage drop across each bulb.

   Bulb 1 ___4.46___ volts

   Bulb 2 ___4.46___ volts



Part 3 – Testing 3 bulbs in series

8. ☐ Connect 1 more bulb (for a total of 3 bulbs) in series with the 9 V battery.

9. ☐ Measure the voltage drop across each bulb and record the voltage drops below.

   Bulb 1 ___2.92___ volts

   Bulb 2 ___2.92___ volts

   Bulb 3 ___2.92___ volts

Part 4 – Testing 4 bulbs in series

10. ☐ Connect 1 more bulb (for a total of 4 bulbs) in series to the 9 V battery.

11. ☐ Measure the voltage drop across each bulb. �(6.1) Record the voltage drops below.

Bulb 1 ___1.87___ volts

Bulb 2 ___1.87___ volts

Bulb 3 ___1.87___ volts

Bulb 4 ___1.87___ volts

12. Try adding more bulbs to your circuit. How many bulbs can you attach before the lights start to dim significantly or before you cannot see any light at all?

Student answers will vary. It is likely that after eight bulbs are added to the circuit with a fresh battery, some of the bulbs will not light.

Answering the Question

Analysis

1. How does the sum of the voltage drops of the 2 bulbs, 3 bulbs, and 4 bulbs in series compare to the voltage of the battery?

The sum of their voltages is equal to the voltage of the battery. Also, the voltage of the battery is divided equally between the 2, 3, or 4 bulbs in series in the circuit.

2. How did your predictions compare to your results?

Student answers will vary. One group answered: Our predictions were wrong. We thought there would be the same amount of voltage across the bulbs in each arrangement, but there was less with more bulbs in the series. In each case the voltage of the bulbs added up close to the voltage of the battery.

3. How does the sum of the voltage drops compare to the voltage of the battery with four bulbs in the circuit?

When four bulbs are added, the individual voltage of each bulb decreases so that the overall sum still equals the voltage of the battery.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. In the water faucet-hose analogy of an electric circuit, which part represents the wire in a real electrical circuit?

   A. The faucet
   B. The hose
   C. The water

2. Which of the following does electricity need in order to flow?

   A. A complete path or circuit
   B. More than one light bulb in a series
   C. Only one light bulb in the circuit

3. Which is a reason that a holiday "mini" light might fail to light up?

   A. One end of the wire was not stripped
   B. Only one "mini" light was placed in the circuit
   C. Both ends of the wire were stripped

4. Suppose you are given three different circuits that have been built using one 9-volt battery. Which order has the circuits arranged from dimmest to brightest?

   A. Two-bulb circuit, one-bulb circuit, three-bulb circuit
   B. One-bulb circuit, two-bulb circuit, three-bulb circuit
   C. Three-bulb circuit, two-bulb circuit, one-bulb circuit

True or False

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

____T____1. A light bulb is a form of resistor in an electric circuit.

____F____2. Electricity can flow through an open circuit if all the elements of the circuit are in series.

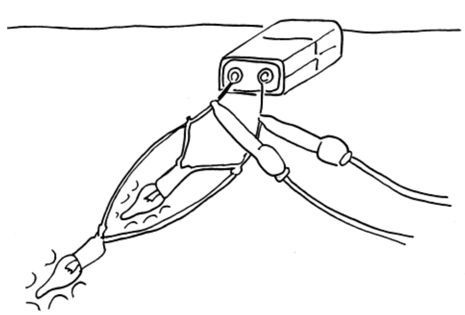
____T____3. In a series of four bulbs connected to a 9-volt battery, the sum of the voltages of the bulbs is equal to the voltage of the battery.

____T____4. In a series of 3 bulbs of the same resistance, one-third of the voltage of the battery can be measured across each bulb.

____T____5. Part of a student's responsibility in the lab is to follow all safety rules.

Further Investigations

What is the voltage drop of a parallel circuit of 2 bulbs as shown below?



What would be the voltage drop across different bulbs in a complex circuit containing bulbs in parallel and series? Predict and then measure the voltage drops across each bulb and group of bulbs.

Rubric

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

11. Motion Graphs

Follow the Leader

Objectives

In this activity students discover the spatial meaning of such terms as "position," "fixed reference point," and "frame of reference." Students use the motion sensor to measure their motion and then kinesthetically match their motion with the motion represented on a position versus time graph. This activity prepares students for the concept of velocity, because it provides background experience with direction of motion as well as speed.

Students investigate their position and observe how it changes while:

- Recognizing position as the distance and direction of an object relative to a fixed point of reference (or frame of reference)
- Recognizing motion as the change in an object's position
- Relating the frame of reference to the location of the observer
- Moving back and forth relative to the motion sensor, in order to match the pattern of their motion with the pattern on a target graph of position versus time
- Using math skills to analyze motion represented by a specific position versus time graph
- Gaining skills in using scientific measurement tools, the motion sensor, as well as the graphing capability of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the position of a moving object
- Walking backward and forward before the motion sensor to match a graph of position versus time as plotted by another student
- Relate slope of a line with rate of speed, given distance and time

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	50 minutes
Lab activity, Part 2 – Follow the leader	50 minutes
Lab activity, Part 3	50 minutes
Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ Motion sensor
- ☐ Reflector (optional)

For each student or group:

- ☐ Data collection system
- ☐ Motion sensor
- ☐ Reflector (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Reference points commonly used in daily life to describe distances and directions
- Process skills such as using a meter stick or ruler to measure the length of objects, or distances from one point to another
- Be able to read and interpret a coordinate graph
- The SI unit used to measure length is meters.
- The basics of using the data collection system.

Related Labs in This Guide

Labs conceptually related to this one include:

- Speed and Velocity
- Mapping the Ocean Floor

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 a sensor to the data collection system �(2.1)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)

- Displaying multiple data runs in a graph �(7.1.3)
- Saving your experiment �(11.1)
- Printing your experiment �(11.2)

Background

The terms "distance," "position," and "distance traveled" are often used interchangeably in everyday language. This can cause confusion when students begin their study of motion because the terms often have very different meanings when they are used in science. (Motion is a change in position relative to a frame of reference.)

"Distance" refers to the amount of space between points. In other words, it is a length. "Position" refers to the location of an object relative to a frame of reference. Position includes both direction and distance from the frame of reference. If you tell someone the *distance* to your house, you might say "five kilometers" (5 km). If you tell someone the *position* of your house, you might say "5 kilometers (km) east of the mall." In this description the distance is *5 km*, the direction is *east,* and the frame of reference is *the mall*.

"Distance traveled" is the total distance required to get from one position to another. Assuming that you travel on a straight road to the mall, your distance traveled is 5 km and your position is 5 km west of your home. Now, imagine that you turn around and travel from this position toward your house, going a distance of 2 km. Your distance traveled is then 7 km (5 km + 2 km), but your position is 3 km (5 km – 2 km) east of your house. In this example the distance is *3 km*, the direction is *west*, and the frame of reference is the location of your house.

"Frame of reference" refers to the location of the observer while measurements of position or motion are made. For example, if the observer is in a moving car, the car is not moving relative to the observer. Therefore, the observer in the car could say that the position of the car is *constant*. However, if the observer is standing on the side of the road, the car is moving relative to the observer. Therefore, the observer on the side of the road would say that the position of the car is *changing*.

Pre-Lab Discussion and Activity

Post the following questions on the board before the students enter the classroom:

- Where do you live?
- Where are you right now?
- What is motion?
- What does position mean?
- What does distance mean?
- What does distance traveled mean?

Direct the students to "Thinking About the Question." Instruct the students to use a frame of reference when discussing the first two questions. Have students discuss these questions in their lab groups. After a few minutes, ask the student lab groups to share some of their answers with the class. If necessary, direct students' attention toward including both distance and direction relative to a frame of reference. Record on the board the students' ideas about the meaning of position compared to distance traveled.

Demonstrate the use of the motion sensor to record position versus time. Show students how to walk toward and away from the motion sensor and the resulting position versus time graph. Show students what the graph looks like if the motion sensor loses its echolocation "target," and remind them to walk straight in front of the sensor's metal screen and avoid side-to-side motion. Demonstrate the use of a reflector to improve the ability of the motion sensor to "see" the object in motion.

Now direct the students to "Investigating the Question."

Preparation and Tips

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

- Prepare ahead of time to demonstrate the use of the motion sensor. Show the students the round gold screen, and refer to it as the reference point. All motion will be measured relative to the reference point. Allow students to hear the clicking sound the motion sensor emits when it is collecting data. If you choose, you can explain to the students that the motion sensor sends out pulses of ultrasonic sound waves that reflect from an object and return to the sensor. Using the speed of ultrasonic sound waves and the time to and from the object, the software calculates the position of the object relative to the sensor. The motion sensor works like the sonar that dolphins and whale use.

- Make sure the selector switch on each motion sensor is set to "person" (broad beam) instead of "cart" (narrow beam).

- Be sure to supervise students as they set up their work area, so that they have a safe, clear path in which to move toward and back away from the motion sensor. Remove obstacles that the students may trip on.

- Each student group needs to have one student chosen to be the "walker" in Part 2 and Part 3 of the activity, to serve as the "leader" for the other members to follow. You may pre-select these students or have them volunteer in their groups. Every student in each group will have the chance to make at least one motion graph.

- Make sure that students understand that the followers need to be able to see the graph of the leader while they are walking, so they must set up their work area to account for this.

- Students need to complete their position match walks within 10 to 20 seconds of beginning data collection.

- Circulate among the groups as they work. Check to see that they are successfully collecting motion data. If you notice "spikes" in their graphs, the student volunteering as the "walker" may be inadvertently stepping outside of the narrow cone of sound waves. Also, the motion sensor may be too high or too low for the particular student. The sensor "loses" the target of its echolocation and instead bounces the sound waves off the next nearest object, which may be the back wall of the classroom.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Make sure there is a clear path in front of the motion sensor.
- Do not allow obstacles to obstruct students' path or they may trip.

Driving Question

How do you know where you are going?

Thinking about the Question

Describing your location, or position, is based upon describing the distance between you and some fixed reference point. When you change your position, you experience motion.

If you have ever ridden a rollercoaster at an amusement park, you have probably used the ground as your fixed reference point. How did you know you were getting higher? If the rollercoaster went through loops or spirals, how could you tell if you were upside down? Sometimes people who are scared during the ride close their eyes. Do you think this might help? Why or why not? Regardless of whether the rollercoaster was fun or scary, the ride is eventually over. How would you know that the rollercoaster had stopped? Would it be possible to use a fixed reference point other than the ground?

> Students may say that closing their eyes during the ride prevents them from being able to tell when they are upside down because they lack a reference point such as the ground, or they would not be able to see the sky at their feet. Students may describe using the horizon or the sky as a fixed reference point. They may also describe using another landmark in an amusement park, such as a different rollercoaster or attraction that is visible. When the ride comes to a stop, students may describe using some aspect of the ride's structure as the reference point, as well as or instead of the ground.

Discuss with your lab group members how to compare where you are right now to where you live. How do you use a fixed reference point to help in this comparison? What does "frame of reference" mean? Do you need to use a direction and a distance? What is motion? How do you know if an object is in motion?

> Answers will vary. Students may refer to knowing how many miles away they live from school, and they may know the compass direction they travel to go from home to school and vice versa. They may discuss using familiar landmarks such as buildings, parks, or particular streets as reference points to use as comparisons. Students may use the term "landmark" in their description of "frame of reference." Students should recognize that they need to include both direction and distance in order to describe motion fully. They should recognize that a change in position or distance from a fixed reference point is used to tell if an object is in motion.

Sequencing Challenge

Note: This is an optional ancillary activity that may be omitted.

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.

2/3	1	3/2	4	5
Determine how far away from the motion sensor 50 cm is, so the walker knows where to begin.	Make sure that each lab group member is aware of safety rules and procedures for this lab.	Determine the maximum distance away from the motion sensor the walker may move.	Start recording position versus time data.	Begin walking backward and forward when the clicking sound of the motion sensor becomes audible.

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. ☐ The job of the "walker" in this activity is to walk back and forward in front of the motion sensor. The walker's position relative to the motion sensor will change throughout this activity. Write your predictions about the walker for the following:

    a. How will a graph of position versus time change when the walker moves closer to the fixed reference point (the motion sensor)?

    b. How will the graph of position versus time change when the walker moves away from the fixed reference point?

    c. If the walker's distance from the fixed reference point does not change, how would this appear on the graph of position versus time?

    Students should predict that the slope of the line will decrease or go down as the walker moves closer. They should predict that the slope of the line will increase or go up as the walker moves away. They should predict that the slope of the line will be zero, or flat, while the walker's distance does not change. Some students may erroneously predict that the graph of position will drop to zero when the walker's position does not change.

2. ☐ Write your predictions for the following:

   Suppose a walker begins two meters away from the reference point and walks slowly toward it until stopping at 0.5 meters away from it. Then a second walker takes the same walk, but walks much more quickly. How would the graphs of these two motions compare? How would they differ? You may sketch your predictions or describe them using words.

   Students should predict that both the slow walker and the fast walker would have a graph that goes down (or has a negative slope). They should predict that the faster walker will have a graph that goes down faster (with a steeper negative slope). Students may also predict that the total time elapsed for the faster walker is less than for the slow walker.

Part 2 – Follow the leader

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

4. ☐ Connect the motion sensor to the data collection system. �(2.1)

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

6. ☐ Change the sampling rate to take position measurements 5 times per second (5 Hz). �(5.1

7. ☐ Select one student to be the first walker. This person will be the leader for this part of the activity. The walker should stand in front of the motion sensor at a distance of 50 cm from the metal screen. Why is it important to choose one particular fixed object to measure the distance from?

   It is important to choose one particular fixed object to measure distance from because the definition of motion is the change in distance from something to a fixed reference point, as measured by a particular observer in a particular frame of reference. The metal screen of the sensor in this case is our fixed reference point.

8. ☐ Start data recording. �(6.2)

9. ☐ The walker should now move as follows:

   a. Stand still for 2 seconds

   b. Back away from the motion sensor slowly for 6 seconds

   c. Stop and stand still for 2 seconds

10. ☐ Stop data recording. �(6.2)

11. ☐ If necessary, adjust the scale of the graph to show all data. �(7.1.2) The pattern on the graph shows the motion of the leader. The other members of your lab group will each try to match the position graph of the leader, walking the same distances in the same amounts of time.

12. ☐ Select a new walker to follow the leader. The new walker should stand in front of the motion sensor at a distance of 50 cm from the metal screen.

13. ☐ Start data recording. �(6.2)

14. ☐ The new walker should now move in such a way as to follow the motion of the leader, matching the leader's position graph as closely as possible.

15. ☐ At the end of the 10 seconds stop data recording. �(6.2)

16. ☐ Hide the last walker's data run so only the leader's graph shows. �(7.1.1)

17. ☐ Select the next walker to follow the leader. The next walker should stand in front of the motion sensor at a distance of 50 cm from the metal screen.

18. ☐ Start data recording. �(6.2)

19. ☐ The next walker should now move in such a way as to follow the motion of the leader, matching the leader's position graph as closely as possible.

20. ☐ At the end of the 10 seconds stop data recording. �(6.2)

21. ☐ Hide the last walker's data run so only the leader's graph shows. �(7.1.1)

22. ☐ Repeat the activity for each member of your lab group.

23. ☐ Save your experiment according to your teacher's instructions. �(11.1)

Part 3 – Matching position

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

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

26. ☐ Change the sampling rate to take position measurements 5 times per second (5 Hz). �(5.1

27. ☐ Select one student to be the first walker. This person will be the leader for this part of the activity.

28. ☐ The leader should stand in front of the motion sensor at a distance of his/her choice, but no closer than 15 cm from the metal screen.

29. ☐ Start data recording. �(6.2)

30. ☐ The leader should now begin moving slowly and steadily toward or away from the motion sensor, standing completely still at least once during the walk. The entire walk should take between 10 and 20 seconds.

31. ☐ Stop data recording. �(6.2)

32. ☐ Select a new walker to follow the leader. The new walker should stand in front of the motion sensor at the same initial distance from the motion sensor at which the leader began. For an added challenge, group member should not watch the "leader's" movement while they are making the graph.

33. ☐ Start data recording. �(6.2)

34. ☐ The new walker should now move in such a way as to follow the motion of the leader, matching the leader's position graph as closely as possible.

35. ☐ As soon as the new walker has matched the position graph of the leader, stop data recording. �(6.2)

36. ☐ Hide the last walker's data run so only the leader's graph shows. �(7.1.1)

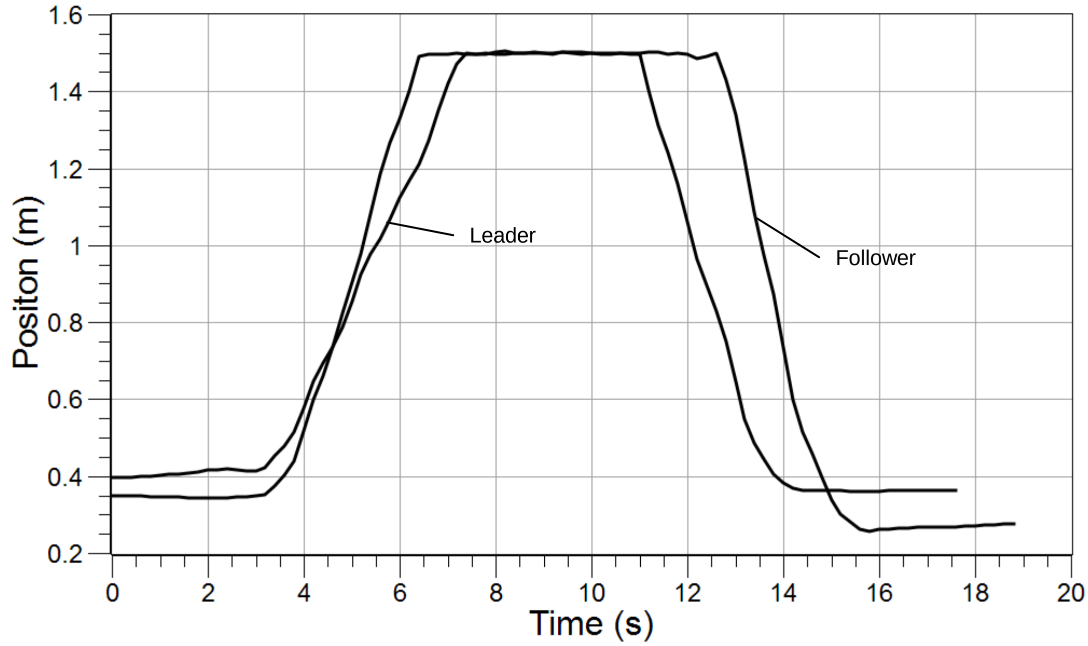
37. ☐ Repeat the activity for each member of your lab group.

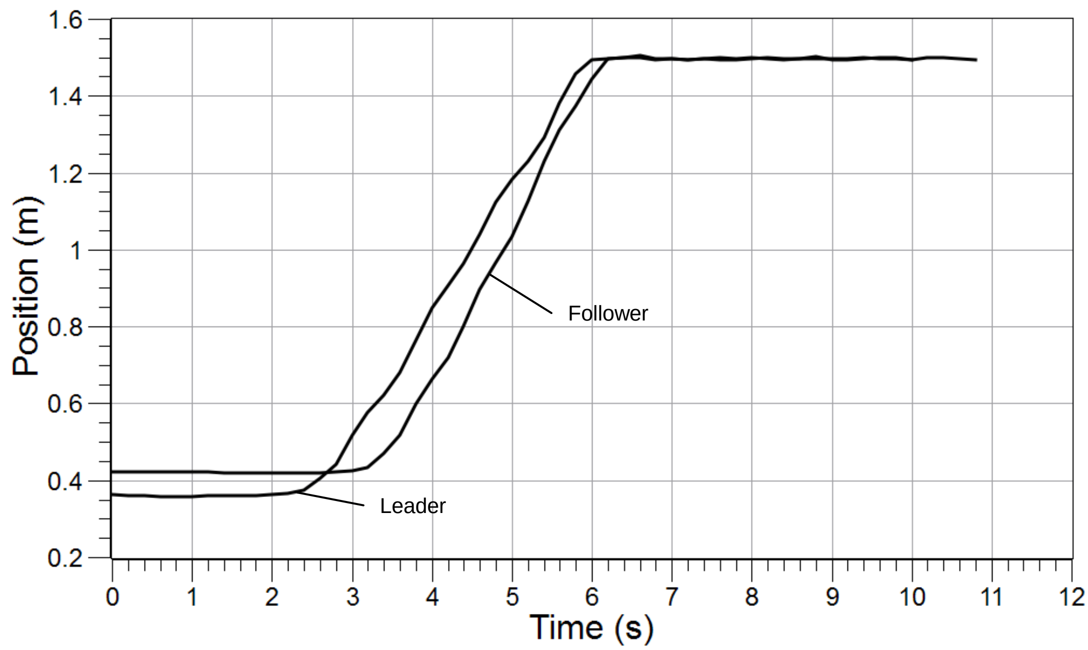
38. ☐ Save your experiment according to your teacher's instructions. �(11.1)

39. ☐ What did you observe about matching the leader's position graph? Write your observations in the space below.

Answers will vary. One student group answered as follows: It is harder to match the graph than it seems. The hardest part is knowing how fast to walk, and walking evenly. At first we could not get the slanted parts of our graphs to match the leader's position at all. It took several tries to get better at it. We discovered that taking very small steps helps to make the sloped parts smoother.

Sample Data





Answering the Question

Analysis

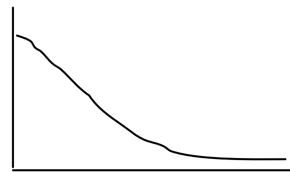
1. How did your predictions from Part 1 compare to the results in Part 2?

   Answers will vary. One group answered as follows: We predicted that the graphs would go down when the target moved closer to the reference point, and up when the target moved farther away from the reference point, and this turned out to be correct. However, when someone stops, their graph does not drop to zero, it just stays flat. If you look at the y-axis, you can tell how far away from the reference point they were when they stopped.

2. What does the slope, or steepness, of the graph tell you about the walker's motion?

The steepness or slope tells how fast or slow a target was moving. A steeper slope means the walker was going faster.

3. If you wanted to model a rollercoaster car coming to a stop at the end of the ride, the walker could represent the rollercoaster car, and the motion sensor could represent the boarding platform of the ride, where riders get on and off the rollercoaster. Describe or sketch the graph of the ride coming to a stop.



The graph looks like this. As the rollercoaster car slows down, its graph gets less steep. Then, once it stops, the graph is flat, or it has a slope of zero.

4. For Part 2, review your data carefully. Look at the position graph for the leader and each follower. �(7.1.3) Compare the motion of each follower individually to the motion of the leader. Select a data run that you think is a good example of the follower matching the leader's motion well. How did you make your decision? Describe what characteristics of the graphs you looked at to decide how well the follower matched the leader's position over time.

Answers will vary. One group answered as follows: When we looked at each graph compared to the leader's we looked at how close the follower's distance from the motion sensor at that second matched the leader's distance at the same second. Also, on the sloped part, we looked for the graph that was as close to parallel with the leader's graph as possible.

5. For Part 3, perform the same data analysis to compare each walker's motion to that of the leader. Choose one graph that you think is a good example of following the motion of the leader.

6. Get your teacher's permission to print out the example graph you have selected. �(11.2)

7. Write a thorough, detailed description of the motion of the two walkers. You may write your description on the graph print-out, or in the space below. You may find it helpful to label important points along the motion graph in order to help you refer to them (for example, point A, point B, point C, et cetera).

Answers will vary. One group answered as follows: At point A the person was standing still. They were 0.5 meters away from the reference point. They stood still for 2 seconds. At point B they started to move backward steadily and somewhat rapidly until the graph reached point C 3 seconds later. Then they stopped, and stood still for 2 seconds until the point we labeled D on our graph. They then walked toward the motion sensor for 2 seconds and stopped. We stopped recording data one second after that. At the end of the walk, they were about 1.8 meters away from the motion sensor.

8. From which frame of reference is this motion observed?

This motion was observed from the frame of reference of the motion sensor.

9. How could you have matched this position-time graph better?

Answers will vary. One group answered as follows: With more practice, we think we could do even better, because now we know how to do it, and we also know about how fast we would have to back away from the motion sensor. Also, we learned that it is really important to stand very still when you are supposed to be stopped. We decided that we would like to discuss the motion and describe it first before trying to follow the leader to match a position graph the next time. It is helpful to know the distance we are supposed to walk and the amount of time to cover the distance.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. In the SI System of measurement, distance is measured in:

   A. Feet
   B. Meters
   C. Miles

2. A change in position relative to a fixed reference point is known as:

   A. Motion
   B. Distance
   C. Speed

3. Another term for how steep a line on a graph appears is:

   A. Slope
   B. Rise
   C. Run

4. In order to get information about their motion as they take off from the launch pad at Cape Canaveral, the astronauts on board the Space Shuttle compare their position to:

   A. The military and civilian aircraft flying nearby
   B. The ground beneath them
   C. The other astronauts in the cockpit with them

5. On a position versus time graph of motion, the fastest motion toward or away from the fixed reference point is where the graph:

   A. Remains flat and horizontal for a period of time
   B. Has the steepest slope
   C. Has the least steep non-zero slope

True or False

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

___T___ 1. In order to know if an object's position has changed, you must measure its distance to a fixed reference point.

______F______ 2. If you are riding in a car that is traveling south at 60 km/h, your position is changing compared to the car.

______T______ 3. If you are riding in a car that is traveling south at 60 km/h, your position is changing compared to the road.

______T______ 4. To say that you are stopped means that your distance from some fixed reference point is not changing.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

distance	fixed frame of reference	motion	x-axis	y-axis

1. A measurement of ___distance_____ is also a measurement of length.

2. On a graph of position versus time, position is plotted on the ____y-axis______, while time is plotted on the ____x-axis_____.

3. An object whose position is changing relative to a fixed reference point is said to be in motion .

4. The round gold screen on the motion sensor serves as a _fixed frame of reference_________ for determining motion.

Further Investigations

Use the predict tool �(7.1.12) in the software to create an original position-time graph, then ask another student group to try to match it!

Note: If you use the Xplorer GLX as your data collection system, be aware that this device does not have a predict tool.

Use the predict tool in the software to draw a large circle in the middle of the graph. Investigate the possibility of matching this position-time graph.

Research the mathematical definitions of function and the vertical line test for a function. Use the predict tool in the software to show that it is impossible to match the position-time graph that fails the vertical line test.

Rubric

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

12. Neutralizing an Acid and a Base

Balancing Act

Objectives

In this activity, students neutralize a base with an acid.

- Students determine the point of neutralization of an acid mixed with a base while they:
  - Recognize that if substances react in similar ways they often are placed in categories or groups (such as acids or bases)
  - Identify other variables in an experimental design that must be controlled in order to isolate the effect of one variable
  - Gain skills and confidence in using a scientific measurement tool, the pH sensor, as well as the graphing capacity of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure change in pH
- Performing a simple titration of two different concentrations of vinegar and baking soda
- Using the pH sensor, students determine the endpoint of a titration.

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	25 minutes
■ Lab activity, Part 2 – Neutralizing baking soda with vinegar	25 minutes
■ Lab activity, Part 3 – Neutralizing double the concentration of baking soda	25 minutes
■ Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ pH sensor
- ☐ Erlenmeyer flasks (2), 250-mL
- ☐ Balance (1 per class)
- ☐ Graduated cylinder, 100-mL
- ☐ Pipet or eyedropper
- ☐ Vinegar, 50 mL
- ☐ Baking soda, ~2 g
- ☐ Sample paper
- ☐ Buffer solution pH 4, 25 mL
- ☐ Buffer solution pH 10, 25 mL
- ☐ Water, 100 mL

For each student or group:

- ☐ Data collection system
- ☐ pH sensor
- ☐ Erlenmeyer flasks (2), 250-mL
- ☐ Balance (1 per class)
- ☐ Graduated cylinder, 100-mL
- ☐ Beaker, 200 mL
- ☐ Pipet or eyedropper
- ☐ Vinegar, 50 mL
- ☐ Baking soda, ~2 g
- ☐ Sample paper
- ☐ Water, 100 mL
- ☐ Distilled water, 200 mL, in wash bottle

Concepts Students Should Already Know

Students should be familiar with the following concepts or skills:

- Measuring the mass of a solid and the volume of a liquid
- Using a pipet or eyedropper to transfer a liquid one drop at a time
- Acids, bases, and the pH scale
- Neutral and neutralize in the context of acids and bases
- Reading and interpreting a coordinate graph
- Familiar with the SI unit of measure for mass (grams) and volume (milliliters)
- The basics of using the data collection system including how to change the precision of a measurement to the desired place value

Related Labs in This Guide

Labs conceptually related to this one include:

Suggested Prerequisite:

- Introduction to Acids and Bases

Additional related labs:

- Acid Rain and Weathering
- Acid's Effect on Teeth

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 a sensor to the data collection system �(2.1)
- Changing the number of digits with which a variable is displayed. �(5.4)
- Recording a run of data �(6.2)
- Displaying data in a digits display �(7.3.1)
- Saving your experiment �(11.1)

Background

When certain types of ionic compounds are added to water, the result is more hydrogen ions (H^+) than in pure water. HCl (hydrogen chloride), for example, makes H^+ and Cl^- ions in the water. When there are more H^+ ions in water than there are in pure water, the water is called acidic. Since HCl caused the water to become acidic, it is called an acid. Some acids are stronger than others. This means that some acids will break into ions more easily than others.

When some compounds are added to water, the result is more hydroxide ions (OH^-). NaOH (sodium hydroxide), for example, makes Na^+ and OH^- in solution. When there are more OH^- ions in a solution than there are in pure water, the solution is called basic. Since NaOH caused the solution to become more basic, it is called a base. Some bases are stronger than others. This means that some bases will break into ions more readily than others.

Some compounds, such as ammonia (NH_3) for example, do not contain OH^- ions yet are still able to make bases. NH_3, when dissolved in water, soaks up the H^+ ions made by water, making ammonium ions (NH_4^+). This results in "mismatched" or "extra" OH^- ions, which makes the solution basic. The actual concentration of H^+ ions in solutions, even in acid solutions, is usually very small. To avoid working with such small numbers all the time, the pH scale was developed. The numbers of the pH scale are the negative logarithm of the hydrogen ion (H^+).

The pH scale for water ranges from 0 to 14. A solution with a pH of zero has the most H^+ ions, while a solution with a pH of 14 has the fewest H^+ ions. A solution with a pH of 7 is neutral; if it has a pH below 7, it is acidic; if it has a pH above 7, it is basic.

Some compounds, such as carbon dioxide and sulfur dioxide, do not contain hydrogen but still make acids. Carbon dioxide (CO_2) is a gas that reacts with water. In water, CO_2 becomes carbonic acid (H_2CO_3) which ionizes to H^+ and $(HCO_3)^-$. The result is the production of H^+ ions. This is why pure water exposed to air will eventually reach a pH of about 5.6. Sulfur dioxide (SO_2) reacts with water to form sulfurous acid (H_2SO_3). This also ionizes a bit, producing H^+ and $(HSO_3)^-$. This is a weak acid because low concentrations of H^+ are made.

When baking soda (a basic substance) and vinegar (an acidic substance) are combined, a chemical reaction occurs. These two substances react with each other, producing salt, water, and carbon dioxide – the gas that produces the little bubbles. The salt produced by this reaction is sodium acetate:

$$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$$

Pre-Lab Discussion and Activity

Neutralization in Cooking

Share with students the fact that cooks are really doing acid and base chemistry when they bake. For example, a cook who is preparing a batch of pancakes for breakfast mixes buttermilk with an ingredient like baking soda. Neutralization occurs, producing carbon dioxide gas and water. The carbon dioxide bubbles expand when the batter is poured on a hot griddle, making the batter rise.

Ask students to explain the acid and base chemistry in pancake baking. Which ingredient is the acid (buttermilk is lactic acid) and which is the base (baking soda)? What does neutralization mean? Ask students to share their thoughts with the class.

Discuss with students that bases are a class of compounds that have characteristics that are opposite to those of acids. The two groups of chemicals, acids and bases, may be thought to balance one another. “Neutralization” is the term given to the chemical interaction of acids and bases that produces salt and water. Direct students to “Thinking About the Question.”

