Physical Science through Inquiry

Teacher Guide

PASCO®

Contributors

PASCO Development Team

- ♦ Freda Husic, *Director of Education Solutions*, *Program Manager*
- ♦ Robert Morrison, *Curriculum and Training Developer*, *Physics*, *Lead Author*
- ♦ Amy Flindt, *Curriculum and Training Developer, Chemistry*
- ♦ Elizabeth Kennedy, *Curriculum and Training Developer, Elementary and Middle School*
- ♦ Patty MacEgan*, Curriculum and Training Developer, Earth Science*
- ♦ Jeffrey "J.J." Plank*, Curriculum and Training Developer, Physics*

Editor

- ♦ Janet Miller, *Lead Editor*

PASCO Production Team

- ♦ Tommy Bishop, *Digital Design and Production Specialist*
- ♦ Dan Kimberling, *Media Specialist*
- ♦ Susan Watson, *Production Specialist*

Physical Science through Inquiry

High School

Teacher Guide
21st Century Science

PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100
Toll Free 800-772-8700
916-786-3800
Fax 916-786-8905

Published by
PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100
800-772-8700
916-786-3800
916-786-8905 (fax)
www.pasco.com

ISBN 978-1-886998-18-6
First Edition
First Printing
Printed in the United States of America
Catalog Number: PS-2843B

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 challenges of rigorous science standard, 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	Background
Time Requirement	Pre-Lab Activity
Materials and Equipment	Materials and Equipment
Concepts Students Should Already Know	
Related Labs in This Guide	
Using Your Data Collection System	
Background	
Pre-Lab Activity	
Lab Preparation	
Safety	Safety
Sequencing Challenge	Sequencing Challenge
Procedure With Inquiry	Procedure (+ conceptual questions)
Data Analysis	Data Analysis
Analysis Questions	Analysis Questions
Synthesis Questions	Synthesis Questions
Multiple Choice Questions	Multiple Choice Questions
Extended Inquiry Suggestions	

Electronic Materials

- The storage device with PASCO materials and the storage device with ODYSSEY® materials accompany this manual. See the “Using ODYSSEY Molecular Labs” section for details on ODYSSEY software.

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. Some activities may 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).

Lab	Title	Materials and Equipment	Qty
1	**Scientific Inquiry** This lab is designed to help student familiarize themselves with their data collection system while engaging in scientific investigations.	Data Collection System PASPORT® Temperature Sensor[1] *Cup, 270-mL (9-oz)* *Hot water* *Insulating materials readily available in the laboratory (polystyrene, foil, plastic wrap, cloth, wool, packing peanuts)*	1 1 1 500 mL A variety
		CHEMISTRY	
2	**Significant Figures** Use a four scale meter stick to determine the correct number of significant figures to include when reporting a measurement or a calculated value based upon measurements.	PASCO Four Scale Meter Stick, from the PASCO Significant Figures Set – Single *Graduated cylinder, 10-mL,* *Graduated cylinder, 100-mL,* *Beaker, 100-mL,* *Irregular-shaped object* *Regular-shaped object*	1 1 1 1 1 1
3	**Density** Use a density set to determine that density is an intensive property of a substance independent of the shape or size of an object.	PASCO Density Set Balance *Beaker, 150-mL* *Graduated cylinder, 50- or 100-mL* *Metric ruler (or* caliper*)* Overflow can *String* *Water*	1 2 or 3 per class 1 1 1 1 30-cm 500 mL
4	**Phase Change** Use a fast response temperature sensor and stainless steel temperature sensor to determine how to add heat to a substance without the temperature of the substance increasing.	Data Collection System PASPORT Stainless Steel Temperature Sensor *Beaker, 150-mL or larger* *Crushed ice to fill the beaker* *Distilled (deionized) water* *Graduated cylinder, 10-mL* Hot plate Ring stand *Rock salt* *Stir rod* *Tablespoon* *Test tube rack* *Test tube, 10-mm × 100-mm* Utility clamp	1 1 2 1 104 mL 1 1 1 200 g 1 1 1 1 1

Lab	Title	Materials and Equipment	Qty
5	**Water, the Universal Solvent** Use a conductivity sensor to measure the changes in conductivity of water as substances dissolve in it and to classify substances based on their ability to dissolve in water.	Data Collection System PASPORT Conductivity Sensor Balance *Beaker for waste water* *Beakers, 250-mL* *Distilled water, 400 mL* *Graduated cylinder, 100-mL* *Pencil* *Sample paper* *Solute sample: salt (NaCl)* *Solute samples, 10 g (select two from the following: Epsom salt (MgSO4), alum (KAl(SO4)2, borax (Na2B4O7 or Na2[B4O5(OH)4], sports drink mixes that contain electrolytes, salt substitutes that contain potassium chloride (KCl)* *Stirring rod* *Sugar cube* *Thread, 40 cm* *Wash bottle with distilled water*	1 1 1 per class 1 4 400 mL 1 1 3 ~10 g 2 1 1 40 cm 1
6	**Electrolyte versus Non-Electrolyte Solutions** Use a conductivity sensor to determine which substances in sports drinks (water, sugars, or salts) are electrolytes.	Data Collection System PASPORT Conductivity Sensor *Beaker for collecting rinse water* *Distilled (deionized) water* *Funnel* *Sodium chloride solutions (0.02 M, 0.04 M, 0.06 M, 0.08 M, 0.10 M)* *Sports drink* *Sucrose solutions (0.02 M, 0.04 M, 0.06 M, 0.08 M, 0.10 M)* *Test tube rack* *Test tube, 20-mm × 150-mm* *Wash bottle filled with distilled (deionized) water*	1 1 1 50 mL 1 25 mL of each 25 mL 25 mL of each 1 6 1

Lab	Title	Materials and Equipment	Qty
7	**Properties of Ionic and Covalent Compounds** Use a conductivity sensor to determine if an unknown substance is an ionic, polar covalent, or non-polar covalent compound based on its physical properties.	Data Collection System	1
		PASPORT Conductivity Sensor	1
		Aluminum foil squares, 5-cm × 5-cm	6
		Distilled (deionized) water	30 mL
		Graduated cylinder, 10-mL	1
		Hot plate	1
		Masking tape	1
		Paraffin wax	1 g
		Spatula	1
		Stopper to fit test tubes	3
		Table salt (sodium chloride)	1 g
		Table sugar (sucrose)	1 g
		Test tube rack	1
		Test tube, 15-mm × 100-mm	5
		Tongs	1
		Unknown A (use glucose)	1 g
		Unknown B (use crayon pieces)	1 g
		Unknown C (use potassium chloride)	1 g
		Wash bottle and waste container	1
8	**pH of Household Chemicals** Use a pH sensor and common household chemicals to relate pH and hydronium ion (H_3O^+) concentration, classifying solutions as acidic, basic, or neutral.	Data Collection System	1
		PASPORT pH Sensor	1
		0.5 M Sodium bicarbonate	5 mL
		Beaker, 50-mL	2
		Bleach	5 mL
		Buffer solution pH 4	25 mL
		Buffer solution pH 10	25 mL
		Coffee	5 mL
		Graduated cylinder, 10-mL	1
		Graduated cylinder, 50-mL	1
		Lemon Juice	5 mL
		Liquid soap	5 mL
		Milk	5 mL
		Soft drink	5 mL
		Test tube rack	1
		Test tube, 15-mm × 100-mm	10
		Wash bottle and waste container	1
		Water (from the tap)	5 mL
		White vinegar (~5% acetic acid)	5 mL
		Window cleaner	5 mL

Lab	Title	Materials and Equipment	Qty
9	**Percent Oxygen in Air** Use an absolute pressure sensor to learn about the components of air and how to determine the percent of oxygen in air.	Data Collection System	1
		PASPORT Absolute Pressure Sensor	1
		PASPORT Sensor Extension Cable	1
		Quick-release connector[2]	1
		Tubing connector[2]	1
		Tubing, 1- to 2-cm[2]	1
		Beaker, 150-mL	1
		Glycerin	2 drops
		One-hole rubber stopper to fit test tubes	1
		Paper towels	As needed
		Steel wool, fine mesh (#000)	1 g
		Stir rod	1
		Test tube, 25-mm × 150-mm	1
		White vinegar (~5% acetic acid)	50 mL to 60 mL
10	**Evidence of a Chemical Reaction** Use a fast response temperature sensor to distinguish between physical changes and chemical reactions and identify unknown changes as either physical changes or chemical reactions using evidence to support your decision.	Data Collection System	1
		PASPORT Fast Response Temperature Sensor	1
		0.05 M Silver nitrate	2 mL
		0.1 M Sodium chloride	2 mL
		0.5 M Copper(II) sulfate	2 mL
		1.0 M Citric acid	2 mL
		1.0 M Sodium bicarbonate	2 mL
		1.0 M Sodium hydroxide	2 mL
		Balance	2 or 3 per class
		Beaker for collecting rinse water	1
		Beaker, 250-mL	2
		Calcium carbonate	~0.2 g
		Colored drink powder	~0.2 g
		Effervescent tablet	1
		Graduated cylinder, 100-mL	1
		Graduated cylinder, 10-mL	1
		Hot plate	1
		Lauric acid	~0.5 g
		Spatula	1
		Stir rod	1
		Test tube holder	1
		Test tube rack	1
		Test tube, 15-mm x 100-mm	7
		Wash bottle filled with distilled (deionized) water	1
		Water (from the tap)	255 mL
		Weighing paper	1
		White vinegar (~5% acetic acid)	2 mL

Lab	Title	Materials and Equipment	Qty
11	**Conservation of Matter** Use a balance to test the law of conservation of matter for both physical and chemical changes by finding the mass of the reactants before the chemicals react and the mass of the products after the reaction has occurred.	Balance *0.1 M Sodium sulfate* *0.1 M Strontium chloride* *5% Acetic acid* *Beaker, 250-mL* *Distilled (deionized) water* *Plastic soda bottle (with cap), 500-mL* *Sodium bicarbonate* *Sodium nitrate* *Test tube, 15-mm × 100-mm*	1 5 mL 5 mL 30 mL 1 10 mL 1 8 g 5 g 2
12	**Varying Reaction Rates** Use a fast response temperature sensor to study how temperature affects chemical reaction rates.	Data Collection System PASPORT Fast Response Temperature Sensor *Alka-Seltzer® tablets* *Clear plastic cups or beakers, 300-mL (10 oz)* *Graduated cylinder, 100-mL* *Room temperature water* *Water, ice-cold* *Water, warm, maintained at a constant temperature*	1 1 6 3 1 400 mL 400 mL 400 mL
13	**Endothermic or Exothermic Chemical Reactions** Use a fast response temperature sensor and absolute pressure sensor to obtain evidence of chemical reactions and to determine if the reactions are endothermic or exothermic.	Data Collection System PASPORT Fast Response Temperature Sensor PASPORT Absolute Pressure Sensor Quick-release connector[2] Barbed tubing connector[2] Tubing, 20 to 30 cm[2] Barbed tubing connector[2] *Alka-Seltzer® tablets* *Beaker or clear plastic cup, 250-mL* *Distilled water* *Erlenmeyer flask, 250-mL* *Graduated cylinder, 100-mL* *Instant hot-pack (disposable type)* *Stopper, 1-hole, for Erlenmeyer flask*	1 1 1 1 1 1 1 2 1 100 mL 1 1 1 1
PHYSICS			
14	**Position: Match Graph** Use a motion sensor to introduce the concept of representing motion as a change of position in a graphical form.	Data Collection System PASPORT Motion Sensor *Object to hold (textbook, basket ball) (optional)* Rod stand for motion sensor (optional)	1 1 1 1
15	**Speed and Velocity** Use a motion sensor to test predictions of how the speed and velocity of a cart will differ.	Data Collection System PASPORT Motion Sensor Dynamics cart Dynamics track Dynamics track end stop	1 1 1 1 1

Lab	Title	Materials and Equipment	Qty
16	**Acceleration** Use a motion sensor to introduce the concept of representing motion as a change of position in a graphical form.	Data Collection System PASPORT Motion Sensor Dynamics cart Dynamics track Dynamics track end stop Dynamics track pivot clamp Rod stand	1 1 1 1 1 1 1
17	**Introduction to Force** Use a force sensor to measure and experience contact forces, and some non-contact forces, in relation to gravity.	Data Collection System PASPORT Force Sensor Balance (optional) *Masses (at least three different values)* *Objects (textbook, ball, carts, et cetera)* Right angle clamp Rod stand Short rod	1 1 1 per class 3 Several 1 1 1
18	**Archimedes' Principle** Use a force sensor to explore the relationship between the volume of fluid displaced by a submerged object and the buoyant force experienced by that submerged object.	Data Collection System PASPORT Force Sensor Balance *Cup or beaker to catch water from overflow can* *Graduated cylinder, 25-mL (optional)* *Objects to submerge* Overflow can Right angle clamp Rod stand *Ruler* Short rod *Small cup to add water to the overflow-can* *String* *Water*	1 1 1 per class 1 1 2 1 1 1 1 1 1 25 cm 500 mL
19	**Newton's First Law** Use a motion sensor to determine the influence of force in the motion of an object, and that an object's motion is unchanged in the absence of an external force.	Data Collection System PASPORT Motion Sensor Dynamics cart Dynamics track end stop Dynamics track with feet Mass and hanger set String Super pulley with clamp	1 1 1 1 1 1 1 m 1

Lab	Title	Materials and Equipment	Qty
20	**Newton's Second Law** Use a force sensor and motion sensor to develop an understanding of the relationship between the net force applied to an object, the acceleration of the object, and the object's mass.	Data Collection System PASPORT Force Sensor PASPORT Motion Sensor Balance Dynamics Cart Dynamics Track Dynamics Track End Stop Mass and Hanger Set *String* Super Pulley with Clamp	1 1 1 1 1 1 1 1 per class 1.5 m 1
21	**Newton's Third Law** Use two force sensors to observe the relationship between an action force and the resulting reaction force.	Data Collection System PASPORT Force Sensors Hook and rubber bumpers[2] Large table clamp (optional) *Rubber band* Short rod (optional)	1 2 2 1 1 1
22	**Boyle's Law** Use an absolute pressure sensor to observe the relationship between volume and pressure of an enclosed gas at constant temperature.	Data Collection System PASPORT Absolute Pressure Sensor Quick release connector[2] Syringe, 20 mL[2] Tubing[2]	1 1 1 1 1
23	**Temperature versus Heat** Use a temperature sensor to explore the relationship between heat transfer and temperature change in various substances.	Data Collection System PASPORT Temperature Sensor[1] Balance Basic Calorimetry Set Aluminum mass, 200-g Calorimetry cup Copper mass, 200-g *Beaker, 600-mL* Hot plate *Paper clip* *String, 15-cm* *Vegetable oil* *Water*	1 2 1 per class 2 2 2 2 1 2 4 500 g 500 g
24	**Voltage: Fruit Battery/Generator** Use a voltage sensor to explore both the chemical and physical production of a potential difference.	Data Collection System PASPORT Voltage Sensor Alligator clips (one red, one black) Series/Parallel battery holders *Copper* *Zinc* *Batteries, "D" cell* *Variety of fruit*	1 1 2 3 1 piece 1 piece 3 Minimum 1 piece per student group

Lab	Title	Materials and Equipment	Qty
25	**Faraday's Law of Induction** Use a voltage sensor to explore relationships between the electromotive force generated by passing a magnet through a coil and different parameters of the magnet and coil.	Data Collection System PASPORT Voltage Sensor Coils, 200-, 400-, and 800-turn Magnets, different strengths No-Bounce pad (optional) Rod stand Three-finger clamp *Paper* *Pen or pencil* *Tape*	1 1 1 each 3 1 1 1 1 sheet 1 1 roll
EARTH SCIENCE			
26	**Radiation Energy Transfer** Use a temperature sensor to determine the effect the color of a container has on the temperature of water in the container as it is heated using radiant energy.	Data Collection System PASPORT Temperature Sensor[1] *Graduated cylinder, 100-mL* *Heat lamp (or 150-W lamp)* *Insulated pad* Radiation cans (one black, one silver) *Ring stand* *Water, room temperature*	1 2 of the same 1 1 2 2 1 0.5 L
27	**Insolation and the Seasons** Use a fast response temperature sensor to determine the effect the angle of the sun has on the temperature of a given surface.	Mobile Data Collection System PASPORT Fast Response Temperature Sensor Base and support rod *Black construction paper, 15 x 15 cm* *Cardboard, 15 x 15 cm* *Drinking straw* *Glue* *Protractor* *Scissors* *Sunlight* *Tape* *Three-finger clamp*	1 1 1 1 1 1 1 small bottle 1 1 1 1
28	**Specific Heat of Sand versus Water** Use a stainless steel temperature sensor to explore the effect energy has on the temperature of sand and water.	Data Collection System PASPORT Stainless Steel Temperature Sensors Balance *Beaker, glass, 500-mL* *Beakers, glass, 250-mL* *Insulated cup and lid, disposable* *Heat lamp or 150-W incandescent lamp* *Hot plate* *Ring stand* *Sand* *Test tube, glass, 18 x 250 mm (large)* *Tongs and hot pad* *Utility clamp* *Water*	1 2 1 per class 1 2 2 1 1 1 200 g 1 1 2 750 mL

Lab	Title	Materials and Equipment	Qty
29	**Soil pH** Use a pH sensor to determine the pH of three soil samples.	Data Collection System PASPORT pH Sensor *Beaker, 50-mL* *Beaker, 250-mL* Buffer solution pH 10 Buffer solution pH 4 *Digging tool* *Distilled water* *Graduated cylinder, 100-mL* *Paper towels* *Permanent marker* *Plastic bag, sealable, small* *Soil sample* *Stirring rod* *Wash bottle with distilled water* *Waste container*	1 1 2 3 25 mL 25 mL 1 400 ml 1 1 1 3 3 1 1 1
30	**Air Pollution and Acid Rain** Use a pH sensor to determine the effect air pollutants (CO_2, SO_2, and NO_2) have on the pH of water	Data Collection System PASPORT pH Sensor Balance *1.0 M Hydrochloric acid (HCl)* *1-hole rubber stopper for flask* *Beaker 50-mL* *Erlenmeyer flask, 50-mL* *Graduated cylinder, 50- or 100-mL* *Sodium bicarbonate ($NaHCO_3$)* *Sodium bisulfite ($NaHSO_3$)* *Sodium nitrite ($NaNO_2$)* *Tubing connector* *Tubing to fit the tubing connector* *Volumetric pipet with bulb, 10-mL* *Wash bottle containing distilled or deionized water* *Water or deionized water*	1 1 1 per class 15 mL 1 1 1 1 5 g 5 g 5 g 1 20 cm 1 1 60 m L

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

[2]These items are included with the specific apparatus or sensor used in the experiment.

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	8, 29

Activities by PASCO Equipment

This list shows the PASCO specific equipment used in each lab activity. The Chemistry Sensor is a MultiMeasure™ sensor that contains a PASPORT Absolute Pressure Sensor, a PASPORT pH Sensor, a PASPORT Stainless Steel Temperature Sensor, and a PASPORT Voltage Sensor.

Items Available from PASCO	Qty	Activity Where Used
PASCO Density Set	1	3
PASCO Significant Figure Set	1	2
PASPORT Absolute Pressure Sensor[2]	1	9, 13, 22
PASPORT Conductivity Sensor	1	5, 6, 7
PASPORT Fast Response Temperature Sensor	1	10, 12, 13, 27
PASPORT Force Sensor	1	17, 18, 20
PASPORT Force Sensor	2	21
PASPORT Motion Sensor	1	14, 15, 16, 19, 20
PASPORT pH Sensor[2]	1	8, 29, 30
PASPORT Stainless Steel Temperature Sensor[2]	1	4, 28, 26
PASPORT Temperature Sensor[1]	1	1, 23
PASPORT Temperature Sensor[1]	2	26 (2 of the same type)
PASPORT Voltage Sensor[2]	1	24, 25

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

[2]This sensor is available as part of the Chemistry Sensor

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 Physical 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.
- Keep water away from electrical outlets.
- Wear eye protection (splash-proof goggles), lab apron, and protective gloves.
- 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.
- Do not leave the lab with gloves on.
- Wash your hands after handling chemicals, glassware, and equipment.
- Know the safety features of your lab such as eye-wash stations, fire extinguisher, 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 or short pants 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 two or more in case of trouble and help is needed.
- Keep the work area neat and free from any unnecessary objects.
- If you are suffering from any allergy, illness, or are taking any medication, you must inform the instructor. This information could be 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 soft contact lenses, causing eye irritation.
- Any injury must be reported immediately to the instructor; an accident report has to be completed by the student or a witness.

Water-Related Safety Precautions and Procedures

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

Safety Precautions and Procedures Related to Electrical Equipment

- Keep water away from electrical outlets.
- Keep water away from all electronic equipment.
- Never short the terminal on a power supply, battery, or other voltage source unless instructed to do so.
- Be sure to use wire leads and patch cords that have sufficient insulation when creating electrical circuits.
- Avoid using high current (greater than 1 A) in any application for which high current is not prescribed.
- Never test battery voltage and capacity using anything other than a voltage sensor or voltmeter.

Chemical 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 sheets of the chemicals that 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 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.
- 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.
- 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.

Other Safety Precautions

- Experiments involving moving masses can be dangerous. Be aware of moving masses and avoid contact.
- If water or other materials are heated for an experiment involving heat, make sure they are never left unattended. Remember, too, that the hot plate will stay hot well after it is unplugged or turned off.
- Keep sensor extension cables and temperature probe wires away from hot plates.
- Use appropriate caution with the matches, burning splint and foods, and other hot materials.

Additional Resources

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

Chemistry

1. Significant Figures

Objectives

Determine the correct number of significant figures to include when reporting a measurement or a calculated value based upon measurements. Through this investigation, students:

- ♦ Explain the difference between precision and accuracy
- ♦ Rank the precision of different instruments
- ♦ Record the values of length and volume measurements to the proper number of significant figures
- ♦ Record the result of a calculation utilizing measurements to the proper number of significant figures

Procedural Overview

Students conduct the following procedures:

- ♦ Use meter sticks with various scales to record the dimensions of different objects to the proper number of significant figures
- ♦ Use recorded measurements to calculate volumes (multiplication and addition) and report the results with the correct number of significant figures

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	45 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each group:

- ♦ Four-scale meter stick
- ♦ Graduated cylinder, 100-mL, partially filled with water
- ♦ Graduated cylinder, 10-mL, partially filled with water
- ♦ Beaker, 100-mL, partially filled with water
- ♦ Irregular-shaped object
- ♦ Regular-shaped object

Concepts Students Should Already Know

Students should be familiar with the following concepts:

♦ Units of measure for quantities such as volume, mass, and length

♦ Metric-to-metric unit conversions

Related Labs in This Guide

Since the experiments throughout this guide require that data be collected and calculations be made using significant figures, all labs in this guide are related to this one.

Using Your Data Collection System

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

Note: There are no Tech Tips to list in this section as this activity does not use a data collection system.

Background

One of the foundations of science is the collection of data by properly recording measurements. In order for a reported measurement to be useful, it needs to be reliable. Data is reliable if it is both valid and reproducible. The terms accuracy and precision are used when discussing the reliability of scientific data.

Accuracy refers to how closely a measured or calculated value agrees with an accepted value. Accurate measurements can only be recorded if the instrument used has been properly calibrated.

Precision refers to how closely individual measurements or calculations of the same item agree with each other. In other words, it refers to the ability to reproduce the same answer each time the same measurement is made. The precision of a value depends on the instrument being used and can be expressed using significant figures. Significant figures are all of the digits that are known for certain, plus a final estimated digit. This convention automatically indicates the uncertainty in the measurement. It is always important to record scientific results to the correct number of significant figures so that the uncertainty of a measurement will always be known to anyone reviewing the data.

Four rules are used to determine the number of significant figures in a measured quantity:

1. All non-zero digits are significant. (3.42 has three significant figures)

2. All zeros between two non-zero digits are significant. (303.02 has 5 significant figures)

3. All leading zeros that precede the first non-zero digit are never significant. (0.0034 has 2 significant figures) These zeros are there simply to hold place values.

4. Trailing zeros that follow the last non-zero digit are only significant if there is a decimal point in the number. For example, 3400. has 4 significant figures and 3.40 has three, but 3400 only has 2. Here, the decimal point is used to indicate if the zero is simply holding a place value (as in 3400) or whether it was actually a recorded value and has meaning (as in 3400. and 3.40). The difference between 3.40 (with three significant figures) and 3.4 (with two significant figures) is that the hundredths place in 3.40 is known to be exactly zero and not possibly a one or a nine. In 3.4, the value of the digit in the hundredths place is unknown, often because the instrument used to measure the quantity was not precise enough (for example, it lacked markings on the scale) for estimating the hundredths place.

Science often requires the mathematical manipulation of data through addition, subtraction, multiplication, and division. Calculators, as well as data collection systems, often report answers and measurements with every digit that can fit on the screen. Unfortunately, these values are often unrealistic in terms of the number of digits that actually have meaning. For this reason, when performing mathematical operations, additional rules must be followed when expressing the answer to the correct number of significant figures.

When adding and subtracting, the answer should have the same number of decimal places as the least precise measurement (the value with the least number of decimal places). When multiplying and dividing, the answer should have the same number of significant figures as the measurement with the fewest number of significant figures. Often, this requires rounding the result of a calculation to the proper number of significant figures. Although more robust rules for rounding scientific data exist, this guide uses the simpler rules that students are most likely already familiar with:

- ♦ If the digit immediately to the right of the one to be rounded is 5 or greater, the value increases.
- ♦ If the digit immediately to the right of the one to be rounded is 4 or less, the value remains unchanged.
- ♦ The results of intermediate calculations (those to be carried through as part of additional calculations) should not be rounded; any necessary rounding should be performed only on the absolute final result.

Pre-Lab Discussion and Activity

Accuracy versus Precision

Show the following figures representing accuracy and precision, and discuss the difference between accuracy and precision. Explain that the goal of an experimenter is to get all the dots into the very center of the target. Dots representing data points that are closest to the center of the target are closest to the accepted value and have high accuracy. The closer the dots are grouped to each other, the higher the precision of the measurements.

Figure 1

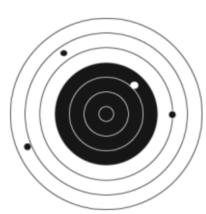


Figure 2

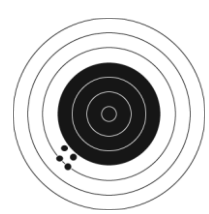


Figure 3

1. Use the terms accurate and precise to describe the results portrayed in Figure 1.

Precision refers to how close the measurements are to each other; accuracy describes how close the data are to the desired, accepted value. The dots are both accurate and precise. They are accurate, because they are all near the center of the bull's-eye (the desired result). They are precise, because they are all close to one another.

2. Use the terms accurate and precise to describe Figure 2.

In Figure 2, the dots are far apart from each other and are not in the center. Therefore, the data is neither precise nor accurate.

3. Use the terms accurate and precise to describe Figure 3.

In Figure 3, the dots are all very close to each other; however, they are not near the center of the target. Even though the dots are precise, they are not accurate.

Accuracy and Precision of Scientific Measurements

To emphasize the importance of taking consistent measurements, have the students take turns measuring the length of the same index card using rulers. Record the values on the board. While discussing the results, the students should agree there exists only one correct answer; this allows for the introduction of the topic of accuracy. Introduce the concept of precision by having the students discuss the number of decimal places the rulers were able to produce.

The accuracy and precision of data collected during an experiment depends on many factors including the procedure followed, the experimenter's technique, and the precision of the instruments used to collect the data. To assess an experiment's accuracy and precision, statistics are used. The accuracy of a result can only be determined if the average experimental value from replicate data can be compared to an accepted value. Percent error is often used to quantify a result's accuracy.

$$\textbf{percent error} = \frac{|\textbf{accepted value} - \textbf{experimental value}|}{\textbf{accepted value}} \times \textbf{100}$$

The precision of a result is determined by the standard deviation of the average value. The smaller the standard deviation, the better the precision. The average (μ) is found by:

$$\mu = \frac{x_1 + x_2 + \ldots + x_{N-1} + x_N}{N},$$

where x is the value of an individual result and N is the number of replicates. If desired, the formula for standard deviation can be given. The standard deviation (σ) is found by:

$$\sigma = \sqrt{\frac{(x_1 - \mu)^2 + (x_2 - \mu)^2 + \ldots + (x_{N-1} - \mu)^2 + (x_N - \mu)^2}{N}},$$

where μ is the average value, x is the value of an individual result, and N is the number of replicates. The following question may be added: What is the standard deviation for the length of the index card? The standard deviation of the length of the index card to the hundredths place using the sample data below is 0.02 cm.

4. What is the length of the index card?

Values will vary depending on the size of the card and the precision of the ruler used. Example values are: 12.66 cm, 12.64 cm, 12.65 cm, and 12.68 cm.

5. If we are all measuring the same card, how many answers should there be?

One.

6. What term is used to refer to the idea that there is only one correct or accepted value?

Accuracy.

7. What is the precision of the rulers used to measure the index card?

Precision is indicated by the number of decimals places recorded. Because the rulers were able to measure to the hundredths of a centimeter, the rulers had a precision of 0.01 cm.

8. What is the average result for the length of the index card?

(12.66 cm + 12.64 cm + 12.65 cm + 12.68 cm) = 50.63 cm / 4 = 12.6575 cm → 12.66 cm

The average length of the index card using the example values to the hundredths place is 12.66 cm.

9. If the accepted or true value of the length of the index card is 12.65 cm, what is the percent error of the experimental result?

$$\textbf{percent error} = \frac{|\textbf{accepted value} - \textbf{experimental value}|}{\textbf{accepted value}} \times \mathbf{100}$$

$$\text{percent error} = \frac{|12.65\text{ cm} - 12.66\text{ cm}|}{12.65\text{ cm}} \times 100 = 0.08\%$$

Accuracy and Calibration

For this activity, one half of the class will use an 80-cm stick scaled with a 100-division label and the other half will use Side C of the four-scale meter stick (1 mm precision) to measure an object (for example, a textbook). This will allow half of the class to obtain precise but inaccurate measurements and the other half to obtain measurements that are both precise and accurate. Place a number line on the board and have the students record their answer on a data pointer and then position it on the number line. After all the groups have submitted their answers, write the true value for the length of the object on a data pointer and add it to the number line.

Teachers Tip: All the items required for this activity are available with the PASCO Significant Figures Set, or individually: Meter Stick Label 80 cm/100 div, Four-Scale Meter Stick, Number Line, and Data Pointers.

10. What is the length of the chemistry textbook? Record the result on a data pointer and place it on the number line

Samples results: 35.1 cm, 35 cm, 28.2 cm, 34.9 cm, 28.3 cm, 28.5 cm, 35.2 cm, 28.2 cm

In this example, the correct value will be taken as 28.2 cm. The results near 35 cm are from the improperly scaled meter stick (80-cm stick with 100 divisions).

11. How many correct answers should there be?

There should be only one correct answer because the same book is being measured.

12. **Look at the measurements on the data pointers posted on the number line. Which measurements were precise?**

Precise measurements will be clustered closely together with other measurements. Data pointers that are isolated by themselves are not precise. Answers will vary by class.

13. **Which measurements on the number line were accurate?**

Accurate measurements will be close to the data pointer with the correct value. Answers will vary by class.

14. **Can results be precise but not accurate? Explain. Which measurements on the number line are precise but not accurate?**

The groups measuring with the shorter meter stick label should give results that are precise (clustered together) but not accurate (not near the data pointer with the correct value).

Precision and Significant Figures

The number of significant figures that can be used in a measurement depends on the number of divisions on the scale of the measuring device being used.

Use magnified pictures of two different graduated cylinders, similar to the ones below, to demonstrate how to take measurements with the correct number of significant figures. Including both a 100-mL and a 10-mL graduated cylinder will produce different levels of precision based on the number of divisions on their scales. All the digits that are known for certain (the marked divisions) plus one estimated digit (between the two smallest divisions) are significant. Because of attractions between the glass and the water molecules, the surface of the water inside the graduated cylinder is curved. This curve is called a meniscus. The meniscus can extend across many division lines on the scale of the cylinder, so the measurement is read at the meniscus's lowest point (the bottom).

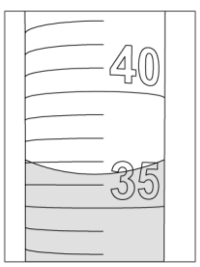


Figure 4: Graduated cylinder, 100-mL

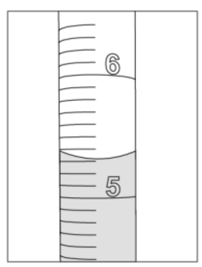


Figure 5: Graduated cylinder,10-mL

15. **When using a given piece of equipment, how can the number of significant figures for a measurement be determined?**

Only the significant figures should be recorded. Significant figures include all the digits that are known for certain plus one estimated digit.

16. **On a graduated cylinder made from glass, the liquid may form a curved line instead of a line straight across the cylinder. What is this curve called and where should the measurement be taken?**

The curve is called the meniscus, and the measurement should be taken at the bottom of the meniscus.

17. What is the volume of the liquid in Figure 4?

It is certain that the meniscus is above the 36-mL mark (the certain digits), but it is not known exactly how much beyond the mark. Because it appears approximately halfway, the final digit must be estimated as 0.5, giving a complete reading of 36.5 mL. Other acceptable answers would be 36.4 mL, or 36.6 mL.

18. What is the volume of the liquid in Figure 5?

It is certain that the meniscus is above the 5.3-mL mark (the certain digits), but it is not known exactly how much beyond the mark. Because it appears only slightly above the mark, the final digit can be estimated as 0.02; the volume should be recorded as 5.32 mL.

19. Which of the two graduated cylinders is the more precise? Explain.

The 10-mL graduated cylinder in Figure 5 is the more precise. The divisions on this cylinder mark every tenth of a milliliter, whereas the divisions on the larger graduated cylinder only mark every whole milliliter.

20. Which digit in each of the measurements is the least reliable? Explain.

The last digit in each measurement is the least reliable because it had to be estimated.

Calculations with Significant Figures

Demonstrate the need for significant figures as they apply to mathematical calculations. Carefully measure 50.0 mL of water into a graduated cylinder. Also, fill a glass jar with no measurement markings with approximately 50 mL of water (not measured). Explain that the water in the graduated cylinder is known to a greater level of precision than that in the glass jar. Add the water from the cylinder to that in the glass jar. Discuss the total amount of water and the precision of the known volume now in the jar. Explain the rules for determining the number of significant figures to be reported in the result of a mathematical calculation. Demonstrate rounding a calculated value to the proper number of significant figures.

21. Is the fifty milliliters in the graduated cylinder or the fifty milliliters in the glass jar more precise? Explain.

The 50.0 mL in the graduated cylinder is more precise because the graduated cylinder is marked with lines that indicate each milliliter, whereas the jar has no divisions at all.

22. After adding the 50.0 mL from the graduated cylinder to the glass jar, how much water is in the jar?

Even though the water from the graduated cylinder had a more precise measurement, the final volume cannot be as precise because one of the measurements was not (the initial volume of water in the glass jar). The final answer can never be more precise than the least precise measurement (measurement with the fewest number of known decimal places).

50.0 mL	(graduated cylinder, tenths place known, 3 significant figures)
50 mL	(glass jar, tens place known, 1 significant figure
100 mL	(total, tens place known, 2 significant figures)

23. What is the answer, to the correct number of significant figures, when adding 12.11, 18.0, and 1.013? Explain your reasoning.

12.11	
+18.0	least precise measurement has one decimal place
1.013	
31.123	→ 31.1

The answer should only have one decimal place, because the final answer can only be reported to the precision of the least precise measurement.

24. What is the answer, to the correct number of significant digits, when multiplying 4.56 by 1.4?

When multiplying and dividing, the answer should have the same number of significant figures as the measurement with the fewest number of significant digits.

4.56 (three significant figures) x 1.4 (two significant figures) = 6.384, which should be rounded to 6.4 to have two significant figures.

Lab Preparation

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

1. Part 1 requires an object of irregular shape. Note the length of the object for later assessment of student work.
2. Part 2 requires an object of a regular geometric shape. Note the length, width, and height of the object for later assessment of student work.
3. Part 3 requires a 100-mL beaker, a 100-mL graduated cylinder labeled “cylinder 1”, and a 10-mL graduated cylinder labeled “cylinder 2”. Fill each with various volumes of water, noting the individual volumes for later assessment of student work. Food coloring may be added to the water to assist the students in seeing the volume easier.

Teacher Tip: For the most efficient use of time and equipment, the class should be divided into small groups and cycled through the experimental procedure set up as three separate stations throughout the laboratory. Replicate stations for each part can be created for larger class sizes. Make sure that each station will produce identical results (objects are of the exact same dimensions and water volumes are exactly equivalent).

Safety

Follow all standard laboratory procedures

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	3	1	5	4
Measure the object and record all of the digits that are known for certain based on the divisions on your measuring device.	Record the last digit by estimating where the object being measured falls between two divisions on your measuring device.	Determine the scale on the measuring device you are using.	Complete the necessary calculations and report the calculated value using the correct number of significant figures.	Continue by recording all additional the measurements using the correct number of significant figures.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Collect Data

Part 1 – Precision of Instruments

1. ☐ Measure the length of the irregular shaped-object provided using each side of the four-scale meter stick: Side A has the largest divisions; Side D, the smallest. Use the proper number of significant figures, remembering to estimate your final digit. Include the proper units for each measurement. Record your results in Table 1 below.

Object measured: Xplorer GLX®

Table 1: Irregular-shaped object's measurements

Length Measured with Side A	Length Measured with Side B	Length Measured with Side C	Length Measured with Side D
0.3 m	2.3 dm	22.6 cm	22.35 cm

2. ☐ What is the value of the divisions on each side of the four-scale meter stick? Record your answers in Table 2 below.

Table 2: Four-scale meter stick divisions

Side	Size of Divisions
A	1 m
B	1 dm
C	0.5 cm
D	1 mm

Part 2 – Volume Calculations with Significant Figures

3. ☐ Measure the length of the object using side B of the four-scale meter stick. Record the length using the correct number of significant figures in Table 3.

4. ☐ Measure the width of the object using side C of the four-scale meter stick. Record the width using the correct number of significant figures in Table 3.

5. ☐ Measure the height of the object using side D of the four-scale meter stick Record the height using the correct number of significant figures in Table 3.

Object measured: cardboard box

Table 3: Regular-shaped object's measurements

Length (Side B of meter stick)	Width (Side C of meter stick)	Height (Side D of meter stick)
31 cm	45.3 cm	61.32 cm

Part 3 – Addition Problems with Significant Figures

6. ☐ Record the volume of the liquid in the beaker in Table 4 using the correct number of significant figures.

Table 4: Volume of liquid in the beaker

Beaker Volume	Cylinder 1 Volume	Cylinder 2 Volume
61 mL	32.1 mL	83.23 mL

7. ☐ Look at the liquid in the graduated cylinders and notice the curve on the surface of the liquid. This is the meniscus. Why does the water curve upward towards the sides of the glass? Should you measure from the top or the bottom of the meniscus?

The water curves upward towards the sides of the glass because the water molecules are attracted to the glass. The liquid should be measured from the bottom of the meniscus.

8. ☐ Measure the volume of the liquid in cylinder 1 and record the volume in Table 4 using the correct number of significant figures.

9. ☐ Measure the volume of the liquid in cylinder 2 and record the volume in Table 4 using the correct number of significant figures.

10. ☐ Clean-up your lab station according to the teacher's instructions.

Data Analysis

Part 1 – Precision of Instruments

1. ☐ Convert all the irregular-shaped object's measurements to centimeters and record them in Table 5.

Table 5: Irregular-shaped object's measurements in centimeters

Side of Ruler Measuring the Object	Show Your Work Converting to cm	Length (cm)
Side A	$0.3\text{ m} \times \frac{100\text{ cm}}{1\text{ m}} = 30\text{ cm}$	30
Side B	$2.3\text{ dm} \times \frac{10\text{ cm}}{1\text{ dm}} = 23\text{ cm}$	23
Side C	Conversion not needed	22.6
Side D	Conversion not needed	22.35

2. ☐ Record this data (Group 1) as well as the data collected by two other groups in Table 6.

Table 6: Irregular-shaped object's measurements collected by three different groups

Group	Side A of Meter Stick (cm)	Side B of Meter Stick (cm)	Side C of Meter Stick (cm)	Side D of Meter Stick (cm)
1	30	23	22.6	22.35
2	20	22	22.4	22.41
3	20	24	22.5	22.39

3. ☐ When given a group of data values, how can you determine if the data is precise?

Precise data will produce the same values every time the same measurement is taken. The closer the values are to each other, the more precise the data.

4. ☐ Which side of the meter stick allowed for the greatest precision? Explain.

Looking at the data table, the measurements taken with Side D of the meter stick were clustered closer together than the measurements taken with the other sides.

5. ☐ Which side of the meter stick showed the least amount of precision? Explain.

Looking at the data table, the measurements taken with Side A of the meter stick were the farthest apart in value.

6. ☐ Rank the sides of the meter stick in order of least to greatest precision.

Side A < Side B < Side C < Side D.

Part 2 – Volume Calculations with Significant Figures

7. ☐ Convert all the regular-shaped object's measurements to centimeters with the correct number of significant figures and record them in Table 7 (as Group 1).

8. ☐ Enter the data collected by two other lab groups in Table 7.

Table 7: Regular-shaped object's measurements and calculated volume

Group #	Length: Side B of Meter Stick (cm)	Width: Side C of Meter Stick (cm)	Height: Side D of Meter Stick (cm)	Volume of Object (cm^3)
1	31	45.3	61.32	86000
2	61	32.4	45.28	89000
3	44	61.4	32.08	87000

9. ☐ How can the volume of a regular-shaped object be calculated?

volume = length x height x width

10. ☐ Calculate the volume of the object with the data collected from each lab group. Record the answer in Table 7. Be sure to use the correct number of significant figures.

31 cm x 45.3 cm x 61.32 cm = 86111.676 cm^3 → 86000 cm^3

11. ☐ Explain how the number of significant figures was decided when recording the volume.

Since calculating volume requires multiplication, the answer is limited to the number of significant figures in the number with the least number of significant figures. The length, which was measured with side B, has only two significant figures; thus, the answer could only be reported with two significant figures.

Part 3 – Addition Problems with Significant Figures

12. ☐ Without actually combining the contents of the glassware, mathematically add the recorded measurements to produce a result that represents the total amount of liquid present in all three containers taken together. Record the value with the correct number of significant figures in Table 8 (as Group 1).

Table 8: Total volume of liquid

Group #	Beaker Volume (mL)	Cylinder 1 Volume (mL)	Cylinder 2 Volume (mL)	Total Volume (mL)
1	61	32.1	83.23	176
2	62	32.3	83.22	178
3	61	32.4	83.23	177

13. ☐ Explain how the number of significant figures was decided when recording the total volume.

Since combining volume requires addition, the sum must be recorded using the same number of decimal places as the measurement with the fewest decimal places (least precision). The volume in the beaker could only be measured to whole milliliters; thus, the answer could only be reported with the same precision (whole milliliters).

14. ☐ Collect the volumes recorded from two other lab groups and record them in Table 8.

15. ☐ Which of the three pieces of glassware provided the most precise measurement? Was this precision seen in the final volume?

The 10-mL graduated cylinder (Cylinder 2) provided the most precise measurement (0.01 mL). This precision was not seen in the final volume, because the final volume was limited by the volume in the beaker which was the least precise (1 mL).

Analysis Questions

1. Do significant figures relate to the accuracy or the precision of the measurement?

Significant figures are closely related to the precision of a measurement because it reports the uncertainty in a measurement. Accuracy is how close a measurement is to its true/accepted value which will depend on the calibration of the measuring device.

2. Explain the reasoning behind the rules for adding, subtracting, multiplying, and dividing with significant figures.

Significant figures reflect the amount of uncertainty in a measurement. When two or more numbers are combined in a mathematical operation, the uncertainty in the least precise measurement will carry over into the final answer. The final answer must display the same amount of uncertainty as the least precise measurement.

3. What determines the number of significant figures in a recorded value?

The number of significant figures is determined by the precision of the measuring device used to make the measurement.

4. What determines the number of significant figures in a calculated value?

If the result is from a multiplication or a division calculation, then the number of significant figures in the answer will be the same as the value with the least number of significant figures.

If the result is from an addition or a subtraction calculation, then the number of decimal places in the answer (precision of the answer) will be the same as the value with the least number of decimal places (least precise measurement).

Synthesis Questions

Use available resources to help you answer the following questions.

1. The density of copper is listed as 8.94 g/mL. Two students each make three density determinations through experimentation. Student A's measurements are 6.3 g/mL, 8.9 g/mL, and 11.1 g/mL. Student B's measurements are 8.3 g/mL, 8.2 g/mL, and 8.4 g/mL. Compare the two sets of results in terms of precision and accuracy.

Student A displayed less precision but more accuracy (due to the one measurement that was very close to the accepted density). Student B displayed less accuracy but more precision (due to having all three measurements fairly close to one another).

2. Five different students take the following measurements of the same object: 1.3 m, 1.5 m, 1.45 m, 1.47 m, and 1.453 m. Why are the measurements different? Which measurement is correct?

The measurements are different because the students used different instruments of varying precision to measure the object. All the measurements may be recorded "correctly" according to the degree of precision of each instrument. The instrument that gave the value of 1.453 however, offers the greatest amount of precision.

3. A student reported finding the mass of an object to be 350 grams. How many significant figures are in this number and which digit has uncertainty?

There are two significant digits in this number (3 and 5). There is uncertainty in the tens digit (5) because it was estimated. The zero is simply holding the place value and is not significant.

Multiple Choice Questions

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

1. Which of the following numbers does NOT have 2 significant figures?

- **A.** 2300
- **B.** 0.000030
- **C.** **51.0**
- **D.** 30.

2. Using the rules of significant figures, calculate the following: (6.167 + 83) / 5.10

- **A.** 17.48
- **B.** **17**
- **C.** 17.5
- **D.** 20

3. The amount of uncertainty in a measured quantity is determined by:

- **A.** The skill of the observer only
- **B.** Neither the skill of the observer nor the limitations of the measuring instrument
- **C.** The limitations of the measuring instrument only
- **D.** **Both the skill of the observer and the limitations of the measuring device**

4. How many significant figures are there in 0.0503 grams?

- **A.** 5
- **B.** 4
- **C.** **3**
- **D.** 2

5. If you need exactly 7.00 mL, which measuring device would you recommend?

- **A.** A 50-mL beaker
- **B.** A 50-mL graduated cylinder
- **C.** **A 10-mL graduated cylinder**
- **D.** A 100-mL graduated cylinder

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. When collecting data for an experiment, it is important to note certain qualities of that data. The **accuracy** of the data is a measure of how close the results are to an expected or accepted true value. The **precision** of the data is how close the results are to each other and is a measure of the repeatability of the results. The precision of an instrument is reported by using **significant figures**; these consist of all the digits of a measurement that are **known** for certain plus one **estimated** digit.

2. To determine the number of significant figures in a measurement, a set of rules is followed. All **non-zero** digits are significant. Zeroes between non-zero digits **are** significant. Leading zeroes before non-zero digits **are not** significant. Zeroes that end a measurement are significant only if there is a **decimal point** in the number.

3. Knowing how many significant figures are in a number is important because they are used when **measurements** are used in calculations. In **multiplication** and **division**, the number of significant figures depends on the measurement with the **fewest** number of significant figures. In **addition** and **subtraction**, the number of digits depends on the number of **decimal places** in the **least** precise number used in the calculation. To report an answer with the correct number of significant figures often requires the final answer to be **rounded**; digits **five** or greater will **be rounded up**, while **four** or less will **remain unchanged**.

Extended Inquiry Suggestions

Measure the diameter and height of a beaker. Calculate the circumference, area, and volume of the beaker using proper significant figures.

Include mass as a quantity to be measured. Use various balances with different levels of precision.

Using a centigram balance (precision of 0.01 g), measure the weight of the same amount of water transferred using various pieces of glassware (beaker, 10-mL graduated cylinder, 50-mL graduated cylinder). Plot the results on a number line to further demonstrate the precision and accuracy of the different pieces of glassware.

2. Density

Objectives

Determine that density is an intensive property of a substance independent of the shape or size of an object. Through this investigation, students:

- ♦ Determine the volume of regular- and irregular-shaped objects using geometric calculations and water displacement methods
- ♦ Use mass and volume data to calculate density using the formula, $\text{density} = \dfrac{\text{mass}}{\text{volume}}$
- ♦ Distinguish between intensive and extensive properties
- ♦ Learn that density is an intensive physical property that can be used to identify unknown substances

Procedural Overview

Students conduct the following procedures:

- ♦ Determine the volume of regular-shaped objects through geometric calculation
- ♦ Determine the volume of irregular-shaped objects through water displacement
- ♦ Measure the mass and volume of various objects and calculate the density by dividing the two values
- ♦ Identify the material a plastic cylinder is made from when given a list of substances and their corresponding densities

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	25 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- ♦ PASCO density set
- ♦ Beaker, 150-mL
- ♦ Overflow can
- ♦ Metric ruler (or calipers)

- Graduated cylinder, 50- or 100-mL
- Balance (2 to 3 per class)
- Water, 500 mL
- String

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Mass measurements
- Volume measurements
- Length measurements
- Physical properties
- Geometric mathematical formula for a cube and a cylinder

Related Labs in This Guide

Labs conceptually related to this one include:

- Significant Figures
- Density

Using Your Data Collection System

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

Note: There are no Tech Tips to list in this section as this activity does not use a data collection system.

Background

A substance can often be identified by its physical properties. For example, a substance that melts at 0ºC and boils at 100ºC might very well be water, especially if that substance is a clear, colorless, odorless liquid at room temperature. Boiling point, melting point, color, and odor are examples of intensive properties. Intensive properties are those that are independent of how much of the substance is being measured. All water, from a small amount contained in a glass to a large amount contained in a swimming pool or a fresh water lake, freezes at 0°C and boils at 100ºC.

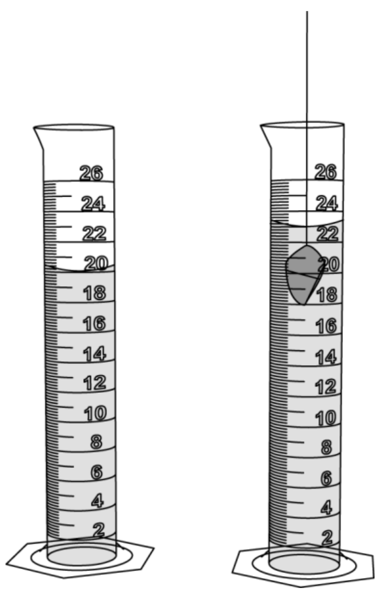
Some properties, however, depend on the amount of substance present. An extensive property changes as the amount of the substance being measured changes. Mass (weight) and volume are both examples of extensive properties. The water in a glass takes up less space and is not as heavy as the water in a swimming pool, even though both contain the same chemical substance.

Objects of the same size might not necessarily have the same mass. For example, an object made from foam weighs less than a lead object of the same size. Density is an intensive physical property of a substance that relates an object's mass to its volume. It is not an extensive property dependent on size because as a sample's mass increases, the sample's volume also increases proportionately. Many substances have similar densities, so density should be used along with other properties to positively identify a substance.

An object's density (ρ, "rho") determines whether it floats in a particular substance. To float, the density of the substance must be less than the density of the fluid in which the object is placed. At room temperature and to two significant figures, water has a density of 1.0 g/mL. This means that objects with densities less than 1.0 g/mL float in water. The fluids are not limited to liquids. For example, helium (ρ_{He} = 0.18 g/L) floats when trapped in a balloon because the density of the surrounding air is much greater (ρ_{Air} = 1.19 g/L).

To calculate density, both the mass and volume of an object must be known. Mass can be found directly using a balance (triple-beam or electronic). To calculate an object's volume, you have two options: 1) If the object has a regular shape, such as a cube or a cylinder, the volume can be calculated using the corresponding mathematical formula for that shape. 2) If the object has an irregular shape, the volume must be determined through other methods, such as water displacement.

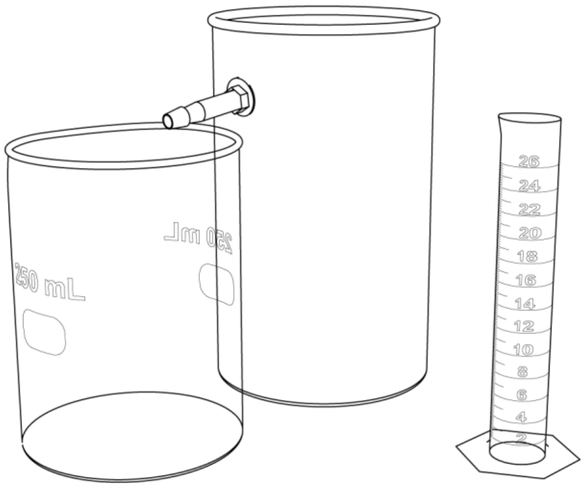
Based on the fact that two objects cannot occupy the same space at the same time, an object that sinks in water displaces a volume of liquid that is equal to its own volume. By submerging an irregular-shaped object in water, it is possible to deduce its volume by measuring the increase of the water level.



In this diagram a small rock caused the water volume to increase from 20 mL to 23 mL. The volume of the rock, therefore, is 3 mL.

Measuring volume of an irregular-shaped object using water displacement.

If the object does not fit into a graduated cylinder, the object can be placed into an overflow container. The water spills out of the container and into a collection beaker. The volume of the water collected in the beaker can then be measured using a graduated cylinder.



Overflow container with a beaker and graduated cylinder.

When the mass and volume have been determined, the density can then be calculated by dividing the two quantities.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Pre-Lab Discussion and Activity

Intensive and Extensive Properties

Use two bottles of soda (same brand and flavor) to demonstrate intensive and extensive properties. Show a small bottle (500-mL) next to a large bottle (2-L). Explain that extensive properties depend upon the amount of substance being measured—larger quantities produce greater values for the extensive property. Intensive properties, however, do not depend upon how much substance is being measured—the value of the property remains constant regardless of how large the quantity.

1. Look at the contents in the two bottles of soda. Are they the same?

If the brand and flavor are the same, the contents should be identical in all regards: taste, sweetness, color, carbonation, and so on.

2. Does the amount of soda you have matter when you decide how large a bottle should be used to contain it?

Yes. The more soda you have, the larger the bottle needs to be.

3. Is volume an intensive or extensive property of soda?

Because the volume increases as you increase the amount of soda you have, volume is an extensive property.

4. Think about the taste of the soda inside the bottles. Does the flavor of the soda change depending on the amount of soda you drink?

No. The taste remains the same no matter how much you pour into a glass.

5. Is flavor an intensive or extensive property of soda?

The taste remains the same no matter how much you drink; therefore flavor is an intensive property.

Density and Archimedes

Relate the following story of Archimedes: Around 250 B.C., King Hiero II wanted a new crown. He gave a block of gold to a goldsmith to use for the crown. The king was suspicious that the goldsmith might keep some of the gold and substitute a less expensive metal, coating only the outside of the crown with gold. The king asked the famous Greek philosopher, Archimedes, to determine if the crown was gold without damaging it. Archimedes knew if it were made of pure gold, the crown would have the same intensive properties as a bar of gold. Archimedes thought long and hard about the problem knowing he couldn't scratch the surface of the crown or melt any part of it. One day, as he stepped into his bathtub, the water spilled over the edge of the bathtub and onto the floor. This helped Archimedes figure out the solution to his problem. He was so excited he jumped out of the tub and forgot to get dressed! He ran through the streets without his clothes shouting "Eureka!" ("I have found it!") on his way to tell the king his idea.

Simulate Archimedes' problem by wrapping same sized blocks of aluminum, iron, and lead with masking tape (or paint these blocks with gold-colored paint). The masking tape or paint represents a thin layer of gold coating the less expensive metal inside. Inform the students they are not allowed to scratch through the surface coating.

6. What is the same about the blocks?

The blocks have the same size (volume) and they have the same outside appearance.

7. What is different about the blocks?

The blocks have different masses (weigh different amounts).

8. Why was the overflowing bathtub important to Archimedes' problem?

The amount of water that overflowed was equal to his volume. He reasoned that the crown's volume could be determined the same way. Finding the crown's mass was straightforward. By finding the ratio of the mass and the volume of the crown, Archimedes could compare the densities of the crown with a sample of real gold.

Regular Soda and Diet Soda

Use four bottles of soda (500-mL and 2-L of soda along with 500-mL and 2-L of diet soda) to demonstrate the concept of density. Record the weights of the different bottles and assist the students in calculating density by dividing the masses by their respective volumes. Record and display the results. Explain that for an object to float in water, it must have a density less than water (ρ_{water} = 1.0 g/mL). Ask the students to predict what will happen to each bottle (float or sink) as it is being placing into a large container of water, such an aquarium. Discuss the results by discussing the similarities and differences between the bottles.

Teacher's Tip: Avoid using the terms heavy and light when describing density. Instead, the terms more dense and less dense are more appropriate. Remember: "What weighs more, a kilogram of lead or a kilogram of feathers?" (Neither: they are both one kilogram of material.) Even though aluminum is not very dense (ρ_{Al} = 2.70 g/cm^3), a 500-kilogram block of aluminum is still very heavy. (It weighs 500 kilograms.)

9. How are the bottles of soda similar?

The bottles of soda all contain a carbonated liquid soda beverage.

10. How are the bottles of soda different?

The bottles of soda are different sizes and contain either regular or diet soda.

11. How is diet soda different from regular soda?

Regular soda contains more calories than diet soda. Regular soda contains sugar while the diet soda contains different types of sweeteners.

12. Which bottles float in water? Why?

Both bottles containing diet soda float. The diet soda has a density less than water. The regular soda sinks in water because its density is greater than water. The difference is in the sweeteners that are used in the soda. Regular soda generally contains between 35 to 45 grams of sugar, but diet soda only contains about 0.1 to 0.2 grams of artificial sweeteners. The regular soda has a much greater amount of sugar within the same volume of liquid, making it more dense.

13. The 2-L bottle of diet soda weighs more than the 500-mL bottle of regular soda, but it still floats while the other sinks. Explain.

Density is an intensive property, independent of the amount of substance present. Density is the ratio of mass to volume; as a sample's mass increases, its volume also increases proportionately to keep density constant for that substance.

Determining Volume

Hold up a box, a cylinder, and an irregular-shaped object (such as a rock) and ask how the volume of these objects could be found. Review the mathematical formulas for calculating volume of regular-shaped objects and demonstrate how to calculate the volume of an irregular-shaped object. Introduce the water displacement method by dropping a rock into an overflow can and then measuring the displaced water using a graduated cylinder.

14. How can the volume of the box be determined?

Measure the length, width, and height of the box and multiple the three measurements together.

Volume of a box = length × width × height

15. How can the volume of the cylinder be determined?

Measure the height of the cylinder as well as the diameter, then divide the diameter by two to find the radius.

Volume of a cylinder = height × πr^2

16. How can the volume of the rock be determined?

Because the rock is an irregular-shaped object, its volume is difficult to determine mathematically. It is much easier to determine the volume of the rock using water displacement. Place the rock in a container and measure the volume of water that is displaced. The volume of water displaced is equal to the volume of the rock.

17. Can the volume of regular-shaped objects be determined using water displacement?

Yes. The volume determined from water displacement should be the same as the volume calculated using the mathematical formulas.

Lab Preparation

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

Safety

Follow all standard laboratory practices.

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.

1	5	2	4	3
Before taking any quantitative measurements, list some qualitative properties of the object being studied.	Identify the object's material based on its density.	Measure the object's dimensions and mass.	Determine the object's density.	Calculate the object's volume.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Collect Data

Part 1 – Brass Objects

1. ☐ List at least two qualitative observations about the brass objects.

Brass is golden in color and has luster (shiny).

2. ☐ Predict how the density of the brass block compares to the density of the brass cylinder.

Because density is an intensive property of the substance, the density of the block should be the same as the density of the cylinder because both shapes are made of brass.

3. ☐ Measure the length, width, height, and mass of the brass block and the height, diameter, and mass of the brass cylinder. Record your results in Table 1 below.

Table 1: Dimensions and mass of brass objects

Object	Length (cm)	Width (cm)	Height (cm)	Diameter (cm)	Mass (g)
Brass block	2.59	1.88	1.58		66.10
Brass cylinder			6.38	2.20	208.16

Part 2 – Aluminum Objects

4. ☐ List at least two qualitative observations about the aluminum objects.

Aluminum is silver in color and has luster (shiny).

5. ☐ Predict how the densities of the three aluminum objects will compare to each other.

Density is an intensive property of the substance, therefore the densities of the three objects should be the same because all three objects are made of aluminum.

6. ☐ Measure the length, width, height and mass of the aluminum block and the height, diameter, and mass of the aluminum cylinder and record your results in Table 2 below.

Table 2: Dimensions and mass of aluminum objects

Object	Length (cm)	Width (cm)	Height (cm)	Diameter (cm)	Mass (g)
Aluminum block	4.88	3.12	1.55		64.85
Aluminum cylinder			6.35	2.20	66.44

7. ☐ Measure the mass of the irregular-shaped aluminum object.

Mass of irregular-shaped aluminum object: __________66.54 g_______

8. ☐ Complete the following steps to measure the volume of the irregular-shaped aluminum object using water displacement.

a. Put the beaker under the overflow can spout.

b. Pour water into the overflow can until it overflows into the beaker.

c. Allow the water to stop overflowing on its own and empty the beaker into the sink.

d. Place the beaker back in its position under the overflow can spout without touching the overflow can.

e. Tie a string to the irregular-shaped object and gently lower the object into the overflow can until it is completely submerged.

f. Allow the water to stop overflowing and then pour the water from the beaker into the graduated cylinder.

g. Measure the volume that was displaced by reading the water level in the graduated cylinder.

h. Record the volume of water that was displaced in units of cm^3 (1 mL = 1 cm^3).

Volume of water displaced: 25.3 mL

9. ☐ Why do you need to use the water displacement method for the irregular-shaped object?

There is no mathematical formula for the volume of an irregularly-shaped object, so you must find the volume through other means.

Part 3 – Unknown Plastic Objects

10. ☐ List at least two qualitative observations about the plastic cylinder.

The plastic cylinder is white in color and is opaque.

11. ☐ Table 3 lists three common plastics and their densities. How might you determine the material that the plastic cylinder is made?

Table 3: Density of plastics

Types of Plastic	Density
Polypropylene	0.95 g/cm^3
Nylon	1.15 g/cm^3
Polyvinyl chloride	1.39 g/cm^3

Measure the volume and mass of the cylinder and then calculate its density. If the cylinder is made of one of these three plastics, its density should match one of the three densities given.

12. ☐ Measure the height, diameter, and mass of the plastic cylinder and record your results in Table 4 below.

Table 4: Dimensions and mass of a plastic cylinder

Object	Height (cm)	Diameter (cm)	Mass (g)
Plastic cylinder	6.35	2.20	23.43

13. ☐ Clean up your lab station according to the teacher's instructions.

Data Analysis

Part 1 – Brass Objects

1. ☐ Use the following equations to calculate the volumes of the brass block and brass cylinder. Show your work and record your results in Table 5 below.

Volume (block) = length × width × height   Volume (cylinder) = height × πr^2

Table 5: Volume of brass objects

Object	Show Your Work Here	Volume
Brass block	Vol = 2.59 cm × 1.88 cm × 1.58 cm =	7.69 cm^3
Brass cylinder	Vol = 6.38 cm × 3.1416 × $(1.10\ cm)^2$ =	24.3 cm^3

2. ☐ Use the following equation to calculate the densities of the brass block and brass cylinder. Show your work and record your results in Table 6 below.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Table 6: Density of brass objects

Object	Show Your Work Here	Density
Brass block	Density = 66.10 g / 7.69 cm^3	8.60 g/cm^3
Brass cylinder	Density = 208.16 g / 24.3 cm^3	8.57 g/cm^3

3. ☐ Did the shape of the brass object have an effect on the resulting density?

No. The densities of the two brass objects were nearly identical.

Part 2 – Aluminum Objects

4. ☐ Calculate the volumes of the aluminum block and the aluminum cylinder. Show your work and record your results in Table 7 below.

Table 7: Volume of aluminum objects

Object	Show Your Work Here	Volume
Aluminum block	Vol = 4.88 cm × 3.12 cm × 1.55 cm =	23.6 cm^3
Aluminum cylinder	Vol = 6.35 cm × 3.1416 × $(1.10\ cm)^2$ =	24.1 cm^3

5. ☐ Calculate the density of the aluminum block, aluminum cylinder, and the irregular-shaped aluminum object. Show your work and record your results in Table 8 below.

Table 8: Density of aluminum objects

Object	Show Your Work Here	Density
Aluminum block	Density = 64.85 g / 23.6 cm^3	2.75 g/cm^3
Aluminum cylinder	Density = 66.44 g / 24.1 cm^3	2.76 g/cm^3
Irregular-shaped aluminum object	Density = 66.54 g / 25.3 cm^3	2.63 g/cm^3

6. ☐ Did the shapes of the aluminum objects have an effect on the resulting densities?

No. The densities of the three aluminum objects were nearly identical.

Part 3 – Unknown Plastic

7. ☐ Calculate the volume of the plastic cylinder. Show your work and record your results in Table 9 below.

Table 9: Volume of plastic cylinder

Object	Show your work here	Volume
Plastic cylinder	Vol = 6.35 cm × 3.1416 × $(1.10\ cm)^2$	24.1 cm^3

8. ☐ Calculate the density of the plastic cylinder. Show your work and record your results in Table 10 below.

Table 10: Density of plastic cylinder

Object	Show your work here	Density
Aluminum block	Density = 23.43 g / 24.1 cm^3	0.97 g/cm^3

9. ☐ From which plastic is the cylinder made?

The density of the cylinder is similar to that for polypropylene. Therefore, the plastic cylinder is most likely made from polypropylene.

Analysis Questions

1. Does the shape of an object affect its density?

No. Density is an intensive property and is always constant for the same substance. The shape and size of the object does not affect its density.

2. Is it possible for two objects to have the same volume and different densities? Explain your answer and provide evidence from this experiment to support your answer.

Yes, the three cylinders had essentially the same volume (~24 cm^3), but they had three different densities (ρ_{brass} = 8.6 g/cm^3, ρ_{Al} = 2.7 g/cm^3, $\rho_{plastic}$ = 0.97 g/cm^3). The cylinders had three different densities because they were made from three different substances.

3. Which material, brass, aluminum, or plastic, was the most dense?

The brass objects have the greatest density (ρ = 8.6 g/cm^3), followed by aluminum (ρ = 2.7 g/cm^3), and then plastic (ρ = 0.97 g/cm^3).

4. Research the accepted values for the densities of aluminum and brass. How do the accepted answers compare to the values you calculated in this experiment?

Aluminum has an accepted density of 2.70 g/cm^3. Brass has an accepted density between 8.4 to 8.8 g/cm^3. Brass is an alloy of variable amounts of zinc and copper, which explains the range of possible densities. These values are similar to those found in the lab.

Teacher Tip: Percent error may be calculated using the following formula:

$$\text{Percent error} = \frac{|\text{accepted value} - \text{experimental value}|}{\text{accepted value}} \times 100$$

Synthesis Questions

Use available resources to help you answer the following questions.

1. Will the brass, aluminum, or plastic cylinder float in water? Explain.

The brass and aluminum cylinders will both sink in water because their densities are greater than the density of water (ρ_{water} = 1.0 g/cm^3). The plastic cylinder will float because its density is less than that of water.

2. If a company buys 200 cm^3 of aluminum, how much would you expect the aluminum to weigh?

The aluminum would weigh 540 g. This value is calculated from the density:

$$200\ \text{cm}^3 \left(\frac{2.70\ \text{g}}{1\,\text{cm}^3}\right) = 540\ \text{g Al}$$

3. A 260-kg tree that is 10 m tall and 25 cm in diameter falls into a river. Explain mathematically why the tree floats, given that the density of water is 1000 kg/m³.

The tree has a volume of 0.49 m^3.

$$V_{\text{cylinder}} = h \times \pi r^2$$

$$V_{\text{cylinder}} = 10\text{ m} \times \pi\left(\frac{0.25\text{ m}}{2}\right)^2 = 0.49\text{ m}^3$$

Its density is 530 kg/m^3.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{density} = \frac{260\text{ kg}}{0.49\text{ m}^3} = 530\text{ kg/m}^3$$

The density of the tree is less than the density of the water, therefore the tree will float.

4. Can a very large object have the same density as a very small object? Explain.

Two different-sized objects can have the same density. Density is an intensive property. If the large object also has a large mass and the small object has a small mass, they could have the same density if their mass/volume ratio is the same. A small lead pipe will have the same density as a large lead pipe because it is made out of the same material.

5. A student has three silver cubes. Although the cubes look the same, one is made of zinc, another is made of lead, and third is made of aluminum. How can the student determine the material that was used to make each cube?

One way to identify the material in each cube is to determine the density of each cube by measuring its mass and volume. The calculated values can then be compared to literature values of these metals. Lead has the highest density (ρ_{Pb} = 11.34 g/cm^3) followed by zinc (ρ_{Zn} = 7.14 g/cm^3). The lowest density is aluminum (ρ_{Al} = 2.70 g/cm^3).

6. A rectangular object weighs 2445 g and its density is 12.9 g/cm³. When measured, its height is 7.43 cm and its width is 3.45 cm. How long is the object?

The object is 7.40 cm long.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$12.9\text{ g/cm}^3 = \frac{2445\text{ g}}{(7.42\text{ cm})(3.45\text{ cm})(\text{length})}$$

$$\text{length} = \frac{2445\text{ g}}{(7.42\text{ cm})(3.45\text{ cm})\left(\dfrac{12.9\text{ g}}{\text{cm}^3}\right)} = 7.40\text{ cm}$$

Multiple Choice Questions

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

1. Diamond has a density of 3.26 g/cm³. What is the mass of a diamond that has a volume of 0.350 cm³?

A. 0.107 g

B. **1.14 g**

C. 9.31 g

D. None of the above

2. What is the volume of a sample of liquid mercury that has a mass of 76.2 g, given that the density of mercury is 13.6 g/mL?

A. 0.178 mL

B. **5.60 mL**

C. 1040 mL

D. None of the above

3. Which statement about density is true?

A. Two samples of nickel may have different densities

B. Density is constant for all types of metals

C. The density of a sample depends on its location on Earth

D. **Density is a constant value for all objects made of the same material**

4. A zinc block has a mass of 20 g and a zinc cylinder has a mass of 40 g. How will the density of the two objects compare?

A. The zinc block will be less dense than the zinc cylinder

B. The zinc block will be more dense than the zinc cylinder

C. **The zinc block and the zinc cylinder will have the same density**

D. There is not enough information to answer the question

5. Density equals:

A. **Mass / volume**

B. Volume / mass

C. Mass × volume

D. Length × width × height

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Properties that depend on the amount of material present are called **extensive** properties, and include **mass** and **volume**. Those properties that are independent of the amount of substance being studied are called **intensive** properties, and include color, **boiling point**, and **density**.

2. **Density** is the amount of matter in a particular amount of space. Density is the ratio of **mass** to **volume**. Substances with large densities feel **heavy** for their size. Substances with densities less than 1.0 g/mL **float** in water. To find an object's density, a **balance** is used to determine its mass. Volume is found either by using a **mathematical formula** or by **water displacement**. Density can be used to **identify** a substance.

Extended Inquiry Suggestions

Pennies produced before 1982 are mostly comprised of copper, while pennies produced after 1982 are mostly zinc covered with a thin layer of copper. The two types of pennies, therefore, have different densities. Determine the densities of pre-1982 pennies and post-1982 pennies. Use ten pennies of each type to get accurate measurements. Use the water-displacement method to find the volume of all the pennies of a particular type at the same time.

Repeat the experiment using only the method of water displacement to determine volume.

3. Phase Change

Objectives

Determine how to add heat to a substance without the temperature of the substance increasing. Through this investigation, students:

- Determine the effect of a phase change on the temperature of a substance
- Explain the difference between heat and temperature
- Determine the melting point and boiling point of pure water

Procedural Overview

Students conduct the following procedures:

- Collect temperature data as they freeze water by inserting it into a salt/ice bath until the water freezes and the ices temperature decreases to –6.0 °C
- Collect temperature data as they add a constant amount of heat to ice until the ice melts and the temperature of the water rises to 8 °C
- Collect temperature data as they add a constant amount of heat to water until it boils for 6 to 8 minutes

Time requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	90 minutes (45 minutes for each part)[1]

[1] Refer to the Lab Preparation section for tips on ways to make this lab fit into one 45 minute lab period.