Ask students to share with the class the reasons for using lemon on fish. Record the students’ ideas on the board. Explain that the scales of fish are coated with a base that makes them slippery. When lemon is squeezed on fish before eating it, what is actually happening is a neutralization of the basic, bitter taste with an acid, thus making it more pleasant tasting by producing salt.

Tips for Collecting Data

Discuss with students the importance of avoiding contamination and false readings by rinsing the pH sensor with distilled water before each use. Review for students the steps involved in using the pH sensor for several samples, the technique for rinsing the probe portion of the sensors, and how to arrange their equipment. Consider setting up a sample work station for students to emulate as they set up their own lab stations.

Mention to the students that a pH sensor can detect neutralization. If the pH is neutral (7.0) the solution has reached the endpoint. The endpoint is when the added acid exactly neutralizes a base or the added base exactly neutralizes an acid. Direct students to “Investigating the Question.”

Preparation and Tips

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

- This activity will be most successful if each pH sensor is calibrated ahead of time. If possible, calibrate the pH sensors just before students start this activity. �(3.6) If you have previously shown students how to do this, allow them time to calibrate the sensors.
- Consider demonstrating for students the steps involved in setting up the apparatus and performing the procedures involved in titrations.
- Leave calibrated pH sensors connected to the data collection systems.
- Encourage students not to "hurry" the neutralization by adding more than one drop at a time.
- Provide students with towels in case of spills or overflows.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Wear safety goggles.

Driving Question

Can common kitchen substances be neutralized?

Thinking about the Question

Acids are characterized by their sour taste and their ability to dissolve metals. Many of the foods you eat, such as oranges, green apples, pickles, and cranberries, taste sour due to the acids that they form.

Bases are generally slippery and taste bitter. Some of the most basic substances found in the kitchen are not actually used for food, but are cleaning supplies. Window cleaner, dish detergent, and oven cleaner are extremely basic. Eggs and baking soda are just slightly basic. When fresh fish is served, a slice of lemon is often placed on the platter. Discuss with your group, in terms of acids and bases, why the lemon is provided.

In this activity, you will investigate *neutralizing* an acid and a base. Since acids and bases are a type of "opposite," the process of neutralizing them involves carefully finding a balance between the two. In physical science the term endpoint describes the point at which an added acid exactly neutralizes a base, or an added base exactly neutralizes an acid. The process of finding an endpoint is called *titration*.

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.

3	2	4	5	1
Dissolve baking soda in water in an Erlenmeyer flask.	Measure the necessary water by volume and baking soda by mass.	Use a pipet to add vinegar, one drop at a time, to the baking soda solution.	Add the final drop of vinegar to the solution just before the pH reaches 7.0.	Make certain that each member of the lab group is aware of the safety rules and procedures for this lab activity.

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. Is it possible to neutralize baking soda with vinegar?

   b. If so, how many drops do you predict it will take to neutralize 0.5 gram of baking soda? If you double the amount of baking soda to 1.0 grams, how many drops will it take to neutralize the 1.0 grams?

   Answers will vary. One group answered as follows: We think we will be able to neutralize the baking soda if we carefully add the right amount of vinegar. For 0.5 gram of baking soda, we predict it will take 17 drops of vinegar. Since 1.0 is the double of 0.5, we predict it will take double the number of drops, which will be 34 drops.

Part 2 – Can a solution of baking soda be neutralized with vinegar?

2. ☐ Measure 50 mL of water into an Erlenmeyer flask.

3. ☐ Measure 0.5 g of baking soda onto the sample paper.

4. ☐ Add the sample of baking soda to the 50 ml of water in the flask. Swirl the solution until all of the baking soda is dissolved.

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

6. ☐ If necessary, connect a pH sensor to the data collection system. �(2.1)

Note: Your teacher may already have connected the pH sensor in order to calibrate it.

7. ☐ Display pH in a digits display. �(7.3.1) Change the number of digits displayed so you can see two digits after the decimal point. �(5.4)

8. ☐ Remove the storage bottle from the pH sensor tip, and set the bottle aside.

9. ☐ Place the pH sensor into the flask.

10. ☐ Begin data recording. �(6.2) Note the pH of solution and record this value in Table 1 below.

11. ☐ Using the pipet, drop vinegar into the solution in the flask one drop at a time. Swirl the flask after each drop is added. Count the number of drops of vinegar you add.

12. ☐ Continue adding drops of vinegar and swirling the flask until the pH of the solution reaches 7.0, then stop data recording. �(6.2)

13. ☐ Note the total number of drops of vinegar. Complete Table 1.

14. ☐ Rinse the pH sensor with distilled water, over the empty beaker. This beaker will hold waste rinse-water.

15. ☐ Save your experiment according to your teacher's instructions. �(11.1)

Table 1: Initial and final pH readings when adding vinegar to baking soda (mass 1)

Mass of Baking Soda	Initial pH	Final pH	Drops of Vinegar
0.5 g	8.54	7.05	90

Part 3 – Neutralizing double the concentration of baking soda

16. ☐ Measure 50 mL of water into an Erlenmeyer flask.

17. ☐ Measure 1.0 g of baking soda onto the sample paper.

18. ☐ Add the sample of baking soda to the 50 ml of water in the flask. Swirl the solution until all of the baking soda is dissolved.

19. ☐ Place the pH sensor into the flask.

20. ☐ Begin data recording. �(6.2) Note the pH of solution and record this value in Table 2 below.

21. ☐ Using the pipet, drop vinegar into the solution in the flask one drop at a time. Swirl the flask after each drop is added. Count the number of drops of vinegar you add.

22. ☐ Continue adding drops of vinegar and swirling the flask until the pH of the solution reaches 7.0, then stop data recording. �(6.2)

23. ☐ Note the total number of drops of vinegar. Complete Table 2.

24. ☐ Rinse the pH sensor with distilled water. Replace the pH sensor tip in the storage bottle.

Table 2: Initial and final pH readings when adding vinegar to baking soda (mass 2)

Mass of Baking Soda	Initial pH	Final pH	Drops of Vinegar
1.0 g	8.54	7.05	176

Sample Data

Answering the Question

Analysis

1. How did your predictions in Part 1 compare to your results in Parts 2 and 3?

   Answers will vary. One group answered as follows: It took a lot more vinegar than we predicted to neutralize our baking soda solutions. We predicted 17 drops for 0.5 grams, but it actually took 90 drops! Then, we predicted 34 drops for 1.0 grams, and it actually took 176 drops. The only part of our prediction that was even close was that we thought it would take double the vinegar to neutralize double the baking soda.

2. For Part 2, were you able to neutralize the baking soda? How many drops did it take?

   Answers will vary. One group answered as follows: We were able to neutralize the baking soda, with 90 drops of vinegar. We are not 100% positive it was exactly 90 drops, because some drops clung to the pipet and would not fall in until they got bigger, so they could have been bigger than one whole drop.

3. For Part 3 were you able to neutralize the double concentration of baking soda? How many drops did it take?

   We did get the double amount of baking soda neutralized. It took 176 drops.

4. How did the number of drops compare between Parts 2 and 3?

   It was almost double the number of drops between Parts 2 and 3, because 90 x 2 = 180, and we used 176 drops for neutralizing the baking soda in part 3.

5. What does neutralization mean to you?

   Neutralization means to make the pH get as close to 7.0 as possible by adding exactly the right amount of acid to the base. It is like canceling out a base with an acid.

6. How did the endpoints for Parts 2 and 3 compare?

   For part 2 the endpoint was 7.05, and for part 3 it was 7.03. If we had added more drops, the pH might have gone below 7.0, but we were trying to get exactly 7.0, which was difficult.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. When an acid is ____________________ with a base, a salt is formed.

   A. De-mineralized
   B. Neutralized
   C. Revived

2. We used the____________________ to determine when the acidic solution is neutralized.

   A. pH sensor
   B. Motion sensor
   C. Neutral sensor

3. We added acid to the base until its pH ____________________and we measured a pH of 7.

   A. De-mineralized
   B. Neutralized
   C. Revived

4. Water is a neutral solution and is neither a/an ____________________or base.

   A. Neutron
   B. Base
   C. Acid

5. A basic substance has a ____________________of 9.

   A. pH
   B. pH sensor
   C. Base

Key Term Challenge

Fill in the blanks from the randomly ordered words below. Note that words may be used more than once:

acid	neutralize	pH scale	pH neutral
pH sensor	base	salt	de-mineralize

1. A/an ____pH sensor____ is used to measure the pH of a solution.

2. A/an ____base____ is a substance that forms hydroxide ions (OH^-) in water and has a pH above 7.

3. A compound formed by a metal such as sodium and a halogen such as chlorine, often as a result of an acid-base neutralization, is called a/an ____base____.

4. The____pH scale____ measures how acidic or basic a solution is.

5. Any substance with a pH of 7 is called ____pH neutral____ .

6. A substance or solution that tastes sour, and has a pH below 7 is called a/an ____acid____ .

7. To ____neutralize____ means to bring an acidic or basic solution to a pH of 7.

Further Investigations

Investigate the endpoint of lemon juice and baking soda. How does it compare to that of vinegar and baking soda?

Investigate the temperature change of the chemical reaction of vinegar with baking soda. When the temperature readings have leveled out, you have reached the endpoint.

Rubric

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

13. Newton's First Law of Motion

May the Force Be with You

Objectives

Students discover how the change in an object's motion is related to the force (push or pull) applied to the object. Students investigate the nature of force and inertia while they:

- Recognize that a force is a push or a pull
- Recognize that forces have magnitudes (strengths) and directions
- Discover that a force applied to an object will change the object's motion
- Describe the key idea of Newton's first law of motion in their own words

Procedural Overview

Students gain experience conducting the following procedures:

- Students use a force sensor to measure the force applied to a cart. They use a motion sensor to measure the cart's motion. By comparing the data from the force sensor with data from the motion sensor, students demonstrate Newton's first law of motion:

  "Every body persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it." —Sir Isaac Newton
- Setting up the equipment and work area to measure position and force on a cart
- Recording position versus time and force versus time for a cart in motion and displaying the data in a graph
- Recording both force and position versus time, simultaneously, and displaying the data in a graph
- Using math and verbal skills to analyze graphical data and express Newton's first law of motion in students' own words

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	25 minutes
■ Lab activity, Part 2 – Investigating pushing and pulling a cart	25 minutes
■ Lab activity, Part 3 – Measuring force and motion	25 minutes
■ Analysis	25 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ Motion sensor
- ☐ Force sensor with hook and rubber bumper
- ☐ Chair with wheels

For each student or group:

- ☐ Data collection system
- ☐ Force sensor with hook and rubber bumper
- ☐ Motion sensor
- ☐ PAScar or other cart or toy car
- ☐ Duct tape or packing tape, several strips
- ☐ Metric ruler or meter stick

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- How to read and interpret a coordinate graph
- SI units of measure for force (newtons) and velocity (meters/second)

Related Labs in This Guide

Prerequisites:

- Speed and Velocity

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)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)

- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple graphs simultaneously �(7.1.11)

Background

Newton's First Law of Motion states that an object at rest stays at rest, and an object in motion stays in motion *unless* an external force is exerted upon that object. Newton's first law is commonly called the "Law of Inertia."

The word *inertia* means resistance to change. The amount of inertia an object has depends on its *mass*. The mass of an object is a measure of the amount of matter in the object. In the metric system, the fundamental unit of mass is the *kilogram* (abbreviated kg). Students will readily understand that an object at rest remains at rest.

It wasn't until astronauts went to the moon that Sir Isaac Newton's Laws of Motion were verified experimentally in the vacuum of space. Alan Shepard, who was the first American in space and the fifth to set foot on the moon, began an interesting tradition that is carried on today by astronauts working on the International Space Station (ISS) – space golf:

> "*Houston … you might recognize what I have in my hand as the handle for the contingency sample return; it just so happens to have a genuine six iron on the bottom of it. In my left hand, I have a little white pellet that's familiar to millions of Americans. I'll drop it down. Unfortunately, the suit is so stiff, I can't do this with two hands, but I'm going to try a little sand-trap shot here.*"

Astronaut Shepard needed two swings before he connected his club with the ball. After the first shot, Shepard dropped another ball to the ground and this time seemed to really enjoy his drive. "Miles and miles and miles," Shepard exclaimed. The swinging club exerted force on the golf ball and the reduced gravity cause a much slower change in its motion after that.

The word *force* is used in everyday language in a variety of ways. In science, a *force* is a push or a pull on an object. To fully describe "force," two pieces of information are required: magnitude and direction. Forces are measured by how strong they are (the magnitude) and by the direction in which they act. The metric unit of force is called a newton (abbreviated N). This unit of force was named after Sir Isaac Newton. A newton is defined as the force needed to accelerate one kilogram of mass at a rate of one meter/second/second. (In other words, it is the force needed to accelerate a kilogram from a speed of zero to a speed of one meter/second—about two miles per hour—in one second.)

Weight is a force; it is a measure of the downward pull of gravity and is defined in terms of the acceleration that a body experiences when placed in an appropriate environment. The English unit of force is called a *pound* (abbreviated lb). A pound is defined as the force needed to accelerate one *slug* of mass at a rate of one foot/second/second. (In other words, it is the force that will accelerate a slug from a speed of zero to a speed of one foot/second in one second.)

To convert from the English unit of force (lb) to the metric unit (N), multiply the weight in pounds by 4.45:

$$\text{weight (newtons)} = \text{weight (pounds)} \times 4.45$$

To convert weight from the metric to the English unit of force, divide the weight in newtons by 4.45:

weight (pounds) = weight(newtons)/4.45

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Most students will have had experience pushing or pulling objects. It will be helpful to refer to these experiences they may have had. Discuss some examples of forces, such as the wind pushing against your skin as you walk in a windstorm, a baby pulling a toy by a string, or a tug-of-war game where teams are alternately pulling on the rope.

Direct students to "Thinking about the Question."

Ask a student volunteer to sit in a chair with wheels. Ask the rest of the students about the various ways they could interact with the volunteer in the chair. Ask the following questions regarding the student in the chair:

- How would you describe his or her motion at this time?
- What would happen if you pushed on the volunteer?
- What would happen if you pulled on the volunteer?

Demonstrate both situations (a push and a pull). Reinforce the knowledge that in both cases (pushing or pulling) it was necessary to interact with the student in the chair—in other words, to act as an outside force.

If the students have not yet used the force sensor or the motion sensor, introduce these tools to the class. Show students that the motion sensor displays the position (distance from itself) of objects. You can use the student volunteer in the chair to help demonstration of this. Push the student directly toward the motion sensor; stop the chair for a few seconds, then pull the student back, directly away from the motion sensor. Students should see that the position is shown on the graph versus time.

Demonstrate the force sensor, if students are unfamiliar with it. Have students see the graph of force versus time as you are pushing on the hook, pulling on the hook, and not touching the hook. Show students the Zero button. Explain to students that the “zeroing” of the sensor is necessary to orient it in Earth’s gravity in the position (in this case, horizontal) you will be using it.

Discuss with the students that the second part of Newton's First Law, “an object in motion will stay in motion,” is not easy to observe in ordinary daily life. There are many factors that interfere with an object in motion (for example, friction, gravity, and other objects). As a quick and graphic discussion starter, you could have a ball sitting still on the floor (or table). Point out its stillness. Roll it toward a wall. Note how it slows as it rolls and what happens when it strikes the wall. Point out to students that even if there were no wall to stop the ball’s motion, it would still eventually stop rolling due to friction with the ground and the air.

Now direct the 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 don't have access to them. Remind students (as often as you know will be necessary) not to push or pull the force sensor hooks past 50 newtons. Students often take the "sensor's limit" as a challenge, and are curious to see if they are strong enough to exceed it. Be aware of this curiosity.

- If you have GOcars, you may want to attach the force sensors ahead of time. Follow the instructions provided with the force sensor and GOcar for using the included thumbscrew to mount the force sensor to the cart.

- If students will be using toy cars, provide them with adequate tape or other means to firmly attach the force sensors. In addition to duct tape or packing tape, you could also try bell wire or even a hot glue gun to provide a rigid connection between the force sensor and the car. When devising an alternate means of attachment, be sure not to cover up the Zero button, or to clog any of the holes in the force sensor with molten glue. Students need to be able to apply the pushing and pulling forces to the hook of the force sensor while it is rigidly attached to the car.

- Make sure students have the work space to allow them to move their cars back and forward in front of the motion sensor for at least half a meter.

- Encourage students that this activity is not about great speed; they are trying to get steady motion. Moving their cars too fast will make for less usable data.

- Prior to demonstrating the motion sensor, connect it to the data collection system you are using and position the chair no closer than 15 cm to it. Point out that the graphed line slopes downward when the chair (or any object) comes closer to the motion sensor and slopes upward when moving away from the sensor.

- When demonstrating the force sensor, point out that the force sensor measures a push as a positive value and a pull as a negative value.

Safety

Add this important safety precaution to your normal laboratory procedures:

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

Driving Question

What can a force do to an object's motion?

Thinking about the Question

The word *force* is used in everyday language in many different of ways. In physical science, a *force* is a push or a pull on an object. When describing forces, it is important to include the strength, or magnitude, of the push or pull. In other words, forces can come in every size imaginable.

It is also important to include the direction of the push or the pull when describing forces. If you have ever played soccer, football, basketball, or any sport that uses a ball, you know perfectly well that the ball has to travel in the *correct direction* if you hope to score! Baseball and softball players know how important both strength and direction are when they are batting. If they hit the pitched ball with a large enough force, they may send that ball right over the wall…but the ball's direction could send it just a few centimeters over the foul line!

Most people have had experience pushing or pulling objects. Discuss with your lab group members some examples of forces you commonly encounter each day. As you list examples, try to include both the strength of the force as well as its direction. For instance, if you use a bowling ball as an example, include the direction it rolls as well as how hard it has to be rolled to get successfully to its targets.

Answers will vary. Students may suggest examples from sports, such as kicking a soccer ball, throwing a football or baseball, hitting a volleyball, or slapping a hockey puck. Pulling forces may include plucking strings of musical instruments, walking animals on leashes, dragging a suitcase on wheels, or towing trailers with vehicles.

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.

2	3/4	5	3/4	1
Connect force and motion sensors to the data collection system. Attach a force sensor to the GOcar or dynamics cart.	Connect force and motion sensors to the data collection system and begin data recording.	Apply a series of pushes and pulls to the cart and analyze the resulting graphs.	Press the zero button on the force sensor once it is in position, to orient it in the earth's gravitational field.	Make certain that each member of your lab group is aware of the safety rules and procedures for this activity.

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. What will happen to an object such as a toy car if no one touches it?

If no one touches a toy car, nothing will happen to it. It will just sit there.

b. What will happen to a toy car if someone pulls it from the right?

If someone pulls on it from the right, the toy car will go toward the right.

c. What will happen to a toy car if someone pulls it from the left?

If someone pulls on it from the left, it will go toward the left.

2. ☐ Write your predictions for the following:

a. What will the graph of position versus time look like for a toy car being pushed gently toward the motion sensor?

The curve showing position versus time for the car being pushed gently toward the motion sensor will slope downwards, indicating the car is coming closer to the sensor, and the gentle, constant push will keep the line steady.

b. If the force sensor is attached to the car, and you pull on the force sensor hook, what will happen to the graph of force versus time?

When the force sensor is attached, the curve showing force should be a negative value when we pull it by the hook; the curve will be a positive value when we push the car. If we use a steady push or pull, the line will be straight but if we slow down or speed up, the line will slope.

c. What will the motion and force graphs look like if no one pushes or pulls on the toy car?

If no one is pushing or pulling, then all the graphs will be flat—parallel to the x-axis.

Part 2 – Investigating pushing and pulling a cart

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

Sensing motion

4. ☐ Connect the motion sensor and the force sensor to the data collection system. �(2.2)

5. ☐ Display Position on the y-axis of a graph with Time on the x-axis.

Note: Make sure the selector switch is set to the cart icon.

6. ☐ Position the cart approximately 50 cm from the metal screen of the motion sensor.

7. ☐ Start data recording. �(6.2)

8. ☐ Slowly and steadily push and pull the cart so it travels as follows:

a. Push the cart toward the motion sensor, stopping about 15 cm in front of the metal screen.

b. Pause for five seconds.

c. Pull the cart back to the beginning position.

d. Pause for five seconds

e. Push the cart toward the motion sensor, stopping again about 15 cm in front of the metal screen.

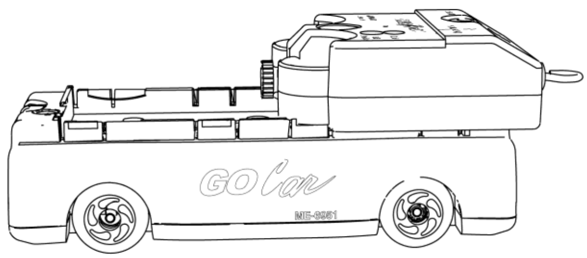
9. ☐ Stop data recording.

10. ☐ Observe the graph of position versus time. Describe your graph.

Our graph starts out flat until we began moving the cart, then the graph slopes down, then it is flat, then it slopes up again, gets flat again, and then slopes down one last time, about parallel to the first down-sloping section.

11. ☐ Print your graph according to your teacher's instructions. � (11.1)

12. ☐ Attach the force sensor to your cart.



Note: If you use tape, be sure to secure the sensor firmly so it does not move when you pull on the hook.

13. ☐ Why do you think the force sensor needs to be attached so securely? How might your data look different if the sensor were loosely attached or able to move while you push or pull it?

One group answered as follows: We need to attach the force sensor carefully and tightly because if we do not, the hook would move when we pulled or pushed it. Then our data might be jittery or it might look like we pulled it more or less than we actually did. It also might look like we pulled it when we really pushed it. The data wouldn't be accurate if the force sensor was not attached correctly.

Sensing force

14. ☐ Zero the force sensor.

Note: The force sensor always needs to be zeroed in the position it will be used.

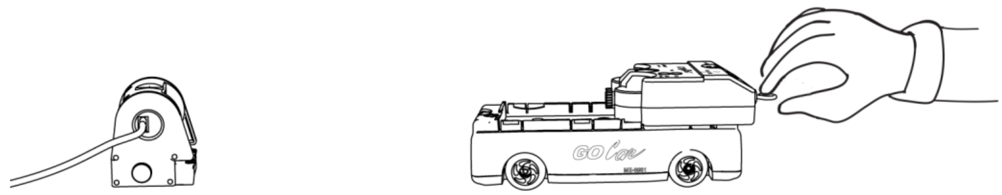
15. ☐ Display Force on the y-axis of a new graph with Time on the x-axis. �(7.1.1)

Note: You do not need to display motion for this part of the activity.

16. ☐ Position the cart approximately 50 cm from the metal screen of the motion sensor.

17. ☐ Begin data recording. �(6.2)

18. ☐ Firmly grasp the hook of the force sensor, and steadily push and pull the car as you did in the first trial—toward the motion sensor, stop for 5 seconds, away from the motion sensor, stop for 5 seconds, and then toward the motion sensor, stopping about 15 cm in front of the metal screen.



19. ☐ Stop data recording. �(6.2)

20. ☐ Observe the graph of force versus time. Describe your graph.

Answers will vary. One group answered as follows: We can tell from our graph where we were pushing or pulling by whether the line on the graph is positive or negative. We can also tell where our cart was stopped. When we were pushing the force is positive and where we were pulling the force is negative. When the cart was stopped the force is at zero, and the line of this part is flat and smooth.

Part 3 – Measuring force and motion

21. ☐ Display two graphs simultaneously. On one graph, display Force on the y-axis and Time on the x-axis. On the second graph, display Position on the y-axis and Time on the x-axis. �(7.1.11)

22. ☐ Begin data recording. �(6.2)

23. ☐ Position the cart approximately 50 cm from the metal screen of the motion sensor.

24. ☐ Begin data recording. �(6.2)

25. ☐ Firmly grasp the hook of the force sensor, and steadily push and pull the car as you did in the first trial—toward the motion sensor, stop for 5 seconds, away from the motion sensor, stop for 5 seconds, and then toward the motion sensor, stopping about 15 cm in front of the metal screen.

26. ☐ Stop data recording. �(6.2)

27 ☐ Again position the cart approximately 50 cm from the metal screen of the motion sensor.

28. ☐ Begin data recording. �(6.2)

29. ☐ Now push and pull the cart through the same series of motions as you did previously, but this time change the speed so that the cart travels faster or slower than in previous trials.

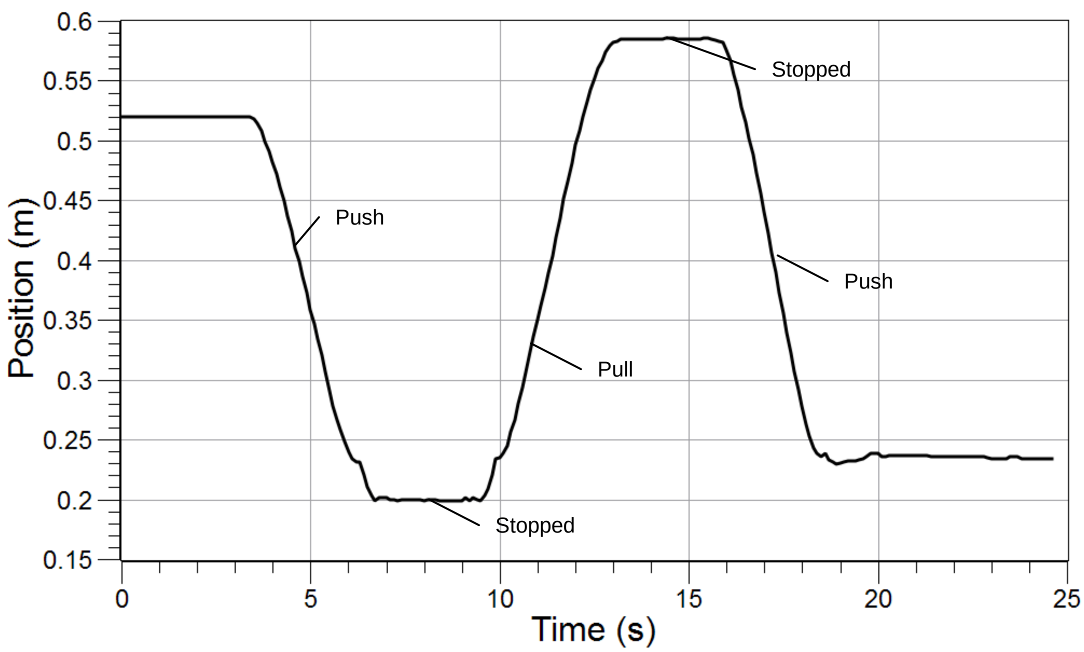
30. ☐ Stop data recording. �(6.2)

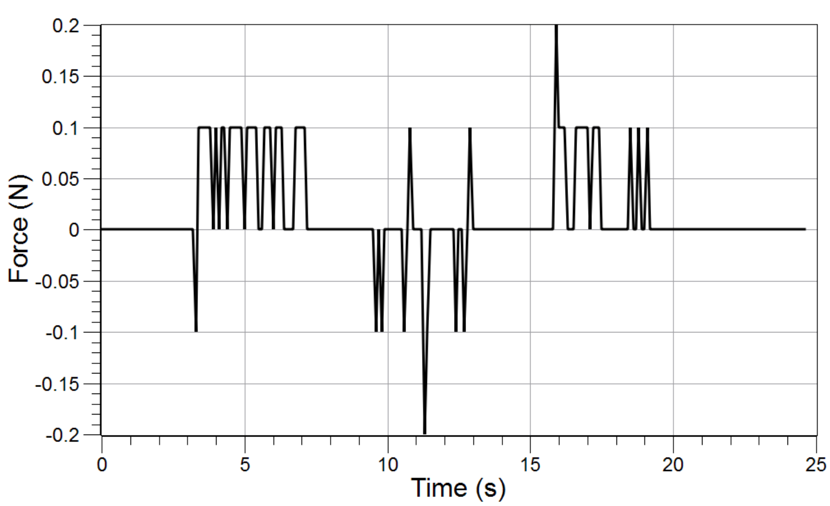
31. ☐ Observe the graph. Record your observations.

Answers will vary. One group answered as follows: We can tell from our motion graph exactly where our cart was stopped, or moving toward the motion sensor, or moving away from it. From our force data we can also tell when we were pushing, pulling, or not putting a force on our cart. Our two graphs show that the stopped car has no force on it and the moving car has force on it, which depends on what direction the car was going.

Moving the cart faster compressed the shape of the lines of the graph; they didn't take as much time.

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 group answered: Our predictions from Part 1 were verified by our experimental results.

2. Describe the car's motion when no force is applied to it.

   When no one was touching the car (not pushing or pulling) it didn't move.

3. Sir Isaac Newton said, "Every body persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it." By *body* he meant "any object," including a toy car. What do you think Newton meant by "a state of rest," and by "uniform motion?"

   One group answered as follows: For "state of rest" we think Newton meant stopped, still, or not moving at all. For "uniform motion" we think he means the steady, unchanging, movement of the cart that would occur if there was no friction acting as an outside force to slow the cart down.

4. If we re-state Newton's idea from question #3 above, so it sounds more modern, we might say, "Every object standing still stays standing still, and every object that is moving keeps on moving, unless some outside force acts upon that object." Suppose Newton was referring to the cart you just used in Part 2 and Part 3 of this investigation. What outside forces acted upon your group's cart?

   One group answered as follows: The outside force on our cart was us when we pulled it or pushed it by the hook on the force sensor.

5. What evidence do you see in your graphs of position and force versus time that supports Newton's idea?

   One group answered as follows: We can tell by our graphs that adding no external force means no motion, and any force (push or pull) at all makes the cart have some type of motion. However, because of friction, another force acting on the cart, if we stopped pushing or pulling on the force sensor hook, then our cart stopped moving.

6. How could you re-state, or paraphrase, Newton's idea, also known as Newton's First Law of Motion, in your own words?

   Answers will vary. Since this activity doesn't measure the effect of friction, answers should focus on the force needed to move an object at rest. One group answered as follows: Carts are stopped unless someone supplies a force, such as a push or pull.

Multiple Choice

Select the definition that best defines the given word.

1. Push
   - A. How far away an object is from a reference point
   - B. The SI unit measure for length
   - **C. One of the two types of force**
   - D. A unit used to measure force
2. Pull
   - A. A push or pull exerted on an object
   - B. A unit used to measure force
   - **C. One of the two types of force**
   - D. A unit used to measure mass
3. Newton
   - **A. The SI unit of measure for force**
   - B. A change in the position or place of something over time in comparison to a reference point
   - C. One of the two types of force
   - D. The law that states that an object will remain at rest or in uniform motion unless acted on by an outside force
4. Motion
   - A. How far away on object is from a reference point
   - B. One of the two types of force
   - **C. A change in the position or place of something over time in comparison to a reference point**
   - D. The SI unit of measure for length
5. Distance
   - A. The law that states that an object will remain at rest or in uniform motion unless acted on by an outside force
   - B. One of the two types of force
   - C. A push or a pull
   - **D. How far away an object is from a reference point**
6. Force
   - A. A unit of measure for mass
   - B. A change in the position or place of something over time in comparison to a reference point
   - C. The SI unit of measure for length
   - **D. A push or a pull**

7. Meter

   A. How far away an object is from a reference point
   B. A length equivalent to 100 centimeters
   C. The unit of measure for force
   D. A unit of measure for mass

8. First law of motion

   A. The law that states that an object will remain at rest or in uniform motion unless acted on by an outside force
   B. One of the two types of force
   C. A change in the position or place of something over time in comparison to a reference point
   D. The SI unit of measure for length

Key Term Challenge

Fill in the blanks from the randomly ordered words below:

meter	newton	motion	sensor
body	magnitude	distance	force
first law of motion	push	direction	pull

1. One of the two types of force is push (or pull).

2. The law that states that an object will remain at rest or in uniform motion unless acted on by an outside force is the first law of motion.

3. Another of the two type of force is pull (or push).

4. The SI unit of measure for length or distance is meter.

5. SI unit of measure for force is newton.

6. A push or a pull is a force.

7. How far away an object is from a reference point is called distance.

8. A change in the position or place of something over time in comparison to a reference point is called motion.

Further Investigations

Use the Internet or resources in your library to research the life and work of Sir Isaac Newton (1642 to 1727).