Materials and Equipment

For each student or group:

- Data collection system
- Stainless steel temperature sensor[1]
- Hot plate
- Beaker (2),150-mL or larger
- Graduated cylinder, 10-mL
- Test tube, 10-mm x 100-mm
- Test tube rack
- Ring stand
- Utility clamp
- Stir rod
- Tablespoon
- Distilled (deionized) water, 103 mL
- Crushed ice to fill the beaker
- Rock salt, 200 g

[1]A fast response temperature sensor is not appropriate for Part 2 of this investigation.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ States of matter
- ♦ Kinetic molecular theory
- ♦ Energy

Related Labs in this Manual

Labs conceptually related to this one include:

- ♦ Temperature versus Heat

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 your 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)
- ♦ Naming a data run �(8.2)
- ♦ Saving your experiment �(11.1)
- ♦ Printing �(11.2)

Background

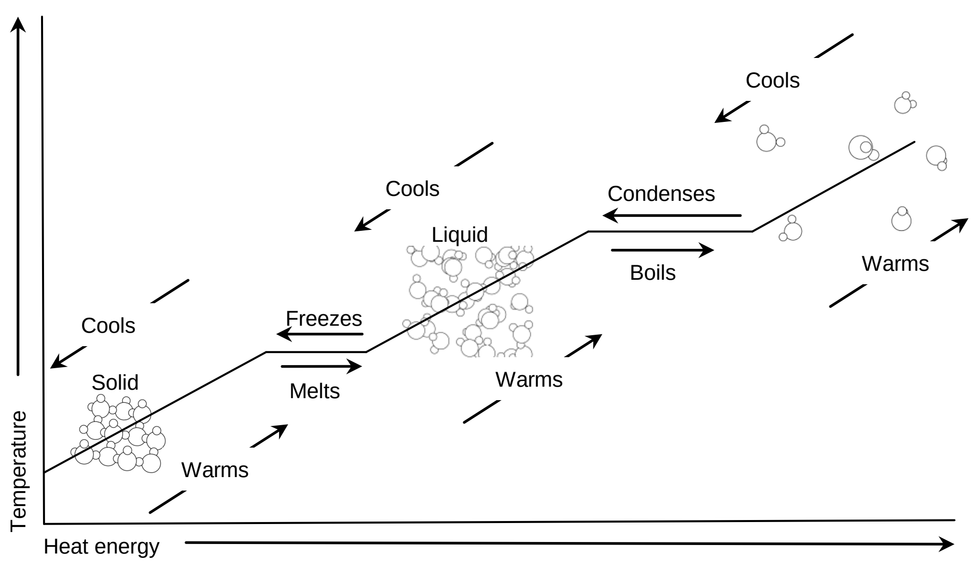
The kinetic molecular theory explains that all matter consists of particles in constant motion. Solid substances contain vibrating particles closely locked into position by electrostatic forces of attraction. Particles that make up a liquid are very close to each other, but with weaker electrostatic attractions between them than those in a solid, enabling the particles to move past one another. As a gas, the particles are far apart from each other, do not exhibit any attraction for each other, and move freely.

All pure substances can exist as a solid, liquid, or a gas, depending on temperature and pressure. (We will assume constant pressure throughout this experiment.) In order for a substance to change phases, energy must be added or removed. During warming, heat energy is absorbed and either makes the molecules move faster or breaks the attractions between particles. During cooling, heat energy is removed by either causing the molecules to move slower or by forming attractions amongst neighboring particles.

Adding heat to a substance will generally cause the temperature of the substance to increase, but not always. Heating a substance in a specific phase causes the temperature of the substance to increase. However, heating a substance as it undergoes a phase change does not result in a temperature change. Understanding the difference between heat and temperature explains this. Heat is generally defined as the flow or transfer of energy due to a difference in temperature. More specifically, heat is a measure of the total change in internal energy of a substance. Total internal energy refers to both the potential energy (attractions between molecules) and the kinetic energy (motion of the molecules). Temperature is a measurement related to the average kinetic energy of molecules only. During a phase change, the added heat only breaks the attractions between the molecules (an increase in potential energy). There is no change in the kinetic energy of the particles and therefore no change in temperature.

For a pure substance, the temperature at which a phase change occurs can identify the substance. The four main phase changes are melting point (solid to liquid), freezing point (liquid to solid), boiling point (liquid to gas), and condensing point (gas to liquid).

Phase Changes



Pre-Lab Discussion and Activity

Boiling Different Volumes of Water

Hold up two small beakers of water. Beaker A should be a quarter of the way filled with distilled water, and beaker B should be filled halfway with distilled water. Ask your students to predict which beaker of water will boil at a higher temperature and have them explain their reasoning. Place the beakers on an already heated hot plate and project the collected data. During data collection, discuss what is happening at the molecular level using the magnetic molecules activity below. Remember to check the beakers of boiling water. You may have to remove beaker A if all the water evaporates.

1. Will the water in beaker A boil at a lower temperature, higher temperature, or the same temperature as the water in beaker B?

Water boils at the same temperature regardless of the amount of water being heated.

2. What are some similarities and differences between what occurs in beaker A and beaker B?

Similarities: Both contain water, receive the same amount of heat from the hot plate, and are heated for the same amount of time.

Differences: The amount of water being heated, and the rate at which the water temperature increases (refer to the live data collection).

Magnetic Molecules

Use magnets to represent the water molecules. Explain to the students that attractive forces between water molecules hold them together similar to the way magnets attract each other. The water molecules in the beaker obtain energy from the heat produced by the hot plate. Similarly, muscle power can transfer energy to the magnets.

With the magnets stuck to each other, shake the group gently to represent energy transfer to the particles motion. The same thing happens to the water molecules in the beaker. As the heat transfers, they are "shaking" faster. Temperature measures the change in molecular motion.

Write the definition of temperature on the board: Temperature is related to the average kinetic energy (motion) of the particles.

Next, pull apart the magnets to represent energy being used to cause a phase change. Guide the students toward understanding that energy is required to pull the particles apart (break the attractive forces). The energy used to pull the particles apart is called potential energy. Write the definition of heat on the board: Heat is the change in the total internal energy which includes both the kinetic energy (motion) *and* the potential energy (breaking attractions) of a substance. Tell the students that unlike temperature, heat cannot be directly measured.

Finally, shake the separated magnets more vigorously to represent another increase in temperature. Have the students help you graph a "shaking" versus "Time" curve to model the expected data the students will collect in this lab.

3. Does energy make the molecules/magnets shake faster? What type of energy does this represent?

Yes. Energy from the teacher's arm transfers to the magnets causing them to move (shake). Similarly, energy from the hot plate transfers to the water molecules causing them to move faster. This energy of motion is called kinetic energy.

4. What is the relationship between particle motion and temperature?

There is a direct relationship between particle motion and temperature. As the temperature of the particles increase, the molecules move faster.

5. What needs to happen to water molecules in the liquid state for them to turn into water vapor? Why does this require energy?

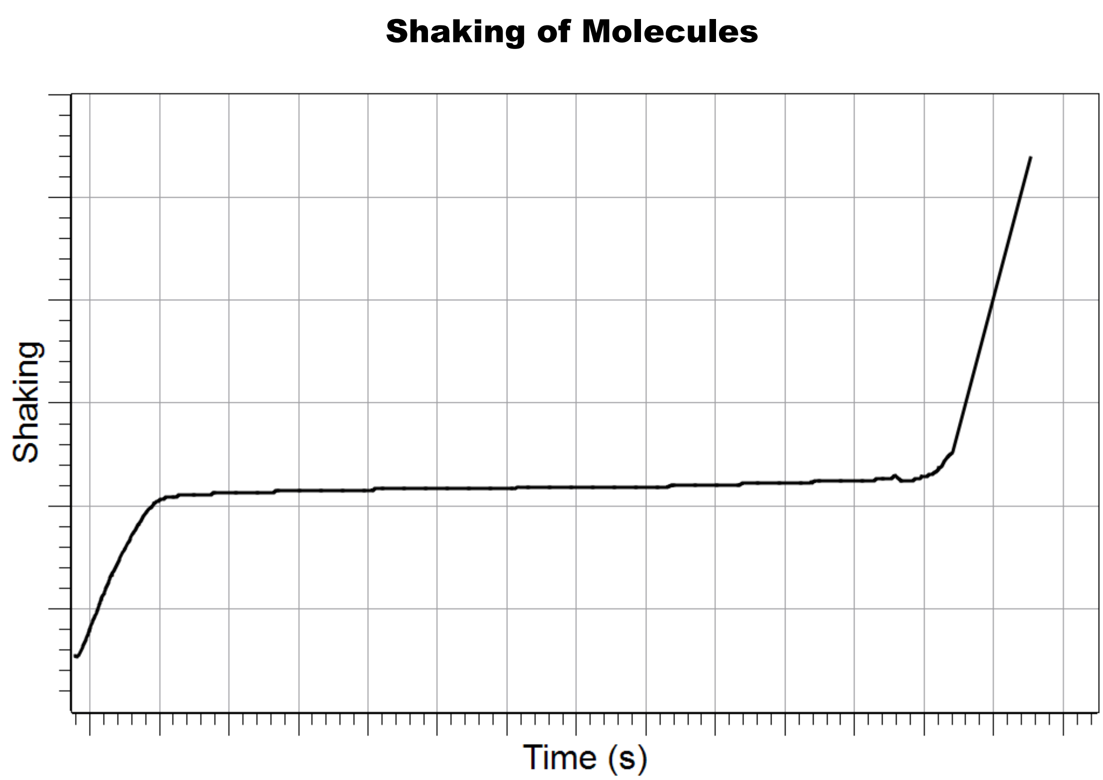
Water molecules in the liquid state must be pulled apart (separated) from each other to turn into water vapor. This requires energy to break apart the attractions that hold the particles together.

6. What are the two types of energy that make up heat? How are they related to individual molecules/magnets?

Heat involves both kinetic energy and potential energy. Kinetic energy makes the molecules move faster and potential energy separates the molecules apart.

7. What would a graph of "shaking" versus "time" look like? Why?

The energy from the heat will be used to make the molecules move faster. When the particles are shaking with enough energy to overcome the attractive forces holding them together, the added energy will be used to pull the particles apart instead of making them "shake" faster. This creates the horizontal line. Once all the particles are separated, the added energy will be used to increase the "shaking" of the individual molecules again.



Boiling Different Volumes of Water – Conclusions

Use the data collected in “Boiling Different Volumes of Water” above to engage the students in a discussion about what the data collected means. Guide the students to understand that no matter how much or little water we have, at a given pressure, pure water always boils at the same temperature. The temperature at which a substance boils is called its boiling point.

8. What happened in our boiling different volumes of water demonstration? Did beaker A boil at a lower temperature, higher temperature, or the same temperature as the water in beaker B? Explain the results.

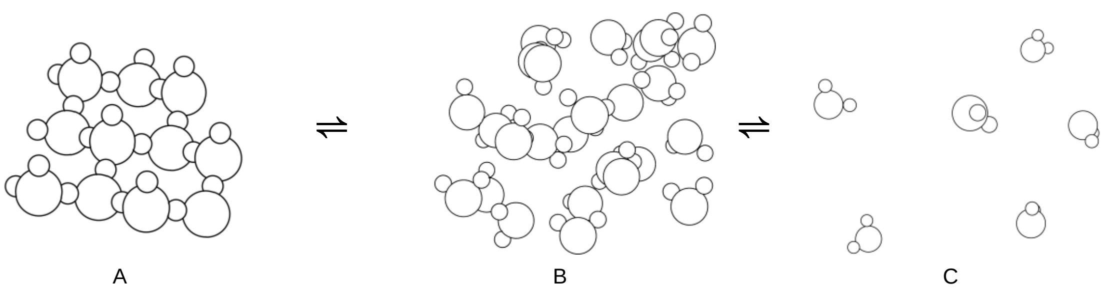
They boiled at the same temperature, but the rate of heating, indicated by the slope of the line, was greater in beaker A than in beaker B. Therefore, the water in beaker B took longer to reach the boiling point. The difference in the quantity of water molecules explains this. Beaker B contained more water, which means there are more water molecules that need to speed up and move apart. It therefore takes more heat, and thus more time, for the water to reach its boiling point.

9. Describe the shape of the graph during boiling? Why does this happen?

During boiling, the graph formed a horizontal line showing no temperature change because the added heat energy only breaks the attractions between particles, which only changes the potential energy. Temperature only measures changes in kinetic energy.

Phases changes at the Molecular Level

Show the students a video or picture of water molecules in its three phases.



10. Name the different phase changes and whether you need to add or remove heat to make these changes take place.

Solid ice to liquid water is melting and requires adding heat. Liquid water to solid ice is freezing and requires removing heat. Liquid water to gaseous water vapor is boiling and requires adding heat. Gaseous water vapor to liquid water is condensing and requires removing heat.

Lab Preparation

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

Teacher Tip: To save time, there are several ways you can have the students perform this lab:

- Do either Part 1 or Part 2 as a demonstration (such as in the Pre-Lab Discussion and Activity section), and have the students perform the other part.

- ♦ Have students start on Part 2 as they are waiting for their ice to melt. This will require two temperature sensors per group.
- ♦ Have some groups do Part 1 and other groups do Part 2, and then share data.
- ♦ Have the students prepare Parts 1 and 2 at the same time, and then collect the data simultaneously. This will require two temperature sensors per group.
- ♦ Freeze the temperature sensors in test tubes filled with 3 mL of distilled water the night before. This allows the students to skip the Set Up section of Part 1.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Do not touch the hot plate or hot glassware.
- ♦ Allow all glassware and equipment to cool thoroughly before handling.

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.

Part 1 – Freezing Water and Melting Ice

3	4	1	2
Place the test tube (with the temperature sensor frozen inside) in a test tube rack.	Record the temperature data and stir constantly as the ice melts and the temperature of the water increases to 8 ºC.	Measure 3 mL of distilled water, and pour it into a test tube. Place the temperature sensor in the test tube containing the water.	Collect temperature data as you freeze the water in the test tube by placing it in a salt and ice mixture until it is –6.0 ºC or cooler.

Part 2 – Boiling Water

2	3	4	1
Assemble the ring stand, utility clamp, and temperature sensor. Fill the beaker with distilled water.	Place the beaker filled with water on the warmed hot plate, and lower the temperature sensor into the water.	Start recording temperature data. Continue recording data until the water has boiled for 8 to 10 minutes.	Turn on the hot plate, and allow it to warm to its highest setting.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Freezing Water and Melting Ice

Set Up

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

2. ☐ Connect a stainless steel temperature sensor to the data collection system. �(2.1)

3. ☐ Create a graph of Temperature (°C) versus Time (s). �(7.1.1)

4. ☐ Predict what a temperature versus time graph will look like for freezing water.

The temperature will decrease until it reaches 0 °C and then it will level off and remain horizontal until all the water is frozen. After the water has all turned into ice, the temperature will steadily decrease again.

5. ☐ Predict what a temperature versus time graph will look like for melting ice.

The temperature will increase until it reaches 0 °C and then it will level off and remain horizontal until all the ice is gone. After the ice is gone, the temperature will steadily increase.

6. ☐ Use a graduated cylinder to measure 3 mL of distilled water and pour the water into the test tube.

7. ☐ Place the temperature sensor into the test tube.

Collect Data

8. ☐ Collect temperature versus time data as you freeze the water in the test tube using a salt/ice mixture. To do this:

- **a.** Fill a beaker halfway full of ice.
- **b**. Add two spoonfuls of rock salt.
- **c.** Use a stir rod to mix the rock salt and ice together.
- **d.** Place the test tube containing the temperature sensor into the ice and salt mixture.
- **e.** Start recording temperature data. �(6.2)

Note: You may need to adjust the scale the axes to observe the changes taking place. �(7.1.2)

f. Carefully add more ice around the test tube and two more spoonfuls of salt.

g. Gently stir the mixture with the test tube. Keep the temperature sensor positioned so the tip freezes in the ice.

Note: Sometimes water in the test tube will super cool (remain liquid at lower than 0 ºC). If this happens, quickly remove the test tube from the salt and ice mixture, and then place it back into the mixture

h. Stop recording temperature data when the temperature of the ice falls to –6.0 ºC or cooler. �(6.2)

9. ☐ Name the data run “freezing ice”. �(8.2)

10. ☐ Start recording another run of data. �(6.2)

11. ☐ Remove the test tube from the salt and ice mixture, and place it in a test tube rack.

12. ☐ Allow the ice to melt. Once the ice has melted enough, twist the temperature sensor so that the ice on the temperature sensor is constantly mixing with the water that has melted.

13. ☐ Continue recording data and constantly stirring until all the ice melts and the water temperature rises to between 8 and 10 ºC.

14. ☐ What are the independent and dependent variables in this experiment?

The independent variable is the time that constant heat is added to the ice.

The dependent variable is the temperature.

15. ☐ Record the temperature at which the water froze and the ice melted.

Ice melts and freezes at (or near) 0 ºC.

16. ☐ From where does the heat causing the ice to melt come?

It comes from the surroundings, in this case, the room temperature air.

17. ☐ Stop recording data when the temperature of the water is between 8 and 10 ºC. �(6.2)

18. ☐ Name the data run “melting ice”. �(8.2)

Part 2 – Boiling Water

Set Up

19. ☐ Ensure that the data collection system is on, that a stainless steel temperature sensor is connected, and that a graph of Temperature (°C) versus Time (s) is displayed. �(7.1.1)

20. ☐ Turn on your hot plate to its highest setting, and allow it to warm completely. This generally takes about 5 minutes.

CAUTION: Ensure that papers, wires, fingers, etcetera do not touch the hot plate.

21. ☐ Allowing the hot plate to warm up ensures that a constant amount of heat is added to the beaker of water. If you did not allow the hot plate to warm up, how would the heat released change over time?

The heat released would slowly increase until meeting the maximum temperature and then it would remain constant.

22. ☐ Why should the hot plate be set to its highest setting?

Any temperature setting could be used as long as it remains at the same setting during the entire experiment (constant amount of heat). Using the highest setting saves time.

23. ☐ Attach a utility clamp onto a ring stand, and securely tighten a stainless steel temperature sensor to the utility clamp.

24. ☐ Fill the beaker with about 100 mL of distilled water.

25. ☐ What do you predict a temperature versus time graph will look like for boiling water?

The temperature will increase until 100 °C and then it will level off. The water will remain at 100 °C until all the water evaporates.

Collect Data

26. ☐ Place the beaker with water in it on the warmed hot plate.

27. ☐ Lower the stainless steel temperature sensor into the water, positioning the sensor in the center of the water. Make sure is the sensor does not touch the bottom or the sides of the beaker.

28. ☐ Begin recording data. �(6.2)

Note: You may need to adjust the scale the axes to observe the changes taking place. �(7.1.2)

29. ☐ Continue recording data until the water has vigorously boiled (large bubbles) for 8 to 10 minutes.

30. ☐ Why is it important for the temperature sensor to remain in the center of the water?

This will ensure that we measure the temperature of the water. If the temperature sensor touches the bottom of the beaker, it will be measuring the temperature of the hot plate, not the water.

31. ☐ What are the independent and dependent variables in this experiment?

The independent variable is the time that constant heat is added to the water.

The dependent variable is the temperature of the water.

32. ☐ Record the temperature when you observe that the water is at a vigorous boil.

Water is boiling at (or near) 100 ºC.

33. ☐ Why is it necessary to boil the water for so long?

To determine how the temperature changes while the water changes from a liquid to a gas.

34. ☐ Stop recording data when the water has been at a vigorous boil for 8 to 10 minutes. �(6.2)

35. ☐ Name the data run "boiling water". �(8.2)

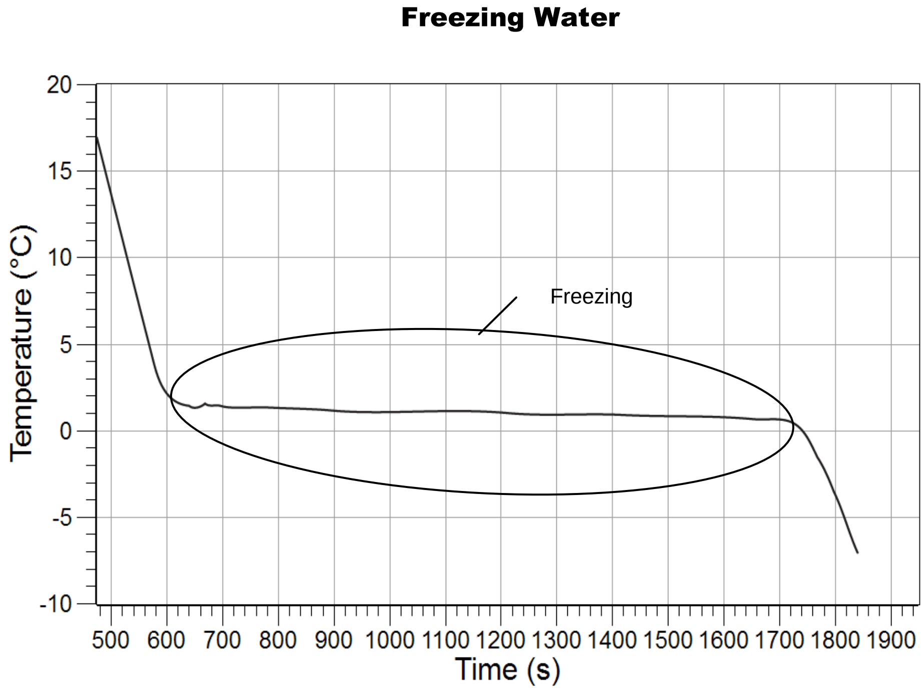
36. ☐ Turn off the hot plate and allow the equipment to cool for at least 20 minutes.

37. ☐ Save your experiment and clean up your lab station according to the teacher's instructions. �(11.1)

Data Analysis

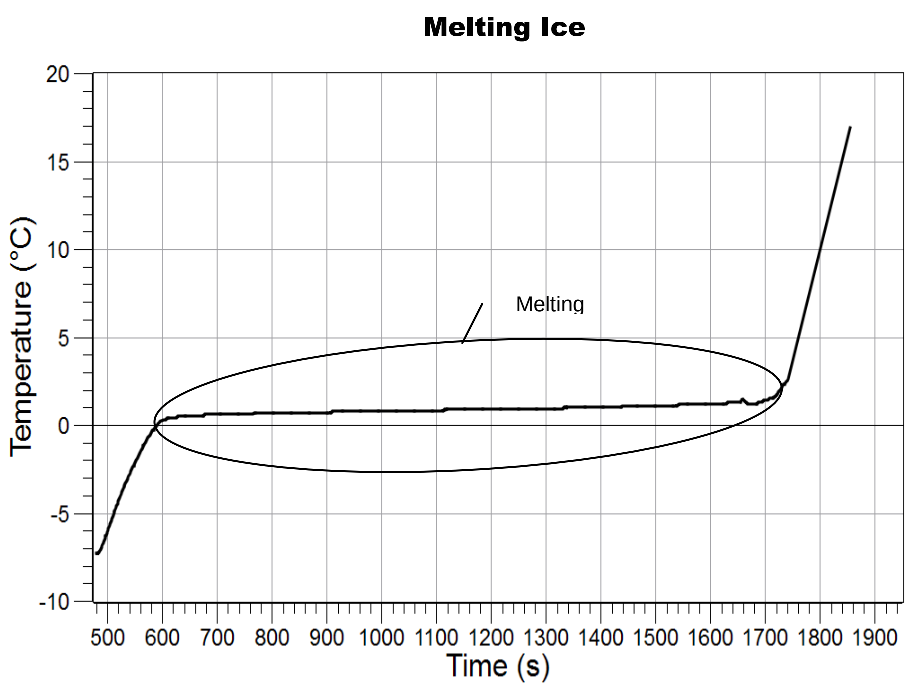
1. ☐ Print or sketch a graph of Temperature (°C) versus Time (s) where heat is removed for freezing water. Label where freezing was occurring. Also label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)

Freezing – horizontal line around 0 °C



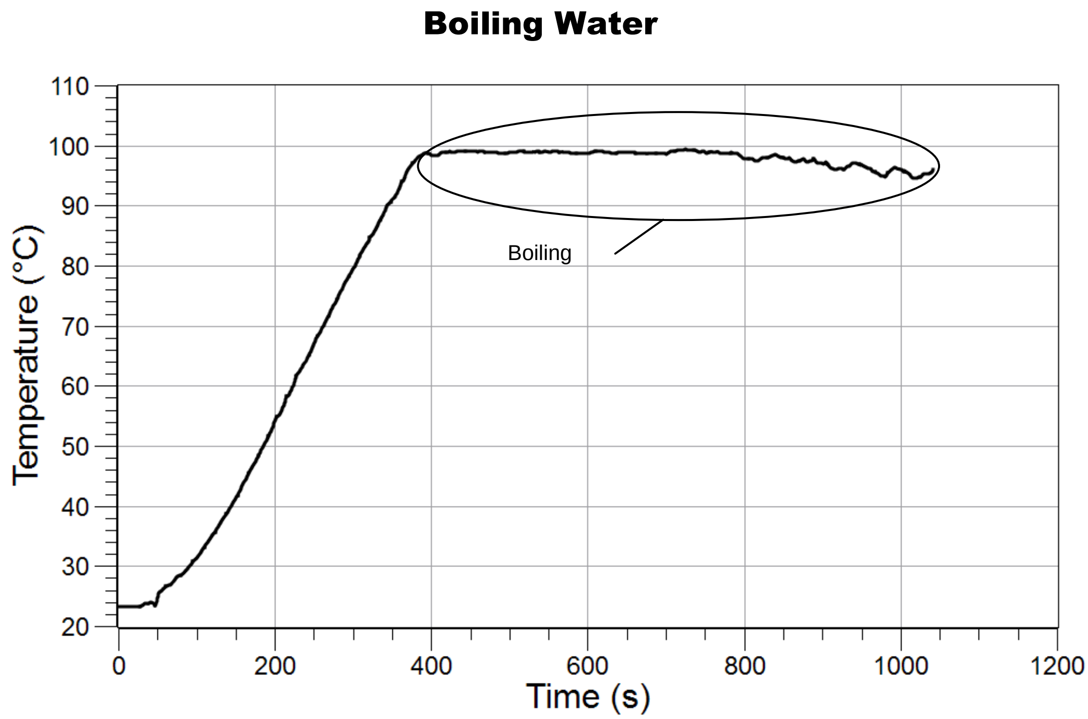
2. ☐ Print or sketch a graph of Temperature (°C) versus Time (s) where heat is added for melting ice. Label where melting was occurring. Also label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)

Melting – horizontal line around 0 °C



3. ☐ Print or sketch a graph of Temperature (°C) versus Time (s) where heat is added for boiling water. Label where boiling was occurring. Also label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)

Boiling – horizontal line around 100 °C



Analysis Questions

1. Relate the shape of your graphs above to the behavior of the water molecules. Hint: Explain whether the heat added caused the molecules to move faster or break attractions.

The upward sloping lines on the graphs indicate that the water molecules are moving faster, which causes the temperature to increase.

The horizontal section on the graphs is where the attractions between molecules are breaking. This causes the phase to change (solid to liquid in the first graph, liquid to gas in the second graph). This only changes the potential energy, and therefore does not change the temperature.

2. Explain how it is possible to add heat to a substance without the temperature of the substance increasing.

If heat is added to a substance during a phase change, then the temperature will not increase. This is possible because the added heat is used to break the attractions between particles instead of increasing the average speed of particles.

3. According to your lab results, what is the melting point and boiling point of distilled water? How do your results compare to your classmates?

The melting point is near 0 ºC, and the boiling point is near 100 ºC. The values should all be within a degree or two of their classmates.

4. Explain how heat and temperature are different.

Temperature is directly related to the movement of the molecules (kinetic energy).

Heat is the total change in the internal energy of a substance. The internal energy comes from both the movement of the molecules (kinetic energy) and the electrostatic forces of attraction between the molecules (potential energy).

Synthesis Questions

Use available resources to help you answer the following questions.

1. When drinking a cold glass of ice water, you notice drops of water forming on the outside of the glass. Explain where the newly formed water came from and what phase change was involved.

The water droplets came from water vapor in air. The phase change was condensation. The water vapor in the air changed into liquid water on the outside of the glass.

2. What phase change occurs when humans sweat? Why does this cool our bodies?

Water changes from a liquid to a gas (evaporation). Sweating cools our body by using body heat to convert water molecules (sweat) into water vapor. The newly formed vapor molecules leave our body and in doing so remove the body heat they have absorbed. Removing heat from something makes it cooler.

3. Is it possible to heat a metal without its temperature increasing?

Yes, if you heat it when it is melting. When heat is added, the temperature of the metal will increase until it reaches its melting point. Once the melting point is reached additional heating will not cause a rise in temperature until the phase change is complete.

4. Is it possible to remove heat from a substance without making the temperature decrease? Use an example to explain your answer.

Yes. If heat is removed from a substance undergoing a phase change, then the temperature will not decrease. For example, if heat was removed from liquid water as it was freezing into ice, then there would be no change in the temperature. Condensation could also be used as an example.

Multiple Choice Questions

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

1. Water at a vigorous boil releases bubbles of gas. What gas is in these bubbles?

- **A.** Air
- **B.** Oxygen gas
- **C.** Nitrogen gas
- **D.** **Water vapor**

2. When heat is added to a substance undergoing a phase change, what happens to the temperature of the substance?

- **A.** It increases
- **B.** It decreases
- **C.** **It remains constant**
- **D.** It decreases slightly and then increases

3. What will happen when heat is added to water that is at room temperature?

- **A.** **The temperature of the water will increase**
- **B.** The temperature of the water will decrease
- **C.** The temperature of the water will remain constant
- **D.** The water will immediately change into a gas

4. At the molecular level, what happens to water molecules as they are heated?

- **A.** The molecules move faster
- **B.** The water molecules are broken apart from other water molecules
- **C.** The hydrogen atoms are broken apart from the oxygen atoms
- **D.** **Either A or B will occur**

5. What is the temperature at which a substance changes from a liquid to a gas known as?

- **A.** **Boiling point**
- **B.** Melting point
- **C.** Freezing point
- **D.** Condensation point

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. The **kinetic molecular theory** explains that all matter is made up of particles that are in constant motion. Adding **heat** to matter generally causes the particles to move faster. Removing heat, on the other hand, causes particles to move **slower**. **Temperature** is related to the average motion (kinetic energy) of the particles.

2. All matter exists as a solid, liquid, or a gas, depending on the temperature (and to some extent on the pressure). The process of changing from one of these phases to another is called a **phase change**. The temperature at which a phase change occurs can be used to identify pure substances. There are four main phase changes. The temperature at which a solid changes into a liquid is called the **melting point**. The temperature at which a liquid changes into a gas is called the **boiling point**. Melting and boiling both require the **addition** of heat. The temperature at which a liquid changes into a solid is called the **freezing point**. The temperature at which a gas changes into a liquid is called the **condensing point**. Freezing and condensing both require the **removal** of heat.

3. During a phase change, the temperature of the substance remains **constant**. The temperature remains constant because the heat being added or removed is used to break or form attractions between particles instead of causing the particles to change speed. The energy stored in the attractions between particles is **potential energy**. Therefore, heat and temperature are different. Heat is both kinetic and potential energy of a substance, while temperature is related only to the kinetic energy of the particles.

Extended Inquiry Suggestions

Determine whether different amounts of water affect the melting point or boiling point of water.

Determine the melting point of lauric acid.

Identify unknowns using melting points or boiling points.

Determine the effect of adding solutes on the melting point or boiling point of water.

Design a method to either increase or decrease the temperature at which water boils.

Make ice cream to explore freezing point depression.

Determine the effects of volume on the temperature of water.

Does water melt at a higher temperature than water freezes?

4. Water—The Universal Solvent

Objectives

Water is one of the most important substances in the universe. To develop students' understanding of this critical substance, they:

- Classify substances based on their ability to dissolve in water
- Measure the changes in the conductivity of water as substances dissolve in it
- Relate water's ability to dissolve different substances to geological formations

Procedural Overview

Students gain experience conducting the following procedures:

- Dissolving a variety of substances in water
- Observing the solvent and solute as the dissolving process occurs
- Measuring the level of conductivity in different solutions

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Conductivity sensor
- Beakers (4), 250-mL
- Beaker for waste water
- Graduated cylinder, 100-mL
- Solute samples to dissolve and test (3), ~10 g each[1]
- Sample papers (3)
- Sugar cube
- Thread, 40 cm
- Stirring rod
- Pencil
- Distilled water, 400 mL
- Wash bottle with distilled water
- Balance, one per class

[1] For a list of possible solutes, refer to the Lab Preparation

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Water, which covers the majority of the earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the water cycle.
- Water is a solvent and when mixed with certain gases, liquids, or solids will form substances detrimental to living organisms.
- Ions are charged particles.
- Ions in an aqueous (water) solution enable the solution to conduct electrical current.

Related Labs in This Guide

Labs conceptually related to this one include:

- Electrolyte versus Non-Electrolyte Solutions
- Properties of Ionic and Covalent Compounds

Using Your Data Collection System

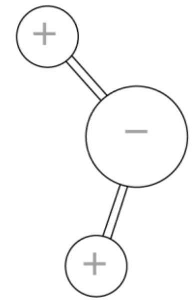
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions 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)
- Setting up a conductivity sensor for a particular measurement range �(4.2)
- Monitoring live data without recording �(6.1)
- Displaying data in a digits display �(7.3.1)

Background

Solutions are mixtures formed by thoroughly and homogenously combining components at the particle level. In a solution, the main ingredient, or component, is called the solvent, and the other components or ingredients present in smaller quantities are called solutes. Solutes are dissolved in the solvent. The resulting mixture is the solution. A substance going into solution is a physical, rather than a chemical process because no new substances are formed.

Water is an excellent solvent for many substances. For this reason, it has been referred to as "the universal solvent." When a solution has water as its main ingredient, it is termed an "aqueous" solution, from *aqua*, the Latin word for water.



In a water molecule, the covalent bonds that hold the two hydrogen atoms to the oxygen atom form at a 105° angle rather than a straight line (180°). The bonding electrons tend to reside closer to the oxygen atom than the hydrogen atoms. The combination of shape and charge distribution makes the water molecule polar. The oxygen side of the molecule is slightly more negative, and the hydrogen side of the molecule is slightly more positive, even though the overall charge of the molecule is neutral.

Some compounds, like sugars, dissolve in water as molecules, with each sugar molecule becoming surrounded by water molecules. The water molecules form hydrogen bonds with the sugar molecule that are weaker than covalent bonds, but stronger than the intermolecular forces that hold the sugar crystal together. The ability of water to dissolve sugars is vital to living organisms, which need dissolved sugars in their cells to provide energy for their life processes.

Other compounds dissolve as charged particles known as ions, not as neutral molecules. For example, in a solution of salt water, the sodium ions (with a charge of +1) and the chloride ions (with a charge of –1) are distributed evenly throughout the water molecules. The oxygen end of the water molecule is attracted to positive ions, such as the sodium ion, and the hydrogen end of the water molecule is attracted to negative ions, such as the chloride ion. Because of their electrical nature, the presence of ions makes the solution conductive. The conductivity of a solution is related to the quantity and nature of the ions present in the solution.

As water passes through geologic formations, the materials that easily dissolve are transported away to become salts in the sea, components of soil, or new formations such as stalagmites and stalactites.

Pre-Lab Discussion and Activity

Engage the students in the following discussion and demonstration.

Solutes and Solvents

Display a sugar cube and labeled samples of salt, powdered drink mix, pepper, baking soda, borax, and alum for students to see. Ask students to consider how each of these common substances is used. If students are unfamiliar with borax and alum, explain that borax is a laundry additive and alum is an astringent, often used in making and preserving pickles.

Ask students the following questions:

1. Which of these substances are used as is, in granular or powdered form?

Students should suggest that most of the substances need to be added to or dissolved in water for use. Pepper and baking soda are often used in this form, but baking soda can also be dissolved in water and used as an antacid.

2. Describe the properties of the beverage that result when powdered drink mix is added to water. For example, does the first sip of the drink taste the same as the next, or do different parts of the drink taste very different?

Students should suggest that because the drink mix is stirred into the water with a spoon, it has dissolved and the beverage tastes the same throughout. In addition, the beverage is the same color throughout.

3. Why do you think the manufacturer of the drink mix makes this product water soluble, that is, able to dissolve in water? Would people enjoy drinking a beverage in which a solid did not uniformly mix throughout the glass of water?

Students should suggest that manufacturers make powdered drink mixes water-soluble so they will dissolve thoroughly because people would probably not like to drink a beverage that is inconsistent in taste or texture. Clumps of undissolved solids are generally not desirable in beverages.

The Universal Solvent

Explain to students that water is special because of its ability to dissolve so many substances. Water is called the "universal solvent" because it is able to dissolve more substances than any other liquid. As a result, wherever water goes, it transports along with it chemicals, nutrients, and minerals—throughout our bodies or throughout the ecosystem.

Divide your students into small groups to discuss what substances dissolve in water. Encourage them to consider substances in addition to food, such as medicines, fertilizers, and even pollutants that can be dissolved in streams, lakes, rivers, or oceans.

Note: Remind your students that matter in all three phases—solids, liquids, and gases—can dissolve in water (some students may be aware there are currently five states of matter that scientists are aware of: solid, liquid, gas, plasma, and Bose-Einstein condensate).

Have each group in turn list one of their suggestions on the board under the heading "solutes." (Explain to students that any substance that dissolves is referred to as the solute in a solution.) As you develop a list of substances, classify them according to whether the substances are helpful or harmful to people.

Students may suggest common kitchen substances such as sugar, salt, food dye, and various spices; beverages such as sodas and colas which have flavoring, coloring, and carbon dioxide gas dissolved in water; fertilizers such as plant food; household products such as soaps, detergents, and cleaners. Students may also suggest that fertilizers, detergents, and cleaners can be carried by rainwater as runoff into water sources, causing pollution.