Investigate how the mass of an object is related to its tendency to resist changes in its motion. How much more force does it take to move a skateboard than it does a toy car? Can you design an experiment using the force and motion sensors that demonstrate your investigation?

Ask your teacher's permission to borrow a chair with wheels. Work with a group of students to see how much force is necessary to pull a classmate sitting in the wheeled chair.

Design an experiment to investigate the effect of friction on "uniform motion" by comparing the change in position of a cart after a single push when the cart is on a smooth, lubricated surface and when it is on a rough, unlubricated surface.

Rubric

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

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

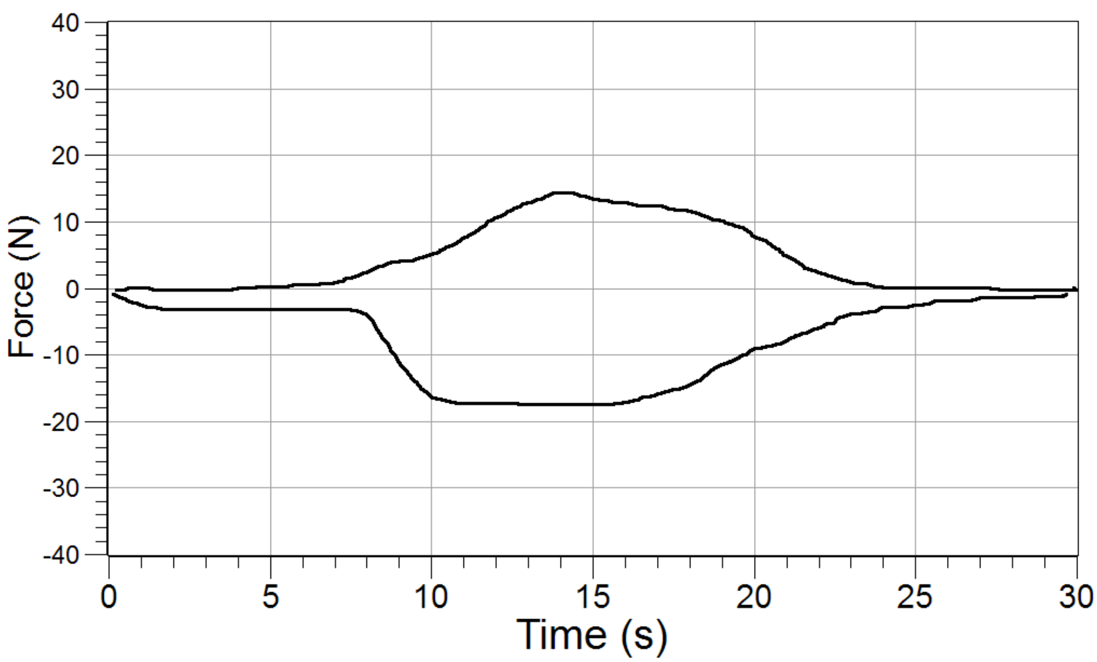
1. ☐ Write your predictions for the following:

   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.

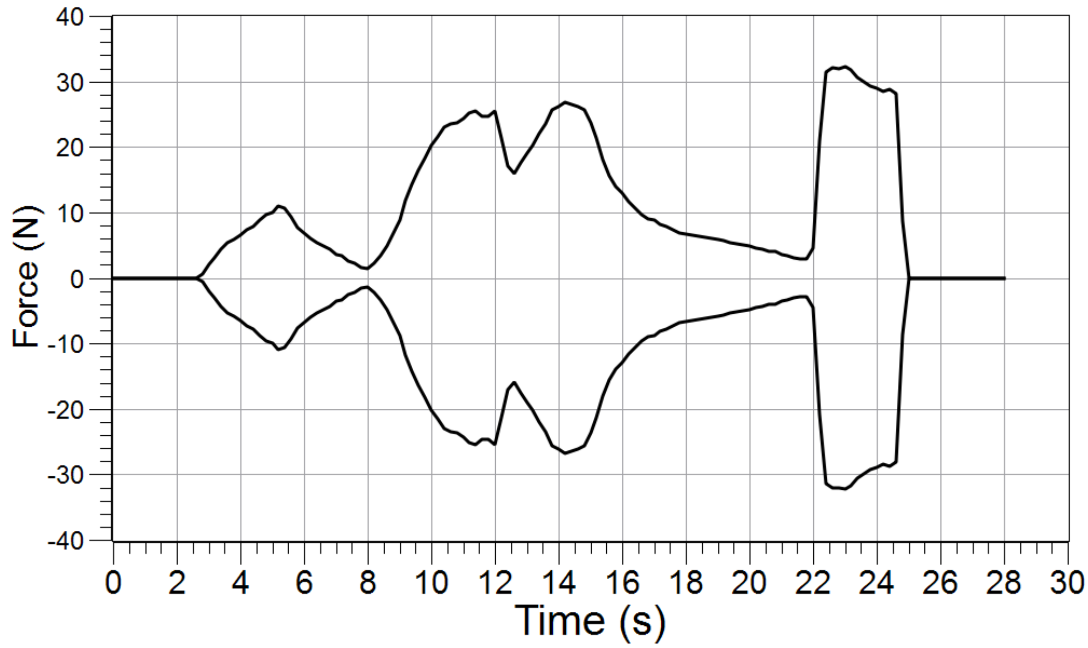
17. ☐ If there is time, have each lab group member take a turn pulling on the force sensors.

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 3^{rd} 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 3^{rd} 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.

15. Observing Freezing Point Depression

Making Popsicles

Objectives

Students investigate the effect of temperature changes on the transition from liquid to solid states of matter. Using the temperature sensor, students graph the cooling curves of pure water and at least one solution. They then use the graphs to identify relationships they see in the temperature patterns.

Students investigate water and water solutions during a phase change from liquid to solid (water to ice) while they:

- Understand that energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, and the nature of a chemical
- Realize that heat moves in predictable ways, flowing from warmer objects to cooler objects, until both reach the same temperature
- Observe effects and changes in the characteristic properties of water such as freezing point and density
- Gain skills and confidence in using scientific measurement tools, the temperature and pressure sensors, as well as the graphing capability of a computer to represent data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment to measure the change in temperature as water cools
- Determining how the temperature of tap water changes as the water changes phase from liquid to solid
- Determining how the temperature of a solution of tap water and salt or sugar changes as it changes phase from liquid to solid

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions and Part 2 – Testing the freezing water	50 minutes
■ Lab activity, Part 3 – Testing the freezing water solutions	50 minutes
■ Analysis	50 minutes

Materials and Equipment

For each student or group:

- ☐ Data collection system
- ☐ Temperature sensor
- ☐ Graduated cylinder or measuring cups
- ☐ Small beaker or cup
- ☐ Measuring spoons
- ☐ Spoon or stirring stick
- ☐ Balance
- ☐ Ice cube tray
- ☐ Plastic food wrap
- ☐ Common kitchen ingredients (salt, sugar, juice, food dye, et cetera)
- ☐ Distilled water, 200 mL
- ☐ Freezer or dry ice

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The use of a graduated cylinder to measure liquid volume
- Be able to read and interpret a coordinate graph
- Be familiar with the SI unit of measure for temperature (degrees Celsius)
- Be familiar with the concept of a solution as it applies to “mixing” or “stirring” a solid such as sugar, or a liquid such as lemon juice into water to dissolve it.

Related Labs in This Guide

Labs conceptually related to this one include:

- Operation Deep Freeze
- Cooling Curves
- Mixing Temperatures

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 a sensor to the data collection system. �(2.1)
- Starting and stopping data recording. �(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 �(7.1.3)
- Saving your experiment �(11.1)

Background

Pure water has a freezing point of $0^{o}C$. If a mixture contains ice and water, the temperature remains constant as long as both the liquid and solid forms are present. Water is unusual compared to most substances in that it actually becomes less dense as its temperature falls. Most substances are denser the colder they become. Water's maximum density occurs at $4^{o}C$. Between $4^{o}C$ and $0^{o}C$, the density of water decreases because the water molecules align in an open formation when water freezes. Such properties explain why the solid form of water floats in the liquid form.

We can see evidence of the open "latticework" formation of water molecules as they freeze by looking at snowflakes. Snowflakes exhibit the characteristic of having six sides or arms arranged in radial symmetry, like the spokes of a bicycle tire. Each arm forms a 60^{o} angle with the adjacent arms, and the perimeter of the snowflake describes a hexagon. This geometry arises from the fact that water has *polar* molecules, meaning that due to the uneven distribution of electrical charge, the molecules themselves are bent like tiny triangles, and as they "stack up" to form a solid, they do so in this particular organization. This pattern idea can be demonstrated idea with Pattern Blocks math manipulatives, using three green equilateral triangles to form or cover up one yellow hexagon. If your students are familiar with snow or even frost, remind them of this behavior of frozen water.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask the students what they think the term *rate* means in the context of cooling off a hot beverage, bowl of soup, or cereal before it can safely be tasted. This will give you the opportunity to assess the students' understanding of what factors can affect cooling rates.

Direct the students to "Thinking About the Question." If students have difficulty thinking of ways to cool the soup, remind them of the fairy tale, in which Goldilocks encounters the hot porridge. Older students may be interested to know that a certain fast-food chain was once taken to court to be sued over too-hot coffee, and as a result had to print cautionary statements on their hot beverage cups. If students have had hot beverages in "to go" cups before, remind them that the cups often have lids and cardboard wrap-around holders. Ask them if they think these two features help the hot beverage to stay hot or help it to cool down. After a few minutes, ask the student lab groups to share some of their ideas with the class. Record the students' ideas on the board.

Direct the students to "Investigating the Question."

Preparation and Tips

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

1. If at all possible, have students do this activity in a school freezer. Make certain that you have made space ahead of time on the freezer's shelves for the students to place their experimental setup. Supervise the placing of the equipment, and do not let the students put the data collection device in the freezer along with the setup. Make certain that the freezer door can close with the temperature sensor cable or cord in place.

2. If you do not have access to a freezer at school, consider letting students take the equipment home and conducting the experiment at home. If you do this, it is wise to send home a letter to parents explaining the procedure and enlisting their help. Activities that are sent home to be completed provide an excellent opportunity for parents to participate in the scientific process with their children. Most often, parents are impressed with the level of technology and proud that their children have been entrusted to carry out such an important activity.

3. If there is simply no freezer option available to you or your students, you can very effectively carry out this activity using dry ice to freeze the water. Dry ice is available for purchase at most large chain supermarkets. Usually you need to ask store personnel to get the ice for you. It is sold by the pound and comes in large chunks. If cost is an issue, you can buy one large chunk of dry ice (several pounds) and do the activity as a demonstration.

4. When handling dry ice, always wear safety gloves, preferably insulated (cooking potholder-type gloves work). You can also use tongs to arrange the pieces of dry ice. Do not let students handle the dry ice, as it can cause thermal burns. Dry ice is frozen carbon dioxide which sublimes (changes from solid directly into gas without ever becoming liquid); it is not harmful for students to breathe the "fumes," but do not allow students to purposely breathe the gas.

5. If you use dry ice as your "freezer," pack it in a cooler and store it with the cooler's lid lightly covering it (not tightly). Help students place and remove their ice cube tray setups.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Wear safety goggles for the duration of this activity.

Driving Question

What happens to the temperature of liquids as they freeze?

Thinking about the Question

You know that in science, substances can be classified by their phase or state of matter. A substance is either a solid, or a liquid, or a gas. Is there any such thing as "in-between" states of matter? What happens to a substance as it is going from the liquid state to the solid state?

Student answers will vary. Students may suggest that a mixture such as ice and water together represent an in-between state, or that a boiling pan of water and steam are in between both states. Students should recognize that two states of matter, such as water and ice together, are not an in-between state, but two different states in equilibrium.

Can you describe what happens to water when it freezes into ice cubes? Does it all freeze instantaneously or does it freeze a little bit at a time? What happens if you fill the ice cube tray to the brim?

> Student answers will vary. Students may say that water does not freeze instantaneously but a little at a time continuously, as long as heat energy is being removed from the water. Students may say that water expands when it freezes. They may point out that if an ice cube tray is filled to the brim, the resulting ice cubes will bulge upward, having a larger final volume than the liquid water did initially.

Discuss with your lab group members the conditions that exist inside a freezer that make liquid water turn into solid ice. What happens if you add sugar and food coloring to the water before freezing it? Will it freeze the same as plain water? Discuss together how freezing plain ice cubes might be different from freezing homemade popsicles.

> Student answers will vary. Students may describe the conditions inside the freezer as being much colder than the surrounding air outside. They may say that a freezer continuously removes heat energy from its inside and transfers it to the outside environment by means of its mechanical parts (compressor, condenser, working fluid, et cetera). Students may state that the warm air that comes off the back of a freezer, or from underneath, is the heat energy that is removed from the inside of the freezer. Students may also state that by adding additional substances such as food coloring or sugar to the water before freezing it will make the freezing process take more time. Substances dissolved in water, in effect, lower the freezing point of the solution. In general, students may say that any solution takes longer to freeze than a pure substance. This is known as freezing point depression.

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.

4/2	1	2/4	5	3
Make a small hole in the covering of the tray, and insert the temperature sensor.	Make sure each lab group member is aware of safety rules and procedures for this lab.	Connect the temperature sensor to the data collection system.	Place the ice cube tray into the freezer.	Fill one compartment of an ice cube tray with distilled water.

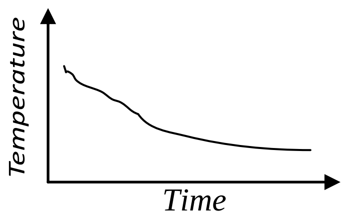
Investigating the Question

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

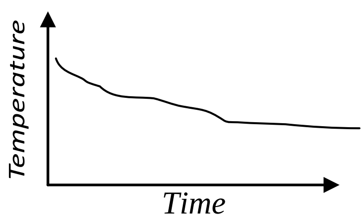
1. ☐ Sketch your prediction for the appearance of a temperature versus time graph of plain water as it freezes.

One student group answered as follows: We think the plain water will cool down steadily. Its graph will be a curve that looks like this:



2. ☐ Sketch your prediction for the appearance of a temperature versus time graph of flavored or colored water as it freezes.

One student group answered as follows: We think the flavored or colored water will cool down steadily, but will take longer to cool down to freezing than the plain water does. Its graph will be a curve that looks like this:

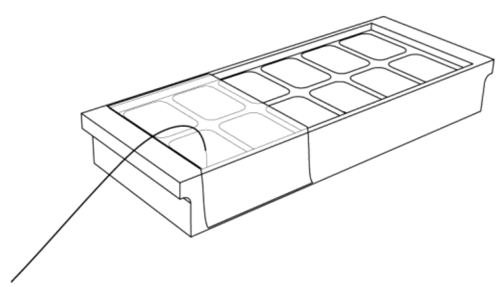


Part 2 – Testing the freezing water

3. ☐ Fill one compartment of the ice cube tray with distilled water.

4. ☐ Cover the end of the tray with plastic food wrap, so that the one filled compartment is covered.

5. ☐ Use the tip of your pencil or pen to punch a tiny hole right in the middle of the plastic wrap over the filled compartment. This is where you will insert the tip of the temperature sensor.



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

7. ☐ Connect a temperature sensor to the data collection system. �(2.1)

8. ☐ Display Temperature on the y-axis of a graph with Time on the x-axis. �(7.1.1)(7.1.2)

9. ☐ Change the sampling rate to 1 sample per minute. �(5.1) Why it is it not necessary to sample the temperature every second in this activity? Why do you need to display this data as a graph rather than digits?

It is not necessary to sample the temperature data every second because the change in temperature will happen slowly. It will be helpful to see the temperature displayed over the period of time we are measuring the change, rather than as a digits display. This is because the digits display only tells us the temperature at that instant.

10. ☐ Place the tip of the temperature sensor into the filled compartment of the ice cube tray.

11. ☐ Place your ice cube tray carefully into the freezer, and run the cord of the temperature sensor past the freezer's door seal. If you are using dry ice as your freezer, place your ice cube tray in the container of dry ice according to your teacher's instructions.

12. ☐ Begin recording temperature data. �(6.2)

13. ☐ Continue collecting data, while checking every few minutes to see if your water sample has frozen solid. Why is it so important to take just a quick look into the freezer and then close the door again?

If we leave the freezer open too long, it will warm up and have to work harder to continue freezing the water. We do not want any heat to flow from the outside environment into the freezer. This will also make it take longer to freeze our water, and will create an unwanted variable in our experiment.

14. ☐ Stop recording temperature data as soon as your water sample has turned to ice. �(6.2)

15. ☐ Save your data. �(11.1)

Part 3 – Testing freezing water solutions

16. ☐ Choose one solid substance, such a sugar or salt, to dissolve in distilled water.

17. ☐ Use a measuring spoon to measure the amount of solid you will use. Record that amount.

    Amount of solid substance for solution1 ____5 g sugar________

18. ☐ Use the graduated cylinder or measuring cup to measure the amount of distilled water you will use to dissolve the solid substance. Record that amount.

    Amount of distilled water for solution 1 ____100 mL_____

19. ☐ Mix the solid into the distilled water until the solid is completely dissolved. This is now Solution 1.

20. ☐ Fill one compartment of your ice cube tray with Solution 1.

21. ☐ Cover the end of the tray with plastic food wrap, so that the one filled compartment is covered.

22. ☐ Punch a tiny hole in the plastic wrap so you can insert the temperature sensor.

23. ☐ Set up to measure temperature exactly as in the first trial in Part II.

24. ☐ Place the tip of the temperature sensor into the filled compartment of the ice cube tray.

25. ☐ Place your ice cube tray carefully into the freezer, and run the cord of the temperature sensor past the freezer's door seal.

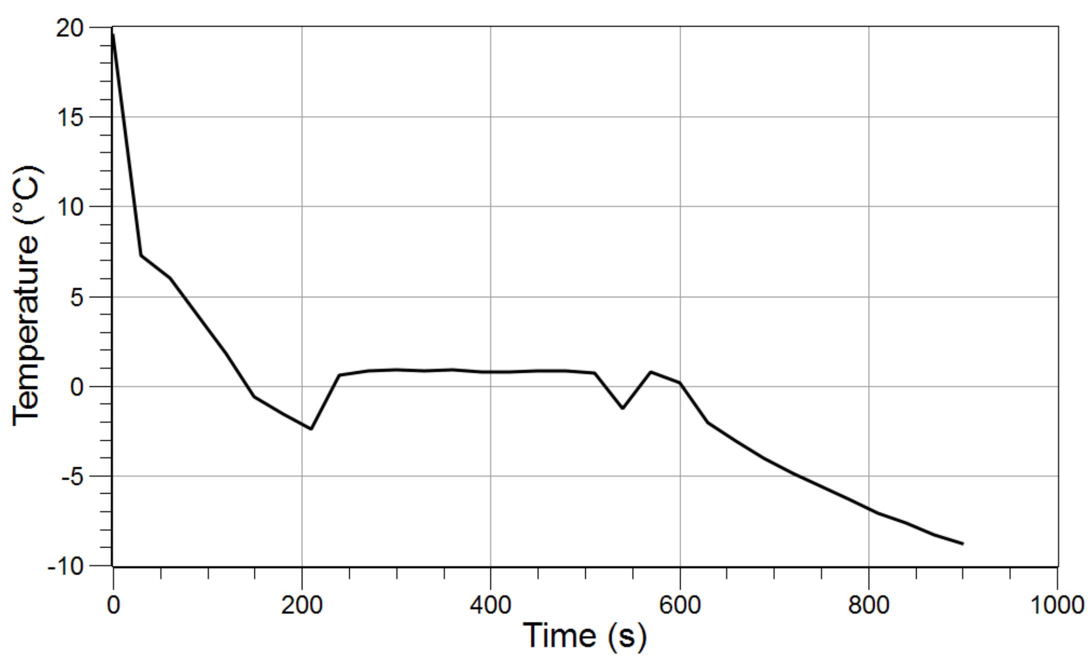
26. ☐ Begin recording temperature data. �(7.1.3) Note that this will be your second run of temperature data.

27. ☐ Continue collecting data, while checking every few minutes to see if your water sample has frozen solid.

28. ☐ Stop recording temperature data as soon as your water sample has turned to ice. �(6.2)

29. ☐ Save your experiment. �(11.1)

Sample Data



Answering the Question

Analysis

1. How did your predictions from Part 1 compare to the results from Part 2? How closely does your predicted graph match what you actually recorded? What role did the pure water play in the experimental design of this activity?

   We predicted that the water would cool down steadily, and it did. The curve of the cooling water showed that it cooled the fastest at first, and then the cooling slowed down as time went on. The temperature eventually leveled off at just about zero degrees Celsius, and then began to drop lower.

2. How did your predictions from Part 1 compare to the results from Part 3? How closely does your predicted graph match what you actually recorded?

   We predicted that a solution of flavoring or coloring and water would cool down steadily but not as fast as pure water. This turned out to be true. Our solution did eventually cool down and freeze, but it took a longer time. It cooled down quickest at first, and then more slowly as time went on. Like the plain water, its temperature went below zero degrees Celsius.

3. Determine the freezing point of pure water and the freezing point of each solution tested. How do the freezing points compare?

   Freezing temperature of pure (distilled) water: ___0___ ^{o}C

   Solution 1 is made of ___5 g of sugar and 100 mL distilled water___

   Freezing temperature of Solution 1: ___–3.1___ ^{o}C

4. Check with several other lab groups to see what types of solutions were made for Part 3. Of the solutions made by your class, which had the lowest freezing temperature? Which had the highest freezing temperature? Which solutions do you think would make the tastiest homemade Popsicle®?

   Student answers will vary, depending on ingredients available. One student group answered as follows: The solution that went to the lowest temperature before finally freezing solid was the salt and orange-colored water solution. This solution was frozen at –6.3^{o}C. The best tasting Popsicle in our class would be the lemon juice and sugar solution.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. A mixture in which a solid substance has been dissolved in a liquid is known as

   A. A compound
   B. **A solution**
   C. Distilled

2. Which best describes a substance in the liquid phase?

   A. **Indefinite shape, definite volume**
   B. Indefinite shape, indefinite volume
   C. Definite shape, definite volume

3. Liquid volume is measured with which of the following?

   A. A test tube
   B. A balance
   C. **A graduated cylinder**

4. The point at which a liquid begins to change state and become a solid is known as the:

   A. Boiling point
   B. **Freezing point**
   C. Melting point

5. Which of the following could NOT happen?

   A. **Distilled water freezing at –5^{o} Celsius**
   B. A salt and water solution freezing at –5^{o} Celsius
   C. A salt and water solution remaining in the liquid phase at 0^{o} Celsius

6. A substance that is partly liquid and partly solid, but is becoming more and more liquid is said to be:

   A. Freezing
   B. In equilibrium
   C. **Melting**

7. Which term describes the amount of space an object takes up?

   A. **Volume**
   B. Mass
   C. Weight

8. Under normal conditions, at what temperature does pure water freeze?

   A. **0^{o} Celsius**
   B. 100^{o} Celsius
   C. 32^{o} Celsius

9. Which is the best description of a substance in thermal equilibrium?

   A. A solid block of frozen ice that is being warmed in a pot on the stove.
   B. A container of water that is being heated up in a microwave oven.
   C. **A glass of ice water in which the same amount of ice is melting as water is freezing.**

10. Suppose you have three liquids and place an equal volume of each in a freezer. If liquid A freezes at 0^{o}C, while the other two do not freeze until they reach lower temperatures, which could be true of liquid A?

   A. **It is distilled water.**
   B. It is a solution of salt, sugar, coloring, and water.
   C. It contains no dissolved substances.

Further Investigations

How does the freezer's temperature affect your cooling curves? Get permission to try different freezer settings. If you have two temperature sensors, measure the freezer temperature while your sample is freezing.

Does the cooling curve look different if you freeze an ice cube on the top shelf of the freezer compared to the bottom shelf?

Investigate the cooling curves of different amounts of water. Do smaller containers always cool faster than large ones? Does the shape of the container have anything to do with the cooling rate?

Investigate the cooling curves for water that begins at different initial temperatures. Which freeze fastest?

Rubric

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

16. Observing Phase Changes

Operation Deep Freeze

Objectives

In this activity, students investigate the effect of solid-liquid transitions on the temperature of ice water solutions. They also:

- Learn that energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, and the nature of a chemical
- Observe effects and changes in the characteristic properties of water such as freezing point and density

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the change in temperature during the heating of two different mixes of ice and water – one with distilled water only and one with salt dissolved in distilled water
- Heating an ice and water mix until all the ice has melted
- Comparing the temperature versus time graphs of melting for the two mixes
- Using math and critical thinking skills to compare and analyze melting points

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	30 minutes
Lab activity, Part 2 – Testing melting ice in pure water	30 minutes
Lab activity, Part 3 – Testing melting ice in a salt solution	30 minutes
Analysis	30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Data collection system
- ☐ Temperature sensor
- ☐ Erlenmeyer flask, 250-mL
- ☐ Ice cubes (at least 5)
- ☐ One-hole stopper
- ☐ Distilled water, 200 mL

For each student or group:

- ☐ Data collection system
- ☐ Temperature sensor
- ☐ Erlenmeyer flask, 250-mL
- ☐ Graduated cylinder, 50- or 100-mL
- ☐ Balance
- ☐ Distilled water, 200 mL
- ☐ Ice cubes (at least 5)
- ☐ Hot plate
- ☐ Measuring spoons
- ☐ One-hole stopper
- ☐ Table salt ~ 2 g
- ☐ Towel

Concepts Students Should Already Know

Students should be familiar with the following concepts or skills:

- How to measure the mass of a substance, salt, on sample paper
- How to measure a volume of liquid in a graduated cylinder
- How to read and interpret a coordinate graph
- How to decipher the SI unit of measure for mass (grams) and volume (milliliters)
- How to use the data collection system, including how to change the precision of a measurement to the desired place value

Related Labs in This Guide

Labs conceptually related to this one include:

- Observing Freezing Point Depression

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 a sensor to the data collection system �(2.1)
- Recording a run of data �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Finding the coordinates of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

Transitions between solid, liquid, and gaseous phases typically involve large amounts of energy compared to the specific heat of the substance. The specific heat is the amount of heat per unit of mass required to raise the temperature by one degree Celsius. Suppose we heat a given mass of ice at a constant rate so it goes through the phase change to liquid water and then from water to steam, and we graph the temperature of the water over the time it takes to go through these changes. The graph would not have a constant slope, because energy required to bring about the phase changes would lead to plateaus in the temperature versus time graph.

If a mixture contains both ice and water, the temperature remains constant as long as both the liquid and solid forms are present. This is because any thermal energy supplied to the mix goes into breaking the crystalline structure of the water molecules that form solid ice. These crystalline bonds have to be broken in order for the water molecules to move away from each other. While solids have a definite shape and volume, in order for the ice to become a liquid, it needs to be able to assume an indefinite shape, which it cannot do if its molecules are locked into their rigid crystalline structure. Ice water and heat energy yield liquid water only after the phase change between the ice and the water has been completed.

Another way of thinking of this is in terms of kinetic and potential energy. Water molecules in solid ice are not free to move around, so the addition of thermal energy increases their potential energy until the molecules have separated from one another and are free to move around. Since temperature is a measurement of the average kinetic energy of the particles in a substance, we are not able to measure any increase in kinetic energy as long as potential energy is increasing. However, the kinetic energy (energy of motion) does begin to increase once the particles can move around in their liquid form – and this is measured as an increase in temperature.

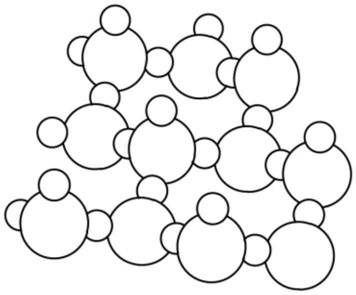
A *freezing point depression* can be caused by any type of *solute* (impurity or additional substance) that is dissolved in a mixture of ice and water. The type of solute added does not matter. For example, salt, sugar, baking soda, alcohol, antacid tablets, or even soap all have the same effect on the freezing point of the water they are dissolved in. This is because their particles all cause a disruption of the water molecules' ability to organize themselves into orderly, repeating patterns associated with the crystalline structure of ice. What does matter, however, is the quantity of solute added. The more solute dissolved in the water, the lower the freezing point.

For every given quantity of solute dissolved in a given quantity of water, the freezing point goes down between 1 and 2 °C. Salt is used on roads and walkways for this purpose because it is usually cheap and easy to get, although during some unusually long or cold winters shortages have been known to occur.

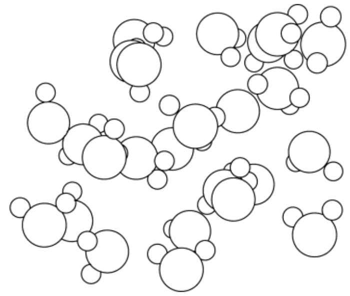
Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Show students an Erlenmeyer flask of ice water. Ask them to observe that both a solid and liquid exist in the glass. Demonstrate the use of the temperature sensor by inserting it through a one-hole stopper, placing it in the ice water, and displaying a graph. Ask the students what would be necessary to make all the water turn to liquid. Students might say that heating the glass or just leaving it in a warm room will make the ice melt. Ask the students to describe melting in terms of an increase in thermal energy. Encourage the students to draw a model of how the increase of energy changes the ice into water.



Ice



Liquid water

Students may say that as more energy is added to the system, the particles or molecules of solid will gain some of the energy. As they do, the solid will lose its rigid, crystalline structure (its definite shape), and the amount of water will increase as a result. Students may point out that as the average energy of the particles increases, the water undergoes a phase change from solid to liquid.

Direct students to the first paragraph of "Thinking About the Question." After a few minutes, ask the groups to share some of their ideas with the class. Explain to the students that as the ice melts into water, it absorbs heat from its surroundings. This additional heat is used to make a phase change of the ice, preventing the rest of the water from increasing in temperature until all the ice is melted.

Direct students to the second paragraph of "Thinking About the Question." After a few minutes, ask the groups to share some of their ideas with the class. Explain that the energy needed for melting is related to the amount of mass of the solid present.

Before the students start their investigations, discuss with the class the testing procedure for Part 3 of the Investigating the Question section. Explain to students that in cold climates, salt is often placed on streets and sidewalks during a snowstorm. Share with students that the rock salt or calcium chloride is usually used on streets and sidewalks to prevent ice from forming. Ask students how the addition of salt to the water solution changes the amount of time to melt the ice. Direct students to "Investigating the Question".

Preparation and Tips

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

- One day or more prior to the lab, make enough ice cubes for the class using distilled water.
- Supervise students during their use of the heat sources. Enforce your laboratory's safety goggle policy. Be vigilant about the orderliness of the students' work space. For example, make sure cords are well out of the way of the hot plates. If necessary, reinforce the students' understanding of the safe use of the heat source by demonstrating correct procedures for the class.
- Assist students as necessary in positioning the temperature sensors so the tips are above the bottom of the Erlenmeyer flasks. Do *not* allow students to touch the temperature sensors to the heat source. This damages the sensors and causes potential safety hazards.
- Provide students with towels in case of spills or overflows.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Use the heat source with caution
- Wear goggles for the duration of this activity
- Handle glassware carefully

Driving Question

What happens to the temperature of ice as it melts?

Thinking about the Question

Can you describe what happens to ice when it melts into a liquid? Does it melt instantaneously? Discuss with the members of your group the conditions found in a glass of water placed in the sun. What makes the ice turn into water?

> Students may say that ice loses its definite shape, but not its definite volume. They may say that the melting process takes time; in order for all of the ice to turn to water, a certain amount of time has to pass. Students may describe the conditions of a glass of ice water placed in the sun as "warming up," "heating up," or similar phrases. Lead students to the idea that ices needs to have energy added to it in order for it to melt.

What happens if you place varying amounts of ice in the water? What happens if you place varying amounts of water surrounding the same amount of ice? Does it take the same amount of time to melt? Discuss with the members of your group how the melting of ice cubes differs based on the number of cubes.

> Students may say that the more ice there is, the longer it will take to turn all of the ice into liquid. They may also say that the proportion of ice and water influences the time necessary for all of the ice to melt. The greater the proportion of ice to water, the longer time it will take before the mix is completely liquid, with no ice remaining.