Lab Preparation

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

- Provide students with samples of ionic compounds to dissolve and test with the conductivity sensor. Ionic compounds that work well include salt ($NaCl$), Epsom salt ($MgSO_4$), alum ($KAl(SO_4)_2$, borax ($Na_2B_4O_7$ or $Na_2[B_4O_5(OH)_4]$, sports drink mixes that explicitly state they contain electrolytes, and salt substitutes that contain potassium chloride (KCl). All of these items are available at grocery stores. Include at least one or two insoluble materials such as pepper or sand.

  Provide two random samples per group and one sample of salt ($NaCl$), so student groups can later compare their results.

- Because some of the substances used for solutes, such as alum, are sold in small quantities, it is helpful to measure solute samples for students ahead of time. Give each group the same mass of each substance. Provide approximately 10 grams of each solute on a piece of sample paper that is marked with the name of the substance.

Note: Do not use sugar as one of the solutes to be tested with the conductivity sensor. Sugar is not an ionic compound, and will not produce ions in the water. The conductivity sensor needs to have dissolved ions to give meaningful data.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Wear aprons to protect clothes.

♦ Wear safety goggles throughout this activity

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	4	3	1
Place a sample of solute into the beaker of distilled water, stirring to dissolve.	Compare the conductivity of different substances.	Measure the conductivity of the solution.	Add distilled water to a beaker.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Observing a sugar cube in water

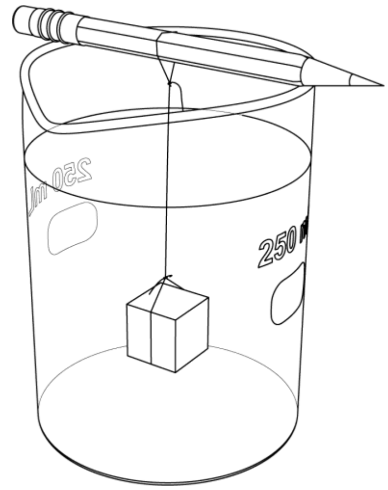
Set Up

1. ☐ What will happen to the sugar cube when you suspend it in a beaker of water and do not stir the water?

Students should predict that the sugar cube will slowly dissolve and become smaller as it does. They may say that it will get smaller and smaller until eventually it falls out of its thread loop, and may eventually disappear completely.

2. ☐ Carefully tie a long thread around a sugar cube so the sugar cube can be hung in a beaker.

3. ☐ Pour 100 mL of distilled water into a 250-mL beaker.



Collect Data

4. ☐ Loop the thread around a pencil or pen and place across the top of the beaker so that the sugar cube is hanging fully submerged in the water.

5. ☐ Observe the sugar cube as it rests suspended in the water. Note any observations in the space below.

NOTE: You may have to look very closely, lowering your eye level to that of the beaker. Kneel down beside the table if necessary.

Students should be able to observe the sucrose in the sugar cube going into solution in the surrounding water, especially near the bottom of the sugar cube. The density of sucrose is greater than that of water, so the sucrose will appear to flow down.

Part 2 – Testing solution conductivity

Set Up

6. ☐ Approximately how long do you think you will have to stir to dissolve 1/2 teaspoon of salt in 100 mL of water?

Answers will vary. Students should predict lengths of time that range from several seconds to a minute or two.

7. ☐ Obtain and label the three solute samples "A", "B", and "C".

8. ☐ Of the substances you are given to test, how many do you predict will fully dissolve in water? Explain why you think this.

Answers will vary depending on samples provided to students. It is likely students will correctly predict that all samples with the appearance of salt, such as Epsom salt, will dissolve.

9. ☐ Setup for measuring the conductivity of samples A, B, and C:

- **a.** Use the 100-mL graduated cylinder to measure and pour 100 mL of distilled water into a beaker.
- **b.** Record the name of the substance for each sample you have to test in Table 1 of the Data Analysis section.
- **c.** Start a new experiment on the data collection system. �(1.2)
- **d.** Connect the conductivity sensor to the data collection system. �(2.1)
- **e.** Select the appropriate range of sensitivity for the conductivity sensor. �(4.2)
- **f.** Display Conductivity in a digits display. �(7.3.1)

Collect Data

10. ☐ Collect data for samples A, B, and C:

- **a.** Insert the conductivity sensor into the beaker and monitor live data without recording. �(6.1)
- **b.** Record the conductivity reading for distilled water in the Table 1 in the Data Analysis section.
- **c.** Slowly add solute sample A to the beaker, stirring to dissolve. Observe how the conductivity level changes as you stir and then let the solution stand still.
- **d.** Record whether or not the substance is soluble (dissolved completely) in Table 1 in the Data Analysis section.
- **e.** When the conductivity reading has stabilized, record the conductivity in Table 1 in the Data Analysis section.
- **f.** Rinse the conductivity sensor with distilled water, using the wash bottle and beaker.
- **g.** Dispose of the sample according to your teacher's instructions.
- **h.** Rinse the beaker and stirring rod.
- **i.** Repeat the data collection instructions for the next sample until you have a conductivity reading for all three samples.

11. ☐ Clean up your lab station according to the teacher’s instructions.

Data Analysis

Table 1: Solution sample conductivity

Solute Sample	Substance	Conductivity (µS/cm)	Soluble (Y/N)
Distilled water	Distilled Water	5	—
A	NaCl	30,029	Y
B	Sports drink	5,420	Y
C	Alum	2,344	Y

Analysis Questions

1. How did your 3 predictions in Part 1 and 2 compare to your results?

Answers will vary. Students are likely to have correctly predicted that the sugar cube would dissolve in the water, even though they did not stir it. It's likely to take between 30 seconds and a minute for the 1/2 teaspoon of salt to dissolve in the water. Predictions about which samples will dissolve depend on the samples.

2. How could you tell that the sugar cube was dissolving in the water? Describe your observations. Were your observations of the sugar cube qualitative or quantitative?

Answers will vary. Students should see the sugar cube appear to be slowly leaking a wavy, clear fluid of a slightly different texture or density than water, falling to the bottom. After a few minutes the edges and corners of the cube become more rounded than they were at the beginning when it was first put it in the water. Also, the faces of the cube get rougher and more irregular. The cube continues to get smaller as time goes on. These observations are qualitative because no numerical measurements are being made.

3. At what point in the procedure was the conductivity the lowest? How can you explain this low reading?

Before adding the samples to the water, conductivity is zero µS/cm. When there is nothing dissolved in the distilled water, which is pure water, there are no ions to conduct an electrical current. The conductivity level goes up as soon as the sample is added and begins to dissolve.

4. At what point in the procedure was the conductivity the highest? How can you explain this high reading?

The conductivity should be at the highest level after the entire sample has been added to and dissolved in the water. At that point the number of charged particles, or ions, which make the solution conductive, is the greatest it will be and therefore the solution conducts the largest electrical current, measured by the conductivity sensor.

5. Water is often called the universal solvent because of its ability to dissolve so many substances. Check with other lab groups in your class to see how many substances tested in class were unable to dissolve in water. What evidence from the class supports the idea that water is a good solvent?

Answers will vary. Students should find that the majority of their samples dissolve in distilled water. In one instance, all samples except for a sample of pepper dissolved. However, the pepper floated on top of the water, but after a lot of stirring, some of it sank and the water turned cloudy, Students concluded that meant at least part of the pepper was soluble in water. Some materials may not dissolve quickly, such as certain minerals in rocks, but over time they do dissolve.

6. Organize the following substances into two categories, water-soluble and non-water soluble: salt, sugar, vegetable oil, pepper, lemon juice, hand soap, baking soda, powdered drink mix.

Water-soluble: sugar, salt, lemon juice, baking soda, powdered drink mix

Non-water-soluble: vegetable oil, pepper

Synthesis Questions

Use available resources to help you answer the following questions.

1. Use what you have observed in this lab activity to explain how salt contaminating the soil in a field could travel for several miles and enter a stream after a rainstorm.

If it rained on a field that had contaminated soil, the salt would be dissolved in the rainwater. Any place the rainwater flowed, the salt would be carried along. The runoff water from the field would travel downhill to the nearest stream, a normal process in a watershed, and the salts from the rainwater would then enter the stream.

2. Suppose a stream flows over a rock composed of a water soluble mineral. The stream meanders along and then disappears underground, where it flows through the rock layers and drips slowly from the ceiling of a cave. Based on your understanding of solvents, solutes, and solutions, do you think that this mineral could accumulate in the cave? Support your answer with evidence.

The mineral from the rock would be dissolved in the stream water, eroding the stream bed. The dissolved mineral would travel in the stream water as it goes underground. Each drip of the water from the roof of the cave would have some of the dissolved mineral particles in it. If the water dripped slowly enough, the water would evaporate, leaving the mineral residue. As time goes on, the mineral from more and more drops would accumulate, both on the floor and ceiling of the cave, creating the formations of stalagmites and stalactites.

Multiple Choice Questions

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

1. In a solution, the substance that does the dissolving is the

- **A.** Solute
- **B. Solvent**
- **C.** Solution

2. In a solution, the substance that is dissolved is the

- **A. Solute**
- **B.** Solvent
- **C.** Solution

3. Which of the following does *not* describe a solution?

- **A.** Salt stirred until it seems to disappear in water
- **B.** Lemon juice mixed into iced tea until the flavor is uniformly spread throughout the tea
- **C. Olive oil added to vinegar, floating on top to give the appearance of layers**

4. Which of the following is true about water?

- **A.** Water is not capable of dissolving a wide variety of substances.
- **B. Water dissolves more substances than any other liquid.**
- **C.** Water dissolves only those substances that exist as crystalline solids.

5. Suppose a bag of salt has been spread on the melting snow at the top of a mountain. Of the following scenarios, which is most likely to occur?

- **A.** The snow will have little to no effect on the salt, nor will the salt have any effect on the snow.
- **B.** The salt will evaporate along with the melting snow, and enter the water cycle through evaporation.
- **C. The salt will dissolve in the melting snow and be carried down the mountainside, until it flows into the creek or stream at the bottom of the watershed.**

6. In order to be called a "universal solvent," water must:

- **A. Dissolve a great many different substances**
- **B.** Be able to exist in all three phases—solid, liquid, and gas
- **C.** Be able to conduct an electrical current

7. Those substances able to dissolve in water are classified as which type of substance?

- **A.** Ionic
- **B.** Salts
- **C. Water-soluble**

8. In order for a substance to be a solute, what must it be able to do?

- **A.** Dissolve other substances
- **B. Dissolve into another substance**
- **C.** Melt at a relatively low temperature

9. Suppose you had measured the conductivity of three solutions but forgot to label your data results. Use what you have learned in this lab activity to figure out which set of data is most likely from salt water made with 1/2 teaspoon of salt, distilled water, and salt water made with 1 teaspoon of salt.

- **A.** 443 µS/cm, 1652 µS/cm, 1203 µS/cm
- **B.** 1203 µS/cm, 1721 µS/cm, 443 µS/cm
- **C. 443 µS/cm, 11 µS/cm, 1203 µS/cm**

10. Imagine you and a friend are spelunking (exploring a cave) and come across what look like icicles hanging from the ceiling of the cave. Upon closer examination, the "icicles" seem to be made of solid rock. These formations in caves are called stalactites. Which of the following is a possible source of the mineral that contributed to the formation of this cave's stalactites?

- **A. Water that has seeped into the ground above the cave and is dripping from the ceiling**
- **B.** Occasional rainstorms that wash large amounts of debris into the cave
- **C.** Material deposited by bats and other cave-dwelling organisms

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Solutions are mixtures formed not through any chemical process but by means of thorough **mixing** at the smallest particle level. In a solution, the main ingredient, or component, is called the **solvent** and the other components or ingredients present in smaller quantities are called **solutes**. Solutes are dissolved in the solvent. The resulting **mixture** is the solution. A solute **dissolving** in a solvent is a physical, rather than a chemical process.

Extended Inquiry Suggestions

Investigate how much of a particular substance will dissolve in a sample of room temperature water. Heat the water and see if more of the substance will now dissolve. What can you conclude about the temperature of the solvent and its ability to dissolve a solute?

Research how minerals are seeded and grown from supersaturated solutions. Make such a solution of alum and water, and grow some seed crystals. Try using a seed crystal to grow a large alum crystal.

Investigate how the rate a solution cools affects the size of the crystals that form from the solution. Use this information to explain how rocks can have different sizes of crystals, from nearly microscopic to coin-sized. Find out which types of igneous rocks cool quickly enough to form no crystals at all.

If time and quantities of substances permit, distribute a random set of substances to each group to classify and report on.

5. Electrolyte versus Non-Electrolyte Solutions

Objectives

In this activity, students determine which substances in sports drinks (water, sugars, or salts) are electrolytes. Through this investigation, students:

- Differentiate an electrolyte solution from a non-electrolyte solution
- Describe the effect concentration has on the conductivity of an electrolyte solution
- Determine the approximate concentration of electrolytes in a sports drink

Procedural Overview

Students conduct the following procedures:

- Measure the conductivity of salt solutions, sugar solutions, and a sample of a sports drink
- Graph conductivity versus concentration
- Use the graph to determine the concentration of electrolytes in a sports drink

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Conductivity sensor
- Test tube (6), 20-mm x 150-mm
- Beaker to collect rinse water
- Test tube rack
- Funnel
- Wash bottle filled with distilled (deionized) water
- Sucrose solutions (0.02 M, 0.04 M, 0.06 M, 0.08 M, 0.10 M), 10 mL of each concentration[1]
- Sodium chloride solutions (0.02 M, 0.04 M, 0.06 M, 0.08 M, 0.10 M), 10 mL of each concentration[2]
- Distilled (deionized) water, 50 mL
- Sports drink, 10 mL

[1] To formulate sucrose solutions using table sugar (sucrose, $C_{12}H_{22}O_{11}$), refer to the Lab Preparation section.

[2] To formulate sodium chloride solutions using table salt (sodium chloride, NaCl), refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Physical properties of matter
- ♦ Ions and molecules
- ♦ Solutions

Related Labs in this Guide

Labs conceptually related to this one include:

- ♦ Water the Universal Solvent
- ♦ Properties of Ionic and Covalent Compounds

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- ♦ Manual sampling mode with manually entered data �(5.2.1)
- ♦ Monitoring live data �(6.1)
- ♦ Starting a manually sampled 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)
- Displaying multiple data runs on a graph �(7.1.3)
- Naming a data run �(8.2)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

We use physical properties to identify and describe matter. Physical properties of matter include color, density, odor, boiling point, melting point, solubility, conductivity, and many others. This investigation uses conductivity to differentiate between different types of matter.

Electrical conductivity is a measure of how easily electric current flows through a substance. An electric current is the flow or movement of charged particles (either electrons or ions). If a substance conducts electricity, it means the substance contains either free-moving electrons or free-moving charged particles (ions).

Electricity can conduct through both solids and liquids. Metals are good electrical conductors because metallic bonds contain delocalized electrons that can move freely throughout the solid metal. Liquids can also conduct electrical current, but only if they contain a sufficient number of ions. Electrolytes are substances that dissociate (produce ions) in solution to form electrolyte solutions. Electrolytes can be classified as strong electrolytes (substance that dissociate completely) or weak electrolytes (substances that partially dissociate). Strong electrolytes include ionic compounds, such as sodium chloride and sodium nitrate, as well as strong acids and bases, such as sulfuric acid and sodium hydroxide.

However, not all substances dissociate when they dissolve into solution. If the substance does not dissociate and produce free ions, the solution will not conduct electricity, even if the substance fully dissolves. Substances that do not conduct an electric current in solution are known as non-electrolytes. Non-electrolytes include pure water, oil, phenol, alcohol, and sugar, among others.

Determining whether or not a solution conducts electricity allows a deeper understanding of what happens at the molecular level. If a solution conducts electricity, we can conclude that the solute dissociated and ions are present in the solution. A solution that does not conduct electricity, on the other hand, does not have ions present. This means the solute dissolved as molecules.

A conductivity probe measures the conductivity of a solution. The probe contains two electrodes: a positively charged anode and a negatively charged cathode. With the probe placed in an electrolyte solution, the positive ions (cations) and negative ions (anions) move toward their oppositely charged electrodes, creating a flow of charged particles that complete the circuit. The concentration of an electrolyte solution is directly proportional to the solution's conductivity. We measure the electrical current created in units of microsiemens per centimeter (µS/cm). The more ions present in the solution, the greater the conductivity value. Extrapolating from a plot of concentration versus conductivity of samples of known concentrations, we can determine the concentration of an unknown solution from its measured conductivity value.

Pre-Lab Discussion and Activity

Metal versus Polystyrene

Use a metal pie plate and a polystyrene plate to engage the students in a discussion of lightning storms and safety. Bring up the idea of electrical circuits and their use in everyday life.

1. Which of these, a metal pie plate or a polystyrene plate, would you willingly hold over your head during a lightning storm?

Students should know the metal pie plate will conduct electricity and should not be held during a lightning storm.

Conductivity of Various Liquids

Using a conductivity tester, with a light bulb whose intensity varies with changes in conductivity, test the conductivity of the metal pie plate, polystyrene plate, distilled water, tap water, bottled spring water, and a sports drink. First, discuss which sample will cause the light bulb to be brightest (most conductivity), dimmest, and have no light at all. Next, have the students list these from brightest to dimmest either on paper or on the board. Finally, test the samples with the conductivity tester, and compare the results to the students' predications as you progress through the questions below.

2. What will happen when you place the electrodes on the conductivity tester in contact with the metal pie plate? With the polystyrene plate?

The light bulb illuminates when placed against the metal pie plate because electrons can flow through it. The light bulb remains dark when placed against the polystyrene plate because electrons are locked in bonds and cannot move. If the electrons are not free to move, electricity cannot flow.

3. Distilled water contains only H_2O molecules. Do you think distilled water will conduct electricity?

A lot of students think that all forms of water, including distilled water, conduct electricity because they have been warned about not using electricity near water. Such warnings include not using electrical appliances in the bathtub and not swimming during a lightning storm. The correct answer is no, distilled water does not conduct electricity because it does not contain ions.

4. Will tap water or bottled spring water conduct electricity? Explain your reasoning.

Both tap water and bottled spring water will slightly conduct electricity because they contain dissolved ions.

5. Explain why distilled water does not conduct electricity but tap water and bottled spring water do conduct electricity.

Freely-moving, charged particles (ions or electrons) are necessary for electricity to flow. The beaker containing distilled water does not conduct electricity because no ions are dissolved in it. Tap water and bottled spring water contain some ions and, therefore, conduct electricity.

Electrolytes

Introduce the term electrolyte. Students may be familiar with sports drinks as electrolyte replacements drinks. Electrolytes are substances that dissociate to form ions when dissolved. Non-electrolytes are substances that do not dissociate when dissolved.

6. Does tap water or bottled spring water contain electrolytes?

Both tap water and bottled spring water must contain electrolytes (dissolved ions) because they both conduct electricity.

7. Do you expect a sports drink to conduct electricity less than, the same as, or better than tap water and bottled spring water? Why?

The sports drink will conduct electricity better than tap water and bottled spring water because the sports drink has electrolytes added to it.

8. Why are electrolytes important in your body? Why must they be replaced during exercise?

Electrolytes are vital for many bodily functions. For example, the body requires electrolytes to conduct the electrical impulses along the nerve pathways between your brain and the rest of your body. Electrolytes are also vital for proper maintenance of blood volume and blood pressure. Muscles require electrolytes for proper function. Electrolytes must be replaced because they are lost through sweating during exercise.

Measuring Conductivity

The light-bulb conductivity tester provides students with qualitative data on the extent to which a solution conducts electricity. Quantitative data can be determined using a conductivity sensor. Re-test each solution, this time using a conductivity sensor, and add the quantitative conductivity values to the table written on the board. Convey that conductivity is measured in microsiemens per centimeter (µS/cm) and that small values (0 to 20 µS/cm) correspond to the light not turning on, and increasingly larger numbers correspond to an increasingly brighter light.

Construct the following table on the board, and have the students help fill it in.

Method	Distilled Water	Tap Water	Bottled Spring Water	Sports Drink
Qualitative Conductivity	dark	dim	dim	very bright
Quantitative Conductivity (µS/cm)	3	102	58	2550

9. Does the light-bulb conductivity tester provide us with qualitative or quantitative conductivity data? Explain your reasoning.

The light-bulb conductivity tester produced qualitative data because the data are descriptive words, such as ‘dark’, ‘dim’, and ‘very bright’. Quantitative data is numerical.

10. Does tap water and bottled spring water contain the same amount of electrolytes? Is qualitative or quantitative data easier to use when answering this question?

In this example, tap water has more electrolytes than the bottled spring water. This is more easily determined from the quantitative conductivity data.

11. What causes the light to illuminate? Why do different solutions produce different amounts of light?

Ions in the solution determine the brightness of the light. The more ions, the brighter the light.

Lab Preparation

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

1. Prepare 100 mL of 0.00 M, 0.02 M, 0.04 M, 0.06 M, 0.08 M, and 0.10 M sucrose solutions. This is enough for 10 lab groups.

   a. Make 30 mL of 1.0 M sucrose solution by dissolving 10.27 g of sucrose in enough distilled water to produce 30 mL of solution.

   b. Use the 1.0 M sucrose solution to create 100 mL of each solution needed in this investigation. Use the volumes listed Table A below to create the solutions.

Table A: Serial dilution volumes

Solution Concentration (M)	Volume of 1.0 M Sucrose Solution (mL)	Volume of Distilled Water (mL)
0.00	0	100
0.02	2	98
0.04	4	96
0.06	6	94
0.08	8	92
0.10	10	90

2. Prepare 100 mL of 0.00 M, 0.02 M, 0.04 M, 0.06 M, 0.08 M, and 0.10 M sodium chloride. This is enough for 10 lab groups.

   a. Make 30 mL of 1.0 M sodium chloride (NaCl) by dissolving 1.75 g sodium chloride in enough distilled water to produce 30 mL of solution.

   b. Use the 1.0 M sodium chloride solution to create 100 mL of each solution needed in this investigation. Use the volumes listed Table A above to create the solutions.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not eat, drink, or taste materials in the lab.

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.

3	1	5	2	4
Dispose of the sodium chloride solutions, clean out each test tube, and repeat steps 1 and 2 using sucrose solutions.	Pour each sodium chloride solution into a test tube with the concentration clearly labeled.	Determine the concentration of electrolytes in the sports drink by comparing it to the conductivity versus concentration data.	Test the conductivity of each sodium chloride solution.	Dispose of the sucrose solutions, clean the test tubes, and then test the conductivity of a sample of sports drink.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Sodium chloride (salt) solutions

Set Up

1. ☐ Label the test tubes “0.00 M NaCl”, “0.02 M NaCl”, “0.04 M NaCl”, “0.06 M NaCl”, “0.08 M NaCl”, and “0.10 M NaCl”.

2. ☐ Use a funnel to pour 10 mL of distilled water into the test tube labeled 0.00 M.

3. ☐ Use a funnel to pour 10 mL of 0.02 M NaCl into its labeled test tube.

4. ☐ Rinse the funnel with distilled water.

5. ☐ Continue to fill each test tube with the appropriate solution, and rinse the funnel between each solution.

6. ☐ Why do you have to rinse the funnel with distilled water before using it again?

This lab deals with small amounts of electrolytes and very little conductivity. Without rinsing the funnel, the next solution will be contaminated with the previous solution. This will affect the accuracy of your results for conductivity.

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

8. ☐ Connect the conductivity sensor to the data collection system. �(2.1)

9. ☐ Configure the data collection system to manually collect conductivity and concentration data in a table. Define concentration as a manually entered data set with units of molarity (M). �(5.2.1)

10. ☐ What do you expect to happen to the conductivity as the concentration of sodium chloride increases?

Sodium chloride should dissociate into the ions Na^+ and Cl^-. As the concentration of sodium chloride increases, the number of ions in solution will also increase. Therefore, conductivity should increase as the concentration of sodium chloride increases.

11. ☐ Identify the dependent and independent variables as well as their units used in this part of the experiment.

The dependent variable is conductivity in units of microsiemens per centimeter (μS/cm).

The independent variable is the concentration of sodium chloride in units of molarity (M).

Collect Data

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

13. ☐ Test the conductivity of each salt solution starting with 0.00 M and moving up in concentration. To test the conductivity follow these steps:

- **a.** Set the range of the conductivity sensor to its lowest setting (0 to 1000 μS/cm) by pressing the green button marked with .
- **b.** Place the conductivity sensor in the test tube containing the sample you are testing.
- **c.** If the conductivity sensor is saturated (reads 1000 μS/cm), then change to the middle setting (0 to 10,000 μS/cm). If the conductivity sensor is saturated at the middle setting (reads 10,000 μS/cm), then change to the highest setting (0 to 100,000 μS/cm).
- **d.** Record the conductivity of the sample. �(6.3.2)
- **e.** Remove the conductivity sensor from the sample and clean the sensor by thoroughly rinsing it with distilled water.
- **f.** Repeat the steps above to test the conductivity of the next sample.

14. ☐ Why do you have to rinse the conductivity sensor with distilled water before using it again?

Without rinsing the conductivity sensor, the next solution will be contaminated with the previous solution and will affect the accuracy of your results for conductivity.

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

16. ☐ Copy the salt solutions conductivity data from your data collection system to Table 1 in the Data Analysis section.

17. ☐ Dispose of your solutions according to your teacher's instructions.

18. ☐ Clean all of your test tubes by rinsing them thoroughly with distilled water so that they can be used in the next part of this investigation.

Analyze Data

19. ☐ Create a graph of Conductivity (µS/cm) versus Concentration (M) on your data collection system. �(7.1.1)

20. ☐ Name the data run "salt solutions". �(8.2)

21. ☐ Explain what happens to the conductivity of the sodium chloride solution as the concentration of sodium chloride increases.

The conductivity increases as the concentration of sodium chloride increases.

Part 2 – Sucrose (sugar) solutions

Set Up

22. ☐ Label the test tubes "0.00 M sucrose", "0.02 M sucrose", "0.04 M sucrose", "0.06 M sucrose", "0.08 M sucrose", and "0.10 M sucrose".

23. ☐ Use a funnel to fill each test tube with 10 mL of the indicated sucrose solution.

24. ☐ What do you expect to happen to the conductivity as the concentration of sucrose increases?

The sucrose solutions will not conduct electricity because sucrose dissolves as molecules not ions. As the concentration of sucrose increases, there will be no change in conductivity.

25. ☐ Identify the dependent and independent variables as well as their units used in this portion of the experiment.

The dependent variable is conductivity in units of microsiemens per centimeter (µS/cm).

The independent variable is the concentration of sucrose in units of molarity (M).

26. ☐ Return to the table display on your data collection system.

Collect Data

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

28. ☐ Record the conductivity of each salt solution. Be sure to rinse the conductivity sensor with distilled water after each test. �(6.3.2)

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

30. ☐ Copy the sucrose solutions conductivity data from your data collection system to Table 1 in the Data Analysis section.

31. ☐ Dispose of your solutions according to your teacher's instructions.

32. ☐ Clean all of your test tubes by rinsing them thoroughly with distilled water so that they can be used in the next part of this investigation.

Analyze Data

33. ☐ Return to your graph of Conductivity (µS/cm) versus Concentration (M) on your data collection system.

34. ☐ Name the run "sugar solutions". �(8.2)

35. ☐ Explain what happens to the conductivity of the sucrose solution as the concentration of sucrose increases.

The conductivity of the sucrose solution does not change when the concentration of sucrose increases.

Part 3 – Sports drink

Set Up

36. ☐ Use a funnel to fill a test tube approximately halfway with a sports drink (at room temperature).

37. ☐ Why does the procedure specify that the sports drink should to be at room temperature?

Temperature may have an effect on conductivity. You can eliminate this variable by ensuring that all of the solutions are at the same temperature.

38. ☐ Configure your data collection system to monitor live conductivity data in a digits display. �(6.1)

Collect Data

39. ☐ Place the conductivity sensor in the test tube containing the sports drink and allow the conductivity reading to stabilize.

40. ☐ Record the brand and flavor of sports drink tested and its conductivity below.

Sports Drink: Brand "X", lemon-lime____________________________

Conductivity (µS/cm): 2210 µS/cm__________________________________ _

41. ☐ Save the data file and clean up your lab station according to the teacher's instructions. �(11.1)

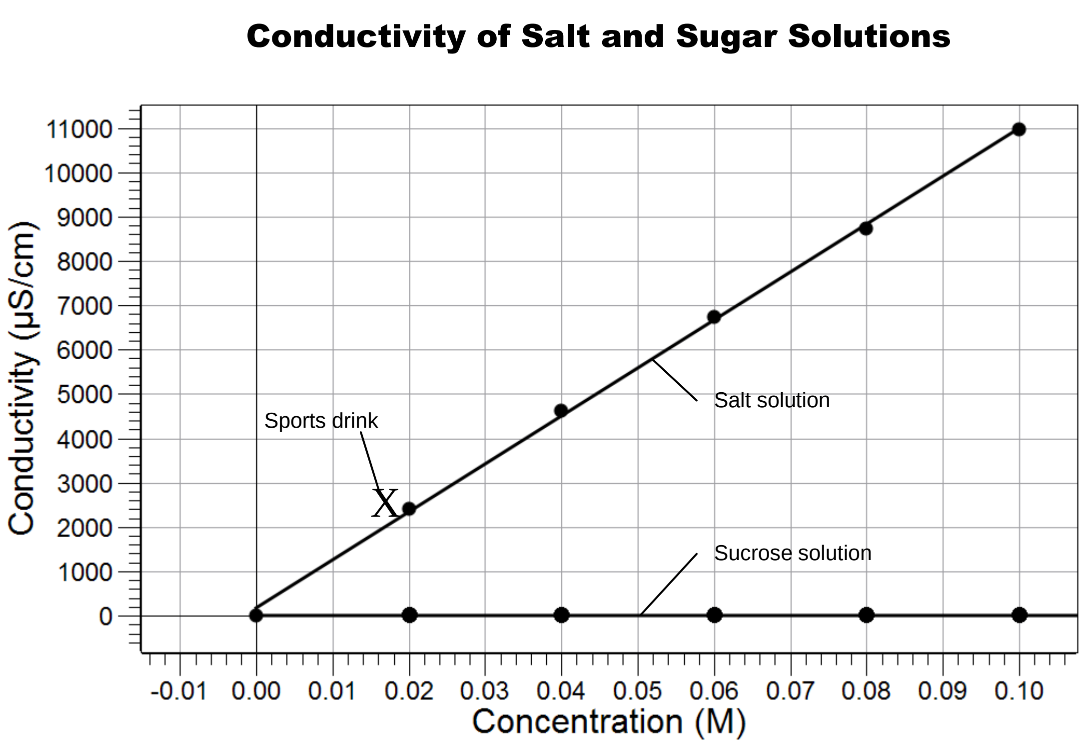
Data Analysis

Table 1: Measured conductivity of salt and sucrose solutions

Concentration of Salt and Sugar Solutions (M)	Conductivity of Salt Solutions (µS/cm)	Conductivity of Sucrose Solutions (µS/cm)
0.00	12	13
0.02	2,414	12
0.04	4,629	12
0.06	6,737	12
0.08	8,740	13
0.10	10,962	13

1. ☐ Return to your graph of Conductivity (µS/cm) versus Concentration (M) on your data collection system and display both the salt solutions data set and the sucrose solutions data set on the graph. �(7.1.3)

2. ☐ Plot or print a graph of Conductivity (µS/cm) versus Concentration (M). Include both the salt solutions data set and the sucrose solutions data set on the same set of axes (clearly label each). Label the overall graph, the x-axis, the y-axis, and include units on the axes.



3. ☐ Where does the sports drink you tested fit on the graph of Conductivity (μS/cm) versus Concentration (M) above? Place an "X" on the graph to mark this location and label it "Sports drink".

Analysis Questions

1. Explain the difference between an electrolyte solution and a non-electrolyte solution.

An electrolyte solution conducts electricity, and the conductivity increases as the concentration increases.

A non-electrolyte solution does not conduct electricity (or is a very poor conductor).

2. Which compounds in a sports drink are electrolytes? Which compounds in a sports drink are non-electrolytes?

The salts are electrolytes. The sugars and water are non-electrolytes.

3. What is the approximate concentration of electrolytes in the sports drink you tested? Explain how you determined this concentration.

Answers will vary (for the sample data, the concentration is between 0.01 and 0.02 M). The concentration can be estimated from the conductivity versus concentration graph.

4. Which effect does concentration have on the conductivity of an electrolyte solution?

Conductivity increases as the concentration of ions in solution increases.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Explain the difference at the molecular level between what happens when salt and sugar dissolve.

Salt dissociates into ions when it dissolves. Sugar dissolves as molecules.

2. Does crystalline table salt (sodium chloride) conduct an electric current?

No. In order to conduct electricity, there must be free-moving ions. In the solid state, the ions that make up sodium chloride are locked into position and cannot move. Because the electrons cannot move, they cannot conduct electricity.

3. Which type of compounds (ionic or covalent) generally makes better electrolyte solutions? Why?

Ionic compounds are generally better electrolytes because they dissociate into ions when dissolved in water.

4. Is human blood an electrolyte or non-electrolyte solution? Explain your answer.

Human blood is an electrolyte solution. Human blood contains ions such as sodium, potassium, calcium, chloride, hydrogen carbonate, and phosphate.

Multiple Choice Questions

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

1. What are solutions that conduct electricity called?

- **A. Electrolyte solutions**
- **B.** Non-electrolyte solutions
- **C.** Dilute solutions
- **D.** Concentrated solutions

2. What do solutions that conduct electricity contain that differentiates them from solutions that do not conduct electricity?

- **A.** Molecules
- **B.** Atoms
- **C. Free-moving ions**
- **D.** Solutes

3. Which of the following solutions would conduct electricity the best?

- **A.** A sugar solution
- **B. A salt solution**
- **C.** Distilled water
- **D.** All of the above

4. What would you expected to happen as the concentration of electrolytes in a solution increases?

- **A. An increase in the conductivity of the solution**
- **B.** A decrease in the conductivity of the solution
- **C.** A decrease followed by an increase in the conductivity of the solution
- **D.** The conductivity of the solution will remain the same

5. What forms of sodium chloride will conduct electricity?

- **A.** In a solid crystalline state
- **B.** In a molten liquid state
- **C.** When dissolved in water
- **D. Both B and C**
- **E.** A, B, and C will all conduct electricity

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. We use physical properties to observe and describe matter. **Physical properties** of matter include color, density, odor, boiling point, melting point, solubility, and conductivity (among others). This investigation uses conductivity to differentiate between different types of matter. **Conductivity** is the ability of an electric current to pass through a substance. An electric current is the flow or movement of charged particles (either electrons or ions).

2. Just as some solid substances, like metal wires, are good conductors of electricity, some liquids can also conduct electrical current. Such liquids are called **electrolyte solutions**. In order to be conductive, a solution must contain charged particles, or **ions**, which are free to move. Ions are formed if a solute **dissociates**, or splits into ions, when dissolved in a solvent (usually water). The free-moving ions enable an electric current to pass through the solution.

3. Not all substances ionize when they **dissolve** into solution. Many substances dissolve as molecules. Because there are no charged particles, the solution will not conduct electricity. Solutions that do not conduct an electric current are known as **non-electrolyte solutions**. Substances such as pure water, oil, phenol, and alcohol are examples of substances that are non-electrolytes.

Extended Inquiry Suggestions

Determine the concentration of sodium chloride in contact lens saline solutions. Do different brands have the same concentration?

Investigate reasons why the conductivity of freshwater lakes, streams, or ponds could change over time.

Compare various brands and flavors of sports drinks.

Compare various brands of bottled water.

Test the effect of temperature on conductivity.

Test water samples from various locations (tap water from different parts of the school or city).

Test environmental water samples from various locations or sources.