What happens if you add salt to the ice water solution? Discuss with the members of your group how the melting of ice cubes differs based on the salt added to the water solution.

> Students who have lived in cold climates, or those who have experienced making ice cream by hand, may recognize that the addition of salt lowers the freezing point of the ice and water mix. They may be able to describe the formation of frost on the outside of the ice cream mixer, or describe the pattern of melting on an icy sidewalk where salt has been sprinkled in the winter. If students have no experience with this phenomenon, lead them to the idea that adding an "impurity" such as salt or sugar to water lowers its freezing point.

Sequencing Challenge

Note: This is an optional ancillary activity that may be omitted.

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.

1	2	4	5	3
Make sure each lab group member is aware of safety rules and procedures for this lab.	Adapt equipment to measure temperature in a flask through a one-hole stopper.	Begin heating the flask of water and ice.	Record the temperature of each sample of water as it cools.	Add ice to distilled water in a flask that can be placed on a burner, and close the flask with the 1-hole stopper.

Investigating the Question

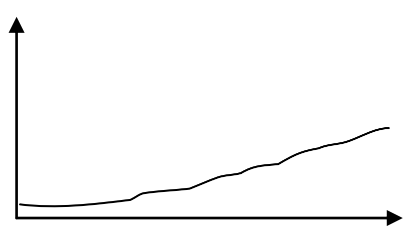
Note: When students see the symbol "�" with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please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

Part 1 – Making predictions

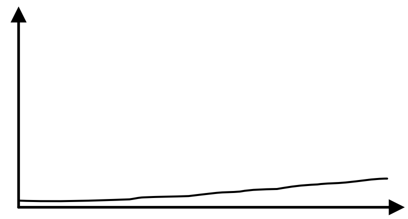
1. ☐ Describe what a temperature versus time graph looks like as ice water melts over time. Explain the graph and the reasoning behind your prediction.

   As the ice in the water melts, the temperature of the ice water mix will stay roughly the same. The temperature will start to rise only after the ice has finished melting. While the ice is melting, the heat energy is used to change the phase of the ice.

2. ☐ In the space below, sketch a temperature versus time graph that reflects your prediction.

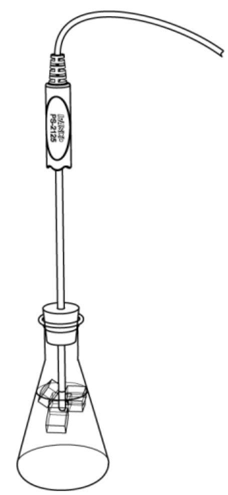


3. ☐ How would the temperature versus time graph differ when salt is added to the melting ice water? Sketch a temperature versus time graph that reflects your prediction. Explain the graph and the reasoning behind your prediction.



The addition of salt to the ice and water mix will lower the freezing point of the water, so the initial temperature will be lower on the graph.

Part 2 – Testing melting ice in pure water



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

5. ☐ Using the graduated cylinder, pour 100 mL of distilled water into an Erlenmeyer flask and add five ice cubes.

6. ☐ Connect the temperature sensor to the data collection system �(2.1) and insert it through the hole of a one-hole stopper.

7. ☐ Insert the stopper in the opening of the Erlenmeyer flask that contains the distilled water and ice cubes. Arrange the sensor inside the flask so that it measures the temperature of the solution and not the temperature of the hot plate. Carefully run the cord of the temperature sensor away from the hot plate. How could your results be affected by using tap water rather than distilled water?

Depending on the source of the tap water, there may be impurities in it that could change the results by acting as solutes. If the water is treated or softened, as in some towns, or if it comes from a well, it could even have some traces of salt in it already. The presence of solutes dissolved in the water will lower the water's freezing point.

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

9. ☐ Turn the hot plate to its highest setting.

10. ☐ Immediately start recording the temperature of the ice water. �(6.2) Keep recording until the ice water has completely turned to water.

11. ☐ Stop recording temperature data. �(6.2)

Part 3 – Testing melting ice in a salt solution

12. ☐ Dissolve 2 g teaspoon of salt in 100 mL of distilled water in an Erlenmeyer flask. Add five ice cubes to this solution.

13. ☐ Why do you think it is important to add the same amount of ice to the flask as you did in Part 2?

The number of ice cubes is a variable, but *not* the one we are testing, so it has to be the same in each trial.

14. ☐ Place the temperature sensor through the hole of a one-hole stopper.

15. ☐ Insert the stopper, with temperature sensor, in the opening of the flask. Arrange the sensor inside the flask so that it will measure the temperature of the solution and not the temperature of the hot plate. Carefully run the cord of the temperature sensor away from the hot plate.

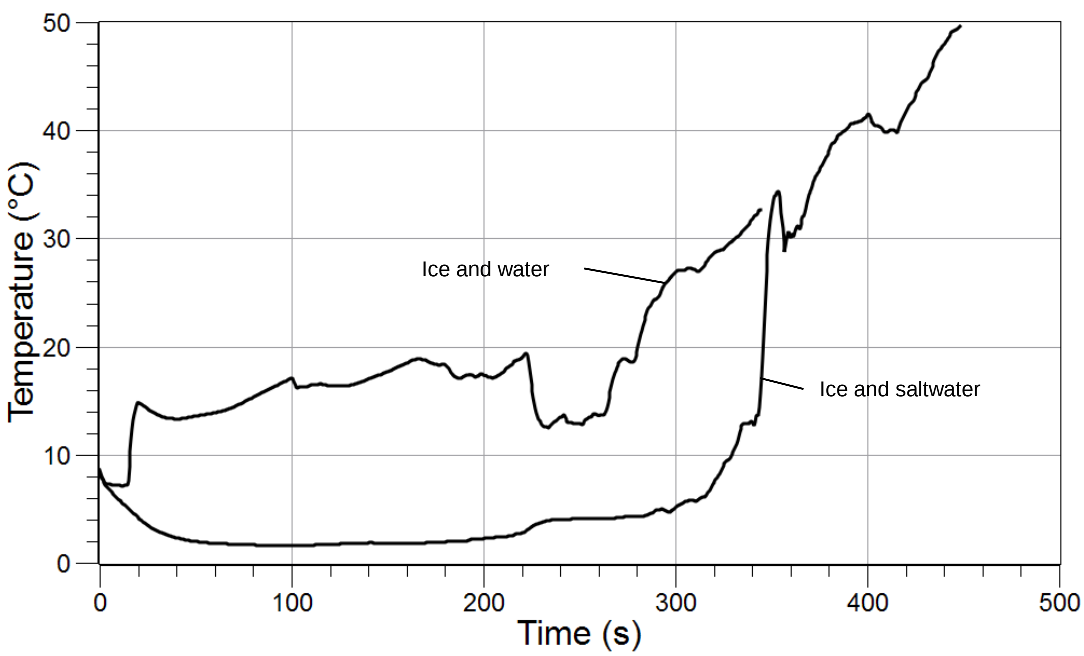
16. ☐ Turn the hot plate to its highest setting.

17. ☐ Immediately start recording the temperature of the ice water. �(6.2) Keep recording until the icy salt water solution has completely turned to water.

18. ☐ Stop recording temperature data. �(6.2)

19. ☐ Save your experiment. �(11.1)

Sample Data



Answering the Question

Analysis

1. Review the temperature graph of the melting ice water. How does your prediction compare to the graph? What was unusual about the melting curve of the ice water?

   Answers will vary. One student group reported the following: Our graph really does not look anything like our prediction. The most unusual thing about it is that there are all kinds of bumps, which sometimes came from an ice cube turning over in the water near the tip of the sensor. We also got bumps in our curve if we adjusted the height of the temperature sensor in the water.

2. Analyze your data and determine the melting point for the ice water. �(9.1) (9.4)

   Melting point for water: 32.5 °C

3. Review the temperature graph of the melting ice in salt solution. How does your prediction compare to the graph?

   Our prediction was right because the salt water and ice did start out colder than the plain water and ice. It was 1.6 degrees C, and the plain ice water was 7.1 degrees C.

4. How did the melting point of the icy salt water compare to the pure ice water? What evidence do you observe in your data to support the use of salt on icy roads and sidewalks in cold winter climates?

   Melting point for icy salt-water: 13.1 °C

   The ice in salty water melted at a lower temperature than the regular ice water. The temperature was lower by 19.4 degrees C.

   In our graph of the temperature of the ice melting in salt water, it seems like the ice water is colder and it would have to be a lot colder to stay frozen. This might be why they put salt on the road in winter.

Multiple Choice

Circle the best answer that most nearly defines the given word below.

1. A solution is:
   - A. A tool used to determine the temperature of a substance or object
   - **B. A homogeneous substance formed by dissolving a solid, liquid, or gas into a liquid**
   - C. The energy of motion of particles in matter
   - D. A measure of the average thermal energy of a substance

2. Thermal energy is:
   - A. A measure of the average thermal energy of a substance
   - B. A mixture in which one substance spreads evenly throughout another
   - **C. The energy of motion of particles in matter**
   - D. The temperature at which a liquid becomes a solid

3. Ice is:
   - A. A mixture in which one substance spreads evenly throughout another
   - B. Glassware with a narrow mouth, used for containing a volume of liquid
   - **C. Frozen water; that is, the solid form of water**
   - D. The temperature at which a solid becomes a liquid

4. Freezing point is:
   - A. The common name of water in its solid state
   - B. A measure of the average thermal energy of a substance
   - **C. The temperature at which a liquid becomes a solid**
   - D. The temperature at which a given substance will change from a solid into a liquid

5. Temperature is:
   - A. Frozen water, that is the solid form of water
   - B. Glassware with a narrow mouth, used for containing a volume of liquid
   - C. The energy of motion of particles in matter
   - **D. A measure of the average thermal energy of a substance**

6. Melting point is:
   - A. A homogeneous substance formed by dissolving a solid, liquid, or gas into a liquid
   - **B. The temperature at which a given substance will change from a solid into a liquid**
   - C. Glassware with a narrow mouth, used for containing a volume of liquid
   - D. The common name of water in its solid state

7. A temperature sensor is:
   - **A. A tool used to determine the temperature of a substance or object**
   - B. The temperature at which a solid becomes a liquid
   - C. Glassware with a narrow mouth, used for containing a volume of liquid
   - D. Frozen water; that is, the solid form of water

Key Term Challenge

Fill in the blanks from the randomly ordered words below:

freezing point	solution	degrees Celsius
solvent	temperature	solute

1. The SI unit for temperature is __degrees Celsius__.

2. Sugar dissolved in water is an example of a __solution__.

3. The __freezing point__ is the temperature at which a substance changes phase from a liquid to a solid.

4. Water is often called the universal ___solvent________ because it has the ability to dissolve so many substances.

5. Adding salt or sugar to distilled water changes the ___temperature_____ at which the solution freezes compared to distilled water alone.

Further Investigations

Investigate the melting curves of different amounts of ice. Is there a difference in the amount of time that temperature stabilizes during the melting process for larger amounts of ice? Can you observe this? Can you explain this?

Try adding different substances such as sugar, vinegar, or lemon juice to the ice water. How do the melting curves vary?

Rubric

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

17. Simple Harmonic Motion

Grandfather Clock

Objectives

This activity introduces students to the simple harmonic motion of a simple pendulum.

Students will:

- Use a motion sensor to measure the period of a simple pendulum
- Describe the energy conversions taking place during the pendulum's swing
- Gain skills using scientific measurement tools
- Conduct a scientific investigation including making and analyzing graphs, making predictions, and analyzing results

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the motion of a swinging pendulum
- Making a simple pendulum from a soda bottle containing a volume of water as its mass
- Measuring the period of the pendulum as it swings through a small angle and a larger angle, first at one mass and then at twice the mass
- Using math skills to interpret the graphs of position versus time

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making a simple pendulum	25minutes
■ Lab activity, Part 2 – Making predictions and Part 3 – Grandfather clock	30 minutes
■ Analysis	30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ 2-liter soda bottle with cap
- ☐ String, non-stretch, ~2 m
- ☐ Food coloring (optional)
- ☐ Tape

For each student or group:

- Data collection system
- Motion sensor
- 2-liter soda bottle with cap
- Meter stick
- String, non-stretch, ~2 m
- Food dye (optional)
- Tape
- Funnel
- Container of tap water (~500 mL)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Different forces
- Potential and kinetic energy
- Energy conversions
- The basics of using the data collection system
- Familiarity with the motion sensor

Related Labs in This Guide

Labs conceptually related to this one include:

- Investigating Seismic Waves

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 a sensor to the data collection system �(2.1)
- Recording a run of data �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Potential energy is stored energy due to an object's position or to the energy associated with chemical bonds. There are different types of potential energy. Gravitational potential energy is due to an object's height above ground. Elastic potential energy can be found in objects such as a stretched rubber band. Elastic materials, such as a spring, trampoline, or rubber band, resist being stretched out of shape.

The different types of potential energy can be converted to kinetic energy. For example, toy airplanes fly as a twisted rubber band unwinds and spins a propeller. The elastic potential energy in the rubber band was converted into kinetic energy. Kinetic energy is the energy of motion. The sum of the potential and kinetic energies make up an object's mechanical energy. The weight of an object is the measure of gravity acting on an object.

A simple pendulum consists of a point mass (a "bob") suspended from a string of negligible mass. Such a system exhibits periodic motion in which it vibrates at a resonant frequency. An example of this type of system is a child's swing on the playground. It is easy to start a swing in motion with a little push. But just by giving the swing the same little push at the right point, you can cause it to go higher and higher. This is because the swing has a resonant frequency, or a frequency at which it "wants" to swing.

Periodic motion is motion that repeats itself in a precise pattern. The simple harmonic motion (SHM) of a pendulum is periodic motion that we describe by its period, frequency, and amplitude. The period is the time it takes the pendulum to complete one full swing, from a starting point back to that same point. The pendulum, therefore, passes through this point twice during each period. The frequency is the number of complete swings made each second. Frequency is usually referred to in terms of cycles per second. The amplitude is the maximum displacement of the pendulum from its equilibrium point, or where it hangs when it is motionless. For small amplitudes of swing (those of a few degrees), the period of a simple pendulum is approximated by the following equation:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where T is the period in seconds, L is the length of the string in meters, and g is the acceleration due to the gravitational force, and has an approximate value of 9.8 m/s^2.

As the pendulum swings back and forth through its arc, its kinetic energy is converted to potential energy and vice versa. Its kinetic energy is at a maximum as it passes through its equilibrium point; its potential energy is at a maximum when it is at its maximum displacement, or distance from its equilibrium point.

Although pendulums have been in existence for many years, it was Galileo who analyzed and codified the functioning of pendulums in the late 16th century. As he was watching a chandelier swing back and forth in the cathedral, he wondered if the length of the chandelier's chain had anything to do with how long it took the chandelier to complete one swing and if a bigger swing took longer to complete than a smaller one. After exhaustive and painstaking experimental work with a variety of pendulums in his laboratory, Galileo determined that:

- Pendulums will always return to almost exactly the same height from which they were released.
- Pendulums eventually come to rest at their equilibrium point, but it takes heavier ones longer to do this than do lighter ones.
- The period of a pendulum is not dependent on the mass of its bob.

- The period of a pendulum is not dependent on the amplitude of its swing.

- The square of the period varies directly with the length of the pendulum.

Galileo's work with pendulums led the way to accurate clocks, as well as much of the basis for the study of motion in modern physics. Today's grandfather clocks are the descendants of Galileo's pendulum timekeepers. The central feature of the grandfather clock is its size, particularly its height. If you look closely at a grandfather clock, you can see that most of its height is due to the pendulum it uses to mark time.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask the students to name and describe the device that musicians use to keep time when they practice a piece of music. Some students who are learning to play the piano may even have these at home.

> Musicians use a metronome. The mechanical models use an inverted pendulum that swings back and forth on an upright metal arm. The pendulum has a mass that can be slid up and down the arm to adjust its tempo or beat. The farther up the arm the mass is, the slower the beat, while the lower down the arm, the faster the beat. Electronic metronomes usually use the vibration of a quartz crystal instead of a metal arm with a mass.

Ask students which piece of playground equipment works most like the metronome. Is the motion of this toy random or is there a pattern? Describe the playground toy's energy conversions as it goes through its motion.

> A swing at the playground works much like a metronome because they are both a type of pendulum. The motion is not random, but has a repeating pattern of back-and-forth. Gravitational potential energy is converted into kinetic energy and back; a person on a swing speeds up during the first half of the swing's arc, then starts to slow down as the swing reaches the highest point of the arc on the opposite side until stopping and reversing direction. The person speeds up until passing through the bottom of the arc and then momentarily stopping again at the top of the arc.

Direct the students to "Thinking About the Question." Discuss the answers to these questions as a whole group.

Ask students if they think a soda bottle pendulum will behave like a playground swing. Specifically, do they think the pendulum will return to its initial height, *but no higher*, when it is allowed to drop? Show the students the demonstration you have rehearsed ahead of time, using yourself or a volunteer to drop the soda bottle.

Now direct the students to "Investigating the Question."

Preparation and Tips

Set up these materials and equipment prior to the lab:

- One day before the lab:
  - Remove the label and fill a 2-liter soda bottle about halfway with water. Add some food dye to color the water so students can clearly see the volume of water. Cap the bottle. Suspend the bottle from the ceiling of the classroom to allow for the longest possible length of string. Have this demonstration set up for students to see at the beginning of the pre-lab discussion.

- Before involving the students in the pre-lab activity, *rehearse ahead of time* the following demonstration until you can perform it confidently:

    1. Pull the soda bottle pendulum back to a height where it just touches your chin or nose.
    2. Carefully, without pushing the pendulum, release it from your hands and allow it to fall.
    3. Do not move.
    4. Allow the pendulum to complete one swing so that it comes almost exactly back to your chin or nose.
    5. On the second swing, grab hold of the soda bottle to bring the pendulum to rest, and return it to its equilibrium position (hanging straight down).

- On the day of the lab, you can ask for student volunteers to perform the demonstration or you can perform it yourself. If you use a student volunteer, consider standing just behind him or her and dropping the bottle yourself to ensure that it is not pushed. To heighten the suspense, position yourself (or the volunteer) with your back to a wall so it is not possible to back away from the pendulum on its return part of the swing.

- Provide the maximum height possible in your classroom for students to suspend their pendulums. The longer the strings they are able to use, the greater the variation they can discover in the periods of their pendulums. Ensure that the support to which the students are attaching their pendulums is rigid; if pendulums are attached to something moveable they will transfer some of their energy to it.

- Show students how to shorten the pendulum's string without disassembling it by tying a loop in the string.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Ensure that students have enough room to safely swing their pendulums.

Driving Question

How does a pendulum measure time?

Thinking about the Question

If you have ever been in a swing, you know that you can be pushed by a friend or family member or you can move in such a way that you start the swing going on your own. If you start the swing on your own, you can make it go higher and higher by adding your own energy to it at just the right moment in the swing. If you are good at this, you can get the swing going to an exciting height. What happens when it is time to slow down and stop the swing? In your lab group, discuss what happens when you stop adding energy to the swing and just sit in it while it slows down. Be prepared to share your thoughts with the class.

> Students should suggest that when they stop adding energy to the swing it immediately begins slowing down. Each swing, or arc, is not quite as high above the ground as the preceding one and the swing eventually comes to a stop after a series of diminishing arcs.

What is gravitational potential energy?

> Gravitational potential energy is stored energy due to an object's position.

What is kinetic energy?

> Kinetic energy is the energy associated with a moving object.

Watch your teacher's demonstration involving the soda bottle pendulum.

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.

4	3	5	1	2
Suspend the soda bottle from an overhead support, positioning the bottle 20 cm above the motion sensor's screen.	Tie a long string to the neck of the soda bottle and make a secure knot.	Record position data as you allow the soda bottle to make a series of swings back and forth.	Make certain that each lab group member is aware of the safety rules and procedures for this lab.	Fill a 2-liter plastic soda bottle one-quarter full of water and replace the lid.

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 I – Making a simple pendulum

1. ☐ Fill an empty 2-liter plastic soda bottle one-quarter full with water.

2. ☐ Add food coloring to the water in the soda bottle.

3. ☐ Cap the bottle tightly. This part of the pendulum system is referred to as the "bob."

4. ☐ Tie one end of a long piece of string around the neck of the soda bottle, under the ring that protrudes from the neck. Make sure the string is securely tied with a knot.

5. ☐ Tie the other end of the string to the ceiling or to the support provided by your teacher.

Part 2 – Making predictions

6. ☐ Write your predictions for the following:

   a. How many seconds do you think it will take your pendulum to make one complete swing from one side to the other and back again?

   Answers will vary. Students may suggest times ranging from a fraction of a second to several seconds.

   b. Will it take more time, less time, or the same amount of time to make one complete swing if you pull the pendulum back farther before letting it go?

   Answers will vary. Students' intuition may lead them to suggest that it will take more time the farther back they pull the pendulum, but this is incorrect; the time will be the same regardless of the release point.

   c. How will the amount of time to make one complete swing be affected if you double the amount of water in your soda bottle?

   Answers will vary. Students' intuition may lead them to suggest that it will take more time the heavier they make the pendulum, but this is incorrect; the time will be the same regardless of the mass of water.

   d. How will the amount of time to make one complete swing be affected if you change the length of the pendulum's string by shortening or lengthening it?

   Answers will vary. The time will decrease for shorter lengths of string, and increase for longer lengths of string.

Part 3 – Grandfather clock

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

8. ☐ Connect the motion sensor to the data collection system. �(2.1)

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

10. ☐ Adjust the height of the soda bottle pendulum so that when the motion sensor is placed on the floor beneath it, there is about 20 cm of space between the bottom of the bottle and the metal screen of the motion sensor.

    Note: The motion sensor should be set to the "person" icon.

11. ☐ Begin data recording. �(6.2)

12. ☐ Gently pull the soda bottle back a few centimeters, so it is just beyond the motion sensor, and let it go. Try not to push it or add any extra vibrations to the pendulum. Why is it important to let the pendulum fall on its own without pushing it?

    It is important not to push the pendulum bob because that gives it extra kinetic energy to begin with. At the beginning it should only have gravitational potential energy due to its position.

13. ☐ Allow the pendulum to swing for 20 seconds.

14. ☐ Stop data recording. �(6.2)

15. ☐ Examine your data of position versus time. You may need to adjust the scale of your graph. �(7.1.2) How can you tell from the graph the number of swings the pendulum made in a certain amount of time?

    We can tell how many swings the pendulum made by counting the number of spikes in the graph because each spike represents the moment when the soda bottle crossed over the motion sensor.

16. ☐ Begin data recording. �(6.2) This will be your second data run on the same graph.

17. ☐ Gently pull the soda bottle back, this time about twice as far beyond the motion sensor, and let it go.

18. ☐ Allow the pendulum to swing for 20 seconds.

19. ☐ Stop data recording. �(6.2) Based on your data, what do you notice about the number of swings the pendulum made in the second trial compared to the first trial?

    Students should observe that the number of swings per period of time remains the same in the two trials.

20. ☐ Carefully remove the cap of the soda bottle without disconnecting the pendulum from the system.

21. ☐ Pour in enough water to double the volume. By doubling the volume of the water, what other property of the water do you double?

    Doubling the volume also doubles the mass. For example, 500 mL of water has a mass of 500 g; 1000 mL of water has a mass of 1000 g.

22. ☐ Begin data recording. �(6.2) This will be your third data run on the same graph.

23. ☐ Gently pull the soda bottle back a few centimeters, so it is just beyond the motion sensor, and let it go.

24. ☐ Allow the pendulum to swing for 20 seconds.

25. ☐ Stop data recording. �(6.2) Based on your data, what do you notice about the number of swings the pendulum made in this trial compared to the previous trials?

Students should observe that the number of swings per period of time remains the same in all the trials.

26. ☐ Begin data recording. �(6.2) This will be your fourth data run on the same graph.

27. ☐ Gently pull the soda bottle back, this time about twice as far beyond the motion sensor, and let it go.

28. ☐ Allow the pendulum to swing for 20 seconds.

29. ☐ Stop data recording. �(6.2) What effect, if any, does the distance from the motion sensor have on the number of swings the pendulum makes per period of time?

Students should observe that there is no significant change in the number of swings per period of time.

30. ☐ Shorten the string of your pendulum so it is about half its initial length. One way to do this is to tie a loop into the string.

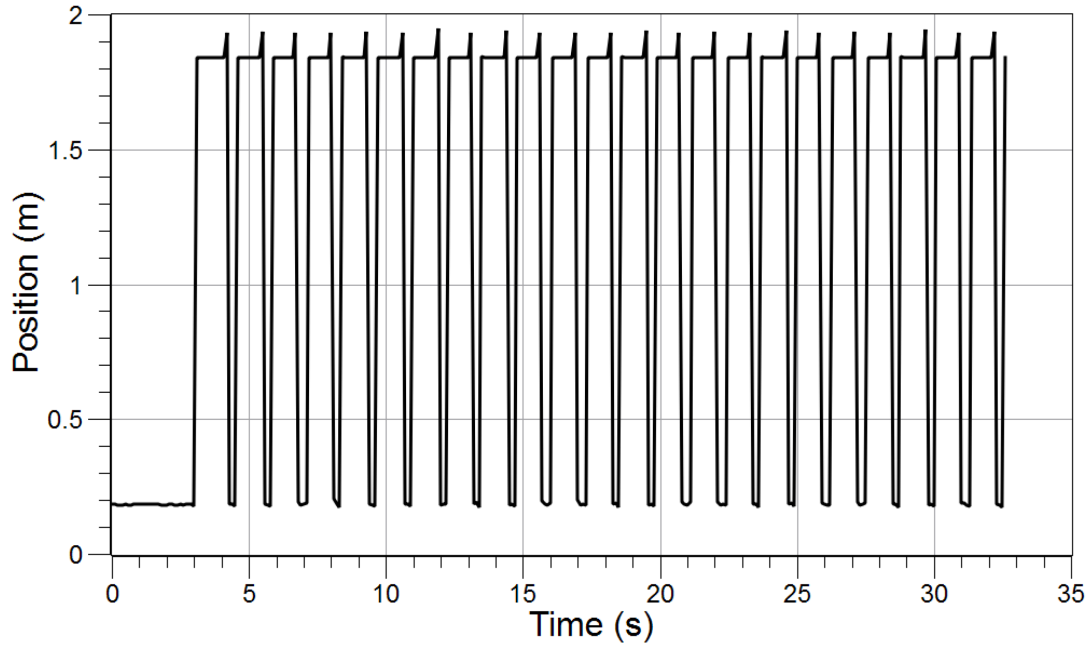
31. ☐ Begin data recording. �(6.2) This will be your fifth data run on the same graph.

32. ☐ Allow the pendulum to swing for 20 seconds.

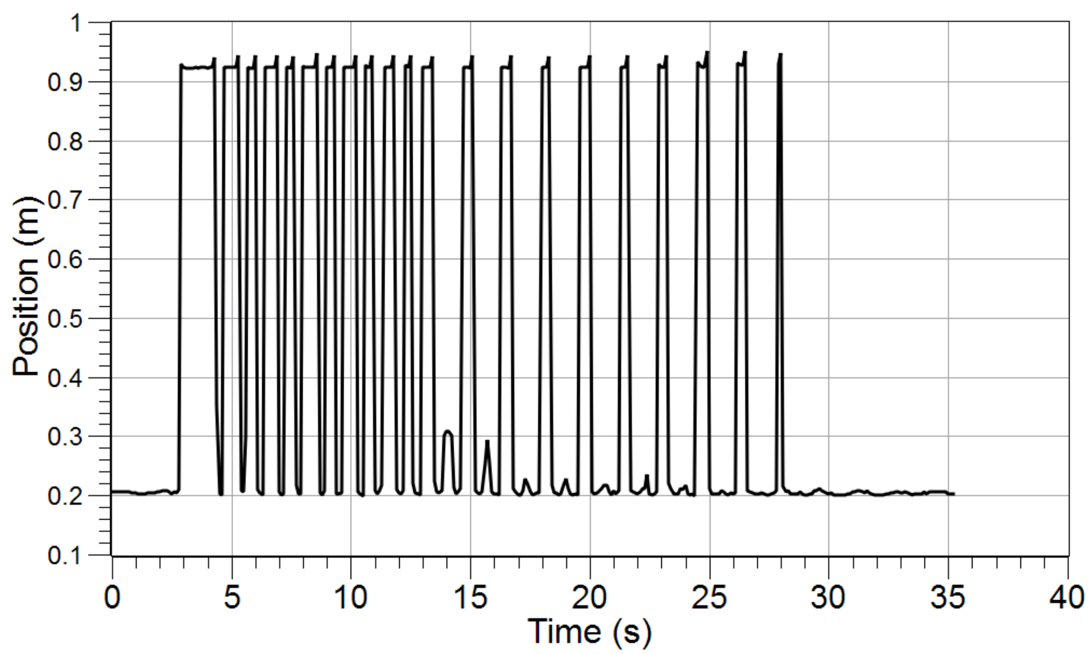
33. ☐ Stop data recording. �(6.2)

34. ☐ Save your experiment according to your teacher's instructions. �(11.1)

Sample Data



Pendulum with longer string



Pendulum with shorter string

Answering the Question

Analysis

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

   Answers will vary. One group answered as follows: We predicted that the amount of time would be longer for our pendulum to swing when we pulled it back farther and when it was twice as heavy with water. We thought it would take less time to make each swing when the string was shortened. Our results showed that the time changed only when we changed the length of the string. When we shortened it, it did take less time to make its swings.

2. Review your data carefully. How many times must the soda bottle bob pass across the motion sensor as it travels through one complete cycle? Explain why this is the case.

   The bottle has to pass across the motion sensor twice to make one complete cycle. This is because a cycle is defined as the pendulum beginning its motion at a particular point and returning to that same point again, like a round trip. If we just considered once past the motion sensor, this would be like making a one-way trip.

3. Draw the pendulum system, including a representation of the pendulum's swing, and label and describe the energy conversions that are taking place. Be prepared to share your drawing and explanations with the class.

   At the top of its swing, all of the energy the pendulum has is gravitational potential energy (GPE). The force of gravity is what is causing the pendulum to fall. On the way down, the pendulum's GPE is being converted into kinetic energy (KE) and the pendulum is accelerating. At this lowest point of the arc, all of the energy is KE that is available in the system. Some of the energy in the system has been converted into thermal energy, due to friction between the string and the support.

4. How much time is required for the pendulum, at the initial length of string, to make one complete cycle?

   Answers will vary. One student group found that it took 2.5 seconds for the pendulum at its initial length to make one complete cycle.

5. How much time is required for the pendulum, at the shortened length of string, to make one complete cycle?

   Answers will vary. One student group found that it took 1.7 seconds for the pendulum at its shortened length to make one complete cycle.

6. The behavior of a simple pendulum, such as the one you made and used in this activity, is ideal for use as a time-keeper. In fact, the metronome used by musicians is an example of a type of time-keeping pendulum. Another example is a grandfather clock. The behaviors which are most helpful for time-keeping are listed below:

   1. The period of a pendulum does not depend on the mass of its bob.
   2. The period of a pendulum does not depend on the size (amplitude) of its swing.
   3. The square of the period varies directly with the length of a pendulum.

a. What evidence does your data provide that supports the first two behaviors?

Answers will vary. One group answered as follows: When we analyze our data we can see that the time it took for the pendulum to make a complete swing was the same when it was both 1/4 full of water and 1/2 full of water. Since the amount of water changed the mass, this shows evidence that changing the mass does not affect the period or time to make one complete swing. Also, our data shows that whether we pull the pendulum bob back just a little distance or a larger distance, the time for one complete swing is not changed. This is evidence that the size or amplitude of the swing does not affect the time to make one complete cycle.

b. What further information would you need to know about your pendulum system to be able to discuss the third behavior?

We would need to know the length of the string of our pendulum.

7. A lab group has set up a pendulum system, has conducted multiple trials to measure the time of the swings, and has measured the length of the pendulum, finding it to be 72 cm long. They have done some research on pendulums and discovered an equation that relates the length of the pendulum to its period. The equation is:

$$Period = 2\pi\sqrt{\frac{\text{Length of pendulum (in meters)}}{g}}$$

The students found the following information in their science text: The variable g stands for the acceleration due to gravity, and has an approximate value of 9.8 m/s^2.

How much time, on average, does it take this lab group's pendulum to complete each cycle of back-and-forth swing? Show your work. Remember to convert the length measurement to meters.

$$\text{Period} = 2\pi\sqrt{\frac{\text{Length of pendulum (in meters)}}{g}}$$ Length Conversion: 72 cm = 0.72 m

$$\text{Period} = 2\pi\sqrt{\frac{0.72\text{ m}}{9.8\text{m / s}^2}}$$

$$\text{Period} = 2\pi\sqrt{0.0735}$$

$$\text{Period} = 2\pi(0.271)$$

$$\text{Period} = 1.7\text{s}$$

8. Pendulums will always return to almost exactly the same height from which they were released. What evidence do you have from this lab activity that supports this statement about pendulums?

Answers will vary. Students should reference the pre-lab demonstration in which the pendulum returned almost to touch the tip of the demonstrator's chin. They may also suggest that their pendulums returned to nearly their initial starting heights.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. Motion that repeats itself in a predictable pattern is called:

    A. Simple harmonic motion
    B. Newtonian motion
    C. Chaotic motion

2. The size of a pendulum's swing is also known as the pendulum's:

    A. Amplitude
    B. Period
    C. Cycle

3. Each complete back-and-forth swing a pendulum makes is referred to as a/an:

    A. Amplitude
    B. Period
    C. Cycle

4. The amount of time required for a pendulum to complete one back-and-forth swing is:

    A. The pendulum's amplitude
    B. The pendulum's period
    C. The pendulum's cycle

5. Because of the simple harmonic motion of pendulums, they are useful for:

    A. Maintaining lengths of string under tension
    B. Measuring the passage of time
    C. Demonstrating random motion

6. At the top of its swing, or the maximum distance from equilibrium, a pendulum's energy is:

    A. Entirely kinetic energy
    B. Almost equally kinetic energy and gravitational potential energy
    C. Entirely gravitational potential energy

7. A grandfather clock's pendulum has a small adjustment knob on its bob so that in case it is running fast or slow, it can be adjusted to keep better time. What must this knob adjust in order to change the clock so it keeps accurate time?

    A. The mass of the pendulum (the knob adds or removes mass).
    B. The distance the knob can swing (the knob changes the amplitude)
    C. The length of the pendulum (the knob lengthens or shortens the pendulum)

8. In order for a pendulum to continue swinging, what must be added to it?

    A. Energy
    B. Mass
    C. Time

9. An object that is not being subjected to a force will continue to move at a constant speed, yet the pendulum eventually stops swinging and comes to rest in its equilibrium position. What force or forces cause this simple harmonic motion to stop?

A. Gravity and friction

B. Gravity and magnetism

C. Magnetism and friction

10. Which of the following statements about energy is **not** true?

A. Energy can neither be created nor destroyed; it can only be transformed from one kind to another.

B. Gravitational potential energy is stored energy due to an object's position and height above the ground.

C. Kinetic energy is the one form of energy that is not conserved; it can be both created and destroyed.

Further Investigations

Do research to find out where some of the largest pendulums are located and what they look like. How long are the periods of some of these pendulums? In your research, try to discover why some of these large pendulums are displayed with a circular border around them on which the hours of the day are marked. Does the pendulum rotate or does the earth rotate under the pendulum?

Investigate how a pendulum can be used as a seismic wave detector.

Design an experiment to see how much you can vary the period of a pendulum. Can you make a pendulum whose period exceeds 3 seconds? Even longer?

Is there such a thing as a chaotic pendulum or is this a contradiction in terms?

What are damped and driven pendulums?

Rubric

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

18. Simple Machines and Force

Simply Forceful

Objectives

In this activity, students investigate the way simple machines decrease the amount of force necessary to cause an object to move. Using the force sensor, students measure the force required to lift an object, and then lift that same object with the use of two different arrangements of pulleys – a fixed pulley and a moveable pulley. Students then graph the force versus time for each system.

Students will investigate force and simple machines while they:

- Recognize that a force is a push or a pull
- Recall the six simple machines
- Recognize that force is measured in newtons (N) and mass is measured in kilograms (kg)
- Identify that a simple machine can change the direction or the amount of force required to do work
- Gain skills and confidence 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 equipment and work area to measure the force required to lift a mass with varying configurations of fixed and moveable pulleys
- Designing and building structures to test how pulley systems change the direction or amount of applied force, or both
- Assembling fixed and moveable pulley systems

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	40 minutes
Lab activity, Part 2 – Force with fixed pulley	30 minutes
Lab activity, Part 3 – Force with moveable pulley	50 minutes
Analysis	30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Tinker Toys™ or other suitable building materials
- ☐ Pulley
- ☐ String

For each student or group:

- ☐ Data collection system
- ☐ Force sensor (with hook)
- ☐ Pulleys (2)
- ☐ String
- ☐ 0.2 to 0 .5 kg mass
- ☐ Balance
- ☐ Tinker Toys™ or other suitable building materials

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Know the six simple machines and be familiar with the vocabulary associated with each.
- Experience with the force sensor, ideally including having done the Archimedes' Principle activity or something similar.
- Be able to design and construct a pulley and support system from toy parts (such as Tinker Toys™).
- Measure mass in SI units of kilograms and grams.
- Be able to read and interpret a coordinate graph.
- Basics of using the data collection system.

Related Labs in This Guide

- Simply Forceful – The Sequel

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 a sensor to the data collection system �(2.1)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Simple machines are those with few or no moving parts, and were devised in ancient times to make work easier. Archimedes of Syracuse (287 to 211 BC) is quoted as having said, “Give me a place to stand, and I can move the earth,” a reference to his treatise on levers. Archimedes’ name is also given to a type of water-lifting device that consists of an inclined plane spiraling around a cylinder, fitted within a water-tight pipe. The *Archimedes’ screw*, as it is known, is still used today as a lifting mechanism, particularly in agricultural settings.

Even earlier in human history, when people fashioned stone into tools and weapons, they were doubtless keenly aware that the sharper the edge, the more effective the tool or weapon was at doing its job. A sharp stone knife is simply a double-sided inclined plane, or a wedge.

The six simple machines are the inclined plane, the wedge, the lever, the wheel and axle, the pulley, and the screw. Nearly all machines with moving parts are made from combinations of these simple machines and all are designed to make work easier. Work is done any time a force, such as a push or a pull, is exerted over a distance.

Work = Force x Distance

or

W = F x D

Machines cannot change the amount of work that is done, but they can change the amount of force exerted, or the direction that force is exerted in, or the distance over which the force must be exerted. This is often referred to as a “mechanical advantage.” For example, an inclined plane gives us a mechanical advantage by increasing the distance over which the force must be applied. If you push your new refrigerator up a 2-meter-long ramp into your kitchen, you may have lifted the refrigerator only a few centimeters. But it would have been *much* more difficult (required more lifting force from your muscles) to lift the massive refrigerator straight up those few centimeters into the kitchen.

Pulleys come in two basic arrangements – either fixed or movable. A fixed pulley changes the direction in which the force is exerted, but does not change the amount of force that must be applied to lift an object. Moveable pulleys, on the other hand, decrease the amount of force needed to lift objects, but the direction in which the force must be exerted is not changed. You may have to pull in an *upward* direction to lift an object *up*, when using a movable pulley. Generally, the more pulleys in a system—and therefore the number of “sections” of string that support the lifted object—the greater the mechanical advantage of the pulley system.

The ancient Romans devised just such a system, known as the block-and-tackle, which combined a fixed and a movable pulley attached to the object to be lifted. With this device, the Romans could lift very massive objects to impressive heights. The block-and-tackle was just one of a multitude of simple machines used in combination by the extremely skilled Roman engineers.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask students to give several examples of common machines. List their examples on the board, dividing them into two categories as you go – mechanical machines and electronic machines. Cars, bicycles, lawn mowers, blenders, and washing machines are mechanical, for example. Computers, cell phones, MP3 players, and most TVs are electronic. With the advent of MP3 players such as the iPod, recorded music can now be heard with the total absence of moving parts.

It may interest students to know that in order to listen to recorded music, people once had to rotate large vinyl discs on a mechanical device, while simultaneously dragging a tiny diamond needle along the equally tiny grooves in the vinyl. The vibrations then were amplified by another mechanical device before the music could be heard. If you happen to have an old turntable and an LP or a 45 record, consider showing it to the students. Most will never have seen such a device, and the contrast between it and the MP3 player becomes the basis for excellent discussion about technology's role in our daily lives.

Have students speculate on what makes a machine mechanical rather than electronic. The students should offer the idea of "moving parts."

Once students have considered the lists on the board, direct their attention to "Thinking About the Question." If students have difficulty listing the six simple machines, give them clues. Consider using as many examples as possible from the sports or activities your students do. For example, if you have students who enjoy painting, challenge them to classify the paint brush they use by the type of simple machine it is.

Then direct students to "Investigating the Question."

Preparation and Tips

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

- Students will need time to design and construct their pulley support "towers." Tinker Toys™ are absolutely ideal for these structures, as they have all the necessary parts, including the pulley wheels and string. However, if Tinker Toys™ are not available, wire coat hangers can be straightened and reshaped to support a small commercially available pulley.
- Small pulleys that are relatively inexpensive are available at all hardware stores.
- Build a prototype pulley structure ahead of time for the students to see. Tell them that they are free to design their own "style" or to use your design. Be sure to check each group's structure for effectiveness.
- If you do not have access to mass sets, consider using soda cans or plastic water bottles. Have students use a balance to determine the mass of the empty container, and then add water to the container. Since water has a mass of 1 gram for every milliliter, you can either add a measured amount of water or measure the mass of water you add to the container.
- Students are asked to predict the force required to lift a mass of 0.2 kg (200 g); however, if you are using a very different mass than this, you may want to tell students to make their predictions based on the mass they will actually be using instead.
- If students will be using hardware pulleys or those that require some modification, provide tape, wire, additional string, et cetera for these modifications.

Safety

Add this important safety precaution to your normal laboratory procedures:

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

Driving Question

Do simple machines reduce the force needed to move an object?

Thinking About the Question

When most people think of machines they often think of devices that are common in everyday life, such as cars, computers, televisions, ovens, washing machines, and lawn mowers. Each of these machines certainly helps make life easier in many ways. The machines mentioned, however, are quite complex, having electronics and several moving parts.

There are only six simple machines, but they are important in science and technology because they serve as the building blocks for almost all other machines. Simple machines have been in use for thousands of years. They were invented by people to help make work easier. In physical science, work means using a force to move an object.

In this activity, you will be working with two different arrangements of a simple machine to determine if they change the amount of force necessary to move an object.

Discuss with your lab group members the six different simple machines, and give at least one example of each. For each example your group lists, discuss where and how a force is applied and what object is caused to move as a result of the force.

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.

4	3	2	5	1
Build the structure to hold a fixed pulley.	Use string to connect the object to be lifted to the pulley system.	Given a set of toy parts and pieces, design a structure to hold a fixed pulley.	Use the data collection system to measure the force needed to lift an object using the pulley and structure you built.	Make sure each lab group member is aware of safety rules and procedures for this lab.

Investigating the Question

Part 1 – Making predictions

1. ☐ What amount of force will be necessary to lift a 0.2 kg (200 gram) mass off the table?

   a. How will the necessary amount of force change if you attach a fixed pulley so you can pull down on the string to lift the mass?

   b. How will the necessary amount of force change if you attach a movable pulley to the mass and pull up on the string to lift the mass?

Answers will vary. One group answered as follows: We predict that not very much force will be needed to lift 0.2 kg of mass off the table because that is 200 grams, which is pretty light. We predict that pulling down on the mass to lift it will not change the amount of force, just the direction we have to pull. We predict that attaching a moveable pulley to the mass and pulling up will decrease the amount of force we have to exert.

Part 2 – Force with a fixed pulley

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

3. ☐ Make sure the force sensor has the hook installed.

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

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

6. ☐ Hold the force sensor with its hook down, and press the “zero” button. Why do you think it is important to zero the sensor before using it to apply force?

When you do not zero the sensor, the readings can be off by a certain amount.

7. ☐ Gently attach the force sensor’s hook to the mass.

8. ☐ Begin data recording. �(6.2)

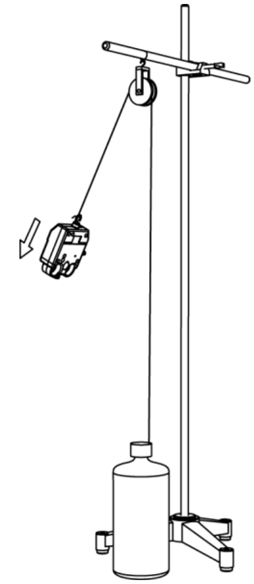
9. ☐ Holding the force sensor steady, lift the mass until it is off the table and hold it in place until the force data stabilizes. Why does the force data tend to fluctuate (change) when you do not hold the sensor as still as possible?

The force data will not stabilize until the sensor is perfectly still. This is because gravity is exerting a force on the hook and on the object attached to it; moving the object pulls back against gravity. The object and force sensor are like a mass on a spring, oscillating about an equilibrium point.

10. ☐ Stop data recording. �(6.2)

11. ☐ Observe your graph of force versus time. What do you notice about your data?

Our data shows that our mass takes 3.4 N of force to hold it up and steady.



12. ☐ Now set up a pulley to change the direction of the applied force. To do this, you will need to build a structure out of toy parts and pieces. Arrange the structure, pulley, and string so that when the force sensor is pulled down, the mass is pulled up. This pulley arrangement is known as a *fixed pulley*. Have your teacher approve your structure before continuing.

13. ☐ With the force sensor's hook pointing up, press the "zero" button.

14. ☐ Gently attach the force sensor's hook to the string.

15. ☐ Begin data recording. �(6.2)

16. ☐ Holding the force sensor steady, pull down on the string until the mass is lifted off the table and up as far as it can go; hold it in place until the force data stabilizes.

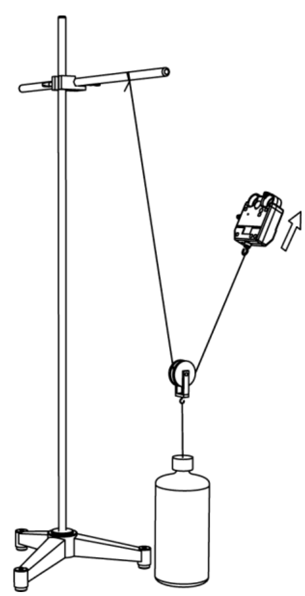
17. ☐ Lower and raise the mass very slowly one or two more times.

18. ☐ Stop data recording. �(6.2)

19. ☐ Observe your graph of force versus time. You may need to rescale your graph. �(7.1.2) What do you notice about your data?

Answers will vary. One group answered as follows: Our data shows that using the pulley to lift our mass by pulling down and holding it steady requires the same amount of force as just lifting it straight up with the force sensor.

Part 3 – Force with a moveable pulley



20. ☐ Set up a movable pulley system. To do this, attach the pulley to the mass, and tie the string to the support. The pulley will move with the mass. How does the direction of the force applied to the movable pulley differ from the fixed pulley?

On the fixed pulley we pulled down to raise our mass. On this one, we have to pull up to raise it.

21. ☐ With the force sensor's hook pointing down, press the "zero" button.

22. ☐ Begin data recording. �(6.2) This will be your third data run displayed in your graph. If you wish you may turn off pervious runs during data collection. �(7.1.7)

23. ☐ Holding the force sensor steady, pull up on the string until the mass is lifted off the table and up as far as it can go, and hold it in place until the force data stabilizes.

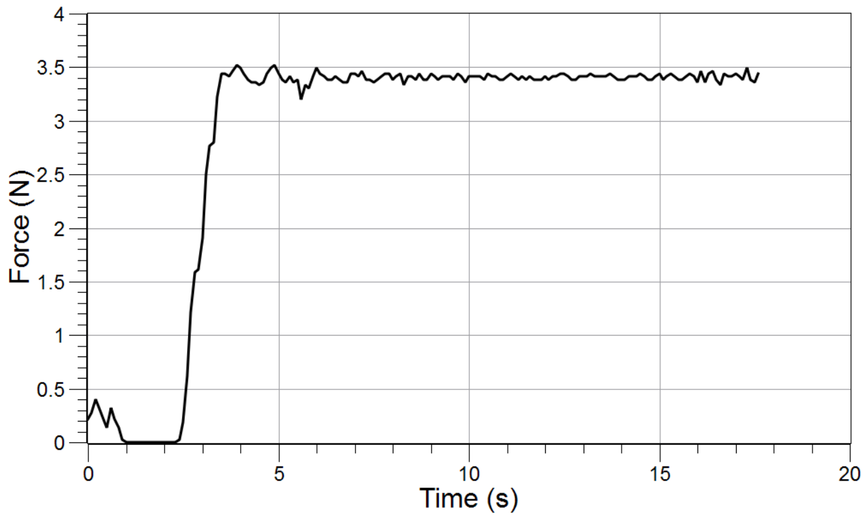
24. ☐ Lower and raise the mass very slowly one or two more times.

25. ☐ Stop data recording. �(6.2)

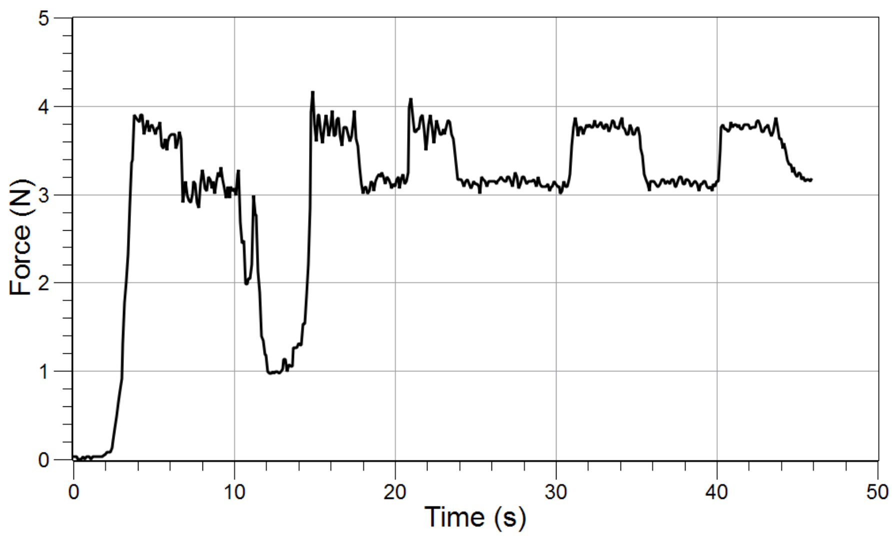
26. ☐ Observe your graph of force versus time, with all of your data runs displayed. �(7.1.3) Note any patterns or other observations you see in your data.

It did not take as much force to lift with the movable pulley as it did with the fixed pulley. On the fixed pulley the force changed by 0.7 N and on the movable pulley it changed by 0.2 N.

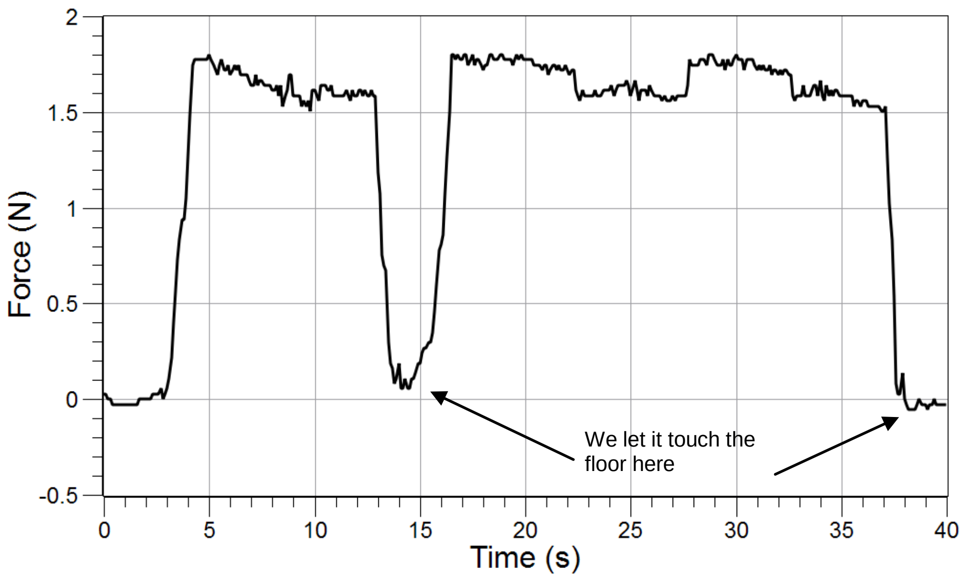
Sample Data



Force Sensor Only



Fixed Pulley



Moveable Pulley

Answering the Question:

Analysis

1. How did your predictions from Part 1 compare to the results from Part 2 and Part 3?

   Our prediction agreed with our results. Our first prediction did not have an actual number in it, it was qualitative not quantitative. The only difference was in the direction we applied the force. When we added the moveable pulley to lift the mass, it took less force to lift the mass than if we had not used a pulley.

2. Examine your data for lifting the mass off the table and for using the fixed pulley. How does the force for lifting the mass and holding it steady compare to lifting the mass with the fixed pulley and holding it steady? Did using the pulley change the amount of force necessary to lift and hold the mass?

   It took the same amount of force both times.

3. Examine your data for using the fixed pulley and for using the movable pulley. How does the force for lifting with the fixed pulley compare to lifting with the movable pulley? Did using the movable pulley change the amount of force necessary to lift and hold the mass?

   Answers will vary. One student group answered as follows: The moving pulley took less force to lift the mass than lifting it with the fixed pulley. It took the fixed pulley a force of 0.7 N and the movable pulley 0.2 N to lift the same mass up and down. Our force is in negative newtons because the force sensor is set to pull being negative.

4. If using one of the pulley systems did not change the amount of force necessary to lift and hold the mass, what did the pulley system change about the lifting?

   Answers will vary. One student group answered as follows: It seems like the only thing the fixed pulley changed was that we got to pull down to lift up our mass. So, the direction was changed, but it did not take less force to move it.

5. What is the advantage to a pulley system that does not decrease the amount of force necessary to move an object?

Answers will vary. One student group answered as follows: In some situations, it might actually be helpful to pull in a different direction, like if you were moving a piano to the second floor and you could tug down on the ropes to move it up. It would be really hard to pull up on a rope to lift a piano.

6. If you were designing a lifting machine and could use any arrangement of pulleys, what type of pulley system would you choose in order to use as little force as possible to lift heavy objects? Explain your reasoning.

Answers will vary. One student group answered as follows: We would use the movable pulley because it takes less force to lift things. You could lift something pretty heavy so long as you could pull up on the rope. You could use a wheel and axle to wind the rope on while you were pulling it. You might be able to use another wheel or pulley to point the rope back down again, and then you could still pull down instead of up.

Key Term Challenge

Fill in the blanks from the randomly ordered words below. It may be necessary to use a word more than once.

lever	force	wedge	pulley
kilogram	screw	simple machine	rope
wheel and axle	moveable pulley	inclined plane	newtons

1. The __kilogram__ is the SI unit of mass.

2. There are six simple machines: the inclined plane, the wedge, the __screw__ the lever, the pulley, and the wheel and axle.

3. A __rope__ is *not* a type of simple machine.

4. Using a fixed pulley allows a downward __force__ to lift an object.

5. A knife is a __wedge__ .

6. A ramp and __inclined plane__ are both types of simple machines that increase the distance over which a force is applied.

7. There are 1000 grams in a __kilogram__ .

8. A wheelbarrow is an example of a complex machine that uses a/an __lever__ and a wheel and axle.

9. The seesaw on the playground is an example of a/an ____lever______ , which is one of the six simple machines.

10. The force sensor measures force in units called ____newtons______ .

11. A wheelchair ramp is an example of a/an ____inclined plane______ , which is one of the six simple machines.

12. A/an ____pulley______ is a simple machine that can make lifting an object easier by changing the direction or amount of force that must be applied.

13. A/an ____force______ is a push or a pull.

Further Investigations:

If you have the opportunity to observe a construction crane in use, notice the arrangement of pulleys and how they are used.

Design an investigation where multiple pulleys, both fixed and movable, are incorporated into the lifting arrangement. How does the amount of force change with each system?

Investigate one or more of the many uses for block-and-tackle pulley systems.

Rubric

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

19. Speed and Velocity

Are You Speeding?

Objectives

In this activity, students learn about the related concepts of speed and velocity and how to graph speed and velocity versus time. They also:

- Observe that speed is the rate at which position changes and that average speed is the distance an object travels divided by the time it was traveling
- Observe that a complete description of velocity includes speed, direction, and a frame of reference
- Measure and describe their own velocity (speed and direction)

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the position and velocity of a moving object
- Measuring distance and time data and plotting it on a graph
- Recording their own motion as they follow instructions that include distance, speed, direction, and time
- Using math skills to compute rate of speed, given distance, and time

Time Requirement

■ Introductory discussion and lab activity Part 1: Making predictions	25 minutes
■ Lab Activity, Part 2	25 minutes
■ Lab Activity, Part 3	25 minutes
■ Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Watch with second hand, or stopwatch

For each student or group:

- ☐ Data collection system
- ☐ Motion sensor
- ☐ Reflector (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Position and frame of reference
- How to use a motion sensor, ideally having performed the Position Match Graph activity
- How to measure length (distance) in meters and centimeters
- How to read and interpret a coordinate graph
- How to compute distance divided by time (decimal division)
- How to use the data collection system, including how to display two graphs—in this case position versus time and velocity versus time

Related Labs in This Guide

Labs conceptually related to this one include:

- Motion Graphs
- Crash Test

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 a sensor to the data collection system �(2.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjust the scale of the graph to show all data �(7.1.2)
- Displaying multiple data runs in a graph �(7.1.3)

- Displaying multiple graphs simultaneously �(7.1.11)

- Saving your experiment �(11.1)

Background

Speed is the rate at which an object changes its position. Finding the speed of an object involves measuring the distance traveled and the time of travel. After these two quantities have been determined, speed is calculated by dividing the distance traveled by the time of travel. For example, if a skier traveled 100 meters of distance in 10 seconds, her speed would be as follows:

$$\text{Speed} = \frac{100\ \text{meters}}{10\ \text{seconds}} = \frac{10\ \text{meters}}{1\ \text{seconds}} = 10\ \frac{\text{meters}}{\text{second}}$$

The distance traveled divided by the time it took to travel that distance is called the average speed of the skier. In reality, the skier may have moved faster or slower than 10 meters/second at different times during the 10 seconds. However, the skier covered the same distance as she would if she stayed at a constant speed of exactly 10 meters/second for the entire time. The formula for average speed is as follows:

$$\text{Average Speed} = \frac{\text{Distance Traveled}}{\text{Time}}$$

Throughout this activity, we will assume that all speeds are constant or uniform, which simplifies our study of motion. When an object's speed is uniform or constant, the speed of the object does not change. The speed then is always equal to the object's average speed. Some examples of constant speed are a car on the highway with its cruise control set and an airplane flying at a constant speed while at "cruising" altitude.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask students what they think the word *speed* means. Record their answers on the board. Hopefully, their ideas include distance traveled and time.

Introduce Motion

See the Preparation and Tips section below for suggestions on how to organize the following pre-lab activity:

Ask several students to demonstrate for the class their ability to walk at a constant pace along the premeasured "course." Encourage a student volunteer who wears a watch to count seconds aloud as the "walkers" are demonstrating. Lead students to the conclusion that walking a particular distance in a certain time will give an average speed, which can be computed.

Choose at least three student volunteers to walk the course at a constant pace. Ask another student volunteer to use a clock or stopwatch to time each walk. On the board, record the distance and time for the first walker. Guide the students through the arithmetic of calculating the first student's average speed. Instruct each subsequent student volunteer walker to complete the course in the same amount of time. Lead the class through the calculations for the average speed of the rest of the volunteer walkers.

Allow the students who walked the course to share their thoughts on the activity. Was it difficult or easy to maintain a constant pace? How did they use a frame of reference to judge their pace? By what frame of reference did the rest of the class know they were moving?

Answers will vary. Students may answer that it was not too difficult to maintain a constant pace, but it was necessary to pay attention while walking. They may say that they counted or used some form of rhythm to maintain their pace. They may say they used the tiles in the floor, or items of furniture as a frame of reference.

Preparation and Tips

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

Prelab Activity

- Measure a walking "course" in the lab for students ahead of time. For ease of calculation, use a whole number of meters (3 or 4 meters at least). Mark the course, using any materials available, so students will clearly be able to tell where to walk. If you have time and are so inclined, make up a "speed limit" sign that says "2 meters/second" or something similar.

- If no students are wearing watches (with second hand or stopwatch timer), provide a stopwatch for timing the volunteers' walks.

Lab Activity

- Make sure the selector switches on the motion sensors are set to "person" (broad beam) instead of "cart" (narrow beam). Check students' set-ups to make sure that the motion sensor will "see" the walkers and give good data. Make sure students realize that they must always be in front of the motion sensor's gold screen. They cannot move from side to side.

- If the student walked in such a way that the sensor "lost" the target of its echolocation and instead measured the position of the back wall of the classroom, 4.5 meters away, this would be an example of bad data.

- Help students prepare for taking turns as starter and walker pairs. Middle school students often feel more comfortable knowing ahead of time when their turn will be, in which order they will start, and so on. You will know best how much help to give your students in this regard.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Make sure students have a clear area in which to work, with no tripping hazards.

Driving Question

What is speed and how is it related to velocity?

Thinking about the Question

In everyday language the word “speed” is used in many ways. You might have heard the expressions “speeding up,” “speeding ticket,” “speed limit,” “speed trap,” and “need for speed.” You might even have experience with the speedometer of your family’s car and observing specific rates of speed during particular types of trips. If you have ever taken a trip, you are also probably familiar with the expressions “one-way” and “round trip.” Traveling by any means of transportation involves familiarity with distances, times, speeds, and directions.

In science, “speed” refers to the rate at which an object changes its position. Your experience with traveling in daily life will be very helpful to you as your lab group investigates speed and velocity.

In this activity, you will be working with speed and velocity by walking at a constant pace; that is, walking at a steady rate without speeding up or slowing down. Discuss with your lab group members how you know when you are walking at a constant pace. Practice one another’s ideas until you are certain that you can walk without going faster or slower.

> Answers will vary. Some possible answers include: keeping time by clapping, with the walker taking one step for every beat of rhythm; watching the seconds on the classroom clock and counting out loud for the walkers; or using a metronome to keep a steady tempo.

Sequencing Challenge

Note: This optional ancillary activity may be omitted.

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.

4	2	3	1
Record and display data on position versus time.	Familiarize yourself with the motion sensor's gold screen so you know where the fixed frame of reference is located.	Begin walking when you hear the clicking sound of the motion sensor.	Make certain that every member of the group is aware of the lab safety procedures.

Investigating the Question

Note: When students see this 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 prediction for the following activity:

   Using the motion sensor as the frame of reference, predict what the graph of position versus time will look like for a person who walks away very slowly, stops and pauses just long enough to turn around, and then walks back toward the motion sensor at the same very slow pace.

   The graph of the person walking away slowly will be sloped up. When the person stops, the graph will be flat and horizontal. When they walk back, the graph will be sloped down.

2. ☐ Write your prediction for the following activity:

   What would the graph of position versus time look like if the same person completed the same walk as above, but instead walked very quickly?

   The graph for someone walking the same but faster would have the same shape, but the sloped parts would be steeper and the part where they stopped might be a very small flat spot or even a pointy spot.

3. ☐ If two people ***w***alk along a path for the same distance, but one person walks the path in less time than the other, predict how the speeds of the two walkers will compare.

   We predict that the person who walked the path in less time would be the faster person, meaning that their speed would be faster. The person who took more time was slower and had less speed. Also, the slope of the graph would be steeper for the faster person

Part 2 – How do you know if you are speeding?

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

5. ☐ Connect the motion sensor to the data collection system. �(2.1)

6. ☐ Make sure you have a clear area in which to walk backward and forward relative to the motion sensor. You need at least three meters of clear space.

7. ☐ Place a marker, such as a book, water bottle, or other object, at the end of the walking distance, to signal the walker to stop and turn around. Why is it important for the walker to walk in a straight path directly in line with the gold screen of the motion sensor?