6. Properties of Ionic and Covalent Compounds

Objectives

Determine if an unknown substance is an ionic, polar covalent, or non-polar covalent compound based on its physical properties. Through this investigation, students:

- Review physical properties, including conductivity, solubility, hardness, and melting point
- Determine differences in physical properties for ionic and molecular covalent compounds
- Explain the differences between intramolecular and intermolecular forces

Procedural Overview

Students conduct the following procedures:

- Test the conductivity, solubility, hardness, and melting point of ionic, polar covalent, and non-polar covalent compounds
- Identify an unknown substance as an ionic, polar covalent, or non-polar covalent compound

Time Requirement

Preparation time	10 minutes
Pre-lab discussion and activity	30 minutes
Lab activity	45 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Conductivity sensor
- Hot plate
- Graduated cylinder, 10-mL
- Test tube (5), 15-mm x 100-mm
- Test tube rack
- Stopper, (3) to fit the test tubes
- Spatula
- Tongs
- Aluminum foil square (6), 5-cm x 5-cm
- Masking tape
- Wash bottle and waste container
- Distilled (deionized) water, 30 mL
- Table salt ($NaCl$), 1 g
- Table sugar ($C_{12}H_{22}O_{11}$), 1 g
- Paraffin wax, 1 g
- Unknown A, 1 g[1]
- Unknown B, 1 g[1]
- Unknown C, 1 g[1]

[1] Use glucose (also called dextrose, $C_6H_{12}O_6$) for unknown A; use crayon pieces for unknown B; and use potassium chloride (KCl) for unknown C.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Physical properties
- Types of bonds
- Polar versus non-polar molecules

Related Labs in This Guide

Labs conceptually related to this one include:

- Density
- Electrolyte versus Non-Electrolyte Solutions

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 �(2.1)
- Monitor live data �(6.1)

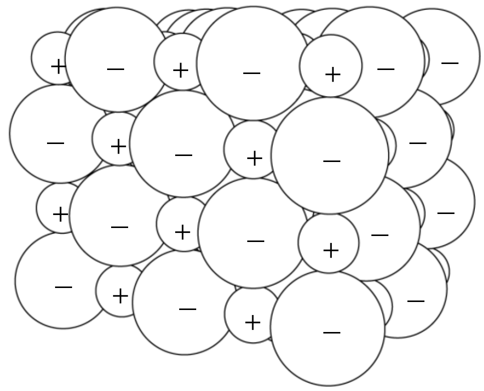
Background

In nature, a wide variety of forces exist. In chemistry, different electrical forces of attraction hold substances together. These electrostatic forces are the result of atoms interacting with electrons (subatomic particles with negative charge). Within the nucleus exists protons (subatomic particles with positive charge); it is the attraction between the positively charged nucleus and the outer negatively charged electrons that result in electrostatic forces of attraction.

Atoms are chemically bonded to each other as a result of intramolecular forces. These bonds exist within molecules because of a sharing of electrons between two bonding atoms. When each atom contributes an electron to the pair being shared between two atoms, it is called a covalent bond. If one atom shares a pair of electrons originally belonging to only itself with another atom, the result is a coordinate covalent bond. Metallic bonding occurs when electrons are equally distributed between a number of metal atoms, such that they are surrounded by a “sea of electrons.”

In some pairings of atoms (those between a metal and a non-metal), the electron is not shared. Instead, it is completely transferred from the metal to the non-metal. In such an instance, the metal completely loses one or more electrons and becomes positively charged, forming an ion (cation), while the non-metal completely gains the electrons and becomes negatively charged forming an ion (anion). Here, opposite charges attract the ions together much like a collection of magnets. The resulting electrostatic interaction forms an ionic bond.

The mass of alternating positive and negatively charged ions forms a crystal lattice. Because the units are not discrete, compounds formed between ions are not able to be called molecules. Instead, they are referred to as ionic compounds.

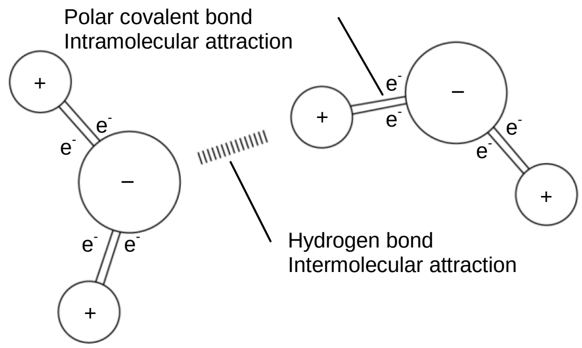


Sodium chloride in a solid crystal lattice arrangement.

Differentiating between covalent and ionic bonds depends upon the relative degree that the electrons are shared between atoms. This differentiation is based on the individual atoms' tendencies to gain or lose electrons, measured as electronegativity. Electronegativity is ordered on the Pauling scale (named after the American chemist, Linus Pauling) and has a range of 0 to 4. The larger the electronegativity value, the greater the atom's tendency to gain an electron.

Electronegativity differences between two atoms determine the bond classification: those with differences greater than 1.7 are considered ionic and those with differences less than 1.7 are considered covalent. With covalent bonding, even though electrons are shared an atom in the pair might have a greater affinity for the electrons. In these instances (electronegativity differences between 0.5 and 1.7), the electron is not equally shared and results in a polar bond, where the negative charge of the electron resides heavily with the atom with the greater electronegativity. For those pairings of atoms where there is not a great difference in tendency to gain or lose electrons (electronegativity values less than 0.5), the electron is equally distributed between the two atoms and results in a non-polar bond.

Neighboring molecules may also feel the attractions between the nuclei within its own molecule and the electrons of the molecule next to it. Intermolecular forces hold molecules together to form liquids and solids and are much weaker than the forces holding atoms together to form individual molecules. These intermolecular forces can be overcome with the input of energy. This causes solids to melt and liquids to boil, simply by overcoming the intermolecular forces holding the molecules to one another.



Water molecules

The properties of a substance are a direct result of the different intramolecular and intermolecular forces that exist because of the substance's composition and structure. Because atoms and molecules cannot be seen directly (even with the most powerful microscopes), chemists must rely upon macroscopic properties, such as conductivity, hardness, melting point, and solubility to determine the types of attractions present for a particular substance.

Pre-Lab Discussion and Activity

Demonstrations

Engage the students in a discussion about why different substances behave differently by demonstrating the following situations. Hold up a piece of chalk and a piece of plastic in front of the class and drop both of them. Next, place a packaging peanut in a beaker of water and another packaging peanut in a beaker of acetone (or nail polish remover). Discuss the results, emphasizing that different materials behave in different ways.

1. What happened to the chalk and the plastic when dropped? Why?

The chalk broke into pieces but the plastic did not change. Chalk and plastic consist of different substances that are held together with different types of chemical bonds.

2. What are packaging peanuts made up of?

Packaging peanuts are made up of plastic (polystyrene) and air.

3. Do packaging peanuts behave the same way in water and acetone?

Packaging peanuts remain unchanged when placed in water. When placed in acetone, however, the packaging peanuts dissolve and the air inside of them is released.

4. Why do packaging peanuts behave differently in water and in acetone?

Water molecules and acetone molecules are different and contain different types of bonds. Water is a polar substance and polystyrene is a non-polar substance so polystyrene does not dissolve. Acetone, on the other hand, has non-polar bonding and, therefore, dissolves the polystyrene.

Teacher's Tip: The rule “like dissolves like” can be included as a discussion topic here.

Ways That Atoms Combine to Form Macroscopic Matter

Review that the properties of matter are explained by the atoms that make them up and the way in which these atoms bond. Show a model of an ionic lattice structure, a covalent lattice structure, and a model (or drawing) of how molecular substances establish intermolecular attractions to form macroscopic matter.

5. What makes up all the different types of matter?

There are 117 known atomic elements which all have different properties and behaviors. In addition to their individual atomic properties, these atoms can also bond with other atoms to form the vast array of different types of compounds making up matter.

6. If atoms are so small they cannot be seen, even with a microscope, how is it possible that we can see matter?

Matter is made up of lots of atoms. We may not be able to see one atom, but when we have enough of them we can see them.

Teacher's Tip: Demonstrate this by putting one small grain of sand into a large jar and holding it at a distance. Compare this to when the jar is filled with sand.

7. How do atoms combine? What are these structures called?

Atoms combine in different ways. Some atoms bond to other atoms in lattice structures to form ionic compounds, while other atoms combine together into molecules and the molecules are held to each other by intermolecular forces.

8. Based on your understanding of how atoms combine, explain why the chalk broke when it was dropped and the plastic did not?

Chalk breaks when it falls because the ions in the lattice structure are shifted so that like charges are next to each other and they repel, causing the chalk to break. The plastic on the other hand did not break because it does not contain charged particles. Plastic is made up of molecules (macromolecules) that are intertwined with each other. When plastic hits the ground, the group of molecules shifts, but there is no sudden repulsion and, therefore, no breakage.

9. Why is water a liquid at room temperature, but oxygen is a gas?

Both water and oxygen are covalent molecular substances. The difference in their state of matter at room temperature is due to the strength of the intermolecular forces holding the molecules together. Water molecules are polar and oxygen molecules are non-polar. The polar water molecules are held together with stronger intermolecular attractions than the non-polar oxygen molecules.

Properties of Matter Explained

Substances that contain similar bonds have similar properties. So if you know the type of bonding in a substance, the material properties can be predicted. The reverse is also true. If you know the properties of a certain substance, then the bonding involved can be inferred.

10. How can you explain why certain substances have characteristic properties?

The properties of the substance are based on the type of atoms in the substance and the way they are bonded.

11. How can you predict the types of bonding in a given substance?

If you know the general properties of certain types of bonding, you can use the properties to predict the type of bonds in the substance.

Lab Preparation

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

Place the unknown substances in containers labeled "unknown A", "unknown B", and "unknown C".

Recommended unknowns are:

Unknown A: a polar covalent compound such as glucose (commonly called dextrose, $C_6H_{12}O_6$) or aspartame ($C_{14}H_{18}N_2O_5$), an artificial sweetener

Unknown B: a non-polar covalent compound such as crayons

Unknown C: an ionic compound such as potassium chloride (KCl)

Safety

Add these important safety precautions to your normal laboratory procedures:

- The hot plate gets extremely hot. Avoid contact with the hot plate until it has completely cooled.
- Keep all materials, especially electrical cords and paper, away from the hot plate while it is hot.

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.

4	3	1	2
Identify the bonding characteristics of the unknown compounds.	After testing the known compounds, test the physical properties of each of the unknown substances.	Obtain the equipment and label all materials that will be used in the experiment.	Test 4 different physical properties for each of the known compounds.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

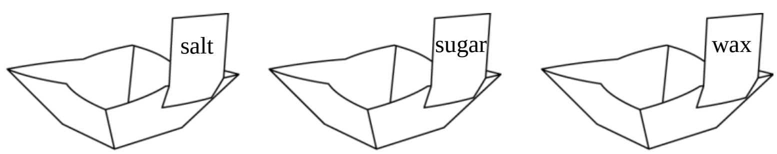
1. ☐ Plug in the hot plate and set it to its highest setting.

2. ☐ Place four test tubes in a test tube rack. Label the test tubes “salt”, “sugar”, “wax”, and “distilled water”.

3. ☐ Create and label three aluminum foil dishes.

a. Fold three pieces of aluminum foil (5-cm × 5-cm squares) into small dishes.

b. Place a piece of tape on each dish and label the dishes “salt”, “sugar”, and “wax”. These dishes will eventually be placed on the hot plate, so make sure that the label is positioned so that it will not directly touch the heating surface.



4. ☐ Why is it important to label the test tubes and aluminum dishes?

Many substances have similar appearances. By labeling their containers, you avoid confusion.

5. ☐ Use a spatula to place a pea-sized sample of each substance in the appropriately labeled aluminum dish and another pea-sized sample of each substance in the appropriately labeled test tube.

Collect Data

6. ☐ Test the hardness of each compound by rubbing a small sample between your fingers. Record the hardness as either soft and waxy, or brittle and granular. Record your observations in Table 1 below. Wash your hands after testing.

Table 1: Observed physical properties of salt, sugar, and wax

Physical Property	Ionic Compound: salt (sodium chloride)	Covalent Compound Polar Molecular: sugar (sucrose)	Covalent Compound Non-polar Molecular: wax
Hardness (soft and waxy or brittle and granular)	brittle and granular	brittle and granular	soft and waxy
Melting point (high or low)	high	low	low
Soluble in water (yes or no)	yes	yes	no
Conductivity in water (µS/cm)	56,223	59	14
Conductor or non-conductor	conductor	non-conductor	non-conductor

7. ☐ Place the aluminum dishes containing the samples onto the hot plate and heat them for a maximum of three minutes. If a substance melts, use tongs to carefully remove the aluminum dish from the hot plate, allow it to cool, and record the melting point as low (in Table 1 above).

8. ☐ After three minutes of heating, turn the hot plate off. If a substance did not melt, record its melting point as high in Table 1 above.

9. ☐ Explain the types of bonds that are being overcome during the melting of ionic and covalent molecular compounds.

For ionic compounds, the ionic bonds must be overcome for the substance to melt.

For covalent molecular compounds, the intermolecular attractions must be overcome for the substance to melt.

10. ☐ Fill each of the test tubes containing the separate samples with approximately 5 mL of distilled water.

11. ☐ Stopper each test tube and gently shake the test tubes for two minutes or until dissolved.

12. ☐ Observe each test tube and record whether the substance dissolved or not. Record your observations in Table 1 above.

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

14. ☐ Connect the conductivity sensor to the data collection system. �(2.1)

15. ☐ Configure your data collection system to monitor conductivity in a digits display. �(6.1)

16. ☐ Set the range of the conductivity to its lowest setting (0 to 1000 µS/cm) by pressing the green button marked with .

17. ☐ Test the conductivity of the distilled water by placing the conductivity sensor in the test tube filled with distilled water. Record the results below.

Conductivity of distilled water (µS/cm): ____14 µS/cm____

18. ☐ Test the conductivity of the three remaining samples by following the steps below:

a. If the substance did not completely dissolve, decant the solution into another test tube.

b. Place the conductivity sensor in the test tube containing the decanted liquid.

c. Start with the conductivity sensor at its lowest setting: (0 to 1000 µS/cm). If the conductivity sensor is saturated (reads 1000 µS/cm), then change to the middle setting (0 to 10,000 µS/cm). If the conductivity sensor is saturated at the middle setting (reads 10,000 µS/cm), then change to the highest setting (0 to 100,000 µS/cm).

d. Record the conductivity (µS/cm) in Table 1 above.

e. Clean the conductivity sensor using distilled water and then repeat for the next sample.

19. ☐ If the conductivity is similar to distilled water, record the sample as a non-conductor in Table 1 above. If the conductivity of the sample is much greater (100 times or more) than the distilled water, record the sample as a conductor in Table 1 above.

20. ☐ What does conductivity indicate about the molecular structure of a compound?

Conductivity occurs when there is a flow of charged particles. If a substance conducts electricity, then it must be composed of ions that are free to move.

21. ☐ Dispose of the solutions and solids and clean the glassware so that it can be used to test the unknowns.

22. ☐ Obtain the unknown samples and repeat the experiment to find the properties of each of the unknown substances. Record the results in Table 2 below.

Table 2: Observed physical properties of unknowns

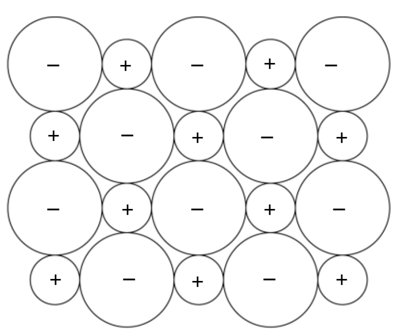
Physical Property	Unknown A	Unknown B	Unknown C
Hardness (soft and waxy or brittle and granular)	hard and brittle	soft and waxy	hard and brittle
Melting point (high or low)	low	low	high
Soluble in water (yes or no)	yes	no	yes
Conductivity in water (µS/cm)	25	32	43,011
Conductor or non-conductor	non-conductor	non-conductor	conductor

23. ☐ Clean the lab station according to the teacher's instructions.

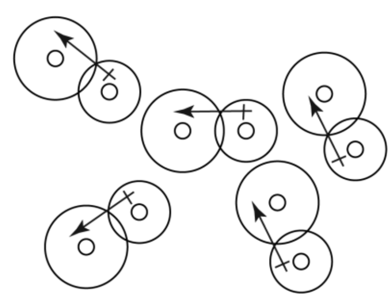
Data Analysis

1. ☐ Draw pictures that illustrate the molecular structure of each of the following:

Ionic compounds:



Molecular Polar Covalent Compounds:



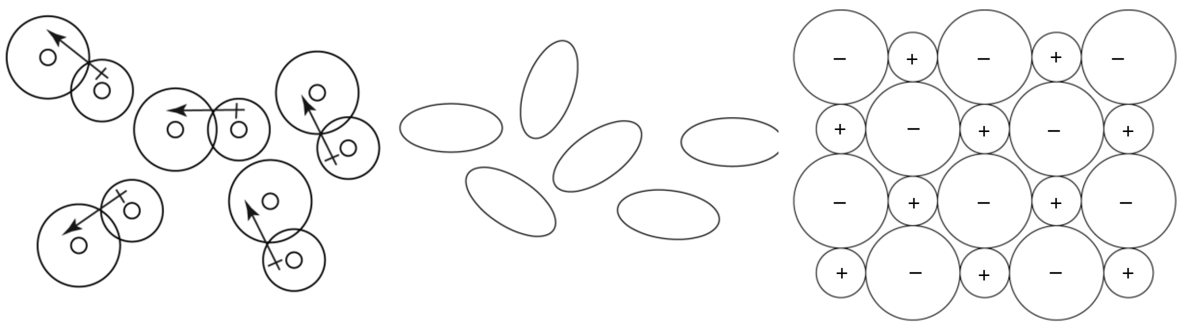
Molecular Non-polar Covalent Compounds:

2. ☐ Identify the molecular bonding (compound type) of unknown A, unknown B, and unknown C, and briefly explain the evidence supporting your decision.

Unknown	Type of Bonding	Evidence
Unknown A	polar molecular covalent compound	low melting point, soluble in water, low conductivity
Unknown B	non-polar molecular covalent compound	low melting point, insoluble in water, low conductivity
Unknown C	ionic compound	high melting point, soluble in water, high conductivity

3. ☐ Draw pictures that illustrate the molecular structure of unknown A, of unknown B, and of unknown C.

Unknown A　　Unknown B　　Unknown C



Analysis Questions

1. How can you determine if an unknown substance is an ionic compound or a molecular covalent compound (either polar or non-polar)?

Observe the macroscopic properties of the substance. Substances that dissolve in water, conduct electricity, and have a high melting point are ionic compounds. Substances that do not dissolve in water, do not conduct electricity, and have low melting points are molecular covalent compounds.

2. What properties are the same for ionic and molecular covalent compounds (either polar or non-polar)?

Both may be hard and granular, and both may be soluble in water.

3. What is the difference between an ionic bond and an ionic compound?

Ionic bonds exist between two atoms. Ionic compounds are an entire network (lattice structure) of ionic bonding between many atoms.

4. What properties can be used to determine if a molecular covalent is polar or non-polar?

Polar covalent molecules will have high melting points and will be soluble in water while non-polar covalent molecules will have low melting points and will not be soluble in water.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What are the two main chemical components of air? Predict the type of bonding for each. Explain your reasoning.

Air is approximately 78% nitrogen and 21% oxygen. The remaining 1% is other gases, including argon, carbon dioxide, and water vapor.

Both nitrogen and oxygen gases are non-polar covalent compounds. They both must have very low melting points because they exist as gases at room temperature.

2. Odor is another physical property that can be tested. Which type of compounds (ionic or molecular covalent) would you expect to have a stronger odor? Why?

Covalent compounds have lower melting points and require less energy to overcome the intermolecular forces holding the molecules together in solid form. This also applies to the intermolecular forces that must be overcome for the molecules to vaporize into individual gas molecules of the substance. The substance must be in vapor form so that the molecules can enter the nose and be smelled.

3. Oil does not dissolve in water. Based on this observation, would you classify oil as a non-polar covalent, polar covalent, or ionic compound? Explain.

Oil is a non-polar covalent compound. If oil were ionic or polar covalent, it would dissolve in water.

Multiple Choice Questions

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

1. Which of the following is a property of an ionic compound?

- **A.** Conducts electricity in the solid state
- **B. Conducts electricity when dissolved in water**
- **C.** Has a low melting point
- **D.** Is soft and waxy

2. How are molecules in covalent compounds held together?

- **A. Intermolecular forces**
- **B.** Intramolecular forces
- **C.** Ionic bonds
- **D.** Covalent bonds

3. What substance most likely exists as a gas at room temperature?

- **A.** Ionic compound
- **B.** Polar covalent compound
- **C. Non-polar covalent compound**
- **D.** Metal

4. What substance most likely does not dissolve in water?

- **A.** Ionic compound
- **B.** Polar covalent compound
- **C. Non-polar covalent compound**
- **D.** Gaseous compound

5. What substance most likely dissolves in water but in solution does not conduct electricity?

- **A.** Ionic compound
- **B. Polar covalent compound**
- **C.** Non-polar covalent compound
- **D.** Metal

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. **Intramolecular** forces cause atoms to be attracted to one another within molecules. These forces result when the **positive** charged nuclei of two atoms are attracted to the same set of **negative** charged electrons. If the electrons are shared between the atoms, then a **covalent** bond is formed. If the electrons are taken completely by one atom, the atom becomes an ion and forms **ionic** bonds.

2. Atoms do not have the same tendencies to gain and lose electrons. **Electronegativity** is the measure of how much an atom tends toward gaining an electron. When one atom in a **covalent** bond has a greater affinity for the electron, a **polar covalent** bond is formed because the electron is **unequally** shared between the bonding atoms. If the electrons are **equally** shared, then the negative charge is distributed between the atoms equally forming a **non-polar covalent** bond.

3. When forces of attraction exist between neighboring molecules, they are called **intermolecular** forces. These forces are **weaker** than the forces holding atoms together and cause the molecules to form solids and liquids. The types of forces holding atoms and molecules together give substances their different **physical** properties, such as **melting point**, electrical **conductivity**, and **solubility** in water.

Extended Inquiry Suggestions

Investigate whether the amount of the substances tested affects the physical properties measured in this investigation (intensive versus extensive properties).

Investigate a variety of liquids to determine which is the most polar.

Ask students to draw and/or build molecules of these compounds to help them visualize the unequal distribution of charge in polar bonds and polar molecules.

Explore the effects of temperature on the solubility of an ionic substance.

7. pH of Household Chemicals

Objectives

Working with common household chemicals, students develop an understanding of the relationship between pH and the hydronium ion (H_3O^+) concentration. Through this investigation, students:

- Classify solutions as acidic, basic, or neutral based on their pH or hydronium ion (H_3O^+) concentration
- Compare the relative strengths of acids and bases based on their pH or H_3O^+ concentration

Procedural Overview

Students conduct the following procedures:

- Measure the pH of common household chemicals and classify them as acids or bases
- Calculate the hydronium ion (H_3O^+) concentration from the measured pH values and graph pH versus H_3O^+ concentration

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	40 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Beaker (2), 50-mL
- Graduated cylinder, 50-mL
- Graduated cylinder, 10-mL
- Test tube (10), 15-mm x 100-mm
- Test tube rack
- Wash bottle and waste container
- Buffer solution pH 4, 25 mL
- Buffer solution pH 10, 25 mL
- White vinegar (~5% acetic acid), 5 mL
- Lemon Juice, 5 mL
- Soft drink, 5 mL
- Window cleaner, 5 mL
- Tap water, 5 mL
- Milk, 5 mL
- Coffee, 5 mL
- 0.5 M Sodium bicarbonate (baking soda), 5 mL[1]
- Liquid soap, 5 mL
- Bleach, 5 mL

[1] To formulate using solid sodium bicarbonate (baking soda), refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Properties of acids and bases
- Concentration (molarity)
- Calculations involving logarithms

Related Labs in This Guide

Labs conceptually related to this one include:

- Soil pH
- Air Pollution and Acid Rain

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- Calibrating a pH sensor �(3.6)
- Manual sampling mode with manually entered data �(5.2.1)
- Starting a manually sampled 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)
- Showing and hiding connecting lines between data points �(7.1.8)
- Adding a measurement to a table �(7.2.2)
- Creating calculated data �(10.3)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

We are surrounded in life by acids and bases. Acids are found in numerous substances including soft drinks, salad dressing, the human body, rain water, and batteries. Acids taste sour, cause indicators to change color (turn litmus red), react with certain metals to form hydrogen gas, and react with bases to form a salt and water.

Bases can be found in soap, cleaning products, baking soda, and beer. Bases taste bitter, feel slippery or soapy, cause indicators to turn color (turn litmus blue), react with oil and grease, and react with acids to form a salt and water.

At the molecular level, an acid is able to donate a hydrogen ion (Brønsted-Lowry acid). The donated hydrogen ion can bond with any available water molecule to form a hydronium ion (H_3O^+). Acids are ranked based on how easily they give up their hydrogen ions. The terms "strong" and "weak" refer not to the concentration of the acid, but the degree to which the acid dissociates (separates into hydrogen ions and the conjugate base).

A strong acid is one that readily and completely dissociates. In a strong acid, every acid unit breaks into a hydrogen ion and the negative counter ion. For example, with hydrochloric acid every unit of HCl splits into H^+ and Cl^-.

In contrast, a weak acid is one that only partially dissociates. In a weak acid only a fraction of the available acid units break into hydrogen ions and the negative counter ions. For example in acetic acid of 100 $HC_2H_3O_2$ units, only one splits into H^+ and $C_2H_3O_2^-$ while the remaining 99 remain combined as $HC_2H_3O_2$.

A base is the complement of an acid. A base is a substance that accepts a hydrogen ion (Brønsted-Lowry base). The more readily a chemical substance bonds with hydrogen ions, the stronger the base.

The pH scale provides a numerical measure of the acid concentration of a chemical substance in solution. The term pH refers to the concentration of H_3O^+ in a solution of the substance. The pH scale is based on the observation that water has a slight tendency to autoionize into H^+ and hydroxide ions (OH^-). Because there is a one-to-one mole ratio, equal amounts of the H_3O^+ ion and the OH^- are formed. At 25 °C, 1.0 x 10^{-7} M of each ion forms.

$$H_2O(l) + H_2O(l) \rightarrow H_3O^+(aq) + OH^-(aq)$$

$$K_{eq} = K_w = [H_3O^+]\,[OH^-] = (1.0 \times 10^{-7})(1.0 \times 10^{-7})$$

The equilibrium constant for this reaction is $K_w = 1.0 \times 10^{-14}$, also called the ion-product constant for water.

The concentration of H_3O^+ ions and OH^- ions is inversely related. If the concentration of H_3O^+ ions increases, then the OH^- ion concentration must decrease and vice versa. The following table shows the two extremes after adding a strong acid or a strong base to water to make a 1.0 M solution.

Table: Concentrations of H_3O^+ and OH^- in 1 M solutions of a strong acid and a strong base

Add a strong acid to create a 1.0 M solution:	Add strong base to create a 1.0 M solution:
$\left[H_3O^+\right] = 1.0\ M = 10^0$ $\left[OH^-\right] = \dfrac{K_w}{\left[H_3O^+\right]} = 1 \times 10^{-14}$	$\left[H_3O^+\right] = \dfrac{K_w}{\left[OH^-\right]} = 1 \times 10^{-14}$ $\left[OH^-\right] = 1.0\ M = 10^0$

The range of H_3O^+ ion concentrations will therefore generally be between 1 and 1 x 10^{-14}. Because of the extreme range of values, the pH scale simplifies these numbers by taking the negative logarithm of the H_3O^+ ion concentration to give a range from 0 to 14.

$$pH = -\log [H_3O^+]$$

When there are equal concentrations of H_3O^+ ions and OH^- ions, a solution is said to be neutral and has a pH value of 7. When there are greater amounts of H_3O^+ ions than OH^- ions the solution is acidic and has a pH less than 7. The lower the pH value the more acidic the solution. When there are fewer H_3O^+ ions than OH^- ions, the solution is basic and has a pH greater than 7. The higher the pH value the more alkaline (basic) the solution.

Pre-Lab Discussion and Activity

Discuss acids, bases, and pH with your students using the following activities and questions.

pH and Consumer Products

1. Where have you heard the terms acid, base, or pH used? What type of consumer products use these terms on their labels?

Acids – battery acid, acids in foods, stomach acid, build up of lactic acid during exercise, drugs, acid rain, acidic soil, amino acids for body building.

Bases – soaps, cleaning products, baking soda, antacids, beer.

pH – consumer products such as cosmetics, deodorants, and shampoos are often labeled as “pH balanced.” Also, pH is referred to in swimming pool maintenance, fish tanks, and water quality.

2. What are some properties of acids and bases?

Acids – tart or sour tasting, turn litmus red, react with certain metals to form hydrogen gas, react with bases to form a salt and water.

Bases – bitter tasting, feel slippery or soapy, turn litmus blue, react with oil and grease, react with acids to form a salt and water.

3. What is pH and how is it related to acids and bases?

The pH scale measures the acidity of a substance. Acids have a pH less than 7 and bases have a pH greater than 7.

4. At the molecular level what makes something more or less acidic?

At the molecular level, acidity is a measure of the H_3O^+ ion concentration in a solution. The greater the concentration of H_3O^+ ions, the more acidic the solution.

Conductivity of Acidic, Basic, and Neutral Solutions

Use a conductivity sensor or a light bulb conductivity tester to test the conductivity of a 0.1 M hydrochloric acid (HCl) solution, a 0.1 M sodium hydroxide (NaOH) solution, and distilled water.

Help the students to understand that both acids and bases have a significant amount of ions present, but that distilled water has very few ions. Write the chemical equation for each reaction on the board and help the students analyze the concentration of each ion present.

Write the following table on the board and have students help you fill it in.

Table: Conductivity of 0.1 M HCl, distilled water, and 0.1 M NaOH

	0.1 M HCl	Distilled H_2O	0.1 M NaOH
Conductivity tester	bright light	no light	bright light
Conductivity sensor (μs/cm)	32,227	15	16,658

5. What do these conductivity readings tell us about hydrochloric acid, sodium hydroxide (base), and distilled water?

Conductivity is a measure of how easily electric current can flow. In order for an electric current to flow, ions (charged particles) must be present in the solution. Good conductors have a greater concentration of ions in the solution. Both hydrochloric acid and sodium hydroxide are good conductors, thus we know their solutions contain many ions. Poor conductors do not contain ions or the concentration of ions is extremely low, therefore distilled water is a poor conductor.

6. What ions are involved in each of the solutions tested? What is the concentration of each ion present?

0.1 M Hydrochloric Acid: $HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$

Hydrochloric acid completely dissociates to produce 0.1 M of H_3O^+ and 0.1 M Cl^-.

0.1 M Sodium Hydroxide: $NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$

Sodium hydroxide completely dissociates to produce 0.1 M Na^+ and 0.1 M OH^-.

Distilled water: $H_2O(l) + H_2O(l) \rightarrow H_3O^+(aq) + OH^-(aq)$

The self-ionization of pure water occurs to a very small extent. At 25 °C pure water contains 1.00×10^{-7} M H_3O^+ ions and 1.00×10^{-7} M OH^- ions. Pure water has a very small amount of each ion (0.0000001 M) which explains why it is such a poor conductor.

Hydronium Ion Concentration and the pH Scale

Use a pH sensor to test the pH of 0.1 M HCl, 0.1 M NaOH, and distilled water.

Discuss with students how pH is a measure of the H_3O^+ ion concentration (acidity) of a solution and how a substances ability to donate H^+ ions affects the H_3O^+ ion concentration and pH. Explain that acids are substances that *donate* H^+ ions and bases are substances that *accept* H^+ ions. The addition or removal of H^+ affects the balance H_3O^+ ions and OH^- ions that exist in pure water. The concentrations of H_3O^+ and OH^- are inversely proportional. As the concentration of H_3O^+ increases, the concentration of OH^- decreases. The product of the concentration of H_3O^+ and OH^- is a constant, and is known as the ion-product constant for water.

$$K\mathrm{w} = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$$

When the concentrations of H_3O^+ and OH^- are equal, the solution is neutral (pH = 7). If the concentration of H_3O^+ is greater than the OH^- concentration, the solution is acidic (pH < 7). If the H_3O^+ concentration is less than the OH^- concentration, the solution is considered alkaline or basic (pH > 7).

Add the following rows to the table you wrote on the board in the previous activity and have the students help you fill it in.

Table: Conductivity, pH, and concentrations of ions in 0.1 M HCl, distilled water, and 0.1 M NaOH

	0.1 M HCl	**Distilled H_2O**	**0.1 M NaOH**
Conductivity tester	bright light	no light	bright light
Conductivity sensor (µs/cm)	32,227	15	16,658
pH	1	7	13
Concentration of H_3O^+ (M)	1×10^{-1}	1×10^{-7}	1×10^{-13}
Concentration of OH^- (M)	1×10^{-13}	1×10^{-7}	1×10^{-1}
Acidic, basic, or neutral? (M)	Acidic	Neutral	Basic

7. How are acids and bases defined in terms of H^+ ions?

Acids are substances that donate H^+ ions and bases are substances that accept H^+ ions.

8. What happens to the concentration of H_3O^+ when an acid is added to water? When a base is added to water?

Acids donate H^+ ions and therefore cause the concentration of H_3O^+ to increase.

Bases accept H^+ ions and therefore cause the concentration of H_3O^+ to decrease.

9. Compare the concentrations of H_3O^+ ions in acids, bases, and neutral solutions to their pH values.

Acidic solutions have larger concentrations of H_3O^+ ions and therefore low pH values. Bases have low concentrations of H_3O^+ ions and therefore high pH values. Neutral solutions have an equal number of H_3O^+ and OH^- ions and therefore have a pH of 7.

Logarithmic Scales and pH

Explain to students that pH is a logarithmic scale and that logarithmic scales are used when there is a wide range of values involved. The logarithmic scale simplifies cumbersome numbers by referring to the exponent to which a base (in this case 10) must be raised to yield the number as opposed to talking about the number itself.

Demonstrate the difference between a logarithmic scale and a linear scale by changing volumes of water as explained below. End by providing the definition of pH as the negative log of the concentration of H_3O^+ ions.

Linear scale demonstration: Start with an empty 100 mL graduated cylinder. Add 10 mL. Record the volume and repeat this 5 times. Explain that linear scales are based on addition and subtraction. Each change involves adding or subtracting the same amount.

Logarithmic scale demonstration: Add 10 mL of water to an empty 100 mL graduated cylinder. This time, multiply 10 mL by 10. Fill the graduated cylinder to the top (100 mL). Multiply 100 mL by 10 and transfer the water to a 1000 mL graduated cylinder and fill it up. Continue the process by having the students suggest larger containers that could be used to hold the increasing amount of water. As you are doing this emphasize that the "log" is the power (exponent) to which 10 is being raised to give the volume of water.

Have the students help you fill out a table as you perform the demonstrations:

Table: Comparison of a linear scale and a logarithmic scale

Number of Changes	Linear Scale	Logarithmic Scale	
	Increase the volume by 10 mL each time	Increase the volume by multiplying by 10.	Log
1	10	10 10^1	1
2	10 + 10 = 20	10 ×10 =100 10^2	2
3	20 + 10 = 30	100 × 10 =1,000 10^3	3
4	30 + 10 = 40	1,000 × 10 =10,000 10^4	4
5	40 + 10 = 50	10,000 × 10 =100,000 10^5	5

10. Why do we have the concept of pH if it is simply the concentration (molarity) of H_3O^+ ions?

The molarity of H_3O^+ ions ranges from 1 x 10^{-1} M to 1 x 10^{-14} M. This is a huge range of numbers and the numbers themselves are cumbersome and difficult to write. The pH scale was implemented to simplify discussions of acids and bases.

11. How is a logarithmic scale different than a typical linear scale? When is logarithmic scale preferred over a linear scale?

A linear scale is based on addition/subtraction. Each step on the scale is the same. A logarithmic scale is based on powers of 10. Each step increases or decreases in size. Logarithmic scales are useful when there is a large range of values being covered.

12. Does a linear scale or a logarithmic scale cover a wider range of values?

A logarithmic scales cover a wider range of values. In the example above the linear scale changed from 10 to 50. The logarithmic scale changed from 10 to 100,000 which is a much larger range.

13. What is pH? Relate the concentration of H_3O^+ ions to the pH.

pH is defined using the following equation: $pH = -\log [H_3O^+]$

The concentration of H_3O^+ ions is typically less than 1 M, therefore the exponents are negative. Since it is easier to work with positive numbers, pH was defined as the –log.

Table: Relating concentration of H_3O^+ to pH

Concentration of H_3O^+ (M)	Exponent Notation (M)	Log of $[H_3O^+]$	$-\text{Log}\ [H_3O^+]$ = pH
1	10^0	0	0
0.1	10^{-1}	–1	1
0.01	10^{-2}	–2	2
0.0000001	10^{-7}	–7	7
0.0000000000001	10^{-13}	–13	13

14. Does a solution with a pH of 4 have more or less H_3O^+ ions than a solution with a pH of 7? How many times more or less?

A solution with a pH of 4 has 1000 times more H_3O^+ ions than a solution with a pH of 7. One change in pH results in10 times the number of H_3O^+ ions.

Calculating H_3O^+ Ion Concentration from pH

Guide the students through an example of calculating H_3O^+ ion concentration from pH and then let them practice before starting the lab.

15. Calculate the H_3O^+ ion concentration of an unknown solution that has a pH of 10.6.

pH = $-\log [H_3O^+]$

The log is the power (or exponent) to which 10 (the logarithmic base) must be raised to give the original number. Therefore $10^{-pH} = [H_3O^+]$

$10^{-10.6} = [H_3O^+]$

$2 \times 10^{-11} = [H_3O^+]$

16. Calculate the H_3O^+ ion concentration of an unknown solution that has a pH of 2.2.

$10^{-pH} = [H_3O^+]$

$10^{-2.2} = 6 \times 10^{-3} = [H_3O^+]$

Lab Preparation

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

The following instructions will make 100 mL of baking soda (sodium bicarbonate) solution. This is enough for 20 lab groups.