   If somebody is walking and they step out of the path of the motion sensor, the sensor does not see them and the data will spike or jump where the sensor saw the wall or something far away.

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

9. ☐ Choose one lab group member to be the starter (the person who starts and stops data recording), and another lab group member to be the first walker.

10. ☐ The starter should ask the first walker to stand in front of the motion sensor, facing away from it. This student will walk a distance at a constant pace, pause, turn around, and walk back at the same pace.

11. ☐ The starter should make sure the walker is ready, and then start data recording. �[(6.2)]

12. ☐ On the starter's signal to begin, the walker should walk slowly away from the sensor, at a constant pace, pause at the marker for one or two seconds, turn around, and then walk back toward the motion sensor at the same constant pace.

13. ☐ Stop data recording. �[(6.2)]

14. ☐ Choose a new starter and walker for the second trial.

15. ☐ Start recording the second data run. �[(6.2)]

16. ☐ Repeat the same walk that the first walker took, but this time the walker should walk at a constant pace that is a little faster.

17. ☐ Stop recording the second data run. �[(6.2)] Observe the graphs of position versus time for the two walkers. Note your observations below.

Answers will vary. One group answered as follows: The first walker's graph has a part that is sloped up, then a flat part at the top, and then a part that is sloped down. The graph looks like a pyramid with a flat top. The second walker's graph has the same general shape, but the "pyramid" is steeper on each side, and the flat part at the top is shorter.

18. ☐ If your teacher says there is time for additional trials, continue collecting data with new starter and walker pairs. Remember to take the same walk as the first walker, making sure to keep a constant pace for the same distance. Why do you think it is important to walk the same distance in each trial?

We are trying to find out about speed, which has to do with distance and time. If we keep the distance variable the same for each trial, and only change the time variable, it might make our experiment easier or might make this a better-designed experiment.

19. ☐ Display the data runs for each walker. �[(7.1.3)] What do you notice about each of the graphs?

We noticed that the people who went the fastest had the steepest slopes on their graph. The shape of the graph is the same for everyone, but we can tell by the shape who was fastest, medium speed, and slowest.

Part 3 – What does speed have to with velocity?

20. ☐ Prepare a clear area the same way you did to measure position, except this time you will measure velocity.

21. ☐ On a new graph, display both Position on the y-axis and Velocity on the y-axis with Time on the x-axis. �(7.1.10)

22. ☐ You will again work in pairs of starter and walker.

23. ☐ The first walker should choose a distance to walk, and mark that distance with a marker (book, water bottle, or something similar).

24. ☐ Start data recording. �(6.2)

25. ☐ On the starter's signal to begin, the walker should walk at a constant pace away from the motion sensor (toward the marker), and stop. The walker should then turn and face the motion sensor and walk back toward the motion sensor at a different speed.

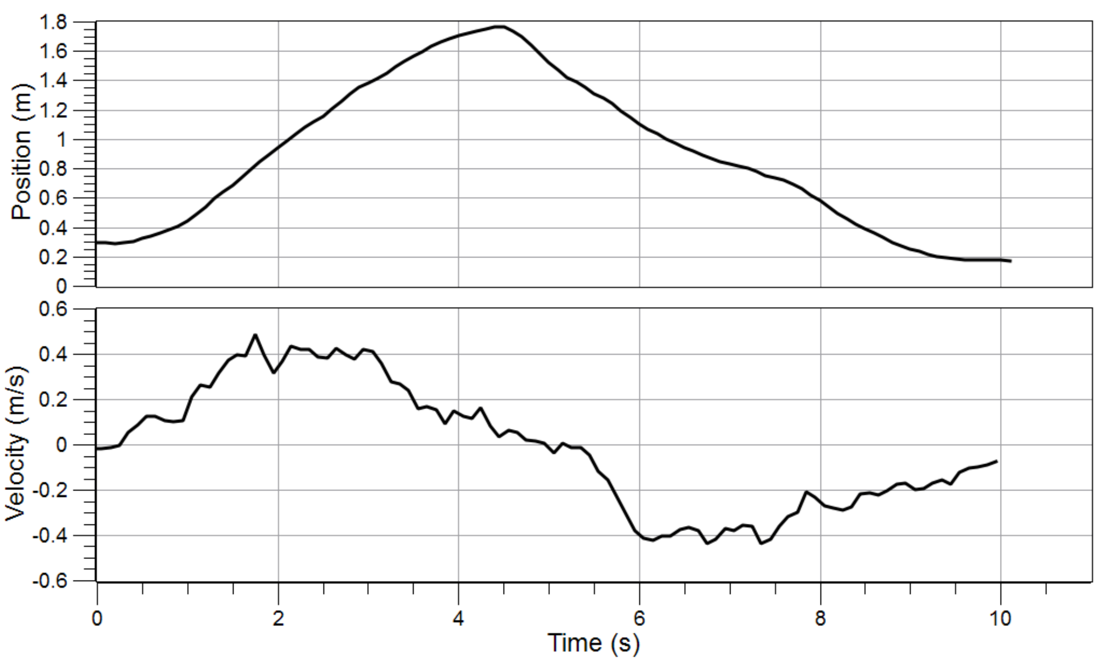
26. ☐ After the walker has arrived back at the motion sensor, stop data recording. �(6.2)

27. ☐ Review your position versus time and velocity versus time data for this walker. Note below any patterns or observations you see:

Answers will vary. One student group answered as follows: We noticed that when the walker is moving away from the motion sensor, the position graph slopes up and the velocity graph is positive. However, when the walker is moving toward the motion sensor, the position graph slopes down and the velocity graph is negative. We also noticed that when the walker stopped, the position graph is flat and the velocity graph is at zero. Finally, we noticed that a steeper slope on the position graph corresponds to a greater absolute value on the velocity graph.

Sample Data

Position and Velocity Graphs



Answering the Question

Analysis

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

   Our predictions turned out to be almost exactly the same as the actual results. The only difference was that no one's graph had a point at the top, they were all rounded and not flat.

2. Choose two data runs from Part 2 to compute the speed of the walkers. To do this, look at the portion of the graph where the walker was moving away from the motion sensor. Determine the total distance for that part of the walk, and determine the time it took for the walker to complete that part of the walk. The speed is found by dividing the distance by the time:

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{2.5\text{meters}}{6.5\text{seconds}} = 0.38 \,{}^{\text{m}}\!/_{\text{s}}$$

3. Follow the same procedure to compute the speed of both walkers for the portion of the graph where the walkers were moving away from the motion sensor and for the portion of the graph where the walkers were walking towards the motion sensor.

   Student 1: speed walking away and then back towards sensor

$$\frac{2.4\text{meters}}{9.7\text{seconds}} = 0.25 \,{}^{\text{m}}\!/_{\text{s}}$$

$$\frac{2.5\text{meters}}{9.8\text{seconds}} = 0.26 \,{}^{\text{m}}\!/_{\text{s}}$$

   Student 2: speed walking away and then back towards sensor

$$\frac{2.5\text{meters}}{16.4\text{seconds}} = 0.15 \,{}^{\text{m}}\!/_{\text{s}}$$

$$\frac{2.6\text{meters}}{14.2\text{seconds}} = 0.18 \,{}^{\text{m}}\!/_{\text{s}}$$

4. Examine your graphs of position versus time. How does the slope, or steepness, of the graphs, compare to the speeds of the walkers you just calculated?

   The steeper the slope, the faster someone is walking. Steepness tells you the speed.

5. How can you tell from the position graph where each walker's speed was zero?

   On the graph you can tell when someone's speed was zero because the line has a flat slope.

6. How can you tell from the position graph the direction each walker was walking?

   Walking away from the motion sensor causes the line to slope up, and walking towards it causes it to slope down. If stopped, it causes a flat slope.

7. Now look at your graphs of position and velocity versus time. How can you tell from the velocity data when the walker's speed was zero?

   It seems like any time someone was stopped, their velocity was zero meters per second. If velocity is zero speed is also zero.

8. How can you tell from the velocity data which direction the walker was walking?

We can tell if the person was going away from or coming back towards the motion sensor by whether the person's velocity graph is positive or negative. If they are walking away, their velocity is positive, and if they are walking toward the motion sensor, their velocity is negative.

9. What is the difference between a velocity of 0.5 meters per second (m/s) and a velocity of –0.5 meters per second (m/s)?

We think the only difference would be that the person was walking forward or backward, but they would be walking the same speed or pace. They would just be changing their direction compared to the reference point.

10. How are speed and velocity related to each other?

Speed and velocity are related to each other because they represent not only how fast or slow you are going but also which direction you are going. Higher numbers mean faster, and lower numbers mean slower. Also, zero means stopped, or no motion or speed at all. Velocity could tell you how fast you are going and which direction you are going. Speed only tells how fast you are going.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. If the distance between you and your ________________________changes, then your position has changed.

   A. Velocity
   B. Constant speed
   C. Frame of reference

2. The____________________________of a moving object can be positive or negative.

   A. Constant speed
   B. Final speed
   C. Velocity

3. On a position versus time graph, the______________________________of the graph indicates the speed.

   A. Speed
   B. Slope
   C. Velocity

4. The motion sensor measures your______________________________as the distance, in meters, you are away from it.

   A. Position
   B. Constant speed
   C. Average speed

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

average speed	frame of reference	position	slope

1. As your distance from the reference point changes, your __position__ changes,

2. In this investigation, the motion sensor is the __frame of reference.__

3. The __average speed__ is the total distance traveled divided by the time it took to travel that distance.

4. On a position versus time graph, the __slope__ of the graph indicates the speed.

Further Investigations

Walk in front of a motion sensor to make a graph of velocity versus time. Share your graph with a classmate and see if your classmate can describe your velocity (speed and direction) relative to the motion sensor.

Design an investigation where the floor or the ceiling of your classroom is the frame of reference, and the motion sensor is the object in motion. Move the motion sensor and display its position and velocity versus time in a graph. Analyze the data to see if your results from this activity still hold true.

Design an investigation to test your sprinting velocity or that of your classmates. Make sure that you allow enough space for the sprinter to safely reach maximum velocity and also slow down and stop safely. Since the motion sensor has a limited range, you will need to incorporate this fact into your experimental design. Check your experimental design with your teacher before carrying out the investigation.

Rubric

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

20. Transfer of Energy in Chemical Reactions

Endothermic or Exothermic?

Objectives

In this activity, students feel the energy transfer produced by different chemical reactions. At the same time, the temperature and pressure sensors record a quantitative measurement. As thermal energy is added, the temperature will rise, and as thermal energy is removed, the temperature will drop. As the reaction consumes oxygen from the air in a closed flask system, the pressure will decrease.

Students investigate endothermic and exothermic reactions while they:

- Recognize that heat—the transfer of energy—can help to classify chemical reactions
- Recognize that thermal energy is either absorbed (endothermic) or is released (exothermic) during the reaction
- Interpret information about the reactant (oxygen) in the exothermic chemical reaction by exploring a pressure versus time graph
- Interpret information about the thermal energy generated during chemical reactions by exploring a temperature vs. time graph
- Gain skills and confidence in using scientific measurement tools, the temperature and pressure sensors, as well as the graphing capability of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the change in temperature of an endothermic reaction and the temperature and pressure change of an exothermic reaction
- Measuring the change in temperature during the reaction of Alka-Seltzer® tablets and water
- Measuring the change in temperature and pressure during the reaction of a chemical hot-pack and air

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	30 minutes
Lab activity, Part 2 – Is the reaction of Alka-Seltzer® and water endothermic or exothermic?	25 minutes
Lab activity, Part 3 – What happens when a hot-pack reacts with the air?	25 minutes
Analysis	30 minutes

Materials and Equipment

For each student or group

- ☐ Data collection system
- ☐ Fast response temperature sensor (1)
- ☐ Absolute pressure sensor (1)
- ☐ Erlenmeyer flask, 250 mL
- ☐ Graduated cylinder, 100 mL
- ☐ Quick-release connector[1]
- ☐ Tubing, 20 to 30 cm[1]
- ☐ 1-hole stopper for Erlenmeyer
- ☐ Beaker or clear plastic cup, 250 mL (1)
- ☐ Instant hot-pack (disposable type)
- ☐ Alka-Seltzer® tablets (2)
- ☐ Distilled water, 100 mL

[1]Included with PASPORT Absolute Pressure Sensor

Concepts Students Should Already Know

Students should be familiar with the following concepts or skills:

- Use of a graduated cylinder to measure liquid volume, as well as the meaning of the term volume
- The terms reactants and products as well as a basic understanding of the nature of a chemical change (reaction)
- The indicators of a chemical change or reaction
- How to read and interpret a coordinate graph
- The SI unit of measure for temperature (degrees Celsius)
- Basics of using the data collection system

Related Labs in This Guide

There are no labs conceptually related to this one in this guide.

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)

Connect a sensor to the data collection system �(2.1)

Connecting multiple sensors to the data collection system �(2.2)

Changing the sample rate �(5.1)

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 graphs �(7.1.11)

Saving your experiment �(11.1)

Background

Qualitative observations are a crucial means of determining whether a chemical reaction is occurring. Several different types of evidence can serve as indicators of a chemical reaction. This evidence includes formation of a gas or of a solid (known as a *precipitate*), a color change, the disappearance of a solid, and the giving off or absorbing of heat. While the formation or disappearance of a substance, or a change in color are relatively easy for students to observe, a change in thermal energy is apparent only if students are able to handle the vessel in which the reaction is occurring – and the change is significant enough to be perceived. However, using a temperature sensor to measure any change in temperature as evidence is an excellent means for students to make both qualitative and quantitative observations.

The *energy of reaction* is the energy released or absorbed during a chemical reaction. In a chemical reaction, the energy stored in the reacting molecules is rarely the same as the energy that is stored in the product molecules. Depending on which is the greater, energy is either released to or absorbed from the surroundings. Chemical reactions that release thermal energy to the surroundings are called *exothermic*; those that absorb thermal energy are called *endothermic*. *Heat* is the transfer or "flow" of thermal energy. Exothermic reactions will heat the surroundings because they release energy. In an exothermic reaction, the surrounding temperatures may get warmer. Endothermic reactions will cool the surroundings, because they absorb energy. In an endothermic reaction, the surrounding temperatures get cooler.

Most disposable (one-use) chemical hot-packs operate as a chemical reaction with air. Since the reactants include iron, salt (a catalyst), and water, the oxygen in the air is required for the iron to oxidize, or produce iron oxide, commonly referred to as rust. This oxidation reaction is exothermic. The salt is a catalyst for the reaction, speeding it up in much the same way that it does for the undersides of cars in climates where winter roads are salted compared to places where roads are not salted. Hot-packs have other ingredients as well, including carbon (often in the form of charcoal) to disperse the flow of thermal energy, and substance called vermiculite, which serves as an insulator to help retain the heat.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Review with students the indicators of a chemical reaction: gas production, formation of a precipitate, a color change that is permanent, and a change in thermal energy (absorption of thermal energy – endothermic or release of thermal energy – exothermic). Challenge students to identify different chemical reactions that they observe in a typical day.

Discuss the ingredients of Alka-Seltzer® and the uses of the product (read to the students the directions or indications on the package). What is an Alka-Seltzer® tablet made of? It contains aspirin, heat-treated sodium bicarbonate (baking soda), and citric acid. When the tablets are dropped into water, the sodium bicarbonate and citric acid react to produce sodium citrate plus gas (bubbles).

Direct students to "Thinking About the Question." After a few minutes, ask the groups to share some of their ideas about observable indicators with the class. List their ideas on the board. If necessary suggest any indicators of chemical reactions the students have missed. Ask students to describe the methods or senses they would use to qualitatively observe a change in thermal energy.

Students' identification of typical daily chemical reactions will vary. If they have difficulty in coming up with chemical reactions, prompt them with a suggestion of fireworks (which give off energy in the form of heat and light) and include other prompts of combustion reactions if necessary. For endothermic reactions, suggest chemical cold-packs used for first aid. Make sure to use the terms endothermic and exothermic as you guide students' contribution to the discussion. If necessary, help them create a mnemonic device to remember which term means "gets colder" and which means "gets warmer."

Direct students to "Investigating the Question."

Preparation and Tips

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

- Each lab group will need a total of two Alka-Seltzer® tablets. To save on cost, you may choose to purchase a generic brand of effervescent tablets. The distilled water in which the tablets are to be dissolved should be at room temperature.

- Any brand of disposable (one-use) chemical hot-pack will work. Do not use the gel-type packs with the metal disc. Allow at least ten minutes for the chemical hot-pack to warm up in the air. Students should shake the hot-packs several times to enable the contents to mix adequately with the air. If time is critical, you may want to activate the hot-packs yourself before the students arrive. You may also wish to provide students with an activity to work on, or a topic for discussion during Part 3, while they wait for the hot-pack reaction to occur in the closed flask. You will know best how to monitor your students' attention spans and needs during this roughly 10 to 15 minute period of time.

- If you use the rapid response temperature sensors, their thin wire will easily be sealed between the rubber stopper and the wall of the flask. However, if you prefer to use stainless steel temperature sensors, you will need to modify the rubber stoppers in the following way: provide two holes; one for the tubing of the pressure sensor, and one for the temperature sensor. The hole to accommodate the temperature sensor may be larger in diameter than the probe part of the sensor, in which case you will need to put an additional “collar” around the probe (this plastic collar is included with the stainless steel temperature sensor). If these modifications are necessary, you can either make them ahead of time or show the students how to make them. If time permits, allow the students to work out the solution for the modifications themselves.

- Provide lab groups with towels in case of spills.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear safety goggles for the duration of this activity.
- Handle glassware carefully.

Driving Question

Is heat absorbed or given off by some chemical reactions?

Thinking About the Question

You have learned about the differences between physical and chemical changes. You probably have heard chemical changes referred to as chemical *reactions*, and you may even be able to describe some of the evidence to look for to tell if a chemical reaction has occurred.

Discuss with the members of your lab group the various evidence that you can observe to tell if a chemical reaction has taken place, or is taking place. For example, if you add vinegar to a beaker that contains baking soda, a chemical reaction will take place almost immediately. What do you observe that tells you this is the case? Which of your senses do you use to make these observations? When you use your senses to perceive and observe, are you making qualitative or quantitative observations?

> Answers will vary. Students may say that there is fizzing, foaming, or bubbling that takes place when the vinegar and baking soda mix. They may say that they can tell by their senses of sight, hearing, and perhaps smell. Students may point out that the reaction can be both seen and heard, and although the carbon dioxide gas produced in the reaction cannot be seen directly, evidence of its formation includes bubbles and the ability to extinguish a candle flame. Students should say that by using their senses to perceive and observe, they are making quantitative observations.

In this activity you will be working with two types of chemical reactions that are classified according to whether they give off or absorb heat. Reactions that give off heat energy are called *exothermic reactions*. Reactions that absorb heat energy from their surroundings are called *endothermic reactions*. As you discuss this in your lab group, come up with a list of chemical reactions that give off heat energy (exothermic) or absorb heat energy (endothermic).

> Answers will vary. Students may suggest various combustion reactions such as the burning of wood, charcoal, or gas, as exothermic reactions. They may suggest the type of first aid cold pack that needs to have an inner pouch broken to activate it as an endothermic reaction. Other common endothermic reactions include the baking of bread and the cooking of an egg.

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.

3	1	2	4	5
Place two Alka-Seltzer tablets into a beaker of distilled water.	Make sure each lab group member is aware of safety rules and procedures for this lab.	Measure 100 mL of distilled water to be added to a beaker.	Begin measuring temperature and observing the data for any change in temperature.	Observe the reaction of the Alka-Seltzer in water to determine what indicators of chemical change are present.

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. ☐ Predict whether the reaction of Alka-Seltzer® and water is exothermic (energy released) or endothermic (energy absorbed).

   We predict it will be endothermic when we put the Alka-Seltzer into the beaker of water.

2. ☐ Predict whether the reaction of the disposable hot-pack is exothermic (energy released) or endothermic (energy absorbed).

   We predict this reaction will be exothermic because it will get hot.

3. ☐ Predict what will happen to the reaction of the disposable hot-pack when it is placed in a flask and sealed off from the air.

   When we put the hot-pack in the Erlenmeyer flask, we predict it will get hotter and the pressure will build up so much that it will pop the stopper off. Then the pressure will suddenly drop instantly.

Part 2 – Is the reaction of Alka-Seltzer® and water endothermic or exothermic?

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

5. ☐ Connect a temperature sensor to the data collection system. �(2.1)

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

7. ☐ Measure 100 mL of distilled water into a beaker.

8. ☐ Place the temperature sensor in the water in the beaker.

9. ☐ Begin data recording �(6.2).

10. ☐ Drop two Alka-Seltzer® tablets into the water.

11. ☐ Continue recording data until the Alka-Seltzer® tablets are completely dissolved, and the temperature data is no longer changing. Stop data recording. �(6.2)

12. ☐ Observe your graph of temperature data. You may need to adjust the scale of the graph to view all of your data. �(7.1.2) Record your observations below.

The temperature has gone down during this reaction.

13. ☐ Save your experiment. �(11.1)

Part 3 – What happens when a hot-pack reacts with the air?

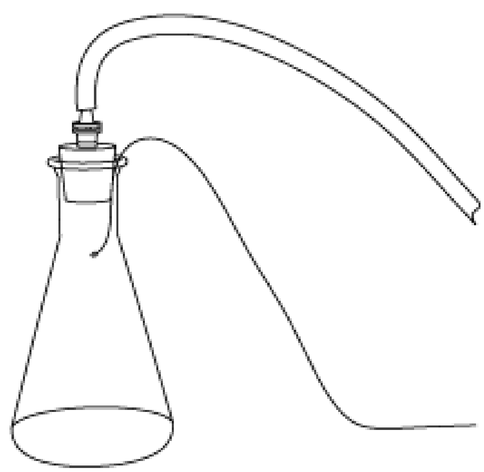
14. ☐ Open the hot-pack and shake it gently to expose the chemicals within its pouch to the surrounding air. You will need to let the hot-pack's chemicals react with the air for several minutes.

15. ☐ While you are waiting for the hot pack to begin reacting, prepare the stopper for use with the Erlenmeyer flask:

    a. Insert the tubing of the pressure sensor into the hole in the stopper.

    b. Connect the tubing to the pressure sensor using the quick-release connector.

    c. Position the temperature sensor in the flask so that it will be sealed tightly in between the mouth of the flask and the stopper.



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

17. ☐ Connect the pressure sensor and the temperature sensor to the data collection system. �(2.2)

18. ☐ Display two graphs simultaneously. On one graph, display Temperature on the y-axis with Time on the x-axis. On the second graph, display Pressure on the y-axis with Time on the x-axis. �(7.1.11)

19. ☐ Change the sampling rate to take a measurement every 2 seconds. �(5.1)

20. ☐ Use your sense of touch to monitor the temperature of the hot-pack as its chemicals react with the air. You may need to shake the hot-pack a few times as it is reacting in order to allow enough air into the chemicals. Why do you think this is important?

The directions on the hot-pack said to do this. It is probably important because the chemicals are not going to react the way they are supposed to if they are not exposed to enough air.

21. ☐ Gently place the hot-pack into the flask.

22. ☐ Arrange the temperature sensor in the flask so it is touching the hot-pack. How would the results differ if the temperature sensor was not touching the hot-pack?

If it did not touch, we would be measuring the temperature of the air above the hot-pack, instead of the actual temperature of the hot-pack itself.

23. ☐ Begin data recording. �(6.2) Observe the temperature graph for 2 to 3 minutes before closing the flask.

24. ☐ Place the stopper, with the pressure sensor tube, into the mouth of the flask, sealing it tightly and holding the temperature sensor in place. Why is it important to make sure the stopper seals the temperature sensor into the flask tightly?

If the Erlenmeyer flask is not sealed, the pressure will leak out and the pressure data will not be correct.

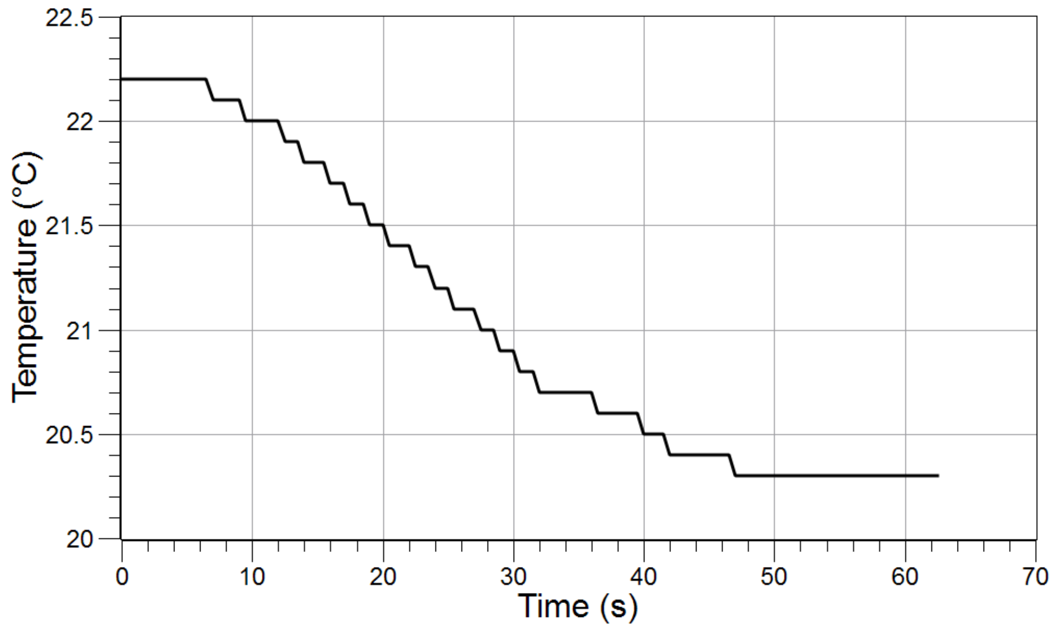
25. ☐ Continue recording temperature and pressure data until there are no further changes.

26. ☐ Stop data recording. �(6.2)

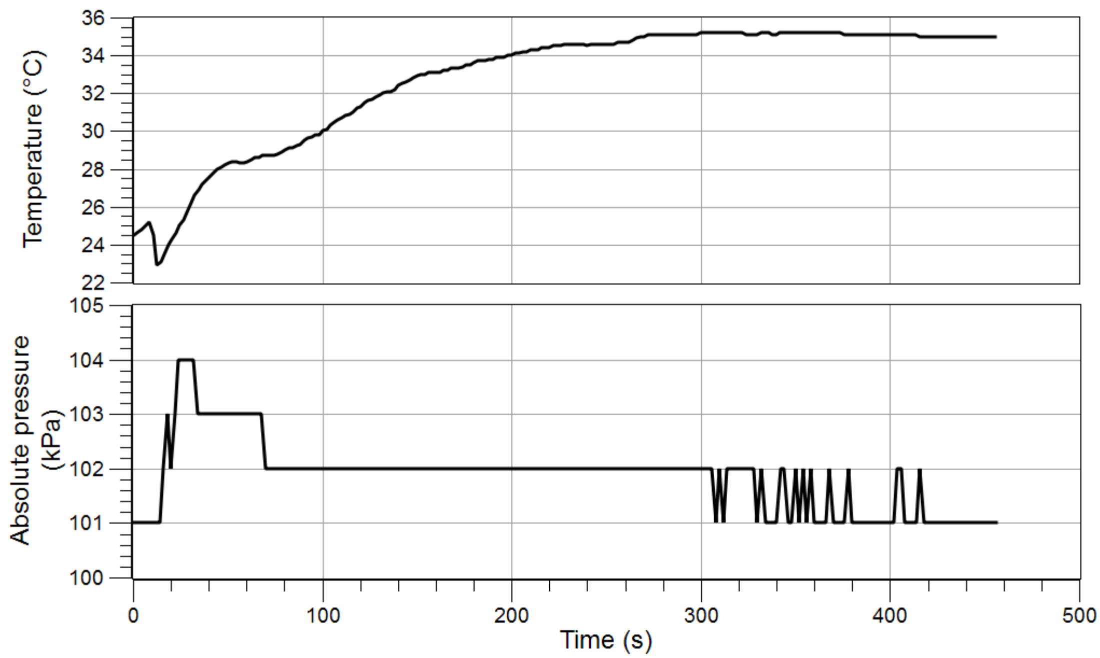
27. ☐ Observe your graphs of temperature versus time and pressure versus time. Record your observations below:

The pressure went down evenly and steadily the whole time. The temperature dropped down really fast from 58.4 degrees C to 27.7 degrees C.

Sample Data



Alka-Seltzer® data



Hot-pack data

Answering the Question:

Analysis

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

   We predicted the Alka-Seltzer would be endothermic and the hot pack would be exothermic. This is what happened in the experiments.

2. How did your predictions from Part 1 compare to your results in Part 3?

   We predicted that the pressure in the flask would build up and increase, but the exact opposite thing happened. The pressure dropped significantly during this part of the experiment.

3. Examine your temperature data from Part 2. Was the reaction of Alka-Seltzer® in water endothermic or exothermic? Explain your reasoning.

   This reaction was endothermic because the temperature dropped during the time that the Alka-Seltzer tablets were reacting, which meant that energy was being absorbed by the reaction.

4. Examine your temperature data from Part 3. Was the reaction of the hot-pack with air endothermic or exothermic? Explain your reasoning.

   The hot-pack was exothermic. It gave off a lot of energy as heat during its reaction.

5. Examine your pressure data from Part 3. Describe what happened to the pressure inside the flask during the experiment.

   As soon as we put the stopper in the flask to seal it, the pressure went up a tiny bit for just a few seconds. We think that was from pushing down hard on the stopper to get it in. Then the pressure began to drop a bit, and did not increase again.

6. The chemical reaction between the hot-pack and the air required oxygen to happen. What evidence do you see in your data that oxygen from the air in the flask was used for the reaction?

   In a way, this reaction is like a fire or candle burning inside a jar. Since it needs oxygen to burn, it stops burning when the oxygen runs out. When we did our Percent of Oxygen in Air experiment, we measured about 20% of the air as oxygen. We think that the hot-pack used up the 20% of air in the flask that is oxygen to do the reaction; then when it had used it all up, it could not react any more.

7. Write a general statement about how to classify chemical reactions according to whether they give off energy in the form of heat or absorb heat energy from their surroundings.

   When a chemical reaction gets warmer it is giving off energy as heat and is called an exothermic reaction. When a chemical reaction gets colder it is taking in energy by absorbing heat, and is called an endothermic reaction.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. A new chemical substance formed as a result of a chemical reaction is a:

   A. Reactant
   B. Solid
   C. Product

2. The term used in science to describe a reaction that absorbs energy in the form of heat is:

   A. Exothermic
   B. Endothermic
   C. Reactant

3. Conduction, convection, and radiation are three forms of transferring:

   A. Reactants
   B. Thermal energy
   C. Matter

4. A reaction that gives off heat is classified as:

   A. An endothermic reaction
   B. A phase change
   C. An exothermic reaction

5. Pressure is measured in SI units known as:

   A. Newtons
   B. Pascals
   C. Joules

6. Suppose you mix two colorless, odorless liquids together while measuring the temperature of this mixture. You observe that the initial temperature is 23 °C, and that 5 minutes later the temperature has changed by 11.6 °C and the liquid is now light pink in color. Which of the following could be true?

   A. If the final temperature represents an increase, an exothermic reaction has occurred.
   B. Because of the color change, no chemical reaction could have occurred.
   C. If the color changed, then the temperature should have stayed the same.

7. Consider the scenario in the previous question. Under what condition could you say that an endothermic reaction had possibly occurred?

   A. If there had been no color change instead of a change from clear to light pink.
   B. If the final temperature represents an increase compared to the initial temperature.
   C. **If the final temperature represents a decrease compared to the initial temperature.**

8. Consider the scenario in Question 6 again. If the reaction is exothermic, what is the final temperature of the liquid?

   A. 11.4 °C
   B. 34.6 °C
   C. 266.8 °C

9. Which of the following is *not* true for an endothermic reaction?

   A. Thermal energy flows from the reaction into the surroundings.
   B. Thermal energy flows from the surroundings into the reaction.
   C. Thermal energy is absorbed from the surroundings by the reaction.