Prepare 100 mL of 0.5 M sodium bicarbonate ($NaHCO_3$) solution by adding 4.2 grams of baking soda to enough distilled water to create 100 mL of solution.

Teacher Tips:

- The pH sensor calibration is saved in the data file in which it was performed. This requires the pH sensor be recalibrated every time a new file is opened or a different data collection system is used.

- To save time and materials, prepare a class set of labeled test tubes that are already ⅓ full with each of the ten household items. Reuse the same samples for multiple class periods. Be sure to remind the students to not contaminate their solutions.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Many household chemicals are skin, eye, and respiratory irritants, including window cleaner, vinegar, lemon juice, and bleach.

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.

4	1	3	2
Graph pH versus hydronium ion (H_3O^+) concentration.	Place 5 mL of each household chemical in a clearly labeled test tube.	Calculate the hydronium (H_3O^+) ion concentration for each household chemical using the measured pH values.	Measure the pH of each household chemical.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

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

2. ☐ Connect a pH sensor to your data collection system. �(2.1)

3. ☐ Place 25 mL of pH 4 buffer solution in a 50-mL beaker and 25 mL of pH 10 buffer solution in a second 50-mL beaker. Use these solutions to calibrate the pH sensor.�(3.6)

4. ☐ Using the terms "accuracy" and "precision," explain why is it necessary to calibrate the pH sensor?

A pH sensor needs to be calibrated to ensure accurate results. A pH sensor that is not calibrated will give precise results, but they may not be accurate.

5. ☐ Configure the data collection system to manually collect pH for different household chemicals in a table. Define household chemicals as the manually entered text data. �(5.2.1)

6. ☐ Obtain 10 clean, dry test tubes.

7. ☐ Label each test tube with a household chemical name. The household chemicals are listed in Table 1 in the Data Analysis section below.

8. ☐ Add 5 mL of each household chemical to the appropriately labeled test tube. Each test tube should be approximately one third full.

9. ☐ Does the amount of liquid used in each test tube need to be exact? Explain.

No. The volume required needs to be enough for the pH sensor to be fully submerged in the solution, but not so full that it overflows when the pH sensor is inserted. The amount of solution used does not affect the pH.

Collect Data

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

11. ☐ Place the pH sensor into the first sample. Make sure the bulb of the pH sensor is fully submerged.

12. ☐ Leave the pH sensor in the solution until the reading stabilizes (about 1 minute) and then record the data point.�(6.3.2)

13. ☐ Remove the sensor from the sample and thoroughly rinse it with clean water.

14. ☐ Repeat the steps above to determine the pH for all the samples.

Note: Remember to thoroughly rinse the pH sensor with clean water after testing each solution.

15. ☐ Why is it necessary to rinse the pH sensor after each sample is tested?

To avoid contaminating the next sample. If any of the samples mix together, the pH values will change.

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

17. ☐ Save your data file and clean up according to the teacher's instructions.�(11.1)

Data Analysis

1. ☐ Calculate the hydronium ion (H_3O^+) for each of the household chemicals using the measured pH value. Follow the steps below to do this on your data collection system.

a. Enter the equation given below into your data collection system's calculator. �(10.3)
concentration = 10^–(pH)

b. Add a column to the table on your data collection system to display the calculated hydronium (H_3O^+) ion concentration. �(7.2.2)

2. ☐ Copy the pH and H_3O^+ ion concentration data from your data collection system to the corresponding columns in Table 1 below.

Table 1: Household chemicals, their pH and H_3O^+ concentrations

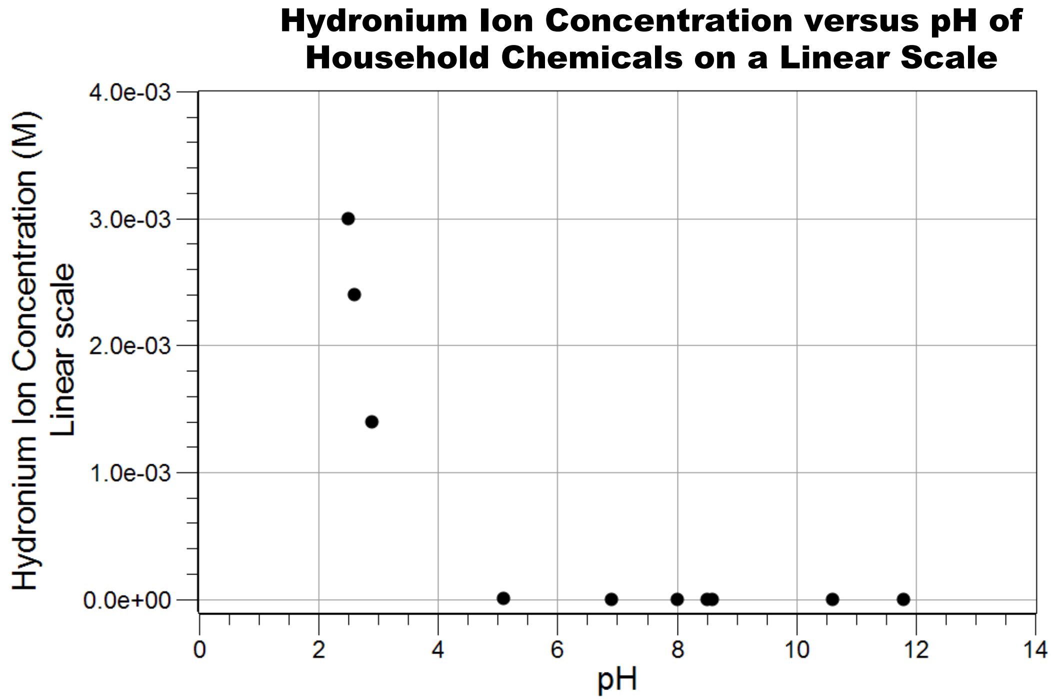
	Household Chemical	pH	$[H_3O^+]$ (M)
1	Vinegar	2.6	3×10^{-3}
2	Lemon juice	2.5	3×10^{-3}
3	Soft drink	2.9	1×10^{-3}
4	Window cleaner	8.6	3×10^{-9}
5	Tap water	8.0	1×10^{-8}
6	Milk	6.9	1×10^{-7}
7	Coffee	5.1	8×10^{-6}
8	Baking soda	8.5	3×10^{-9}
9	Liquid soap	10.6	2×10^{-11}
10	Bleach	11.8	1×10^{-12}

Teacher Tip: Notice that the $[H_3O^+]$ has only one significant figure due to the rules of significant figures with logarithms. The number of decimal places in the pH reading indicates the number of significant figures that the $[H_3O^+]$ has in its coefficient.

3. ☐ Display H_3O^+ concentration versus pH on a graph.�(7.1.1)

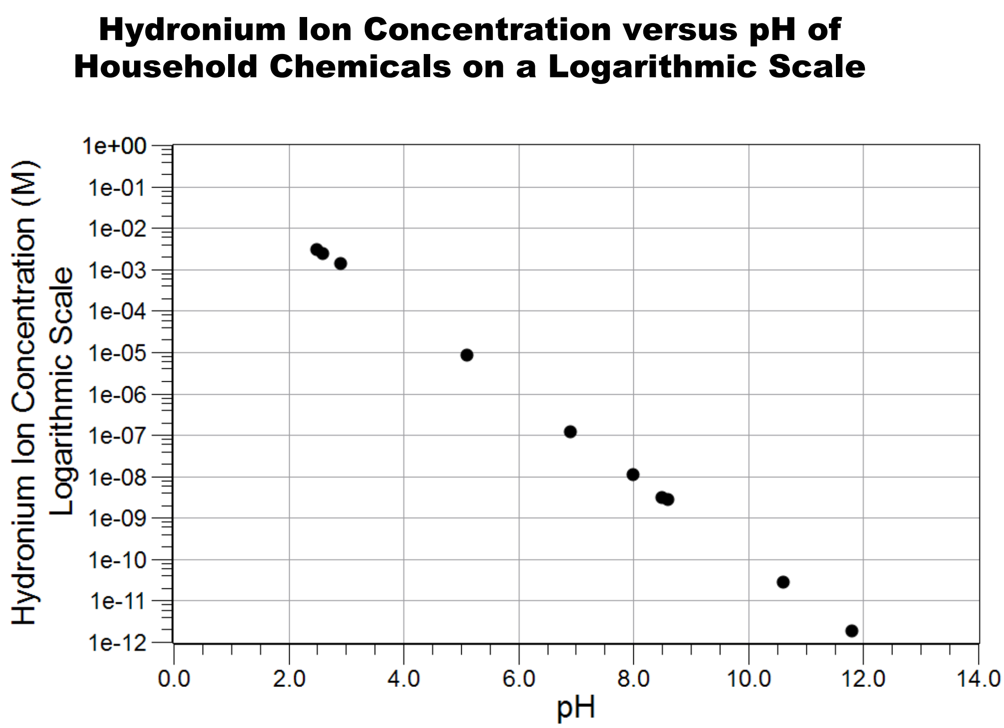
Note: To graph a scatter plot of the data points hide the connecting lines between data points feature. �(7.1.8)
If needed, adjust the scale of the graph to show all the data points. �(7.1.2)

4. ☐ Plot or print a copy of the graph of H_3O^+ Concentration (M) versus pH. Label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



5. ☐ Draw a scatter plot of H_3O^+ ion concentration versus pH on a logarithmic scale.

Teacher note: This graph will need to be drawn because the data collection system cannot create a logarithmic scale on its axes.



Analysis Questions

1. What is pH and why is the pH scale used?

pH is a measure of the concentration of H_3O^+ ions and is mathematically defined as pH = $-\log [H_3O^+]$. The pH scale is used because the numbers 0 to 14 are easier to use than the numbers 1 through 1×10^{-14}.

2. Explain the relationship between pH and H_3O^+ ion concentration.

There is an inverse relationship between pH and H_3O^+ ion concentration. As the pH increases, the H_3O^+ ion concentration decreases.

3. Define the term "acid" and explain the why there are strong and weak acids.

An acid is a substance that donates H^+ ions. The strength of an acid depends on the degree to which the acid dissociates. Strong acids completely dissociate producing a greater number of H_3O^+, whereas weak acids only partially dissociate and produce a smaller amount of H_3O^+ ions.

4. Identify which of the household chemicals tested are acids and list them in order from the lowest to highest pH.

Lemon juice, vinegar, soft drink, coffee, milk

5. Define the term base and explain why there are different strengths of bases.

A base is a substance that accepts H^+ ions. The strength of a base depends on the degree to which the base attracts H^+ ions. Strong bases bond readily with all possible H^+ ions and thus remove the H_3O^+ ions from solution. Weak bases, on the other hand, do not attract H^+ ions as strongly and thus allow a portion of them to remain in solution.

6. Identify which of the household chemicals tested are bases and list them in order from highest to lowest pH.

Bleach, liquid soap, window cleaner, baking soda solution, tap water

Synthesis Questions

Use available resources to help you answer the following questions

1. A nitric acid solution has a pH of 1 and a hydrochloric acid solution has a pH of 3. Which acid solution is more concentrated and by how much?

The nitric acid solution is 100 times more concentrated than the hydrochloric acid solution.

2. What is pOH and how is it related to pH?

pOH is a measure of the hydroxide ion concentration. Mathematically pOH = $-\log [OH^-]$. There is an inverse relationship between pH and pOH. As the pH value of a substance increases, its pOH value decreases.

$[H+][OH^-] = K\text{w}$

$-\log[H+] + -\log[OH^-] = -\log K\text{w} = -\log 1.0 \times 10^{-14}$

pH + pOH = 14

3. If an acid is added to a basic solution, what do you expect to happen to the pH of the basic solution? Why?

The pH of the basic solution should decrease because the added hydrogen ions increase the concentration of H_3O^+ ions in the solution and thus lower the pH.

Multiple Choice Questions

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

1. Why is a 0.1 M hydrochloric acid solution a stronger acid than a 0.1 M acetic acid solution?

- **A. Because more of the H^+ ions dissociate into the solution**
- **B.** Because less of the H^+ ions dissociate into the solution
- **C.** Because there are equal numbers of H^+ ions in the two solutions
- **D.** Because there are equal numbers of OH^- ions in the two solutions

2. How is an aqueous solution of a base different from an aqueous solution of an acid?

- **A.** A basic solution conducts electricity and an acidic solution does not
- **B.** A basic solutions will cause an indicator to change color and an acid will not
- **C.** A basic solution has a greater concentration of H_3O^+ than OH^-
- **D. A basic solution has a lower concentration of H_3O^+ than OH^-**

3. Pure water has a pH of 7 and toothpaste has a pH of 10. The water contains how many times the number of H_3O^+ ions as toothpaste?

- **A.** 1/100
- **B.** 3
- **C.** 10
- **D. 1000**

4. An unknown solution has an H_3O^+ concentration of 6.0×10^{-10} M. This solution is:

- **A.** Acidic
- **B. Basic**
- **C.** Neutral
- **D.** Concentrated

5. An unknown solution has a pH of 4.0. This solution is:

- **A. Acidic**
- **B.** Basic
- **C.** Neutral
- **D.** Concentrated

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. **Acids** are found in numerous substances all around us such as soft drinks, salad dressing, and rain water. Acids taste **sour**, cause indicators to change color, and react with certain **metals** to form hydrogen gas. At the molecular level, an acid is a substance that **donates** a hydrogen ion (H^+) which will form an increased concentration of the hydronium ion (H_3O^+) when the acid is dissolved in water. **Strong** acids dissociate fully in water, whereas **weak** acids only partially dissociate. Acids have pH values **less than** 7. The lower the pH, the **more** acidic the solution.

2. Bases may not be as familiar to you, but they are just as numerous as acids. **Bases** are found in personal hygiene products, cleaning products, and food. Bases taste **bitter**, feel slippery, and react with oil and grease. At the molecular level, a base is a substance that **accepts** or bonds with a hydrogen ion (H^+). By bonding with the H^+ ion, a base causes the concentration of the hydronium ion (H_3O^+) to **decrease**. **Strong** bases have a strong force of attraction and readily bond with H^+ ions which reduces the H_3O^+ ion concentration in solution. Bases have **pH** values greater than 7. The **higher** the pH, the more basic the solution.

Extended Inquiry Suggestions

Have the students bring in labels of different household chemicals and use the ingredients list to predict the pH of the substance. If possible, have the students test their predictions after making their hypotheses.

Investigate the conductivity of strong and weak acids and bases.

Determine the effect of concentration on pH using different concentrations of household chemicals.

Determine the effect of the amount of a substance on its pH.

Determine the effect of mixing acids and bases on the pH of the newly formed solution.

Compare pH measurements taken with a pH sensor against those determined using pH paper or other indicators.

8. Percent Oxygen in Air

Objectives

Students learn about the components of air and how to determine the percent of oxygen in air. Through this investigation, students:

- Observe a chemical reaction involving different states of matter
- Describe pressure at the molecular level
- Explain how the variables temperature, volume, and concentration affect the pressure of gases

Procedural Overview

Students gain experience conducting the following procedures:

- Use an absolute pressure sensor to measure changes in pressure as atmospheric oxygen reacts with steel wool (iron)
- Determine the percent of oxygen in air from the measured pressure difference

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	45 minutes
♦ Lab activity	40 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Absolute pressure sensor
- Sensor extension cable
- Quick-release connector[1]
- Tubing connector[1]
- Tubing, 1- to 2-cm[1]
- Beaker, 150-mL
- Test tube, 25-mm x 150-mm
- One-hole stopper to fit the test tube
- Stir rod
- White vinegar (~5% acetic acid), 50 to 60 mL
- Steel wool, fine mesh (#000), 1.0 g
- Paper towels
- Glycerin, 2 drops

[1] Included with most PASCO absolute pressure sensors.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Particulate nature of matter
- ♦ States of matter

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Boyle's Law

Using Your Data Collection System

- ♦ Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- ♦ 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)
- ♦ Printing �(11.2)

Background

Air is a mixture made up of approximately 78% nitrogen, 21% oxygen, and 1% of several other gases including argon, carbon dioxide, and water vapor. In this lab, students calculate the percent of oxygen in the air by measuring initial air pressure and air pressure after oxygen has been removed from the air, and determining the difference.

Oxygen is removed from the air using a chemical reaction. The reaction between oxygen and iron was chosen because iron reacts with oxygen in the air, but not with nitrogen. Nitrogen molecules simply bounce off the iron, while the oxygen atoms collide and stick to the iron forming a new substance, iron(III) oxide (rust).

$$3O_2(g) + 4Fe(s) \rightarrow 2Fe_2O_3(s)$$

Steel wool is the source of iron. Steel is an alloy of iron with a very small amount of carbon. Most brands of steel wool are lightly coated with oil or some other rust inhibitor. The students remove the rust inhibitor by rinsing the steel wool in vinegar. The vinegar "washing" also creates a moist, slightly acidic environment that increases the reaction rate.

Solids, liquids, and gases all exert pressure on their surrounding surfaces. Since pressure is the dependent variable in this experiment, it is important that students understand pressure at the molecular level. Pressure is the force applied over an area. Pressure is measured in units of pascal (Pa) or as a newton (N) per square meter, where ($1\ \text{Pa} = 1\ \text{N/m}^2$). The newton is the standard unit for measuring force. At the molecular level, air pressure, like all pressure involving gases, results from molecules colliding with a surface. The greater the number of collisions there are per second, the greater the air pressure.

The temperature, volume, and amount of gas present all affect the frequency of gas particles colliding and thus the air pressure. When air is heated, the particles move faster (greater kinetic energy) causing more collisions per second and therefore increasing the pressure (Gay-Lussac's law). Cooling, on the other hand causes air molecules to move slower, resulting in fewer collisions and less pressure.

When the volume of a container holding a constant number of gas particles increases, the pressure decreases (Boyle's law). This is because the particles have more space in which to move and therefore collide with the walls of the container less often. The opposite is also true: less volume for the gas particles to move in results in a higher pressure because the molecules have less space in which to move and therefore hit the surfaces more frequently.

Air pressure is also dependent on the number of gas particles present (Avogadro's law). The more particles there are in a given container, the more frequently the walls of the container will be struck, causing greater pressure. The opposite holds true also: the fewer the particles present, the lower the resulting pressure.

The method used in this experiment to determine the percent of oxygen in the air works because of Dalton's law of partial pressures. Dalton's law of partial pressures states that the total pressure of a gas mixture is the sum of the partial pressures of each individual gas in the mixture. Therefore, air pressure is equal to the pressure of nitrogen plus the pressure of oxygen plus the pressure of all other gases present in the air. When oxygen is removed, the air pressure will be reduced by an amount directly proportional to the percent of oxygen in the air.

$$\%\,\text{oxygen} = \frac{\text{change in pressure}}{\text{initial pressure}} \times 100$$

Pre-Lab Discussion and Activity

The Concept of Pressure

Introduce the concept of pressure by comparing the pressure exerted in high heel shoes versus tennis shoes.

1. If a woman is wearing high heels on a soft dirt surface, she will sink into the ground. The same woman, however, wearing tennis shoes on the same surface will not sink at all. Why? What is the difference in the two scenarios and how does this difference explain whether or not the woman will sink?

The difference is the shoes that the woman is wearing. More specifically, the surface area touching the ground is significantly different. When the woman is wearing high heels, her body weight exerts force on the ground over a very small area. This creates a lot of pressure and she sinks. When the woman is wearing tennis shoes, she exerts the same force (her body weight) over a larger area and does not sink (she is exerting less pressure).

Calculating Pressure

Provide the students with a mathematical understanding of pressure by comparing the pressure exerted by a textbook in two different positions. Place a textbook on a table in front of the class with its largest side down. Stand a second textbook up on its edge. Write the dimensions and mass of the textbook on the board. (The following dimensions may be used: textbook dimensions, 10.0 in. x 10.0 in. x 2.0 in. textbook weight (force of gravity on the book), 5.0 lb) Explain that the idea of the "amount of force on each square" is called pressure. Write the definition of pressure on the board. Pressure is the force acting on a specific area.

2. Which book is exerting more pressure per unit area on the table? Explain.

The book standing on its edge is exerting more pressure per unit area. Both books have the same mass and are therefore exerting the same force, but the book standing on its edge is supporting the weight over a smaller area.

3. If the book is lying on its side how much of the force (weight) is felt over each square inch?

The weight of 5.0 lb is being shared over 100 square inches (the area touching the table). So each square inch of the book supports 0.05 lb.

4. How much force (weight) does each square inch support when the book is sitting on its edge?

There are fewer square inches (in.^{2}) in contact with the table so each square inch must support more weight. The book still weighs 5.0 lb, but there are only 20 in.^{2} sharing the weight. So each square inch supports 0.25 lb.

5. What is the equation for pressure? Calculate the pressure each book is exerting on the table?

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

The book lying on its side: $P = \dfrac{5.0\text{ lb}}{(10\text{ in.} \times 10\text{ in.})} = 0.05\text{ lb/in.}^2$

The book sitting on its edge: $P = \dfrac{5.0\text{ lb}}{(10\text{ in.} \times 2\text{ in.})} = 0.25\text{ lb/in.}^2$

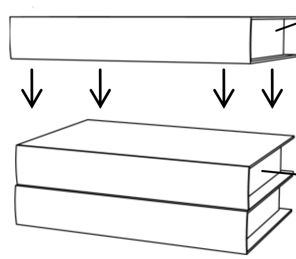
6. What are the units of pressure in the above example? What are the units in the SI system?

In the above example, pressure was measured in pounds per square inch. In the SI system, the unit of force is newton (N) and the unit for area is square meters (m^2). A newton ($(kg \cdot m)/s^2$) is the standard unit of force containing the units for both mass as well as the acceleration due to gravity; combined, these can be thought of as "weight". A N/m^2 is also called a pascal (Pa). One pascal of pressure is really small, so it is common to measure pressure in kilopascals (kPa).

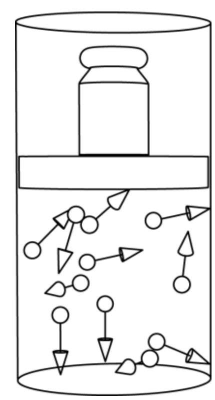
Pressure at the Molecular Level

Explain to the students that in solids and liquids, the atoms or molecules are all in contact with each other. Because of this, all the molecules contribute to the force on the table. Stack two textbooks on top of each other and hold a third text book in your hand. Explain that each book on the table contributes its weight to the total force and pressure being exerted just like each molecule in a solid or liquid contributes all of its weight to the pressure being exerted.

Molecules that make up a gas, however, are different because they are not in contact with each other. A gas particle could be thought of as a third book that is falling toward the stack of books. Drop the third book onto the stack of books. The falling book does not contribute any force to the surface of the table until it hits the stack. For gases, it is the number of collisions that create pressure. End the discussion by showing the students a picture or a video of gas molecules colliding with the surface of their container.



Demonstration of the difference between pressure exerted by solids versus pressure exerted by gases.



Gas molecules create pressure through collisions with the surfaces of their container.

7. Using the textbook example, explain pressure at the molecular level?

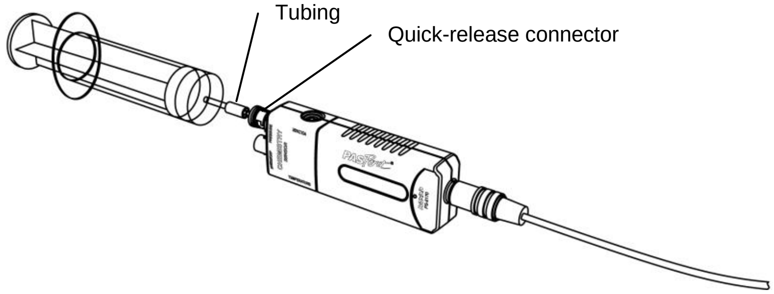
The molecules that make up the book are exerting a force (their weight) onto the table.

8. How is the pressure exerted by molecules different if the molecules are in a solid or liquid state versus a gaseous state?

In solids and liquids, all the molecules are touching each other all the time and thus always contribute to a constant force and pressure. Molecules in the gaseous state, on the other hand, are bouncing around. They contribute to the force when a collision occurs. Collisions are how gas molecules create pressure.

Temperature, Volume, and Air Pressure

Engage the students in a discussion about air pressure and the ways in which pressure can be altered by having students change the temperature and then the volume of air inside a syringe.



Have students set the volume of a syringe to about 20 mL and then connect it to a data collection system. While monitoring pressure in the digits display, have students observe what happens as they heat the air inside the syringe by holding the syringe in the palm of their hand. Next, have students change the volume of the air in the syringe by pushing the plunger in, compressing the gas. Help students analyze their results by explaining what is happening at the molecular level.

9. What are some possible ways to increase the pressure of the air inside the syringe?

Increase the number of collisions by either: 1) increasing the temperature, 2) increasing the number of molecules, or 3) decreasing the size of the container.

10. What do you notice about the pressure when you hold the syringe in the palm of your hand? Why?

The pressure goes up because the gas molecules get warmer. Warmer things move faster so the gas molecules hit the walls inside the syringe more often and with more force producing more pressure.

11. Why is it possible to compress the gas? How does it change the pressure? Why?

The gas can be compressed because there is space between the gas molecules. The molecules can move into this space and essentially squish closer together.

The pressure increased because the molecules hit the walls more often. The molecules hit the walls more often because they did not have to travel as far to hit the walls.

Types of Molecules in Air

Discuss the different types of molecules that make up air and explain that each type of molecule contributes to the pressure exerted by air. This observation is summarized in Dalton's law of partial pressures which states that the total pressure of a gas mixture is the sum of the individual pressures of each type of gas.

Introduce the idea that the number of molecules in a closed container can be increased or decreased through chemical reactions. Explain the chemical reaction that will be performed in this lab and end the discussion by having the students perform a sample calculation using provided pressure data.

Write the following equation on the board:

oxygen gas + iron (steel wool) → rust

$3O_2(g) + 4Fe(s) \rightarrow 2Fe_2O_3(s)$

12. What types of molecules are in the air in your syringe?

Air is a mixture made of nitrogen molecules, oxygen molecules, and a very small amount of other molecules such as argon, carbon dioxide, water vapor, and others.

13. All of the molecules in air are bouncing on the walls and contributing to the total gas pressure. Imagine there were 100 gas molecules. If 50 of them were nitrogen, then what percent of the observed pressure is due to nitrogen molecules?

Half (50%) of the collisions would be nitrogen molecules so half of the pressure would be from nitrogen.

14. We have seen that altering the temperature causes the pressure to either increase or decrease because the number of collisions and the force of the collisions both change. We have also seen that decreasing the volume of the container increases the pressure by increasing the number of collisions. The final variable that affects the pressure is the actual number of gas molecules. How can the number of gas molecules in a closed container change?

The number of gas molecules can either be increased or decreased through a chemical reaction.

15. In this lab, oxygen molecules in the air will bounce into the iron atoms in the steel wool. If the collision is just right, the oxygen reacts with the iron and creates a new molecule (rust). How will the gas pressure be affected as the reaction proceeds? Why?

The gas pressure should decrease because the number of gas molecules should decrease. Before the reaction, oxygen molecules moved freely as a gas. After the reaction, the oxygen will be bonded to the iron in a newly formed solid (rust).

16. How will measuring a change in pressure help you determine the percent of oxygen in the air?

The amount that the pressure decreases is proportional to the percent of oxygen in the air.

$$\%\ \text{oxygen} = \frac{\text{change in pressure}}{\text{initial pressure}} \times 100$$

17. If the starting pressure of the gas in a test tube is 100 kPa and the final pressure is 75 kPa, what was the change in pressure? What percent of the gas molecules were removed?

The change in pressure is 25 kPa (100 kPa – 75 kPa).

$$\%\ \text{gas lost} = \frac{25\ \text{kPa}}{100\ \text{kPa}} \times 100 = 25\%$$

Lab Preparation

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

Safety

Add this important safety precaution to your normal laboratory procedures:

♦ Vinegar is a weak acid. Avoid contact with the eyes and wash your hands after handling glassware, steel wool, and equipment.

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.

3	1	2	4	5
Measure and record the initial pressure.	Clean the steel wool with vinegar so that oxygen can react with the iron.	Create a closed container with air and steel wool.	Measure the final pressure value.	Calculate the percent oxygen in air.

Procedure with Inquiry

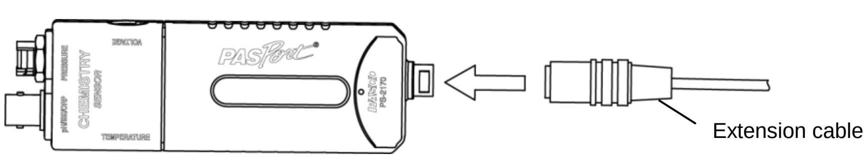
After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

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

2. ☐ Connect the absolute pressure sensor to the data collection system using a sensor extension cable. �(2.1)

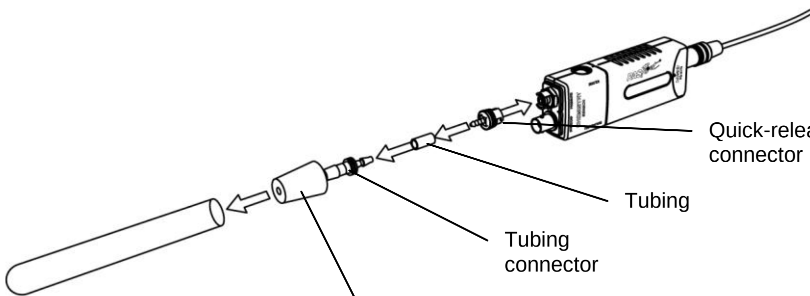


3. ☐ Connect the quick-release connector to the stopper using the tubing connector and the 1- to 2-cm piece of tubing by following the steps below. Use the picture as a guide.

a. Insert the thicker end of the tubing connector into the hole in the stopper. If this is difficult, add a drop of glycerin.

b. Connect the 1- to 2-cm piece of tubing to the other, thinner end of the tubing connector.

c. Insert the barbed end of the quick-release connector into the open end of the 1- to 2-cm piece of tubing. If this is difficult, add a drop of glycerin.



4. ☐ Insert the quick-release connector into the port of the absolute pressure sensor and then turn the connector clockwise until fitting "clicks" onto the sensor (about one-eighth turn).

5. ☐ Create a graph display of Pressure (kPa) versus Time. �(7.1.1)

6. ☐ What are the dependent and independent variables in this experiment? In what units are these variables measured?

The dependent variable is the pressure in units of kilopascals (kPa).

The independent variable is the time that the reaction is allowed to occur in units of seconds (s).

7. ☐ Predict what will happen to the pressure as the reaction occurs?

The pressure decreases as the oxygen gas is consumed by the reaction with iron.

8. ☐ Obtain enough fine mesh steel wool to fill a large test tube about ⅔ full (approximately 1.0 g).

9. ☐ Stretch the steel wool apart so that a large amount of surface area is exposed.

10. ☐ Clean the steel wool by soaking it in a 150-mL beaker containing approximately 60 mL of vinegar for about one minute. Use a stir rod to fully rinse the steel wool in the vinegar.

11. ☐ Why do we need to rinse the steel wool in vinegar?

Rinsing removes the protective coating from the iron so that the oxygen molecules can collide directly with the iron atoms. The vinegar also provides a moist, slightly acidic environment that will cause the reaction to occur faster (increase the rate of the reaction).

12. ☐ Remove the steel wool from the beaker of vinegar and wring it out, draining the vinegar into the beaker.

13. ☐ Stretch apart the steel wool and thoroughly dry it with paper towels.

14. ☐ Change the paper towels and dry it again.

15. ☐ Stretch the steel wool apart and shake it in the air to make sure it is dry.

16. ☐ Put the steel wool in a large test tube making sure that a large surface area is still exposed. Do not pack the steel wool into the bottom of the test tube.

Note: You may have to gently tap the test tube to get the steel wool to slide down into the test tube.

Collect Data

17. ☐ Place the stopper into the top of the test tube and immediately start collecting data. �(6.2)

Note: You may have to adjust the scale of the graph to observe any changes taking place. �(7.1.2).

18. ☐ What molecules are contributing to the pressure you are recording on your data collection system? Be specific.

The pressure is coming from the nitrogen, oxygen, and very small amount of other molecules that make up the air inside the test tube.

19. ☐ Write a sentence explaining the reaction occurring in the test tube. Explain where each substance comes from and its physical state (solid, liquid, or gas).

Oxygen gas from the air is reacting with solid iron in the steel wool to form rust, which is a new solid.

20. ☐ What is happening to the pressure as the reaction occurs? Why?

The pressure is decreasing because the oxygen gas is being incorporated into a solid and therefore is removed from the air.

21. ☐ Write down at least three changes you observe taking place in the test tube.

Water condenses on the side of the test tube, the test tube gets hot, and the steel wool turns brown/orange.

22. ☐ When the pressure has stabilized (after about 20 to 30 minutes), stop data collection. �(6.2)

23. ☐ Save the data file and clean up your lab station according to the teacher's instructions. �(11.1)

Data Analysis

1. ☐ Determine the initial and final pressures and write them in the Table 1 below. �(9.1)

Table 1: Initial and final pressure

Initial Pressure (kPa)	105.21
Final Pressure (kPa)	83.31

2. ☐ Calculate the change in pressure.

Initial pressure (kPa) – final pressure (kPa) = change in pressure (kPa)

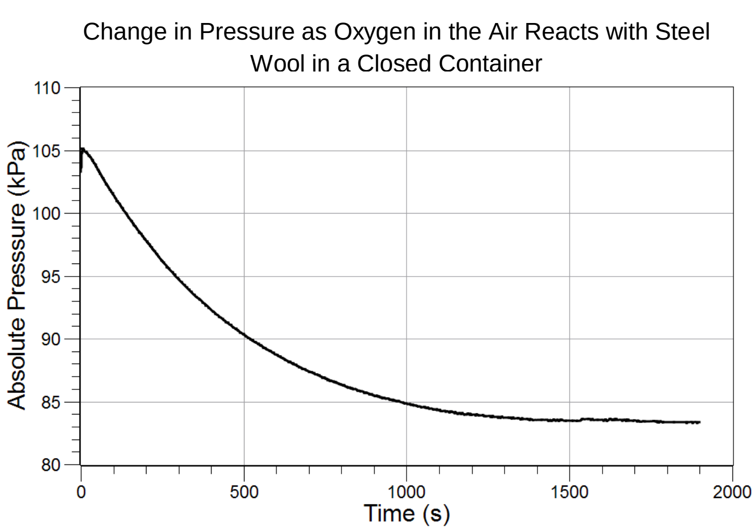
105.21 kPa – 83.31 kPa = 21.9 kPa

3. ☐ Calculate the percent oxygen in air.

$$\frac{\text{change in pressure (kPa)}}{\text{initial pressure (kPa)}} \times 100 = \%\ \text{oxygen}$$

$$\frac{21.9\ \text{kPa}}{105.21\ \text{kPa}} \times 100 = 20.8\%\ \text{oxygen}$$

4. ☐ Sketch or print a copy of the graph of Pressure (kPa) versus Time (s). Label the overall graph, the x-axis, the y-axis and include units on the axes. �(11.2)



Analysis Questions

1. Why did the pressure graph flatten out after a while? (Hint: think about what is happening to the amount of oxygen in the test tube.)

The oxygen in the test tube was being used up. When it was gone, the graph became flat.

2. Why was the pressure not reduced to zero?

The pressure did not make it to zero because there were still other molecules, including nitrogen, carbon dioxide, water vapor, and argon in the test tube. They continued bouncing into the walls, causing pressure.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Gases are often described as having no definite shape and filling the container they occupy. Explain what is happening at the molecular level to give gases these properties.

The gas molecules bounce around and do not bond together. They move through space in a straight line until they hit a wall, so they occupy the entire volume of any size container.

2. Explain why solids have a definite shape.

The molecules or atoms in a solid are bonded together in a fixed pattern. They cannot move around to fill the container.

3. Chemical reactions stop when one of the reactants is used up. This reactant is called the *limiting reactant* because it limits the amount of product that is made. In this lab, rust was the product. What was the limiting reactant?

The pressure stopped changing when the oxygen in the test tube was all used up. This makes oxygen the limiting reactant.