10. Which of the following best describes a chemical reaction that is *either* endothermic or exothermic?

A. A chemical reaction which requires thermal energy to be added to it.

B. A chemical reaction that involves the changing of reactants into products.

C. A chemical reaction in which thermal energy is absorbed or released.

Further Investigations

How could this experiment be changed or modified to illustrate Charles' law?

Investigate the chemical reaction of ammonium nitrate and water.*

Investigate the chemical reaction of hydrochloric acid and magnesium ribbon.*

*For these investigations, use the stainless steel temperature sensor.

Rubric

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

21. Varying Reaction Rates

How Fast Will it Fizz?

Objectives

In this activity, students investigate temperature—a factor that affects reaction rates. They also:

- Observe and compare the varying amounts of time it takes for the reaction to run its course under different conditions
- Measure the amount of time needed for a reaction to occur
- Observe that substances react chemically in characteristic ways with other substances to form new substances (compounds) with different properties

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the temperature of two different systems
- Measure the change in temperature over time during four trials of Alka-Seltzer® tablets as they react and produce bubbles in a container of water
- Using math skills to average temperature results

Time Requirement

Introductory discussion and lab activity, Part 1 – Making predictions	30 minutes
Lab activity, Parts 2 and 3	30 minutes
Analysis	30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Alka-Seltzer® tablet
- ☐ Water, room temperature
- ☐ Clear plastic cup or beaker, 300 mL (10 oz)

For each student or group:

- ☐ Data collection system
- ☐ Temperature sensor, fast response
- ☐ Graduated cylinder, 100-mL
- ☐ Alka-Seltzer® tablets
- ☐ Stopwatch
- ☐ Clear plastic cups or beakers (3), 300-mL (10 oz)
- ☐ Spoon or stirring stick
- ☐ Warm water
- ☐ Ice water

Concepts Students Should Already Know

Students should be familiar with the following concepts or skills:

- How to use a graduated cylinder to measure liquid volume, as well as the meaning of the term *volume*
- How to define the terms *reactants* and *products* as well as have a basic understanding of the nature of a chemical change (reaction)
- How to set up and compute averages
- How to read and interpret a coordinate graph
- Be familiar with degrees Celsius, which is the SI unit of measure for temperature

Related Labs in This Guide

Labs conceptually related to this one include:

- Investigating Evaporative Cooling
- Transfer of Energy in Chemical Reactions

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. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting the temperature sensor �(2.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Showing and hiding data runs in a graph �(7.1.7)

- Adjusting the scale of a graph �(7.1.2)

- Saving your experiment �(11.1)

Background

In an Alka-Seltzer tablet the sodium bicarbonate ($NaHCO_3$) and citric acid($H_3C_6H_5O_7$) are solids and so the H+ and CO_3^{-2} ions are not free to move, collide, and react. When dropped into water, the citric acid and sodium bicarbonate dissolve, freeing the ions to react by the following equation:

$H_3C_6H_5O_{7(aq)} + 3NaHCO_{3(aq)} \rightarrow 3CO_2(g) + 3H_2O(l) + Na_3C_6H_5O_{7(aq)}$

The conditions under which a chemical reaction occurs have a great effect on the speed or rate at which the reaction occurs. These conditions are often termed the factors that affect a reaction rate. The following key factors affect the chemical reaction rate:

- *Temperature,* under which the reaction occurs, affects the rate of the reaction. For a chemical reaction to occur, the particles, atoms, or ions that are reactants must physically come into contact with one another. Anything that increases the frequency of these encounters increases the rate at which products are formed. A general rule of thumb for most (not all) chemical reactions is that the rate at which the reaction proceeds approximately doubles for each 10 degrees Celsius ($10^{o}C$) increase in temperature. At a higher temperature, a greater proportion of the colliding particles possess the necessary energy to effectively undergo a chemical reaction and form products.

- *Concentration* of reacting substances affects the rate of the reaction. The rate of a chemical reaction depends on the frequency of the collisions between the atoms or ions of the reactants. As the concentration of the reactants decreases the frequency of collisions decreases, and the rate of the reactions slows down.

- *Surface area* affects the rate of the reaction. The rate of a chemical reaction is affected by the physical size of the reactants. Decreasing the size of the particles that make up a given weight increases the number of particles represented by the same weight. Smaller particle size results in an increase in the rate of reaction because the surface area of the reactant has been increased.

- *Nature of the reactants* (state and type of reactants) affects the rate of the reaction. If any of the products or reactants involved in a chemical reaction are gases, the rate of reaction decreases as pressure on the system increases. Changing the pressure on a reaction that involves only solids or liquids has no effect on the rate.

- *Presence of catalysts* affects the rate of the reaction. A catalyst is a substance that speeds up a reaction, but is chemically unchanged at the end of the reaction. When the reaction has finished, there will be exactly the same mass of catalyst as there was at the beginning.

To increase the rate of a reaction you need to increase the number of successful collisions. One possible way of doing this is to provide an alternative way for the reaction to happen.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

- Drop an Alka-Seltzer tablet into a plastic cup filled with water at room temperature. Ask the students what they observe. Discuss how many different states of matter are present in the cup. Ask the students if a chemical reaction is occurring in the cup. They should be able to relate the formation of gas bubbles to the production of a new substance, and recognize this as evidence that a reaction is taking place. Explain to the students that the disappearance of the solid Alka-Seltzer tablet when placed in water is due to the reaction of sodium bicarbonate ($NaHCO_3$) and citric acid ($H_3C_6H_5O_7$). Write the chemical formulas for these reactants on the board. If the students are familiar with these chemical symbols—that is, if they know that *C* stands for carbon, *H* for hydrogen, and so on—ask the students which gas they think is released during the reaction (carbon dioxide, or CO_2).
- Direct the students to the "Thinking About the Question" section After a few minutes ask the groups to share some of their ideas with the class. After listening to the students' ideas, summarize by suggesting that conducting a reaction at a higher temperature puts more energy into the system and increases the reaction rate.
- Direct the students to the "Investigating the Question" section

Preparation and Tips

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

- Each lab group needs a total of four Alka-Seltzer tablets. To save money, you can purchase the "store" brand of effervescent tablets.
- Remind students to place the whole tablet into the water because breaking the tablet changes the variable of surface area.
- In order to save time in the ice water step (Part 3), you may choose to have ice water available to the student groups rather than having them make their own ice water.
- Provide lab groups with towels in case of spills.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Handle glassware carefully.
- Do not use water hotter than 40 °C.

Driving Question

How do different temperatures affect the rate of a chemical reaction?

Thinking about the Question

If you have ever helped your family to prepare a meal or if you have ever baked, then you are familiar with changes in the rates of chemical reactions. There are many examples of changes in *reaction rates* in our daily lives, and some of the most easily observed changes happen in cooking. An egg cooks faster in a hotter pan. Bread dough rises more quickly in a warm place than in a cool one.

If you have had a glow-in-the-dark light stick before, such as the kind worn at concerts, you might have heard that putting the used light sticks in the freezer will help make them last longer. Such light sticks work by producing light through a chemical reaction. Placing a light stick into hot water makes it glow more intensely, showing that the reaction runs faster at a higher temperature. Placing it in the freezer slows down the rate of reaction.

The rate of a chemical reaction is the time required for a given quantity of *reactants* to be changed to *products*.

Can you think of other chemical reactions in which rates are affected by changes in temperature? Discuss with the members of your group a general rule that relates temperature to reaction rate.

> When substances or chemicals are warmer they seem to react faster. Chilling substances or chemicals can make them react more slowly. For example, the "Mentos® and Diet Coke" reaction produces a faster and bigger reaction when the soda is at least at room temperature and not right out of the refrigerator. Also, milk can spoil sooner if left out on the table, where it is warmer than in the refrigerator.

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.

1	2	3	5	4
Make sure each lab group member is aware of safety rules and procedures for this lab.	Gather the necessary equipment and materials, or check to see that they have been provided to your group.	Fill a cup or beaker with 200 mL of warm tap water.	Drop the Alka-Seltzer tablet into the cup or beaker of water.	Begin recording the first run of temperature data.

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. ☐ Predict what the reaction rate will be for a chemical reaction that occurs at room temperature.

   We predict that at room temperature there will be a faster reaction of the Alka-Seltzer.

2. ☐ Predict what the reaction rate will be for the same type of chemical reaction that occurs at a temperature close to freezing (ice-cold water).

   We predict that if the same kind of Alka-Seltzer is put into ice water, it will react more slowly than when put into the warm water.

Part 2 – What is the effect of warm temperature on reaction rate?

Trial 1

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

4. ☐ Fill a clear plastic cup or beaker with 200 mL of room temperature water.

5. ☐ Connect the temperature sensor to the data collection system. �(2.1)

6. ☐ Place the temperature sensor in the plastic cup or beaker.

7. ☐ Start recording the first run of temperature data. �(6.2)

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

9. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch. If you are not using a stopwatch, note on your graph the exact time that you dropped the Alka-Seltzer tablet in the water.

10. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph, and then stop recording the first run of data. �(6.2)

11. ☐ Why do you think it is important to note the time as exactly as possible?

    We are trying to find out how long it took the Alka-Seltzer to stop making fizz, so we do not want any time included for other things.

12. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

    Trial 1 ___34.5___ seconds

13. ☐ Pour out the water and dissolved Alka-Seltzer tablet, according to your teacher's instructions.

14. ☐ Rinse and refill the clear plastic cup or beaker with 200 mL of room temperature water.

Trial 2

15. ☐ Start recording a second run of temperature data. �[7.1.3]

16. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch. If you are not using a stopwatch, note on the graph the exact time that you dropped the Alka-Seltzer tablet in the water.

17. ☐ Continue collecting data until the Alka-Seltzer tablet is completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph of data, and then stop recording the second run of data. �[6.2]

18. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

    Trial 2 ___37___ seconds

19. ☐ What is the reason for repeating this trial and averaging the time? Why is this considered good experimental design?

    Conducting more than one trial provides more data to average. More data makes for a better experiment. For example, if the second data run was considerably different from the first run, we might suspect that we made an error because we would have a basis for comparison. In our case, in the first trial (ice-cold water) the temperature was less cold because it had time to mix. In the second trial we used fresh water and ice because, in this particular experiment, the water used in the first trial was spilled.

Part 3 – What is the effect of ice-cold temperature on reaction rate?

Trial 1

20. ☐ Fill a clear plastic cup or beaker with 200 mL of water. Add five ice cubes to the cup, stir to mix, and wait one minute. Measure exactly 200 mL of the chilled water into another cup or beaker.

21. ☐ Place the temperature sensor in the plastic cup or beaker.

22. ☐ Using the same graph as in Part 2, start recording the first run of temperature data. �(6.2)
Note that this will be your third run of temperature data overall. You may choose to hide the previous runs of temperature data while you are conducting this part of the experiment. �(7.1.7)

23. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch, or note the exact time on the graph that you dropped the Alka-Seltzer tablet in the water.

24. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph, and then stop recording data. �(6.2)

25. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

Trial 1 ____110____ seconds

Trial 2

26. ☐ Again fill the clear plastic cup or beaker with 200 mL of water. Add five ice cubes to the cup, stir to mix, and wait one minute.

27. ☐ Rinse and refill the clear plastic cup or beaker from the reaction with 200 mL of the chilled water.

28. ☐ Start recording the second run of temperature data �(6.2) for the ice water. Note that this will be your fourth run of data overall.

29. ☐ Drop the Alka-Seltzer tablet into the water at the same time that you start the stopwatch, or note the exact time on the graph that you dropped the Alka-Seltzer tablet in the water.

30. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. Immediately stop the stopwatch or note the exact time on your graph, and then stop recording the second run of data. �(6.2)

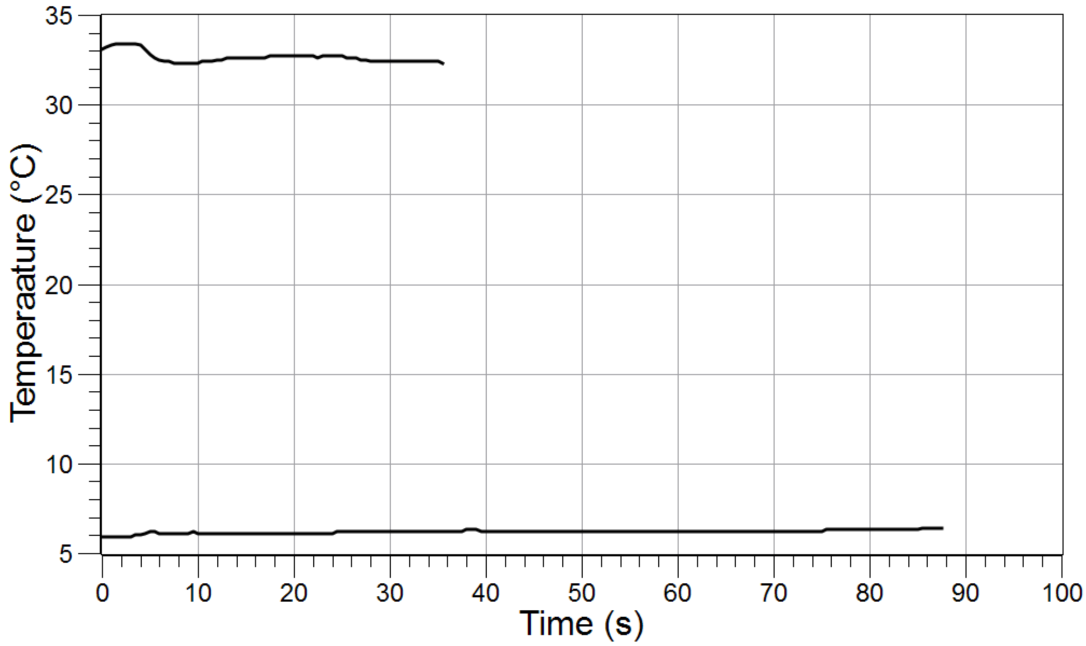
31. ☐ Record the time it took for the Alka-Seltzer tablet to completely finish fizzing.

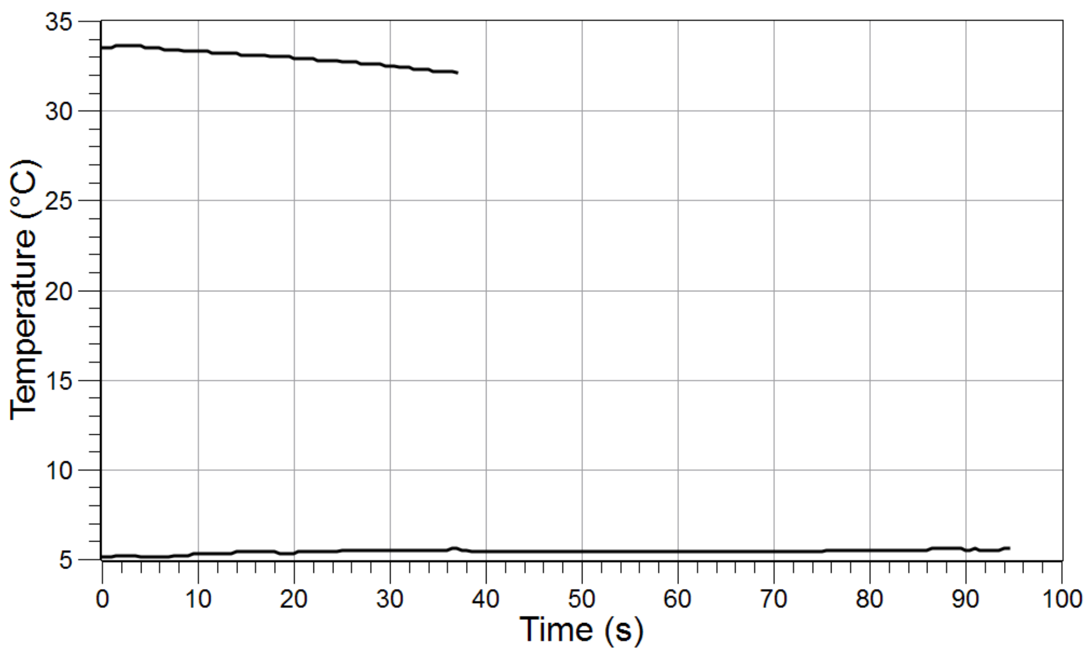
Trial 2 ____70____ seconds

32. ☐ Save your experiment. �(11.1)

Sample Data

The first graph below shows the first runs of warm water and ice-cold water. The second graph shows the second runs of warm water and ice-cold water.





Answering the Question

Analysis

1. Determine the average temperature for the experiment you performed with warm water in Part 2 of the Investigating the Question section.

Average time to finish fizzing in warm water: 37.75 seconds

Sample calculation:

$$\frac{34.5 + 37}{2} = \frac{71.5}{2} = 37.75s$$

2. Determine the average temperature for the experiment you performed with ice-cold water in Part 3 of the Investigating the Question section.

Average time to finish fizzing in ice-cold water: 90.75 seconds

Sample calculation:

$$\frac{87.5 + 92}{2} = \frac{181.5}{2} = 90.75s$$

3. Review the average time needed for the Alka-Seltzer tablet to finish fizzing in each part. Using room temperature water, how many times faster is the reaction rate than with the ice-cold water?

We divided 90.75 by 37.75 to find this out, and we got 2.40 rounded to the nearest hundredth. This means that the reaction in the room temperature water was 2.40 times faster than the reaction in the ice-cold water.

Sample calculation:

$$\frac{90.75s}{37.75s} = 2.40 \text{ times faster}$$

4. How does temperature affect the rate of a chemical reaction?

We found out that the chemical reaction of an Alka-Seltzer tablet was 2.40 times faster in room temperature water than in ice-cold water. We wanted to perform another trial at a medium temperature to see if it took a medium amount of time.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. Rate of reaction:

   A. A measure of how fast a reaction occurs

   B. An equation showing the products and reactants of a chemical reaction

   C. A chemical reaction changes reactants into new products with new properties

   D. An element or compound that enters into a chemical reaction

2. Liquid:

   A. A state of matter that has no fixed shape but that has a definite volume
   B. The process where reactants change to form products
   C. Formulas and symbols are used to show what happens during a chemical reaction
   D. One of the original substances before a chemical reaction takes place

3. Product:

   A. Matter that has a definite shape and takes up a definite amount of space
   B. A substance that undergoes a chemical reaction, often by combining with another substance.
   C. An expression in which symbols, formulas, and numbers are used to represent a chemical reaction
   D. A substance formed by a chemical reaction

4. Solid:

   A. A state or phase of matter in which a substance has no definite shape or volume
   B. A process in which one or more substances are changed into others, including color or temperature changes or bubbles being formed
   C. A state of matter that has a definite shape and a definite volume
   D. Matter with no definite shape but with a definite volume

5. Reactant:

   A. The process where substances change to form products
   B. Element or compound that enters into a chemical reaction
   C. A measure of how fast a reaction occurs
   D. An equation showing the products and reactants of a chemical reaction

6. Reaction:

   A. Matter that has a definite shape and takes up a definite amount of space
   B. A chemical process changes reactants into new products with new properties
   C. An element or compound that enters into a chemical reaction
   D. A state of matter that has no fixed shape but that has a definite volume

7. Chemical equation:

   A. A substance formed by a chemical reaction
   B. A state of matter that has no fixed shape but that has a definite volume
   C. A chemical reaction changes reactants into new products with new properties
   D. Formulas and symbols are used to show what happens during a chemical reaction

8. Gas:

   A. A state or phase of matter in which a substance has a definite volume but no definite shape
   B. A description of a chemical reaction using chemical symbols and formulas to represent reactants and products
   C. A substance that undergoes a chemical reaction, often by combining with another substance
   D. A state or phase of matter in which a substance has no definite shape or volume

Key Term Challenge

Fill in the blanks from the randomly ordered words below.

gas	product	solid	reaction
liquid	a chemical reaction	reaction rate	reactant

1. Iron and oxygen change into iron oxide during a chemical ___reaction___.

2. The rate of ___a chemical reaction___ is the time required for a given quantity of reactants to be changed to products.

3. Matter can be a ___solid___, a liquid, or a gas.

4. Carbon dioxide is a ___product___ of the chemical reaction between vinegar and baking soda.

5. The phase of matter that carbon dioxide is usually found as is a ___gas___.

6. A ___liquid___ takes on the shape of its container.

Further Investigations

Investigate the reaction rate when there is more surface area (smaller particle size) available to react, by breaking up the Alka-Seltzer tablet before recording the time required to completely finish fizzing at warm and cold temperatures.

Investigate the reaction rate for a wider range of temperatures. Can you predict the reaction rate for specific temperatures?

Design an experiment that makes use of the pressure sensor to measure the amount of gas produced by an Alka-Seltzer tablet fizzing in warm and cold water.

If you predicted that the gas produced in this experiment is actually carbon dioxide (CO_2), design an experiment to test your prediction.

Design an experiment to test the reaction rate of Mentos® candy dropped into Diet Coke® or other carbonated cola. Which temperature results in the highest “fountain,” room-temperature or ice-cold? What does this have to do with rate of reaction?

Rubric

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

22. Voltage Time

Running Down

Objectives

In this activity, students build a miniature motor and investigate the energy conversions that take place as the battery supplying energy for the motor becomes exhausted. Students investigate voltage while:

- Observing that electrical circuits provide a means of transferring electrical energy and converting that energy to heat, light, sound, mechanical energy or chemical changes
- Understanding that energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, and the nature of a chemical
- Making explanations and predictions from evidence and drawing logical conclusions
- Identifying variables that can affect the outcome of an experiment. In addition they will learn to identify other variables in an experimental design that must be controlled in order to isolate the effect of one variable
- Gaining skills and confidence in using a scientific measurement tool, the voltage sensor, as well as the graphing capacity of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work space to construct a simple motor to incorporate into a circuit and measure voltage of this circuit
- Building a simple motor
- Measuring the change in voltage of a battery as it is used in a circuit until it runs down
- Using math and graphing skills to interpret and analyze the data obtained

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	25 minutes
■ Lab activity, Part 2 – Building a simple motor and Part 3 – Testing the voltage of your battery	50 minutes
■ Lab activity, Part 4 – Discharging battery	15 minutes to set up + 24 hours to run
■ Analysis	30 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Collection of different batteries for display
- ☐ Battery, D-cell, in holder[1]
- ☐ Magnets, small disk or rectangular, 5
- ☐ Electrical lead wires with alligator clips, 2
- ☐ 20-gauge copper wire, ~ 60 cm[2]
- ☐ Wire strippers or scissors (for insulated wire)
- ☐ Sandpaper (for enameled wire)
- ☐ Large paper clips, 2
- ☐ Cup, plastic, paper, or foam
- ☐ Small rubber band
- ☐ Masking tape
- ☐ Marking pen, permanent, dark color

1 Battery holders may be made out of small blocks of wood with nails; see Preparation and Tips section.

[2] A solid (not stranded) enameled or insulated wire

For each student or group:

- ☐ Data collection system
- ☐ Voltage sensor
- ☐ Battery, D-cell, in holder[1]
- ☐ Magnets, small disk or rectangular, 5
- ☐ Electrical lead wires with alligator clips, 2
- ☐ 20-gauge copper wire, ~ 60 cm[2]
- ☐ Wire strippers or scissors (for insulated wire)
- ☐ Sandpaper (for enameled wire)
- ☐ Alligator clip (optional)
- ☐ Large paper clips, 2
- ☐ Cup, plastic, paper, or foam
- ☐ Small rubber band
- ☐ Masking tape
- ☐ Marking pen, permanent, dark color

1 Battery holders may be made out of small blocks of wood with nails; see Preparation and Tips section.

[2] A solid (not stranded) enameled or insulated wire

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Basic components of electric circuits
- Connecting components to build an electric circuit
- How electromagnets work
- Energy transformations and the conservation of energy

Related Labs in This Guide

Labs conceptually related to this one include:

- Measuring Voltage and Power

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 a sensor to the data collection system �(2.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a digits display. �(7.3.1)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Energy, which can be thought of as the capacity to do work, can exist in a variety of forms, and may be transformed from one type to another. Energy transformations are always constrained by a fundamental fact of nature known as the Law of Conservation of Energy. One way to express this law is to say that "energy can neither be created nor destroyed."

Batteries provide electrochemical reactions that produce electrons. A battery consists of two electrodes and a conducting solution. The electrodes are usually different metals or carbon. The electrode materials give the battery its generic name. For instance, a nickel-cadmium (NiCd) battery has one electrode of the metal nickel and one of cadmium. The most common battery is carbon-lead. Electrons flow from the battery into a wire, and must travel from the negative to the positive terminal for the chemical reaction to take place. Once you connect a wire, the electrochemical reaction begins.

Electrons collect on the negative terminal of the battery. As soon as the wire is connected between the negative and positive terminals, the electrons will flow from the negative to the positive terminal as quickly as they can, which also drains the battery very quickly (this tends to be dangerous and is not something to demonstrate or try out). Normally, some type of *load* is connected to the battery using the wire. Anything that offers resistance as the battery does work on the charge can serve as the load. The simple motor is the load in this activity.

The simple motor works as follows: current flows through a wire coil, creating an electromagnet. One side of the coil becomes a north pole and the other side becomes a south pole. The permanent magnets attract their opposite pole on the coil and repel their like pole, causing the coil to spin. By coloring the top half of the projecting wires with the permanent marker to insulate them, current is prevented from flowing during one-half of each spin. The magnetic field of the loop electromagnet is turned off for that half-spin. As the south pole of the loop electromagnet comes closest to the permanent magnet, the marker ink insulation turns off the electric current. The rotating coil's inertia carries it through half of a turn, past the marker ink insulation. When the electric current starts to flow again, the twisting force in the same direction resumes. The coil keeps rotating in the same direction.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Display the simple motor for students to see. Ask students to name the parts of the circuit such as the wires, the battery, and the load or part that offers resistance. Disconnect one of the wires and as students to identify whether the circuit is open or closed. Review with students the meaning of open and closed circuits. When can electricity flow?

> Electricity can only flow when it has a complete, unbroken path to follow from the negative end of the battery to the positive end of the battery.

Since electrical terms and circuits are often difficult for students to understand, use this analogy: An electrical circuit is much like water running through a hose from a faucet. In this model the water represents the current (represented by the variable I) flowing through the hose that represents the wire. The resistance to flow (represented by the variable R) is dependent on the length or the narrowness of the hose. If you turn the faucet on full, the pressure needed to push the water through the hose is at maximum. The pressure needed to push the water represents the voltage (represented by the variable V).

Demonstrate how to use the voltage leads by testing the battery with voltage leads placed across the terminals of the battery. Be sure to show students the two terminals of the battery and the results of the voltage output when the leads on the terminals are switched. The sign of the voltage depicts direction of flow of the current through the battery.

Direct students to “Thinking About the Question.” Allow students to work within groups for a few minutes and then have them present their answers to the class. Focus their responses on the chemical nature of a battery. A battery continues to produce a voltage as long as there is a supply of each electrode and conducting solution. When one of the electrodes runs out, the cell is dead.

Students may question why different size batteries have the same voltage. Propose the following analogy: Suppose you are watering a garden with your hose. Instead of connecting your hose to a faucet (which implies a never-ending source), you have the option of drawing water from two different ponds. One pond is twice the size of the other and of equal depth. Both ponds rest on a hill an equal distance from the garden. If you place the hose at the bottom of either pond, the water will flow at equal pressure (representing the voltage drop) through the hose. Ask students which pond they would use during a drought if they needed more water for their garden? The larger pond is like the bigger battery. The large pond stores more water. The larger battery stores more chemicals.

Direct students to “Investigating the Question.”

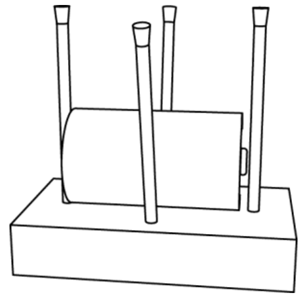
Preparation and Tips

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

- Assemble an example miniature motor so that students can examine it for reference while they are building their own. The construction of this motor takes patience; encourage students to work carefully and to be patient — they will be successful!

- Demonstrate to students how to use wire strippers, scissors, or sandpaper to remove insulation from the ends of the wires. You may need to help some students with this procedure.

- You can make a battery holder from a block of wood and four nails, as shown in the diagram.



- Students will need space to put their motors and data collection systems for the duration of the activity.

- Mobile data collection systems may need to be plugged in to a power supply in order to operate continuously for 24 hours.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Connecting leads directly between battery terminals may result in overheating and damage to the battery.

- Do not test batteries rated higher than 5 volts, as damage to the sensor may result.

- Use caution with sharp objects.

Driving Question

How does a battery's voltage change as it is used?

Thinking about the Question

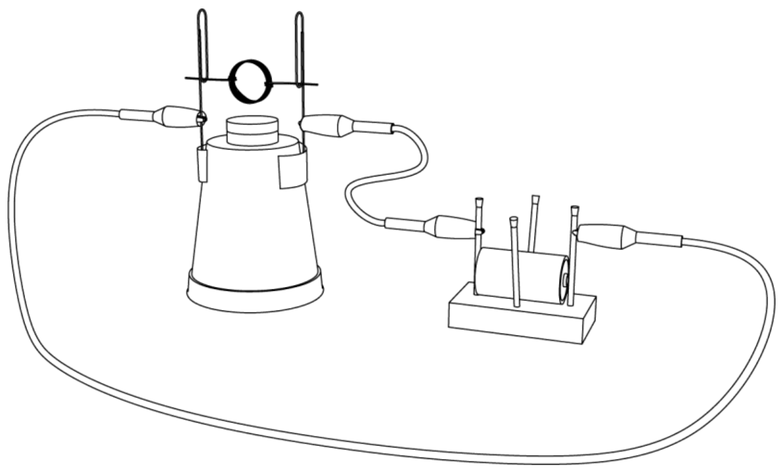
Where would we be without batteries? Batteries provide us with electrical energy that can be converted from a flow of electrons to many other forms, such as heat, mechanical energy, or energy stored in magnetic fields. Discuss with your lab group members the different ways you use batteries in your daily life, and what kinds of energy conversions or transformations happen in the process. Be prepared to share your thoughts with your class.

> Student answers will vary. Students may suggest various electronic items such as music players, games and toys, flashlights, as well as cameras, cell phones, laptop computers, and even cars. Energy is converted from chemical energy to electromagnetic energy (in the form of heat, light, magnetic fields), and mechanical energy.

Observe the collection of different types of batteries. Note the voltage on each of the batteries. What do you think will happen if each type of battery is connected to a circuit for 30 minutes? What if each type of battery was connected to the circuit for 24 hours? Why do you think this will happen? Be prepared to share your thoughts with the class.

> Student answers will vary. Students will often be surprised that so many different types of batteries will have the same voltage. They may suggest that different size batteries will decrease voltage at different rates.

In this activity you will build a very simple motor that runs on one battery, and use the simple motor as the load in your circuit. As you know, a coil of wire becomes an electromagnet when electric current passes through it. If the electromagnet coil interacts with a permanent magnet, it can be made to spin, and keep right on spinning as long as electric current flows through it. You have created an electric motor!



Sequencing Challenge

Note: This is an optional ancillary activity that may be omitted.

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.

2/3	1	3/2	4	5
Determine how far away from the motion sensor 50 cm is, so the walker knows where to begin.	Make sure that each lab group member is aware of safety rules and procedures for this lab.	Determine the maximum distance away from the motion sensor the walker may move.	Start recording position versus time data.	Begin walking backward and forward when the clicking sound of the motion sensor becomes audible.

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. ☐ In this activity you will build a simple motor that runs on the energy from a battery. Predict the different types of energy transformations that will occur in the motor-battery system you build.

   Students may suggest that chemical potential energy will be converted into electrical energy, which will be converted into heat and mechanical energy.

2. ☐ Predict how long the simple motor will be able to run on one battery.

   Answers will vary. Students may predict that their motors will run for anywhere from one hour to up to 24 hours or longer.

3. ☐ Do you think the voltage will decrease slowly over time or suddenly in a short period of time? Write your prediction below.

   Answers will vary. The voltage should remain steady for most of the time, falling off quickly toward the end of the battery's life.