Multiple Choice Questions

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

1. Which of the following variables affects the pressure of a gas?

- **A.** The number of gas molecules
- **B.** The temperature of the gas molecules
- **C.** The volume of the container the gas molecules are in
- **D.** **All of the above**

2. If you increase the temperature of a gas, what will happen to the pressure?

- **A.** It will stay the same
- **B. It will increase**
- **C.** It will decrease
- **D.** Not enough information

3. If you increase the number of gas molecules in a container, what will happen to the pressure?

- **A.** It will stay the same
- **B. It will increase**
- **C.** It will decrease
- **D.** Not enough information

4. Approximately what percentage of air is made up of oxygen gas?

- **A.** Less than 5%
- **B. 20%**
- **C.** 70%
- **D.** More than 80%

5. Pressure is best described as

- **A. A force spread out over an area**
- **B.** The motion of molecules
- **C.** The space between molecules in a gas
- **D.** A strong force

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Pressure is a force spread out over an **area**. Gas pressure is caused by gas molecules flying through space and **bouncing** off surfaces. If the collision rate increases, the **pressure** goes up. An increase in **temperature** causes greater pressure because the gas molecules are moving with more kinetic energy, and therefore are moving faster. A decrease in volume causes an **increase** in pressure because the gas molecules are closer together and have less distance to travel to hit the walls of the container, so collisions are more frequent. At a given temperature, all gas molecules contribute to the total pressure. If 70% of the gas molecules in a container are nitrogen, then **70%** of the pressure will be due to the nitrogen molecules.

Extended Inquiry Suggestions

Have students design an experiment to determine if other metals corrode in the presence of oxygen.

Have students determine the ideal amount of steel wool to use in this lab.

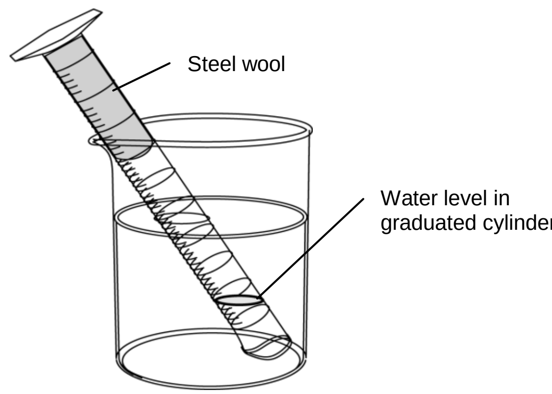
Have students determine the ideal size of a test tube to use in this experiment.

Have students determine the effects of altitude on the percent of oxygen in the atmosphere.

Discuss the following questions with students:

- Does changing the amount of steel wool change the calculated percentage of oxygen?
- Does changing the amount of air available (by using different sizes of test tubes) change the calculated percentage of oxygen?

Have students design an experiment to determine the amount of oxygen in the atmosphere using a water displacement method (see illustration) instead of the absolute pressure sensor. How do the results compare?



Setup for the water displacement method for determining the percent oxygen in air.

9. Evidence of a Chemical Reaction

Objectives

During this investigation, students:

- Observe the four main types of evidence that suggest a new chemical substance has formed
- Distinguish between physical changes and chemical reactions
- Identify processes as involving physical changes or chemical reactions
- Identify the reactants and products in a chemical reaction
- Explain the difference between exothermic and endothermic chemical reactions

Procedural Overview

Students conduct the following procedures:

- Perform three chemical reactions, collect temperature versus time data for each, and record evidence that a new substance was formed for each
- Perform three physical changes, and describe the resulting new physical appearance
- Perform three additional changes, and identify them as chemical reactions or physical changes based on the observations recorded
- Identify each chemical reaction as exothermic or endothermic

Time requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Fast response temperature sensor
- Balance (2-3 per class)
- Hot plate
- Graduated cylinder, 100-mL
- Graduated cylinder, 10-mL
- Beaker (2), 250-mL
- Test tube (7), 15-mm x 100-mm
- Test tube rack
- Test tube holder
- Stir rod
- Spatula
- Beaker for collecting rinse water
- Weighing paper
- Wash bottle filled with distilled (deionized) water
- Water, 255 mL
- Calcium carbonate ($CaCO_3$), ~0.2 g
- White vinegar (~5% acetic acid), 2 mL
- 1.0 M Citric acid ($C_6H_8O_7$), 2 mL[1]
- 1.0 M Sodium bicarbonate ($NaHCO_3$), 2 mL[2]
- 0.5 M Copper(II) sulfate ($CuSO_4$), 2 mL[3]
- 1.0 M Sodium hydroxide (NaOH), 2 mL[4]
- 0.05 M Silver nitrate ($AgNO_3$), 2 mL[5]
- 0.1 M Sodium chloride (NaCl), 2 mL[6]
- Lauric acid ($C_{12}H_{24}O_2$), ~0.5 g[7]
- Effervescent tablet[8]
- Colored drink powder, ~0.2 g

[1] To formulate using anhydrous citric acid ($C_6H_8O_7$) or citric acid monohydrate ($C_6H_8O_7 \cdot H_2O$), refer to the Lab Preparation section.

[2] To formulate using baking soda (sodium bicarbonate, $NaHCO_3$), refer to the Lab Preparation section.

[3] To formulate using anhydrous copper sulfate ($CuSO_4$) or copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$), refer to the Lab Preparation section.

[4] To formulate using sodium hydroxide pellets (NaOH), refer to the Lab Preparation section.

[5] To formulate using silver nitrate ($AgNO_3$), refer to the Lab Preparation section.

[6] To formulate using table salt (sodium chloride, NaCl), refer to the Lab Preparation section.

[7] For ideas on how to re-use the lauric acid samples, refer to the Lab Preparation section.

[8] Ensure that the effervescent tablet contains both sodium bicarbonate and citric acid. Do not use antacids with an active ingredient of calcium carbonate because the rate of the reaction occurs too slowly.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Difference between chemical properties and physical properties
- Pure substances (elements and compounds) versus mixtures
- States of matter

Related Labs in this Manual

Labs conceptually related to this one include:

- Conservation of Matter
- Percent Oxygen in Air

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 sensors 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)
- Showing and hiding data runs in a graph �(7.1.7)
- Naming a data run �(8.2)
- Measuring the difference between two points in a graph �(9.2)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

Chemistry is the study of matter and how it changes. Matter can be classified as either a pure substance or a mixture. Pure substances are either elements or compounds. Elements are the simplest form of matter because they are made up of only one type of atom. Compounds are made up of two or more different elements bonded together in fixed ratios. Pure substances have fixed physical and chemical properties because they always consist of only one type of chemical material. Mixtures, however, are different than pure substances. Mixtures are made up of two or more pure substances (either elements or compounds). The components of a mixture are not chemically bonded to each other in any way; they are simply in the same container at the same time. If the components of a mixture are distributed evenly throughout, it is called "homogeneous." Conversely, if the components are distributed such that some areas of the mixture are different than others, the mixture is called "heterogeneous."

Matter constantly undergoes change. These changes can be classified as either physical changes or chemical changes. A physical change occurs when a substance's physical appearance changes, but there is no change in the substance's chemical composition. Ice melting is a physical change because the ice has changed from a solid state to a liquid state, but its chemical composition, H_2O, remains the same. A chemical change occurs when one or more new chemical substances are produced. Rusting is an example of a chemical change because iron reacts with oxygen in the air to form a new chemical substance, iron(III) oxide. A chemical change is also called a chemical reaction.

When two substances are mixed, it can be difficult to determine whether or not a new chemical substance was formed because we cannot "see" what is happening at the molecular level. However, there are four types of evidence that, if observed, suggest that a new chemical substance has formed. If one or more of these properties are observed, then it is likely, but not definite, that a chemical reaction has occurred. The four principle types of evidence indicating a chemical reaction has occurred are:

1. A precipitate forms. A precipitate is an insoluble solid that remains suspended in the solution or sinks to the bottom. When a precipitate forms as a result of a reaction, the reaction *mixture* appears cloudy. A precipitate may also be colored.

2. A gas is evolved or absorbed. The gas appears as bubbles that effervesce from the solution. The gases may have a noticeable odor. Although it is difficult to observe, a gas can also be absorbed, such as oxygen being absorbed by iron in the formation of rust. This can be observed using an absolute pressure sensor (as used in the Percent Oxygen in Air experiment).

3. Energy is evolved or absorbed. Energy may be released in the form of light, sound, or heat. A change in heat is indicated by a temperature change during the reaction. A temperature change may be perceived by touch or may require the use of a temperature sensor. Chemical reactions nearly always involve a change in energy because chemical bonds must be broken (which requires energy) and new bonds must be formed (which releases energy). Overall, if the reaction requires more energy than it releases, energy is absorbed from the environment, and the temperature decreases. This is called an endothermic chemical reaction. If more energy is released when bonds are broken than when reformed, the reaction is exothermic.

4. There is a significant change in color. If, upon mixing or heating, the color of a substance significantly changes, or color appears from colorless solutions, a new chemical substance has formed.

It is important that students recognize these are only "pieces of evidence" suggesting that a chemical reaction has occurred. The "evidence" may not always be clear. For instance, a boiling substance might appear to show the evolution of a gas, but boiling is a phase change that does not result in a new substance forming. In another case, pouring a clear solution into a blue solution may yield a light blue solution. This may appear to be a chemical color change but only a physical change occurred as the blue solution was diluted.

In this experiment the students will perform the following chemical reactions:

1. Calcium carbonate reacts with acetic acid (vinegar) to form calcium acetate, carbon dioxide and water.

$$CaCO_3(s) + 2HC_2H_3O_2(aq) \rightarrow Ca(C_2H_3O_2)_2(aq) + CO_2(g) + H_2O(l)$$

2. Copper sulfate reacts with sodium hydroxide to form a copper(II) hydroxide precipitate and sodium sulfate.

$$CuSO_4(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$$

3. Citric acid reacts with sodium bicarbonate to form water, carbon dioxide, and sodium citrate.

$$H_3C_6H_5O_7(aq) + 3NaHCO_3(aq) \rightarrow 3H_2O(l) + 3CO_2(g) + Na_3C_6H_5O_7(aq)$$

4. An effervescent tablet contains citric acid and sodium bicarbonate. The chemical equation will be the same as Chemical Reaction 3, above.

5. Silver nitrate reacts with sodium chloride to form a silver chloride precipitate and sodium nitrate.

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

6. When copper(II) hydroxide is heated it decomposes to form copper(II) oxide and water.

$$Cu(OH)_2(s) \rightarrow CuO(s) + H_2O(g)$$

Pre-Lab Discussion and Activity

Crumble, Tear, and Burn Paper

Engage your students in a discussion about the differences between physical and chemical changes by crumbling, tearing, and then burning a piece of paper. Guide the students into understanding that a chemical change results in a completely new chemical substance being formed, but in a physical change, the chemical substance remains the same and only its appearance changes.

Explain to the students the difference between exothermic and endothermic chemical reactions.

Start a list of evidence to indicate that a new substance has formed. In this section, introduce energy being released and the evolution of a gas as evidence to add to the list.

1. When a piece of paper is crumbled, is it a physical change or a chemical change? How do you know?

It is a physical change because no new chemical substance forms. The paper is still paper. The physical size and shape have changed, but no new substance formed.

2. When a piece of paper is torn, is it a physical change or a chemical change? How do you know?

It is a physical change because there is no new chemical substance formed. The paper is still paper. The physical size and shape have changed, but no new substance formed.

3. When a piece of paper is burned, is it a physical change or a chemical change? How do you know?

It is a chemical change because smoke and ash, two new substances, formed, as well as producing energy as light and heat.

4. What term describes a chemical reaction that releases energy?

A chemical reaction that releases energy is an exothermic chemical reaction.

5. What is the difference between a physical and a chemical change?

A physical change causes the physical appearance to change, but its chemical composition remains the same.

A chemical change forms a completely new chemical substance.

6. What did you observe to provide "evidence" that a new substance was formed?

A gas was evolved, and energy (light and heat) was released.

7. What is another name for a chemical change?

Another name for a chemical change is a "chemical reaction."

8. How are the terms "reactant" and "product" used when describing a chemical reaction?

Reactants are the starting substances in a chemical reaction, and products are the newly formed substances.

Iodine Solution Demonstrations

Prepare an iodine solution in advance by dissolving 5.0 g of potassium iodide and 1.5 g of iodine in 500 mL of water. Additionally, prepare a starch solution by dissolving 1.0 g cornstarch in 100 mL boiling water. Allow the starch solution to cool before using.

Teacher Tips:

- ♦ Use a can of spray starch (available from the laundry aisle of your local grocery store) as a quick and easy alternative to powdered cornstarch. Spray a fine mist directly into a beaker of water while stirring.
- ♦ The starch solutions lose their effectiveness if stored for too long. Prepare fresh starch solutions no more than a couple of weeks before performing the pre-lab activity.

Use the iodine solution to engage the students in a discussion about whether or not a color change is evidence of a chemical reaction. Add a few drops of the iodine solution to 10 mL of isopropyl alcohol (available at a local pharmacy). Next, add a few drops of the iodine solution to 10 mL of the cornstarch solution.

9. Is mixing iodine and isopropyl alcohol a physical or chemical change?

This is generally regarded as a physical change. However, the evidence is not clear if the color change is due to the formation of a new substance or whether the color change is due to the dilution of iodine or the presence of iodine impurities. A physical change is further supported in that no gas was evolved, and it does not appear that energy was released.

10. Is mixing iodine and cornstarch a physical or chemical change?

There was a significant color change to dark blue indicating a chemical change. The color is significantly different than either the iodine or the cornstarch and, thus, must be due to the presence of a new chemical substance.

11. Can color change be used as evidence of a chemical reaction?

Yes, but it must be a significant color change.

12. What does the iodine solution test the presence of?

The iodine solution tests for the presence of starch. The students have probably seen this reaction in a biology class.

Precipitation Demonstration

In this section, introduce the formation of a precipitate as the final criteria to determine if a chemical reaction has occurred. Upon completion of this section, add "precipitate forms" to the list of evidence.

Demonstrate the precipitation reaction between sodium carbonate and calcium chloride. Have the students describe the solutions both before and after mixing them.

Put a fast response temperature probe into one of the solutions, and project a Temperature (°C) versus Time (s) graph for the students to see. Start collecting data, and then mix the two solutions. The precipitate will form immediately as a cloudy suspension of small particles. With some time, the solid precipitate will settle to the bottom of the test tube. Use this example and the chemical equation below to demonstrate the meaning of the term "precipitate."

$$Na_2CO_3(aq) + CaCl_2(aq) \rightarrow 2NaCl(aq) + CaCO_3(s)$$

13. Describe both the sodium carbonate solution and the calcium chloride solution.

Both solutions are clear, colorless liquids.

14. Does mixing these two solutions result in a physical change or a chemical reaction?

A new solid is formed. Therefore, this must be a chemical reaction. Additionally, the temperature of the solution changed (increased), indicating that energy was released, which provides further evidence that a chemical reaction took place.

15. What is a precipitate?

A precipitate is an insoluble solid that forms when two solutions are mixed.

16. Was this an exothermic or endothermic chemical reaction? How do you know?

It was slightly exothermic. There was a small increase in temperature during the reaction.

17. Does a change in temperature mean that a chemical reaction occurred?

Not always. However, most chemical reactions involve a change in temperature. Temperature changes also occur when solids dissolve. However, dissolving is generally regarded as a physical change.

Energy being released or absorbed is one form of evidence used to predict that a new substance has been formed. It will generally be accompanied by other changes, such as a precipitate formation, color change, or the evolution of a gas.

18. The beaker contains the newly formed precipitate and a liquid. Use the words "mixture" and "compound" to describe the contents of the beaker.

The beaker contains a mixture of at least two compounds, the newly formed precipitate (solid calcium carbonate) and the liquid (a sodium chloride solution).

19. What is the difference between a physical and a chemical change?

A physical change is one that causes the physical appearance of a substance to change, but the chemical composition remains the same. A chemical change is one in which a new chemical substance forms.

20. What are the four types of evidence that indicate a new chemical substance has formed?

Gas is evolved (usually in the form of bubbles).

Energy is released or absorbed (in the form of heat, light, or sound).

There is a significant color change.

A precipitate is formed.

Lab Preparation

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

1. Prepare 100 mL of 1.0 M citric acid solution. This is enough for 50 lab groups.

Using anhydrous citric acid ($C_6H_8O_7$):

- **a.** Add approximately 50 mL of distilled water to a 100-mL volumetric flask.
- **b.** Add 19.21 g anhydrous citric acid to the water and swirl to dissolve.
- **c.** Dilute to the mark with distilled water.
- **d.** Cap and invert at least three times.

Using citric acid monohydrate ($C_6H_8O_7 \cdot H_2O$):

- **a.** Add approximately 50 mL of distilled water to a 100-mL volumetric flask.
- **b.** Add 21.01 g citric acid monohydrate to the water and swirl to dissolve.
- **c.** Dilute to the mark with distilled water.
- **d.** Cap and invert at least three times.

2. Prepare 100 mL of 1.0 M sodium bicarbonate solution ($NaHCO_3$). This is enough for 50 lab groups.

- **a.** Add approximately 50 mL of distilled water to a 100-mL volumetric flask.
- **b.** Add 8.40 g sodium bicarbonate to the water and swirl to dissolve.
- **c.** Dilute to the mark with distilled water.
- **d.** Cap and invert at least three times.

3. Prepare 100 mL of 0.5 M copper sulfate ($CuSO_4$) solution. This is enough for 50 lab groups.

Using anhydrous copper sulfate ($CuSO_4$):

- **a.** Add approximately 50 mL of distilled water to a 100-mL volumetric flask.
- **b.** Add 7.98 g anhydrous $CuSO_4$ to the water and swirl to dissolve.
- **c.** Dilute to the mark with distilled water.
- **d.** Cap and invert at least three times.

Using copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$):

- **a.** Add approximately 50 mL of distilled water to a 100-mL volumetric flask.
- **b.** Add 12.48 g $CuSO_4 \cdot 5H_2O$ to the water and swirl to dissolve.
- **c.** Dilute to the mark with distilled water.
- **d.** Cap and invert at least three times.

4. Prepare 100 mL of 1.0 M sodium hydroxide (NaOH) solution. This is enough for 50 lab groups.

  a. Add approximately 50 mL of distilled water to a 100-mL volumetric flask.

  b. Add 4.0 g NaOH to the water and swirl to dissolve. The solution may get warm.

  c. Dilute to the mark with distilled water.

  d. Cap and invert at least three times.

5. Prepare 100 mL of 0.05 M silver nitrate ($AgNO_3$) solution. This is enough for 50 lab groups.

  a. Add approximately 50 mL of distilled water to a 100-mL volumetric flask.

  b. Add 0.85 g $AgNO_3$ to the water and swirl to dissolve.

  c. Dilute to the mark with distilled water.

  d. Cap and invert at least three times.

Teacher Tip: Silver nitrate is a light sensitive compound. If you'll store the solution keep it in a dark bottle or one that has been wrapped in aluminum foil. Avoid getting any of the solution on the skin. If this happens, wash the area with soap and water. While there is minimal threat to health, the solution, if not removed, may considerably blacken and temporarily stain the skin (for 1 to 3 days) when exposed to sunlight. Do not try to remove the stains with scrubbing, detergents, or solvents.

6. Prepare 100 mL of 0.1 M sodium chloride (NaCl) solution. This is enough for 50 lab groups.

  a. Add approximately 50 mL of distilled water to a 100-mL volumetric flask.

  b. Add 0.58 g NaCl to the water and swirl to dissolve.

  c. Dilute to the mark with distilled water.

  d. Cap and invert at least three times

Teacher Tips:

- Lauric acid can be melted by heating it in boiling water. When it is removed from the boiling water, it will form a solid at the bottom of the test tube as it cools, which is very difficult to remove. Save the lauric acid in the test tubes, and have your students reuse them from class to class, as well as from year to year.

- The waste generated in some parts of the procedure must be collected and disposed of according to your local, state, and federal regulations. Collect the copper(II) hydroxide produced in Chemical Reaction #3), the silver chloride produced in Unknown Change #2, and the copper(II) oxide produced in Unknown Change #3 in separate containers and process them following the procedures outlined by your organization. The remaining waste products may be flushed down the drain with lots of water.

Safety

Add these important safety precautions to your normal laboratory procedures:

- The silver nitrate ($AgNO_3$) solution may temporarily stain your skin when exposed to bright light. If the solution contacts your skin, wash it with soap and water immediately.

- Many chemicals used in this lab are hazardous to the environment and should not be disposed of down the drain. Make sure you follow your teacher's instruction on how to properly dispose of the chemicals.

- Be careful when working with hot water.

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.

4	2	3	1
Classify the unknown changes as chemical reactions or physical changes based on your observations.	Perform three chemical reactions followed by three physical changes; record the evidence of each type of change occurring.	After you are familiar with the evidence of chemical and physical changes, perform four unknown changes and record your observations.	Pour 150 mL of water into a 250-mL beaker, and start heating it immediately so the water is boiling when you need it later in the lab.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Chemical Reactions

Set Up

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

2. ☐ Connect the fast response temperature sensor to the data collection system. �(2.1)

3. ☐ Display Temperature (°C) versus Time (s) on a graph. �(7.1.1)

4. ☐ Fill a 250-mL beaker with approximately 150 mL of water.

5. ☐ Place the beaker on the hot plate, and allow the water to boil. The boiling water will be used later.

6. ☐ Use Table 1 below to obtain the name and quantity of Reactant #1 and Reactant #2, which you'll use in each procedure for collecting data of chemical reactions.

Reaction Procedure

7. ☐ Place reactant #1, for reaction #1, in a clean test tube labeled "reaction #1".

8. ☐ Insert the fast response temperature sensor into the bottom of the test tube containing reactant #1.

9. ☐ Measure out reactant #2.

10. ☐ Describe at least two characteristics you observe for each reactant under their name in Table 1 below.

Table 1: Chemical reactions

Rxn #	Reactant #1 (quantity, name, and description)	Reactant #2 (quantity, name and description)	Description of the Newly Formed Product(s)	Did the Temperature Increase or Decrease?	Evidence of the Chemical Reaction
1	2 mL vinegar (acetic acid) Description: aqueous, clear, colorless	~0.2 g calcium carbonate Description: solid, white, opaque	bubbles, clear, colorless gas	Increase	Gas was produced Temperature changed
2	2 mL 1.0 M citric acid solution Description: aqueous, clear, colorless	2 mL 1.0 M sodium bicarbonate solution Description: aqueous, clear, colorless	bubbles, clear, colorless gas	Decrease	Gas was produced Temperature changed
3	2 mL 0.5 M copper(II) sulfate solution Description: aqueous, clear,	2 mL 1.0 M sodium hydroxide solution Description:	blue, solid, cloudy	Increase	Precipitate was formed Temperature changed

	blue	aqueous, clear, colorless			

Collect Data

11. ☐ Start recording data. �(6.2)

12. ☐ Add reactant #2 to the test tube containing reactant #1.

13. ☐ Adjust the scale of the graphs so that you clearly see the changes in temperature that are taking place. �(7.1.2)

14. ☐ Stop data recording when the reactants have thoroughly mixed and the temperature has stabilized. �(6.2)

15. ☐ Name the data run "reaction 1". � (8.2)

16. ☐ Record a description of the newly formed substance, whether the temperature increased or decreased, and the evidence for the chemical reaction you observed in Table 1 above.

17. ☐ Remove the fast response temperature sensor from the test tube, and set the test tube and its contents aside for possible reuse later in the experiment.

18. ☐ Thoroughly clean the fast response temperature sensor by rinsing it several times with distilled water.

19. ☐ Repeat the steps in the Reaction Procedure and Collect Data sections for reaction #2, and again for reaction #3.

20. ☐ What is a reactant in a chemical reaction?

A reactant is a starting substance in a chemical reaction.

21. ☐ What is a product in a chemical reaction?

A product is a newly formed substance in a chemical reaction.

22. ☐ Colorless gasses cannot be "seen." How is it possible to know if a gas is being evolved in an aqueous solution?

Bubbles indicate that a gas is being released.

Part 2 – Physical Changes

Collect Data

Physical change #1

23. ☐ Observe the water you started heating at the beginning of the lab, and record your observations for Physical Change #1 in Table 2 below. (Continue to boil the water because you will use it to heat chemicals in the next part of the lab. You may need to add more water to replace what has evaporated.)

Physical change #2

24. ☐ Add approximately 0.2 g colored drink powder to a dry, clean test tube.

25. ☐ Add 5 mL of water.

26. ☐ Record your observations for Physical Change #2 in Table 2 below.

Physical change #3

27. ☐ Break your effervescent tablet into 3 or 4 pieces.

28. ☐ Record your observations for Physical Change #3 in Table 2 below.

29. ☐ Save the pieces to use later in the lab.

30. ☐ Write at least one description in Table 2 below for how the appearance of each chemical substance changed macroscopically even though the molecules making up the substance are still the same.

Table 2: Physical changes

Physical Change #	Physical Change	Description Before the Change	Changes in Appearance (even though the chemical substance is still the same)
1	Heat water (H_2O) until it is boiling	Clear, colorless, liquid	Water is still H_2O, but it is now a gas.
2	Dissolve colored drink powder in water	Drink powder: red color, solid Water:	Water and drink powder are both still present, but they are mixed together. This mixing makes the water

		clear, colorless, liquid	appear colored and makes the drink powder appear to be a liquid.
3	Break the effervescent tablet into 3 or 4 pieces	White, solid, opaque	The size of the effervescent tablet changed, but it is still the same chemical substance.

31. ☐ How are physical changes and chemical changes different from each other?

A chemical change occurs when a new chemical substance is formed through a chemical reaction. A physical change occurs when there is a change in the substance's physical appearance, but the chemical substance remains the same.

Part 3 – Unknown Changes

Collect Data

32. ☐ Record the description of each reactant in Table 3 below before you mix them. A description of "Reactant #2" in Unknown Changes #3 and #4 is not required because it is heat.

Table 3: Unknown changes

Unknown Change #	Reactant #1	Reactant #2	Observations	New Chemical Substance?
1	100 mL of water Description: liquid, colorless, clear	3 or 4 pieces of the effervescent tablet Description: solid, white, opaque	Bubbles were produced Colorless gas Effervescent tablet "disappeared" Temperature decreased	Yes Gas evolved
2	2 mL 0.05 M silver nitrate solution Description: aqueous, colorless, clear	2 mL 0.1 M sodium chloride solution Description: clear, colorless, aqueous	Solid white precipitate formed Cloudy solution Temperature increased	Yes Precipitate formed
3	Blue precipitate from chemical reaction #3 (copper(II) hydroxide) Description: solid, blue	Heat	Blue precipitate changed to a black color Liquid is still present	Yes Color Change
4	Test tube containing ~0.5 g of lauric acid	Heat	Solid turned to a liquid Liquid is clear	No

	Description: solid, white, waxy		and colorless	

Unknown Change #1

33. ☐ Pour 100 mL into a clean 250-mL beaker.

34. ☐ Insert the fast response temperature sensor into the beaker.

35. ☐ Start recording data. �(6.2)

36. ☐ Add the pieces of the effervescent tablet previously set aside.

37. ☐ Adjust the scale of the graph so you can see the temperature change taking place. �(7.1.2)

38. ☐ Stop recording data when the temperature has stabilized. �(6.2)

39. ☐ Name the data run “unknown 1”. �(8.2)

40. ☐ List at least three observations, including any temperature changes, in Table 3 above.

41. ☐ Record in Table 3 whether or not a new chemical substance was formed. If a new chemical substance was formed, list the evidence you can use to support your conclusion.

42. ☐ Remove the fast response temperature sensor, and rinse it thoroughly with distilled water.

Unknown change #2

43. ☐ Pour 2 mL of 0.05 M silver nitrate solution into a test tube.

44. ☐ Insert the fast response temperature sensor into the test tube.

45. ☐ Start recording data. �(6.2)

46. ☐ Add 2 mL of 0.1 M sodium chloride solution.

47. ☐ Adjust the scale of the graph so you can see the temperature change taking place. �(7.1.2)

48. ☐ Stop recording data when the temperature has stabilized. �(6.2)

49. ☐ Name the data run "unknown 2". �(8.2)

50. ☐ List at least three observations including any temperature changes in Table 3 above.

51. ☐ Record whether or not a new chemical substance was formed in the data table above. If a new chemical substance was formed, list the evidence you can use to support your conclusion.

52. ☐ Remove the fast response temperature sensor, and rinse it thoroughly with distilled water.

Unknown change #3 and #4

53. ☐ Use a test tube holder to place the test tube containing the copper(II) hydroxide precipitate formed in chemical reaction #3 into the boiling water.

54. ☐ Use a test tube holder to place the test tube containing the lauric acid into the boiling water.

55. ☐ Allow the test tubes to sit in the boiling water until they have completely changed (about 3 to 5 minutes).

56. ☐ List at least two observations for the changes taking place in each test tube in Table 3 above.

57. ☐ Record whether or not a new chemical substance was formed in Table 3 above. If a new chemical substance was formed, list the evidence you can use to support your conclusion.

58. ☐ Remove the test tubes from the boiling water using the test tube holder.

59. ☐ Turn off the hot plate.

60. ☐ Save your data file and clean up the lab station according to the teacher's instructions, especially those concerning the disposal of used chemicals. �(11.1)

CAUTION: Be sure the hot plate and hot water have cooled before handling them.

Data Analysis

1. ☐ Determine the change in temperature for each experiment in which you collected temperature data.

a. Display the data run you plan to analyze. �(7.1.7)

b. Measure the difference between the initial temperature and final temperature. �(9.2)

c. Record the temperature change in Table 4 below.

Table 4: Identifying changes as endothermic or exothermic based on the observed change in temperature

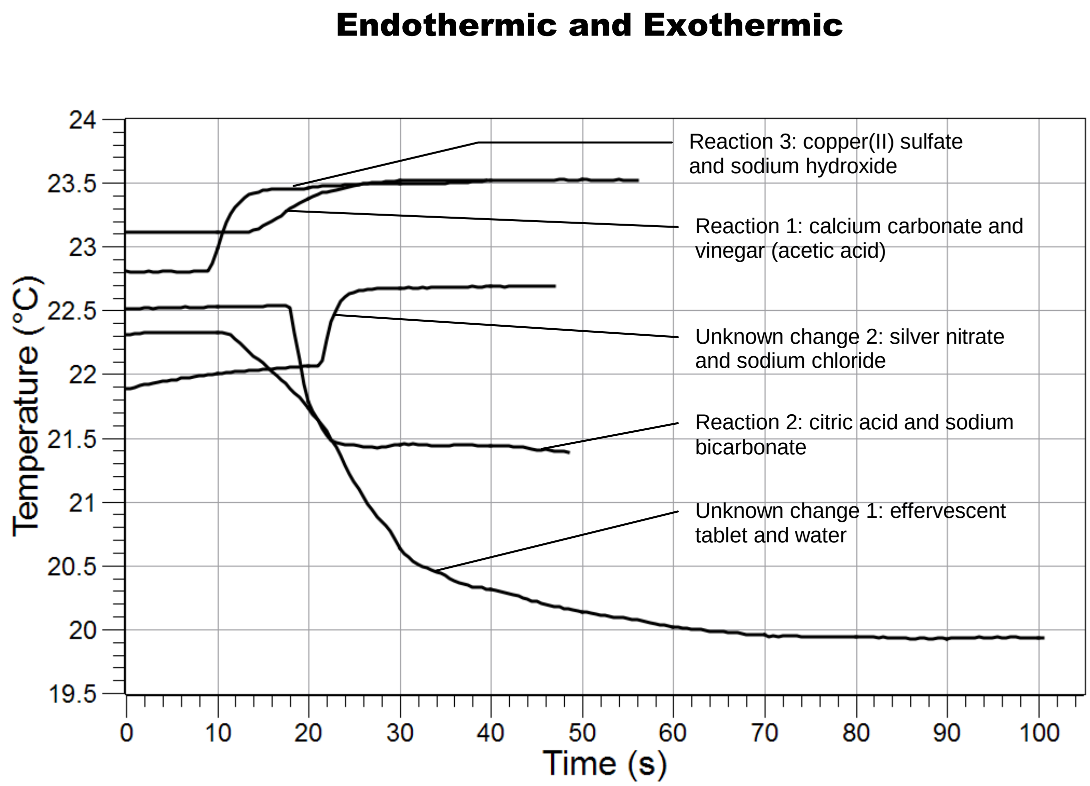
Change	Change in Temperature (°C)	Exothermic or Endothermic?
Chemical Reaction #1: calcium carbonate and vinegar (acetic acid)	0.4	exothermic
Chemical Reaction #2: citric acid and sodium bicarbonate	–1.1	endothermic
Chemical Reaction #3: copper(II) sulfate and sodium hydroxide	0.7	exothermic
Unknown Change #1: effervescent tablet and water	–2.4	endothermic
Unknown Change #2: silver nitrate and sodium chloride	0.6	exothermic

2. ☐ Determine whether the change was exothermic or endothermic using the calculated temperature changes determined above. Record your answers in Table 4 above.

3. ☐ Create a graph of data with all five runs of data displayed on your data collection system. �(7.1.3)

Note: Not all data collection systems will display all five runs of data on one set of axes. If your data collection system cannot display all the data runs, multiple graphs may be used.

4. ☐ Sketch or print a graph of Temperature (°C) versus Time (s) on one set of axes. Label each run of data as well as the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



Analysis Questions

1. Identify each "unknown change" as a physical change or a chemical reaction, and include evidence to support your answers in the table below.

#	Unknown Change	Physical Change or Chemical Reaction	Evidence
1	Effervescent tablet and water	Chemical Reaction	A new substance, a gas, was formed.
2	Silver nitrate solution and sodium chloride solution	Chemical Reaction	A new substance, a white precipitate, was formed.
3	Heating copper(II) hydroxide	Chemical Reaction	A new substance, with a black color, was formed.
4	Heating lauric	Physical Change	No new substance was formed, the lauric acid melted.

	acid		

2. Were unknown change #3 and unknown change #4 endothermic or exothermic? Explain your reasoning.

Both of these processes were endothermic because they both absorbed heat from the boiling water to occur.

3. What is the difference between a physical change and a chemical reaction?

A physical change involves a change in the substance's physical appearance, but remains the same chemical substance.

A chemical reaction is a change in which a new chemical substance is formed.

4. What are the four main types of evidence that indicate a chemical reaction has occurred?

The evidence indicating that a chemical reaction has occurred: the evolution of a gas (seen as bubbles), the release or absorption of energy (as heat, light, or sound), the formation of a precipitate, and a significant change in the color of the substance.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Is mixing salt with water an example of a physical change or chemical reaction? Explain your reasoning.

Dissolving salt in water is a physical change. The salt is still the same substance, but it is just broken into tiny pieces (its ions).

2. List two examples in which a temperature change occurs, but no new substance is formed.

Any phase change of a substance is sufficient: melting, boiling, freezing, and condensing.

3. When a nail becomes rusty, is this an example of a physical change or a chemical reaction? Explain your reasoning.

Rusting is a chemical reaction. The nail (iron) reacts with oxygen in the atmosphere to form a new substance, rust (iron(III) oxide). Evidence for this reaction is a color change. Rust also absorbs a gas, which can be observed by using a pressure sensor, as in the Percent Oxygen in Air experiment.

4. When grass grows, is this an example of a physical change or a chemical reaction? Explain your reasoning.

Chemical reactions are involved when grass grows. Photosynthesis requires that energy from the sun is absorbed (an endothermic process). Gas is also both absorbed (carbon dioxide) and released (oxygen).

Photosynthesis: $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$

5. Is opening a can of soda an example of a physical change or a chemical reaction? Explain your reasoning.

This is an example of a physical change; no new substances are formed.

Multiple Choice Questions

1. In all chemical reactions, ________ turn into ___________.

- **A.** Products; Reactants
- **B.** Molecules; Atoms
- **C.** **Reactants; Products**
- **D.** Atoms; Elements

2. The burning of wood to form soot is an example of a _____________________ change.

- **A.** Physical
- **B.** Slow
- **C.** Fast
- **D.** **Chemical**

3. Which of the following indicates a chemical reaction has occurred?

- **A.** The change is very fast
- **B.** **A precipitate forms**
- **C.** The state of matter changes
- **D.** A dark orange solution turns light orange

4. A chemical reaction that absorbs energy is called a(n) ______________ reaction?

- **A.** **Endothermic**
- **B.** Exothermic
- **C.** Balanced
- **D.** Complete

5. Grinding a large crystal of rock candy into small pieces is an example of a

- **A.** **Physical change**
- **B.** Chemical change
- **C.** Exothermic change
- **D.** Endothermic change

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Matter can undergo both chemical and physical changes. In a **chemical change**, one substance turns into a completely different substance. A chemical change is also called a chemical **reaction**. A **physical change** occurs when a substances changes its physical appearance, but not its chemical identity. Identifying whether a process involves a chemical reaction or a physical change can be difficult because we cannot "see" at the **molecular** level to know whether or not the actual atoms have rearranged. Instead, we must rely on **macroscopic** observations. There are four main types of evidence that suggest a new chemical substance has formed. The formation of a precipitate, the evolution of a **gas**, a significant **color** change, and a change in energy all indicate that a chemical reaction has occurred. A **precipitate** is a solid that forms when two solutions are mixed.