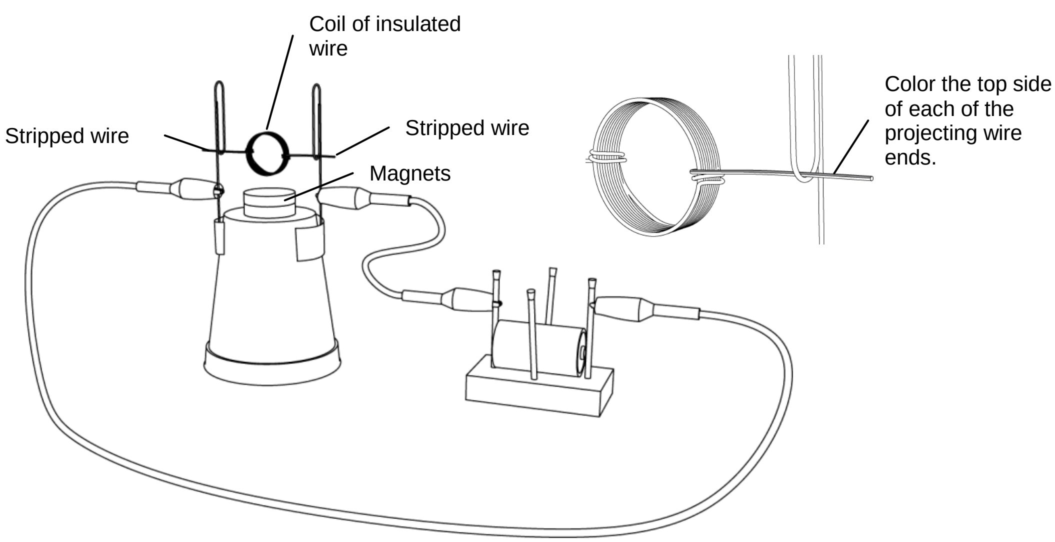
Part 2 – Building a simple motor

4. ☐ Wind the insulated copper wire into a coil approximately 2.5 cm in diameter. Make four or five loops, and leave about 5 cm of wire projecting from each side of the coil. Wind the ends of the wire around the coil on opposite sides to secure the loops of the coil together.

   Note: A good way to make the coil uniformly circular is by wrapping the wire around the D-cell battery, which is the correct diameter.

5. ☐ Remove the insulation from the ends of the wire projecting from the coil.

6. ☐ Re-insulate the one half of the projecting wires as follows: Use the permanent marker to shade the top side of the projecting ends. As you hold the coil vertically, color the top half of one of the wires, then do the same for the other projecting wires.



7. ☐ Arrange the cup so it has three magnets inside on the bottom and two magnets outside on the bottom. The magnets will stick to one another through the cup as long as the opposite poles are facing each other.

8. ☐ Set the cup upside down.

9. ☐ Unfold one end of each paper clip and tape them to opposite sides of the cup, with their unfolded ends down. You may use the rubber band to hold the clips in place while you adjust their height.

10. ☐ Place the ends of the coil in the loops formed by the paper clips.

11. ☐ Adjust the height of the paper clips so that the coil sits about 1 or 2 mm above the magnets. Continue refining the adjustment of the coil and the paper clips until the coil remains balanced and centered while freely spinning on the clips. The better your coil balances and spins, the better your motor will operate.

12. ☐ You may cut off excess wire as necessary, once you know how long the projecting ends of the coil must be to balance well in the paper-clip loops.

13. ☐ Use the wires with alligator clip leads to connect the battery to the paper clips, connecting one terminal of the battery to one paper clip and the other terminal to the other paper clip.

14. ☐ Give the coil a gentle spin to get it to start turning. If it does not continue spinning on its own, check the following:

    a. Make sure that the coil assembly is well balanced when spinning

    b. The enamel has been thoroughly scraped off you used enameled wire

c. The projecting end has been painted with dark marker as described

d. The coil and the magnet are as close to each other as possible without touching each other

e. The distance separating the loops may affect the quality of the contact between the coil and the loops

15. ☐ Continue fine-tuning and adjusting until your motor works.

Part 3 – Testing the voltage of your battery

16. ☐ Begin a new experiment on the data collection system. �(1.2)

17. ☐ Connect a voltage sensor to the data collection system �(2.1)

18. ☐ Display the voltage in a digits display. �(7.3.1)

19. ☐ Change the number of digits with which the voltage is displayed to two digits after the decimal point. �(5.4)

20. ☐ Monitor voltage data. �(6.1)

21. ☐ Place the voltage sensor's red lead on the positive terminal of the battery, and the black lead on the negative terminal. Note the voltage and record it in the space below.

Battery Type: D-Cell

Voltage: 1.32 V

Part 4 – Observing energy transformations

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

23. ☐ Change the periodic sampling rate to take a voltage measurement once every 30 seconds. �(5.1)

24. ☐ Connect the voltage leads to the battery, black lead to the negative terminal and red lead to the positive terminal.

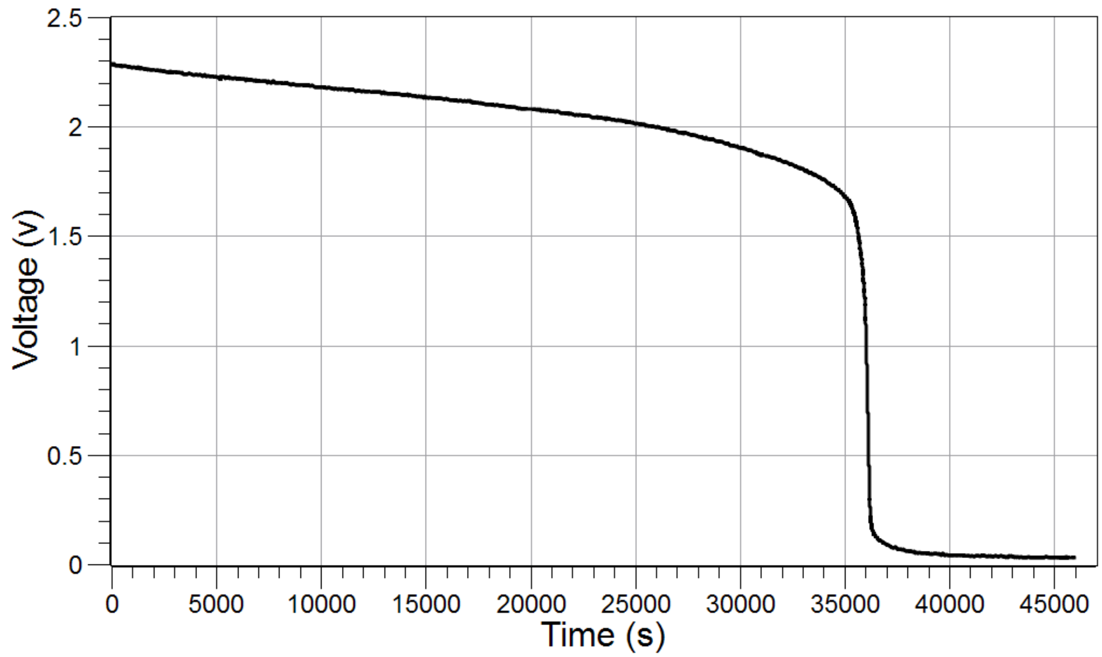
25. ☐ Start data recording. �(6.2) Since you will record the voltage of the battery twice per minute over the life of the battery as it provides energy to your motor, you will need to leave your system set up for the next 24 hours.

26. ☐ Observe the motor carefully as it spins. Note as many possible energy transformations or conversions as you can see.

27. ☐ At the end of the battery's life, stop data recording. �(6.2)

28. ☐ Save your experiment according to your teacher's instructions. �(11.1)

Sample Data



Answering the Question

Analysis

1. Review your data. You may need to adjust the scale of a graph �(7.1.2) How did your prediction from Part 1, about how long the motor would run, compare to your results from Part 4?

Answers will vary. One group answered as follows: We predicted that our motor would still be running when we came back to class today, which would be 24 hours. But it was stopped, and we could not get it to start spinning again. According to our graph of voltage data, the voltage decreased to 0.04 volts, or almost nothing, in 29,085 seconds, which equals 484.75 minutes or 8.1 hours. So our motor may have run for about 8 hours, which is much less time than we predicted.

2. Compare your prediction about the way the voltage would decrease to what your data actually shows.

Answers will vary. One group answered as follows: We predicted that the battery's voltage would slowly run down, and there would be a sort of flat, sloped line on the voltage graph to show that the battery's voltage gradually went down. However, it turned out in our experiment that the voltage began at about 1.05 volts and stayed above 0.8 volts for 13,530 seconds (225.5 minutes or 3.76 hours) and then it dropped to 0.2 volts in just 2160 seconds or 36 minutes. On our graph, this looks like a much steeper slope down than the first part. It looks like a drop-off.

3. Describe the types of energy conversions you observed during the operation of your motor.

   Answers will vary. On group answered as follows: We observed the chemical potential energy from the battery being converted into electrical energy in our circuit, which caused our coil to become an electromagnet. Electromagnets have electromagnetic energy. Because our electromagnet coil was spinning, it had kinetic energy that was mechanical energy. When it was spinning at its fastest, it was making a small breeze that we could feel, which meant that it was pushing the air around. We also found that the paper clips were a little warm when we touched them, so some of the energy was transformed into heat as well.

4. At some point the battery runs down and is no longer able to provide energy for the motor in the circuit. Where has the energy gone? Has it disappeared or is there another explanation? Explain your reasoning.

   Answers will vary. On group answered as follows: The energy from our run-down, dead battery did not disappear. It was used to do work. It spun our motor's coil, which even though it was a tiny motor, it probably move around lots of air molecules while it was running. A lot of the energy was converted into heat through friction. The battery was able to run as long as it had enough chemicals. When its chemicals were used up, it could not keep reacting. The same amount of energy flowed out of our battery as flowed into our circuit and the surrounding air.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. A battery provides energy in the form of:

   A. Mechanical energy
   B. Chemical energy
   C. Gravitational potential energy

2. Batteries of different sizes may have the same:

   A. Voltages
   B. Amounts of chemicals contained in them
   C. Number in the same size and volume package

3. Which of the following is *not* part of an electric circuit?

   A. Wires
   B. Earth's gravitational field
   C. Switches

4. Which of the following statements about energy is *not* true?

   A. Energy can have many different forms
   B. Energy can change from one form to another
   C. Energy can be destroyed

5. An electromagnet is turned on when:

   A. At least three wires are connected together
   B. The coil is made very carefully and neatly
   C. Current flows through the coil

6. Which of these statements best describes the way a battery's voltage varies over its life?

   A. The voltage steadily decreases throughout the life of the battery in a linear fashion

   B. The voltage remains fairly constant and then suddenly begins to drop off near the end of the battery's life

   C. The voltage fluctuates from time to time at different stages of the battery's life, and then increases just before it runs out.

7. Why is it unsafe to connect the terminals of a battery with just a short piece of wire?

   A. It is much easier to cut your skin with a short piece of wire than it is with a long piece

   B. Using a short piece of wire makes it very difficult for the electrons to travel quickly from one terminal of the battery to the other, and the wire can get very hot

   C. Using a short wire makes it very easy for the electrons to travel quickly from one terminal of the battery to the other, and the wire can get very hot

8. An electrical circuit is much like:

   A. Water running through a hose from a faucet

   B. Fire beginning at one end of a rope and burning along the entire length at once

   C. A bowling ball rolling down its lane to strike the pins at the other end

9. Electrical circuits provide a means of ___________________ electrical energy.

   A. Transferring

   B. Creating

   C. Destroying

10. _________________is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, and the nature of a chemical.

   A. Magnetism

   B. Density

   C. Energy

Further Investigations

What voltage is needed to operate a flashlight? Test the voltage over time while the light is on.

Do different kinds of batteries (nickel cadmium, lithium, and alkaline) all run down in the same way? Design an experiment to investigate any differences.

Investigate how the battery discharge is different when a 0.47 ohm, 10 ohm, or 1K ohm resistor is used.

Rubric

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

23. Work and Mechanical Advantage

Simply Forceful - The Sequel

Objectives

In this activity, students further investigate the way simple machines make work easier by combining two simple machines to make a compound machine.

Students will investigate force and simple machines while they:

- Recognize that a force is a push or a pull
- Recall that simple machines change the amount of input force, the direction in which the force is applied, or both
- Recognize that a compound machine is made of two or more simple machines
- Reinforce their understanding of the different arrangements of pulleys
- Recognize that force is measured in newtons (N), mass is measured in kilograms (kg), and length is measured in meters (m)
- Recognize that moving a force through a distance is known as *work*
- Compute mechanical advantage
- Design and conduct a scientific investigation

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up equipment and work area to measure the force required to lift a mass with varying configurations of fixed and moveable pulleys, in combination with an inclined plane (a ramp)
- Designing and building structures to test how pulley systems change the direction of applied force, the amount of applied force, or both
- Assembling fixed and moveable pulley systems and trying these combinations as they apply a force to pull a cart up an inclined plane

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	25 minutes
■ Lab activity, Part 2 – Using a ramp	25 minutes
■ Lab activity, Part 3 – Using pulleys and a ramp	30 minutes
■ Analysis	25 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Tinker Toys™ or other building materials
- ☐ PAScar or other cart or toy car
- ☐ Pulleys
- ☐ String

For each student or group:

- ☐ Data collection system
- ☐ Force sensor with hook
- ☐ Meter stick or ruler
- ☐ Balance
- ☐ Tinker Toys™ or other building materials
- ☐ PAScar or other cart or toy car
- ☐ Pulleys
- ☐ String

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The six simple machines, including the differences between fixed and movable pulley systems.
- How to measure mass in SI units of kilograms and grams, and length in meters.
- How to compute the ratio of two lengths (the length of an inclined plane and the height to which the plane rises).
- How to read and interpret a coordinate graph.
- The basics of using the data collection system.

Related Labs in This Guide

Prerequisites:

- Simply Forceful

Labs conceptually related to this one include:

- May the Force Be With You

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 a sensor to the data collection system �(2.1)
- 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�(7.1.3)
- Saving your experiment �(11.1)

Background

The six simple machines, which are the inclined plane, the wedge, the lever, the wheel and axle, the pulley, and the screw, can be used in combinations to produce compound machines. As with simple machines, compound machines are designed to make work easier. Work is done any time a force, such as a push or a pull, is exerted over a distance.

Work = Force x Distance
or
W = F x D

A key idea of work is the fact that the object to which a force is being applied must move *in the direction of the force*. When moving an object up an inclined plane, or "ramp," for example, the force must be applied in a direction *parallel to the ramp* in order for work to be done.

It is important to remember that no machines can change the amount of work that is done; they can change only the amount of force, the direction of the force, or the distance over which the force is applied. The m*echanical advantage* of the machine is the number of times the input force is multiplied. In a perfect world, the amount of input force would be exactly equal to the amount of output force for any machine, but even the most efficiently designed machines waste some of the input force, generally in the form of friction, which exists in all machines.

Friction is a force that opposes motion, which you may be familiar with from trying to move heavy items. Most people would rather use a hand-truck to move their filing cabinet rather than push it across the carpeted floor. Calculated values for mechanical advantage therefore never perfectly agree with experimental results.

Using a fixed pulley changes the direction of the input force, but does not multiply it; a fixed pulley has a mechanical advantage of one (it multiplies the input force by 1) Using a movable pulley gives a mechanical advantage of 2 (it doubles the input force). The mechanical advantage of an inclined plane or ramp is given by the ratio of the ramp's length to its height. The longer the ramp, the greater the mechanical advantage it has.

Using a combination of two simple machines whose mechanical advantages are both greater than 1 results in a summing effect of the applied input force. In other words, using both a ramp *and* a movable pulley multiplies the input force more than using either one of these machines by itself.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Ask students to review with their lab group members the six simple machines as discussed in the Simply Forceful activity, as well as the different arrangements of pulleys. Have students list the types of pulley arrangements and classify them by type, by direction of input force, and by change in amount of force necessary. Introduce the term "mechanical advantage" and refer to the mechanical advantage as the number that tells us by how much the input force is multiplied.

Ask students, "If a pulley has a mechanical advantage of 2, what does it do to the input force?" They should recognize that the input force is doubled, or multiplied by 2.

Show students an example of the type of inclined plane, or ramp, they will be using for this activity. Ask them how they think the ramp might affect the amount of force necessary to move an object. List their suggestions on the board. Call students' attention to the height of the ramp, and help them to see that the ramp can raise an object to that height.

Once students have considered the suggestions they listed on the board, direct their attention toward Thinking About the Question. Remind students that in this activity they are building on prior knowledge and experiences and that reviewing what they already know is a good way to prepare for extending their learning.

Preparation and Tips

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

- Students will need time to design and construct their pulley support "towers" and devise a means of connecting them to their ramps. Tinker Toys™ are ideal for these structures, as they have all the necessary parts, including the pulley wheels and string. However, if Tinker Toys™ are not available, wire coat hangers can be straightened and reshaped to support a small commercially available pulley.

- Small pulleys that are relatively inexpensive are available at all hardware stores.

- Carts and tracks are the ideal equipment for this activity. Tracks may be inclined by placing books under one end. However, if carts and tracks are not available, other materials will readily suffice. Ramps may be constructed of almost anything available including shelving from the bookcase, meter sticks taped together, portable whiteboards or chalkboards, or items students have brought from home.

- Build a prototype pulley and ramp structure ahead of time for students to see. Tell them that they are free to design their own "style" or to use your design. Be sure to check each group's structure for effectiveness.

- If you do not have access to carts, supply toy vehicles or have students bring toy vehicles from home. The activity is easier if the vehicles are more massive. A larger toy car will give better results than a smaller toy car. If students bring in toys, provide tape or other means of labeling the toys with students' names so they can be returned. If toy cars need modifications so that the force sensor hooks can be attached, provide tape, string, wire, et cetera for students to make these modifications.

- Remind students that not all the ramps need to be the same height or length. It is the *ratio* of the length to the height that determines the mechanical advantage. Make sure students are confident about their length and height measurements; suggest that lab group members check one another's measurements for accuracy and precision. If you know that students will need help computing the mechanical advantage of their ramps, lead them through one or more examples before they begin the activity.

- Install the hooks in each force sensor, if necessary.

- The clean-up time for this activity needs to be taken into consideration as you plan; you can streamline the clean-up process if you have clearly communicated the procedures to students ahead of time.

Safety

Add this important safety precaution to your normal laboratory procedures:

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

Driving Question

What happens to the amount of force needed to move an object when simple machines are used in combination?

Thinking about the Question

In the previous activity, Simply Forceful, you saw that using a simple machine such as a pulley can change the amount of input force necessary to move an object. You also discovered that a pulley can change the direction in which the input force is applied without changing the amount of input force.

As you know, there are only six simple machines, but they serve as the building blocks for almost all other machines. People invented these simple machines to help make work easier by changing either the direction or amount of input force necessary, or both. In physical science, work means using an input force to move an object.

In this activity, you will be working with two different simple machines connected together to determine how they change the direction or the amount of force necessary to move an object. You will also investigate what happens to the amount of necessary force when you change the distance through which the force is applied.

Discuss with your lab group members the way that different arrangements of pulleys change the direction or the amount of force, or both, required to lift an object off the table. Discuss in your group how ramps work, what type of simple machine they are, and how you might construct one using the materials provided in your class.

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.

2/3	1	5	4	2/3
Predict how much force will be necessary to lift a cart off the table.	Make sure each lab group member is aware of safety rules and procedures for this lab.	Compare the data for fixed and moveable pulleys.	Record force data as you pull the cart up the ramp.	Construct a ramp out of available materials.

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. What amount of force will be necessary to lift a cart off the table?

   b. How will the amount of necessary force change if the cart is pulled up a ramp to the same height?

   c. What effect will there be on the amount of force necessary to pull the cart up the ramp if one or more fixed or movable pulleys are used?

   Answers will vary. One student group answered as follows: We predict it will take at least 5 N of force to lift our truck off the table. When we pull the truck up the ramp, it will probably take less force. If we use a fixed pulley, we predict only the direction of the force will change. If we use a movable pulley, it will probably take even less force.

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

Part 2a – Lifting straight up against gravity

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

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

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

6. ☐ Hold the force sensor with its hook down, and press the “zero” button.

7. ☐ Gently attach the force sensor’s hook to your cart, using a piece of string.

8. ☐ Begin data recording. �(6.2)

9. ☐ Holding the force sensor steady, lift the cart until it is off the table and hold it in place until the force data stabilizes.

10. ☐ Stop data recording. �(6.2)

11. ☐ Observe your graph of force versus time. What do you notice about your data?

Once the force data stabilized, our cart pulled with a constant force of 7.2 N. While it was being suspended, the force on it was constant.

Part 2b – Using a ramp

12. ☐ Using materials provided, construct a ramp for your cart to travel on. Test the cart on the ramp to be sure it rolls well. How might a poorly-rolling cart affect your force data?

If it does not roll well, then it would take more force to pull it than it actually would need due to the friction which opposes the cart's motion. Our data and results would reflect this friction.

13. ☐ Measure the length and height of the ramp. Record these measurements below:

Ramp Length: 0.86 M

Ramp Height: 0.15 M

14. ☐ Place a force sensor flat on the ramp and press the “zero” button. This tells the sensor that it is measuring force parallel to the ramp. When is it important to zero the force sensor in experiments?

You have to zero the sensor anytime you change the orientation of the sensor, before recording new data.

15. ☐ Place the cart at the lower end of the ramp, ready to roll.

16. ☐ Gently attach the cart to the force sensor’s hook, using a piece of string.

17. ☐ Begin data recording. �(6.2)

18. ☐ Pull on the force sensor slowly and steadily to roll the cart up the ramp, continuing as far up the ramp as you can pull it.

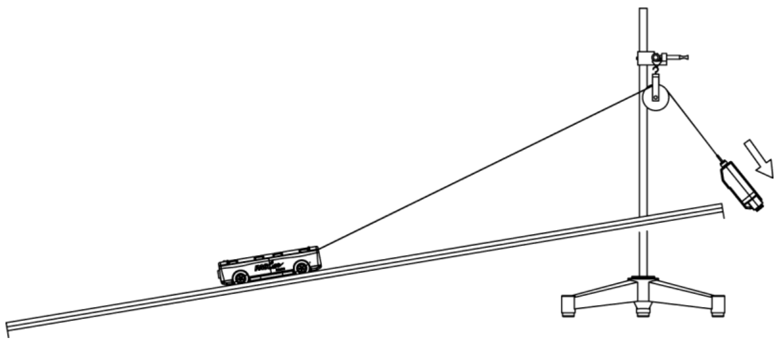
19. ☐ Stop data recording. �(6.2)

20. ☐ Observe your graph of force data. You may need to rescale your graph to see all of your data. �(7.1.2) Note below any patterns or observations you see.

Student answers will vary. One student group answered as follows: We observed that it took less force to pull the truck up the ramp than it did just to lift it straight up off the table.

Part 3 – Using pulleys and a ramp

21. ☐ Using materials as you did in the Simple Machines and Force activity, devise a fixed pulley system. You will pull the cart up the ramp by pulling down on the force sensor.



22. ☐ Test your design to make sure it works as designed. Make adjustments if necessary.

23. ☐ Press the "zero" button while the force sensor's hook is pointing down.

24. ☐ Begin data recording. �(6.2)

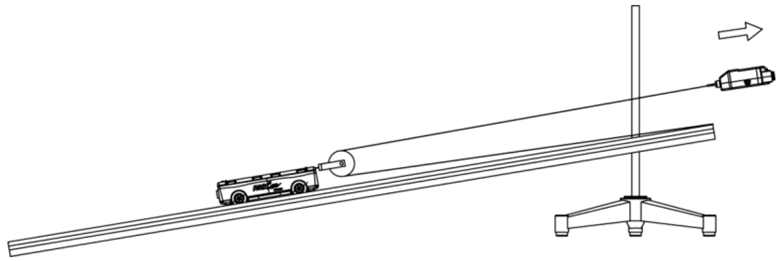
25. ☐ Pull down on the force sensor slowly and steadily, to make the cart travel up the ramp.

26. ☐ Stop data recording. �(6.2)

27. ☐ Observe your graph of force data. �(7.1.3) You may need to rescale your graph to see all of your data. �(7.1.2) Note below any patterns or observations you see:

The force for the fixed pulley was almost the same as for just lifting up the truck,even though we pulled it up the ramp with the pulley.

28. ☐ Again, using materials as you did in the Simple Machines and Force activity, devise a movable pulley system so that the pulley travels along with the cart. You will again pull the cart up the ramp by pulling on the force sensor in a direction parallel to the ramp.



29. ☐ Test your design to make sure it works as designed. Make adjustments if necessary.

30. ☐ Place the force sensor flat on the ramp and press the "zero" button.

31. ☐ Gently attach the string to the force sensor's hook.

32. ☐ Begin data recording. �(6.2)

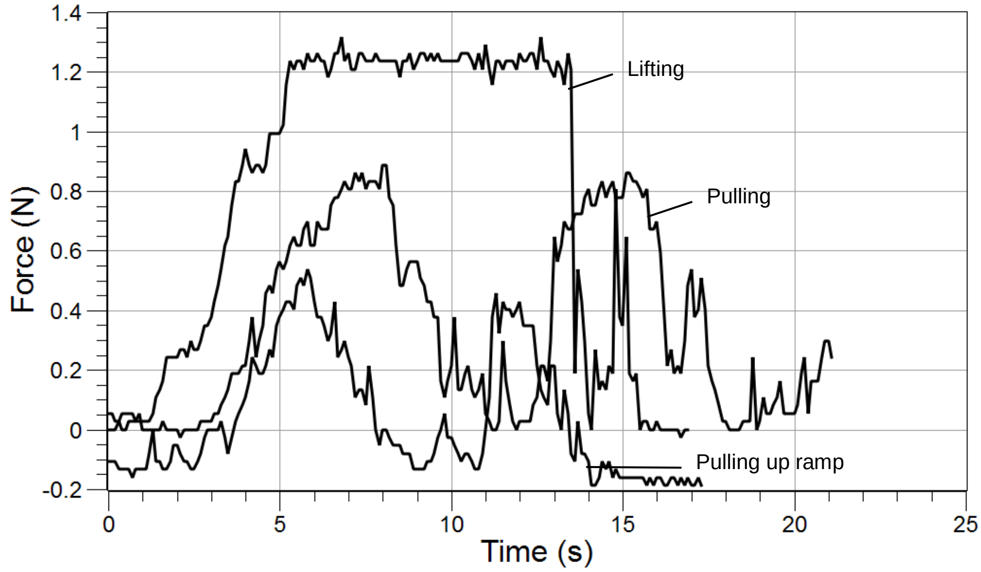
33. ☐ Pull on the force sensor slowly and steadily to roll the cart up the ramp.

34. ☐ Stop data recording. �(6.2)

35. ☐ Observe your graph of force data �(7.1.3) You may need to rescale your graph to see all of your data. �(7.1.2) Note below any patterns or observations you see:

Student answers may vary. One student group answered as follows: The force for the fixed pulley was 7.2 N, and for the movable pulley was 0.9 N.

Sample Data



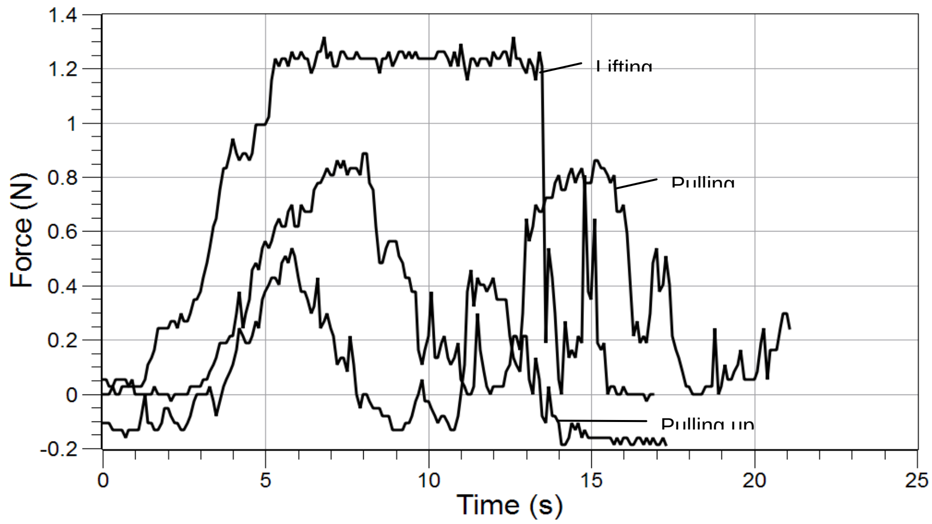
Answering the Question

Analysis

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

   Our prediction agreed with our results since it did take less force when we used the ramp and moveable pulley than when we used the fixed pulley or when we just lifted the truck straight up.

2. Sketch the graphs of force versus time from your experimental trials.



3. The ramp you constructed is an example of an inclined plane which changes the amount of input force you need to apply to lift the cart. The ramp's *mechanical advantage* tells the number of times it increases the force applied to it. The mechanical advantage of a ramp can be calculated from the following equation:

Mechanical Advantage = Length of Incline / Height of Incline

4. Using your measurements from Part 2, calculate the mechanical advantage of your ramp:

Answers will vary. One student group answered as follows:

$$\text{Mechanical advantage} = \frac{\text{length of incline}}{\text{height of incline}} = \frac{0.86\text{m}}{0.15\text{m}} = 5.73 \text{ times}$$

5. About how many times does your ramp multiply your input force on the cart compared to lifting the cart straight up to the same height?

Answers will vary. One student group answered as follows: Our ramp multiplied our force by 5.73 times (almost 6 times).

6. When a force moves an object over a distance, we say that work is done on the object. When you pulled your cart up the ramp, how was work being done on the cart?

Answers will vary. One student group answered as follows: The object we moved was our truck, which we moved by pulling it. The force was the pull. The distance was the ramp it went up.

7. How did the fixed pulley change the amount or direction of input force that was applied to the cart?

The fixed pulley did not take less force, but it did change the direction so we could pull down to move the truck up the ramp.

8. How did the movable pulley change the amount or direction of input force that was applied to the cart?

Answers will vary. One student group answered as follows: With the moveable pulley attached to our truck, it took the least amount of force to lift it up the ramp. It actually took less than 1N of force to pull the truck, compared to 7.5 N to lift it straight off the table.

9. The ramp and pulley system you constructed is an example of a *compound machine* – two or more simple machines working together. Although each simple or compound machine makes work easier, there is always a trade-off of some sort between how much force must be applied and the distance over which that force is applied. Look at your force data for the different combinations of machines as well as for lifting the cart straight up. What combination of simple machines resulted in the least amount of force necessary to move the cart off the table? Do your experimental results tend to agree or disagree with your calculations from questions 3 and 4? Explain your reasoning.

Answers will vary. One student group answered as follows: Our best combination of machines for moving our truck up with the least force was a ramp and a moving pulley attached to our truck. We calculated the mechanical advantage to be 5.73 for our ramp, meaning it multiplied our input pulling force by that amount. But in order to multiply our force by that amount, we had to pull the truck for a much longer distance (the length of the ramp) than we would have had to pull it when lifting it straight up. So, we traded distance for force.

Key Term Challenge

Fill in the blanks from the randomly ordered words below:

newtons	compound machine	work	force
pulley	mechanical advantage	input force	inclined
ramp			

1. The force applied to a machine is called the __input force_.

2. A/an _____compound machine_______ is one made from two or more simple machines.

3. A force acting over a distance to move an object is known in physical science as _______work.

4. The SI unit used to measure the force is _____newtons_______ .

5. The _____mechanical advantage_______ tells us how many times a machine multiplies the applied force. It is a ratio of the input force to the output force.

6. Any push or pull exerted on an object, whether or not it causes the object to move, is known as a/an _____force_______ .

7. A simple machine known as a/an _____pulley_______ is made from a rope, a string, or a belt wrapped around a wheel.

8. A simple machine with a flat, sloped surface that makes it easier to lift a heavy load by using less force over a greater distance is known as a/an _____inclined plane_______ .

9. A pulley that has a mechanical advantage of 3 multiplies the _____input force_______ by three times that amount.

Further Investigations

Design an investigation to see how one of the three classes of levers changes the input force.

Design an investigation to test each of the three classes of levers to find out how they change input force.

Design and test a ramp to demonstrate how the calculated (ideal) mechanical advantage differs from the experimental (actual) mechanical advantage. How close can you get the experimental mechanical advantage to match the calculated mechanical advantage?

Rubric

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