2. A **chemical reaction** always involves a new substance being formed. Therefore, a chemical reaction has starting substances, called **reactants**, and newly formed substances called **products.** When a chemical reaction occurs, the bonds within the original substances are broken apart, the atoms rearrange, and new bonds are formed, creating completely new substances. Energy is required to break the bonds, and energy is released when the bonds are formed. In most chemical reactions, the energy required to break the bonds does not equal the energy released when the new bonds are formed. Therefore, most chemical reactions either absorb energy or release energy. Chemical reactions that absorb energy from their environment result in the temperature decreasing and are called **endothermic** reactions. Chemical reactions that release energy into their environment cause the temperature to increase and are called **exothermic** reactions.

Extended Inquiry Suggestions

Bake bread with the students, and identify each physical change and chemical reaction as you go through the process.

Have students pick a chemical reaction of biological or industrial importance, and describe what makes the process a chemical reaction.

Use a carbon dioxide sensor to monitor the amount of carbon dioxide present, and prove that a new substance is created during either the effervescent tablet experiment or the vinegar-calcium carbonate reaction.

10. Conservation of Matter

Objectives

In this investigation, students test the law of conservation of matter for both physical and chemical changes.

Procedural Overview

Students conduct the following procedures:

- Find the mass of the reactants before the chemicals are reacted and the mass of the products after the reaction has occurred (in a chemical reaction where a precipitate forms)
- Measure the mass of a solute and a solvent separately and the mass of the solution after combining the two
- Determine the mass of gas produced during a chemical reaction by calculating the difference between the mass of the initial reactants and the mass of the final products (the final products do not include the escaped gas)

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Balance
- Test tube (2), 15-mm x 100-mm
- Beaker, 250-mL
- Plastic soda bottle (with cap), 500-mL
- Sodium nitrate ($NaNO_3$), 5 g
- 0.1 M Sodium sulfate (Na_2SO_4), 5 mL[1]
- 0.1 M Strontium chloride ($SrCl_2$), 5 mL[2]
- Sodium bicarbonate ($NaHCO_3$), 8 g[3]
- 5% Acetic acid ($HC_2H_3O_2$), 30 mL[4]
- Distilled (deionized) water, 10 mL

[1]To formulate using solid sodium sulfate (Na_2SO_4), refer to the Lab Preparation section.
[2]To formulate using solid strontium chloride ($SrCl_2$), refer to the Lab Preparation section.
[3]Sodium bicarbonate ($NaHCO_3$) is household baking soda.
[4]Household vinegar can be used for the 5% acetic acid ($HC_2H_3O_2$).

Concepts Students Should Already Know

Students should be familiar with the following concepts:

♦ Mass

♦ Chemical and physical changes

♦ Evidence of a chemical reaction

Related Labs in This Guide

Labs conceptually related to this one include:

♦ Evidence of a Chemical Reaction

Using Your Data Collection System

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

Note: There are no Tech Tips to list in this section as this activity does not use a data collection system.

Background

The law of conservation of matter states that matter cannot be created or destroyed by a physical or chemical change. In both cases, the number of atoms remains the same before and after the change. The law of conservation of matter does not apply to nuclear reactions, where matter may be changed to energy.

In a physical change, the substances before and after the change remain chemically the same, although the arrangement of the *molecules* and average motion of the particles may be different. During a chemical reaction, chemical changes occur and the *atoms* of one or more substances undergo rearrangements. The result of these rearrangements is the formation of new and different substances. The substances are made of the same atoms but are put together in a new way. All of the original atoms are still present.

Because of the law of conservation of matter we are able to write balanced chemical equations. Such equations make it possible to predict the masses of individual reactants and products that are involved in a chemical reaction.

In the first part of this experiment, sodium sulfate (Na_2SO_4) chemically reacts with strontium chloride ($SrCl_2$) to form dissolved sodium chloride (NaCl) and strontium sulfate ($SrSO_4$). Strontium sulfate is a white, solid precipitate. The balanced chemical equation for this reaction is:

$$Na_2SO_4(aq) + SrCl_2(aq) \rightarrow 2NaCl(aq) + SrSO_4(s)$$

In the second part of this experiment, a solution is made by physically dissolving sodium nitrate in water to form a solution. This becomes cold to the touch and is an example of an endothermic process.

$$NaNO_3(s) \rightarrow NaNO_3(aq)$$

In the third and fourth parts of this experiment, sodium bicarbonate ($NaHCO_3$) chemically reacts with vinegar (acetic acid, $HC_2H_3O_2$). This reaction produces sodium acetate ($NaC_2H_3O_2$), water (H_2O), and carbon dioxide gas (CO_2).

$$NaHCO_3(s) + HC_2H_3O_2(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l) + CO_2(g)$$

First, the reaction is performed in an open system. Then it is performed again in a closed system. In the open system, the carbon dioxide gas is allowed to escape to the atmosphere. A loss of mass between the reactants and products occurs, but is not a violation of the law of conservation of matter. This is proven when the reaction is repeated in a closed system, in which the carbon dioxide gas is retained.

Pre-Lab Discussion and Activity

Physical and Chemical Changes

Place a small beaker containing an ice cube on a balance. As the ice cube melts, record its mass periodically while engaging the students in a discussion about change. Review the differences between physical and chemical changes. Discuss whether particular properties of the substance change when the substance undergoes a physical or chemical change. Discuss the effects of chemical and physical changes on the total mass of the system.

1. What is a physical change? Give several examples.

A physical change is one in which the physical appearance of a substance changes, but the chemical structure of the substance remains the same. Water (H_2O) is an example. Melting ice, boiling water, and condensing steam are all examples of physical changes in which a specific chemical substance is in different physical forms.

2. When an ice cube melts, what remains the same? What changes?

Ice is made of H_2O molecules as is liquid water. Therefore, the chemical substance stays the same. The number of water molecules present also does not change, which means that the mass of the ice cube is the same as the mass of the liquid water.

The physical appearance of the water changes. This is because the speed of the water molecules and the distance between the water molecules changes.

3. Does the mass before and after a physical change always stay the same?

Yes, during the physical change, the number of molecules before and after the change remains constant. Therefore, the mass does not change. This aligns with the law of the conservation of matter. It states that matter can neither be created nor destroyed, only changed.

4. What is a chemical change (or chemical reaction)? What evidence suggests a chemical change has occurred? Give several examples.

A chemical change is one in which a completely new substance is formed. The formation of a solid product from dissolved reactants (precipitate), the evolution of gas, a significant color change, and a change in temperature all indicate that a chemical change has occurred. For example burning paper, rusting, and reacting an acid with a base are all examples of chemical changes.

5. Does mass stay the same during a chemical change?

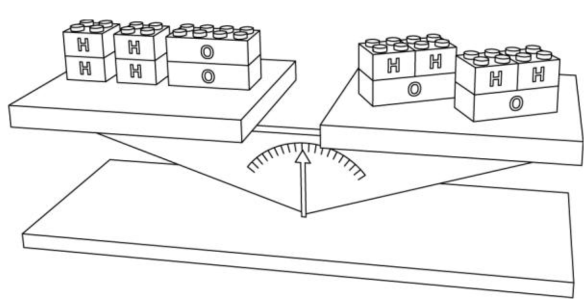
Yes, the atoms of reacting substances can rearrange and form new molecules. New substances form, even though the number of atoms of the total system remains unchanged. Often this is not obvious. For example, when burning paper, the mass of the paper seems to decrease, however the missing mass is simply changed into the gases that are released during burning. This aligns with the law of the conservation of matter which states that matter can neither be created nor destroyed.

Law of Conservation of Matter

Write the law of conservation of matter on the board: "Matter cannot be created or destroyed, only changed in form." Write the equation for the composition of water, $2H_2 + O_2 \rightarrow 2H_2O$, on the board. Ask the students what each of the numbers mean. As they are telling you, build each model using a model kit. Use an elementary school, double-pan balance and place the models on the pans. Place the reactants on one side and the products on the other. Most elementary school balances are not very precise and the students should see the reactants and products balance (even if there are minor variations in the mass of the individual components making up the models).

Teacher Tip: If you do not have a double-pan balance, you can simply measure the mass of the models on an electronic balance or single-pan balance and record the results. A less precise scale is preferred.

Teacher Tip: If you do not own a model kit, models of compounds can be built using large plastic preschool building blocks. Write the symbols for common elements on the different colored blocks.



$$2H_2 \quad + \quad O_2 \quad \rightarrow \quad 2H_2O$$

6. The law of conservation of matter states that matter cannot be created or destroyed. What does this mean in your own words?

Everything must be accounted for. Atoms cannot disappear or appear from nowhere. They can only be rearranged.

7. For the reaction of hydrogen with oxygen to produce water, what does each number in the equation mean? How can we build models of the molecules involved in this reaction?

The subscripts refer to the number of atoms of that type in each molecule. The subscript "2" in O_2 means there are two oxygen atoms in one molecule of oxygen. The coefficient (the number in front of the molecular formula) refers to the number of molecules. The "2" in front of the hydrogen molecule ($2H_2$) means there are two hydrogen molecules.

8. A different chemical reaction involves the decomposition of hydrogen peroxide to form water and oxygen gas. Beginning with two molecules of hydrogen peroxide (H_2O_2), how many water and oxygen molecules are produced to balance the pans?

The balanced chemical reaction is: $2H_2O_2 \rightarrow 2H_2O + O_2$. Two molecules of hydrogen peroxide decompose into two molecules of water and one molecule of oxygen. Notice on the reactant side, that there are a total of four hydrogen atoms and four oxygen atoms making up two hydrogen peroxide molecules. On the product side, the law of conservation of matter is obeyed. Although the four hydrogen atoms and four oxygen atoms are rearranged into different molecules, they exist on the product side as well.

Teacher Tip: Build two hydrogen peroxide molecules. Then allow the students to use the same number of each type of block to build the product molecules. Place their products on the balance and compare with the original reactant molecules.

Lab Preparation

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

1. Prepare 100 mL of 0.1 M sodium sulfate (Na_2SO_4). This is enough for 20 lab groups.

   Dissolve 1.4 g of anhydrous Na_2SO_4 in 100 mL of distilled water.

   Alternatively, dissolve 3.2 g of sodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$) in 100 mL of distilled water.

2. Prepare 100 mL of 0.1 M strontium chloride ($SrCl_2$). This is enough for 20 lab groups.

   Dissolve 1.6 g of anhydrous $SrCl_2$ in 100 mL of distilled water.

   Alternatively, dissolve 2.7 g of strontium chloride hexahydrate ($SrCl_2 \cdot 6H_2O$) in 100 mL of distilled water.

3. Sodium bicarbonate ($NaHCO_3$) is household baking soda.

4. The 5% acetic acid ($HC_2H_3O_2$) may be replaced with household vinegar.

Safety

Follow all standard laboratory procedures.

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	5	3	4
Determine the total mass of the starting substances and the glassware they are contained within.	Measure the starting substances and place in them into a 250-mL beaker.	Compare the mass and of the starting substances and the ending substances.	Mix the starting substances and record any observations.	Measure the mass all of the final substances and glassware.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Collect Data

Part 1 – Sodium Sulfate Solution and Strontium Chloride Solution

1. ☐ Place 5.0 mL of sodium sulfate solution (Na_2SO_4) into a test tube, and place the test tube in a 250-mL beaker.

2. ☐ Place 5.0 mL of strontium chloride solution ($SrCl_2$) into another test tube, and place it in the 250-mL beaker with the other test tube containing Na_2SO_4.

3. ☐ Determine the total mass of the solutions, test tubes, and beaker by placing them on a balance. Record this initial mass below.

Initial mass of Na_2SO_4, $SrCl_2$, and glassware (g): 135.10 g

4. ☐ Predict the amount of product that is produced from these reactants.

There should be the same mass of products as there are reactants.

5. ☐ Carefully pour the strontium chloride solution and the sodium sulfate solution into the beaker. Observe the chemical reaction and record your observations below.

A white solid forms (a precipitate) making the solution look cloudy.

6. ☐ How do you know a chemical reaction took place?

When mixed, the reactants formed a precipitate. The mixed solution appears milky. The bottom of the beaker may have become slightly cooler.

7. ☐ Place *both* test tubes back inside the beaker and measure the mass of the test tubes, beaker, and solution again. Record the final mass below.

Final mass of Na_2SO_4, $SrCl_2$, and glassware (g): __________135.08 g ________

8. ☐ Why is it important to measure the mass of all the glassware together after the reaction occurs?

The initial mass also includes the mass of all the glassware. If the test tubes are removed and not measured after the reaction, the final mass is missing the mass of the original test tubes. This distorts the comparison.

9. ☐ Dispose of the solutions according to your teacher's instructions and then clean your glassware so that it may be used in the next part of this investigation.

Part 2 – Dissolving of Sodium Nitrate

10. ☐ Place approximately 5 g of solid sodium nitrate ($NaNO_3$) into a 250-mL beaker.

11. ☐ Place 10 mL of distilled water into a test tube, and place the test tube inside the 250-mL beaker containing the 5 g of $NaNO_3$(s).

12. ☐ Determine the total mass of the water, test tube, $NaNO_3$(s), and beaker by placing them on the balance. Record this initial mass below.

Initial mass of $NaNO_3$, H_2O, and glassware (g): __________133.71 g ________

13. ☐ Predict the amount of product that is produced from these reactants.

Again, there should be the same mass of products as there are reactants.

14. ☐ Pour the water into the beaker with the solid and swirl the mixture until all of the solid dissolves. Record your observations below.

The solid dissolves and it feels cold.

15. ☐ Does a chemical reaction take place? Explain your reasoning.

No chemical reaction happens because no new substance is formed. The heat absorbed is used to break the lattice structure, but no new substance forms.

16. ☐ Place the test tube back inside the beaker and measure the mass of the test tube, beaker, and solution again. Record the final mass below.

Final mass of $NaNO_3$, H_2O, and glassware (g): _______133.70 g ________

17. ☐ Dispose of the solutions according to your teacher's instructions and then clean your glassware so that it may be used in the next part of this investigation.

Part 3 – Sodium Bicarbonate and Acetic Acid (Open System)

18. ☐ Place approximately 5 g of solid sodium bicarbonate ($NaHCO_3$) into a 250-mL beaker.

19. ☐ Pour 10 mL of 5% acetic acid ($HC_2H_3O_2$) into one test tube and an additional 10 mL into a second test tube. Place both test tubes inside the 250-mL beaker containing the $NaHCO_3$(s).

20. ☐ Determine the total mass of the $HC_2H_3O_2$, test tubes, $NaHCO_3$(s), and beaker by placing them on the balance. Record this initial mass below.

Initial mass of $NaHCO_3$, $HC_2H_3O_2$, and glassware (g): 153.23 g

21. ☐ Predict the amount of product that is produced from these reactants.

The mass of the products will appear to be less than expected. This is because the reaction takes place in an open system. One of the products of the reaction is a gas. The gas escapes to the atmosphere and therefore is not measured. This is not a violation of the law of conservation of mass. Instead, it is an example of not measuring all of the components together. (This is similar to neglecting to add the test tubes when measuring the mass of the products.)

22. ☐ Pour the acetic acid from one of the test tubes into the beaker with the solid and swirl the mixture until the reaction subsides.

23. ☐ Pour the acetic acid from the second test tube and swirl the mixture until the reaction stops. Record your observations below.

Bubbles form.

24. ☐ Does a chemical reaction occur? Explain.

Yes, a chemical reaction occurs. The presence of bubbles indicates that a new substance (a gas) is produced.

25. ☐ Place the test tubes back inside the beaker and measure the mass of the test tubes, beaker, and solution again. Record the final mass below.

Final mass of $NaHCO_3$, $HC_2H_3O_2$, and glassware (g): 152.50 g

26. ☐ Dispose of the solutions according to your teacher's instructions and then clean your glassware so that it may be used in the final part of the experiment.

Part 4 – Sodium Bicarbonate and Acetic Acid (Closed System)

27. ☐ Place approximately 3 g of solid sodium bicarbonate ($NaHCO_3$) in a clean 500-mL plastic soda bottle.

28. ☐ Pour 10 mL of 5% acetic acid ($HC_2H_3O_2$) into a test tube.

29. ☐ Carefully slide the test tube inside the plastic bottle containing the $NaHCO_3$(s), making sure not to spill any of the acetic acid.

30. ☐ Screw on the cap of the plastic bottle tightly.

31. ☐ While still being careful not to spill the acetic acid, place the bottle and its contents on a balance. Record this initial mass below.

Initial mass of the soda bottle and its contents (g): __________46.48 g________

32. ☐ Why must you be careful not to spill the acetic acid at this point in the experiment?

The point of this experiment is to compare the mass of the system before and after a chemical change occurs. If even a small amount of acetic acid and sodium bicarbonate mix, they partially react.

33. ☐ Gently tip the bottle until the test tube inside spills the acetic acid into the sodium bicarbonate. Record your observations below.

Bubbles form and the pressure within the bottle increases.

34. ☐ Once the reaction is complete, and without unscrewing the cap, measure the mass of the bottle and its contents. Record the mass below.

Final mass of the closed soda bottle and its contents (g): ________46.45 g ________

35. ☐ Remove the cap from the bottle and allow the gas to escape.

36. ☐ Why did the pressure inside the bottle increase?

One of the products of the reaction between sodium bicarbonate and acetic acid is a gas (carbon dioxide). Because the gas is unable to escape, it remains trapped inside the bottle, causing the pressure to increase.

37. ☐ Compared with the mass of the bottle and its contents before unscrewing the cap, do you expect the mass to be greater, less, or the same after the gas escapes?

Carbon dioxide gas is matter. It has mass and occupies space. Opening the bottle allows the carbon dioxide to escape. This causes the mass of the system to be less than when the carbon dioxide is trapped inside the bottle.

38. ☐ Screw on the cap and measure the mass of the bottle and its contents. Record the final mass below.

Final mass of the open soda bottle and its contents (g): ________46.17 g ________

39. ☐ Dispose of the solutions and clean up according to your teacher's instructions.

Data Analysis

1. ☐ Determine the change in mass for each process. Record the results in Table 1 below.

Table 1: Initial mass, final mass, and change in mass

Experiment	Initial Mass (g)	Final Mass (g)	Change in Mass (g)
Part 1: $Na_2SO_4 + SrCl_2$	135.10	135.08	0.02
Part 2: Dissolving $NaNO_3$	133.71	133.70	0.01
Part 3: $NaHCO_3 + HC_2H_3O_2$ (open system)	153.23	152.50	0.73
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system before opening the bottle)	46.48	46.45	0.03
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system after opening the bottle)	46.48	46.17	0.31

2. ☐ How many grams of gas (CO_2) were formed in part 3 and part 4 of this investigation? How do you know?

In part 3 of this experiment, 0.73 g of CO_2 gas were formed. In part 4 of this experiment, 0.31 g of gas were formed. The amount of gas released is equal to the difference between the mass of the reactants and the products.

3. ☐ Calculate the percent change in mass for each part of the experiment and record them in Table 2.

$$\text{percent change} = \left|\frac{\text{change in mass}}{\text{initial mass}}\right| \times 100$$

Table 2: Percent change in mass

Experiment	Show Your Work Here	Percent Change in Mass
Part 1: $Na_2SO_4 + SrCl_2$	$\left\|\frac{0.02\text{ g}}{135.10\text{ g}}\right\| \times 100 = 0.007\%$	0.01%
Part 2: Dissolving $NaNO_3$	$\left\|\frac{0.01\text{ g}}{133.71\text{g}}\right\| \times 100 = 0.007\%$	0.007%
Part 3: $NaHCO_3 + HC_2H_3O_2$ (open system)	$\left\|\frac{0.73\text{ g}}{153.23\text{ g}}\right\| \times 100 = 0.48\%$	0.48%
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system before opening the bottle)	$\left\|\frac{0.03\text{ g}}{46.48\text{ g}}\right\| \times 100 = 0.06\%$	0.06%
Part 4: $NaHCO_3 + HC_2H_3O_2$ (closed system after opening the bottle)	$\left\|\frac{0.31\text{ g}}{46.48\text{ g}}\right\| \times 100 = 0.67\%$	0.67%

Analysis Questions

1. Why is the percent change in mass not always exactly 0%?

Balances are very sensitive pieces of equipment. Slight variations in the environment of the balance as well as unavoidable losses or gains in mass during the experimental procedure can change the final, displayed results.

2. What happens to the mass in part 3 and the second part of 4? Is this a case where the law of conservation of matter is untrue? Explain.

In both part 3 and the second part of 4, the reaction is open to the atmosphere. The gaseous products are allowed to escape from the container. The mass of the escaped gas could not be measured. Accounting for the mass of any gas in the reaction helps support the law, not refute it.

3. Do your results confirm the law of conservation of matter? Why or why not?

Yes, the results confirm the law of conservation of matter. In parts 1, 2, and the first part of 4, the masses before and after the change are essentially the same (different by less than 0.1%). In part 3 and the second part of 4, the final mass is less than the beginning mass, but these differences are due to the gas that escaped.

4. Does the law of conservation of matter apply to both physical and chemical changes?

Yes. In this experiment, part 1 is a chemical change and part 2 is a physical change. In both cases matter is conserved.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In the process of electrolysis, electricity is used to convert water into its gaseous elements, hydrogen (H_2) and oxygen (O_2): $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$. If electrolysis is performed using 30 grams of water, how many grams of gas are produced?

After all of the water reacts, 30 grams of gas are produced. The law of conservation of matter states that you cannot gain or lose any mass during the reaction.

2. Pyrite is a shiny yellow mineral also known as "fool's gold". It is composed of iron and sulfur. If a 36.4 gram sample of pyrite is broken down into its elemental components and 17.3 grams of iron are produced, how many grams of sulfur are produced?

There are 19.1 grams of sulfur produced. That is the difference between the pyrite (36.4 g of combined iron + sulfur) and the iron (17.3 g).The law of conservation of matter states that you cannot gain or lose any mass during the reaction.

3. When a log burns, the resulting ash has less mass than the log. Why does this loss of mass not violate the law of conservation of matter?

When a log burns, gases (mainly carbon dioxide and water vapor) are formed and escape into the atmosphere. The ash (carbon) that remains after burning has less mass than the original log.

$$\text{Log(s)} + O_2(g) \rightarrow CO_2(g) + H_2O(g) + C(s)$$

Multiple Choice Questions

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

1. In a chemical reaction how does the mass of the products compare with the mass of the reactants?

- **A.** Greater than
- **B.** Less than
- **C.** **Equal to**
- **D.** Depends on if the reaction is endothermic or exothermic

2. If 7 grams of sodium (Na) reacts with 12 g of chlorine (Cl_2), how much table salt (sodium chloride, NaCl) is produced?

- **A.** 5 grams
- **B.** 13 grams
- **C.** **19 grams**
- **D.** 26 grams

3. What is the mass of the resulting gas when 3 grams of dry ice (solid carbon dioxide, CO_2) sublimes to gaseous CO_2?

- **A.** 0 grams
- **B.** 2 grams
- **C.** **3 grams**
- **D.** 5 grams

4. During a chemical reaction how does the total number of atoms of the reactants compare with the total number of atoms of the products?

- **A.** **Equal to**
- **B.** Greater than
- **C.** Less than
- **D.** Depends on the type of reaction

5. Which of the following states that matter cannot be created or destroyed?

- **A.** Kinetic molecular theory
- **B.** Collision theory
- **C.** Atomic theory
- **D.** **Law of conservation of matter**

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. The l**aw of conservation of matter** states that **matter** cannot be created or destroyed, only changed in form. This means that any atoms present at the beginning of a reaction must also be present at the end of the reaction. The **number** of atoms can be counted in the laboratory by using a **balance** and measuring the **mass** of the reactants and the products. The mass before a change and after a change is **the same**.

2. During **physical** changes atoms do not rearrange to form new substances even though the **appearance** of the substance changes. An example is ice melting into liquid water. During **chemical** changes the atoms do rearrange to form new substances. If any of these new substances are gaseous, they may escape from a reaction. This occurs in **open** systems. C**losed** systems seal reactions from their surroundings so that gaseous products can be trapped and measured.

Extended Inquiry Suggestions

Perform an experiment in which either oxygen or carbon dioxide gas is one of the products. Use either a carbon dioxide gas sensor or an oxygen gas sensor to measure the ppm (parts per million) being produced. Calculate the mass of the gas along with the other products to determine if the mass of the reactants is the same as the mass of the products.

Determine the effect of melting or freezing on the mass of a substance.

Determine the effect of melting and freezing multiple times on the mass of a substance.

11. Varying Reaction Rates

Objectives

Students recognize temperature is a factor that affects chemical reaction rates.

Procedural Overview

Students gain experience conducting the following procedures:

- Observing and comparing the time it takes for a reaction to run its course under different temperature conditions
- Measuring the time needed for a reaction to occur based on a graphical representation
- Using math skills to average temperature results

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Fast response temperature sensor
- Graduated cylinder, 100-mL
- Clear plastic cups or beakers (3), 300-mL (10 oz)
- Alka-Seltzer® tablets (6)
- Room temperature water, 400 mL
- Warm water, maintained at a constant temperature, 400 mL
- Ice-cold water, 400 mL

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- How to use a graduated cylinder to measure liquid volume, as well as the meaning of the term volume
- The terms reactants and products as well as an understanding of the nature of a chemical change (reaction)
- How to set up and compute averages
- How to read and interpret a coordinate graph

Related Labs in This Guide

Labs conceptually related to this one include:

- Water—The Universal Solvent
- Evidence of a Chemical Reaction

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Finding the coordinate of a point in a graph �(9.1)
- 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, 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 to form carbon dioxide, water, and trisodium citrate:

$$H_3C_6H_5O_7(aq) + 3NaHCO_3(aq) \rightarrow 3CO_2(g) + 3H_2O(l) + Na_3C_6H_5O_7(aq)$$

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. 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 °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. 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*. 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). 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 reaction rate.

- *Presence of catalysts*. 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, the number of successful collisions must increase. The rate of the Alka-Seltzer reaction is dependent on both the rate at which the solids dissolve and the rate at which they react once in solution.

This activity focuses on the chemical reaction for this experiment. You may wish to clarify for students that dissolving the Alka-Seltzer tablet is a physical change, rather than a chemical change. The chemical reaction occurs once the reactants are in solution. This may help deter confusion.

Pre-Lab Discussion and Activity

Engage students in the following activity and discussion:

Drop an Alka-Seltzer tablet into a plastic cup filled with water at room temperature and ask the following questions.

1. What do you observe?

When the tablet enters the water it begins to bubble vigorously.

Discuss how many different states of matter are present in the cup (gas, liquid, and solid).

2. Is a chemical reaction is occurring in the cup?

The formation of gas bubbles indicates the production of a new substance, and this is evidence that a chemical reaction is taking place.

3. What gas do you think is released during the reaction?

The gas is carbon dioxide

Note: The presence of CO_2 can be demonstrated with a CO_2 gas sensor.

Explain to students that the evolution of the CO_2 gas is directly related to the disappearance of the solid Alka-Seltzer tablet. When dissolved in water, the sodium bicarbonate ($NaHCO_3$) and citric acid ($H_3C_6H_5O_7$) react to form CO_2.

If the students are familiar with these chemical symbols ("C" stands for carbon, "H" for hydrogen, and so on; "aq" stands for aqueous, or dissolved in water, "g" for gas, "l" for liquid), write the equation for the chemical reaction so they can see it:

$$H_3C_6H_5O_7(aq) + 3NaHCO_3(aq) \rightarrow 3CO_2(g) + 3H_2O(l) + Na_3C_6H_5O_7(aq)$$

or simply write the formulas for the two reactants, citric acid, $H_3C_6H_5O_7$, and sodium bicarbonate, $NaHCO_3$.

Lab Preparation

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

- ♦ Each lab group needs six Alka-Seltzer tablets (the "store" brand of effervescent tablets with the same ingredients can be used).
- ♦ Remind students to place the whole tablet into the water because breaking the tablet changes the variable of surface area.
- ♦ The ice-cold water should always have ice cubes in it to maintain the temperature.
- ♦ The warm water should be kept at a constant temperature.
- ♦ Provide lab groups with towels in case of spills.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Handle glassware carefully.
- ♦ Handle hot water with care to avoid burns.

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	5	3	4
Start recording temperature and drop the Alka-Seltzer tablet into a cup with room temperature water at the same time.	Connect the temperature sensor to the data collection system	Compare the average time to complete the reaction at different temperatures.	Use the graph of Temperature versus time to find how long it took to complete the reaction	Average the time it took to complete two trials at the same temperature

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Room temperature reaction

Set Up

1. ☐ How long do you think it will take for the tablet to dissolve completely?

Answers will vary. At room temperature the tablet dissolves in 40 to 60 seconds.

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

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

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

5. ☐ Change the sampling rate to 10 Hz, or 10 samples per second. �(5.1)

6. ☐ Fill a clear plastic cup or beaker with 200 mL of room temperature water.

7. ☐ Why do you think it is important to use a clear cup or beaker?

In order to find out how long it takes for the Alka-Seltzer to stop fizzing (producing gas), students need to be able to watch the process.

8. ☐ Place the tip of the temperature sensor in the plastic cup or beaker so it is not touching the sides of the container.

Collect Data

9. ☐ Drop the Alka-Seltzer tablet into the water and at the same time, start recording temperature data. �(6.2)

10. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. When it has stopped fizzing, stop recording the first run of data. �(6.2)

Analyze Data

11. ☐ Find the time it took to dissolve the tablet and the final temperature on your graph for each trial. �(9.1)

12. ☐ Record the time it took for the tablet to stop fizzing and the final temperature in Table 1 in the Data Analysis section.

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.

15. ☐ Replace the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container, and repeat data collection and data analysis for a second trial.

16. ☐ What is the reason for doing a second trial at the same temperature?

Conducting more than one trial provides data to average. An average of multiple trials can give a better indication of overall behavior and provide information about the precision and accuracy of the measurements.

17. ☐ Sketch the room-temperature runs on the graph provided in the Data Analysis section, leaving room for data runs for the other trials (using warm and ice-cold water) on the same graph.

Part 2 – Warm temperature reaction

Set Up

18. ☐ How do you think the time to dissolve the tablet in warm water will compare to the time it took to dissolve in room temperature water?

The tablet will dissolve faster in warm water because the additional molecular motion of the warm water will increase the rate at which molecules interact.

19. ☐ Fill a clear plastic cup or beaker with 200 mL of warm water.

20. ☐ Place the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container.

Collect Data

21. ☐ Drop the Alka-Seltzer tablet into the water and start recording temperature data at the same time. �(6.2)

22. ☐ Continue collecting data until the Alka-Seltzer tablet has completely finished fizzing. When it has stopped fizzing, stop recording the first run of data. �(6.2)

Analyze Data

23. ☐ Find the time it took to dissolve the tablet and the final temperature on your graph for each trial. �(9.1)

24. ☐ Record the time it took for the tablet to stop fizzing and the final temperature in Table 1 in the Data Analysis section.

25. ☐ Pour out the water and dissolved Alka-Seltzer tablet, according to your teacher's instructions.

26. ☐ Rinse and refill the clear plastic cup or beaker with 200 mL of warm water.

27. ☐ Replace the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container, and repeat data collection and data analysis for a second trial.

28. ☐ Sketch the warm-temperature runs on the graph provided in the Data Analysis section.

Part 3 – Cold temperature reaction

Set Up

29. ☐ How do you think the time to dissolve the tablet in cold water will compare to the time it took to dissolve in room temperature water?

The tablet will dissolve slower in cold water because slower molecular motion of the cold water will decrease the rate at which molecules interact.

30. ☐ Fill a clear plastic cup or beaker with 200 mL of ice-cold water.

Note: Obtain only the water. There should be no ice cubes in the cup.

31. ☐ Place the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container.

Collect Data

32. ☐ Drop the Alka-Seltzer tablet into the water and start recording temperature data at the same time. �(6.2)

33. ☐ Continue collecting data until the Alka-Seltzer tablet has stopped fizzing, and then stop recording the first run of data. �(6.2)

Analyze Data

34. ☐ Find the time it took to dissolve the tablet and the final temperature on your graph for each trial. �(9.1)

35. ☐ Record the time it took for the tablet to stop fizzing and the final temperature in Table 1 in the Data Analysis section.

36. ☐ Pour out the water and dissolved Alka-Seltzer tablet, according to your teacher's instructions.

37. ☐ Rinse and refill the clear plastic cup or beaker with 200 mL of ice-cold water.

38. ☐ Replace the tip of the temperature sensor in the plastic cup or beaker so that it is not touching the sides of the container, and repeat data collection and data analysis for a second trial.

39. ☐ Sketch the ice-cold temperature runs on the graph provided in the Data Analysis section.

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

Data Analysis

Reaction time at different temperatures

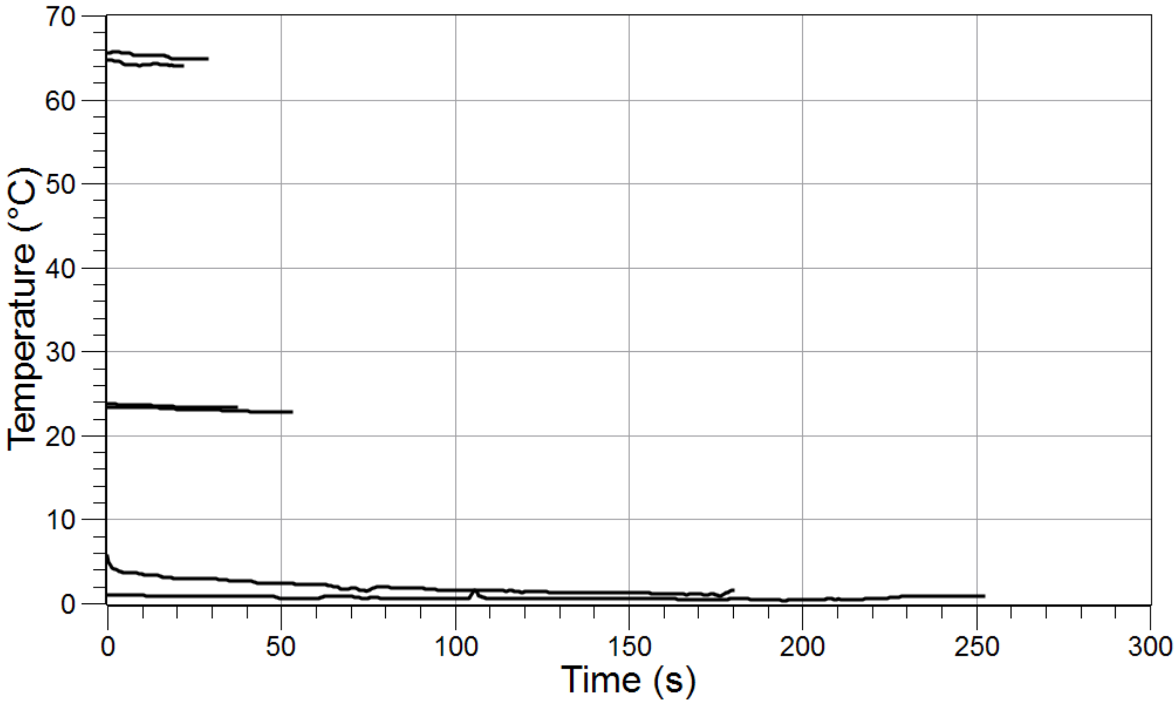


Table 1: Reaction time of Alka-Seltzer in water

Reaction Condition	Trial	Temperature (°C)	Reaction Time (s)
Room temperature water	1	23.9	37.0
	2	23.9	53.0
Warm water	1	65.0	28.5
	2	65.5	21.5
Cold water	1	2.0	180.0
	2	1.1	252.0

Analysis Questions

Table 2: Average reaction time of Alka-Seltzer in water

Reaction Condition	Average Reaction Time (s)
Warm water	25.0
Room temperature water	45.0
Ice cold water	216.0

1. Determine the average reaction time for the trials performed with room temperature water. Record this time in Table 2.

$$\frac{37.0\text{ s} + 53.0\text{ s}}{2} = \frac{90.0\text{ s}}{2} = 45.0\text{ s}$$

2. Determine the average reaction time for the trials performed with warm water. Record this time in Table 2.

$$\frac{28.5\text{ s} + 21.5\text{ s}}{2} = \frac{50.0\text{ s}}{2} = 25.0\text{ s}$$

3. Determine the average reaction time for the trials performed with cold water. Record this time in Table 2.

$$\frac{180.0\text{ s} + 252.0\text{ s}}{2} = \frac{432.0\text{ s}}{2} = 216.0\text{ s}$$

4. Review the average time needed for the Alka-Seltzer tablet to finish fizzing in each part. How many times faster is the reaction rate using warm water than using ice-cold water?

The reaction in the warm water was 8.6 times faster than the reaction in the ice-cold water:

$$\frac{\text{Ice-cold: } 216.0\text{ s}}{\text{Warm: } 25.0\text{ s}} = 8.6\text{ times faster}$$

5. How does temperature affect the rate of this chemical reaction?

In this example, the chemical reaction of an Alka-Seltzer tablet was 8.6 times faster in warm water than in ice-cold water. The higher the temperature, the faster the reaction.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In this experiment, you collected data until the water "stopped fizzing." What is another, more generic, way of stating what caused the reaction to stop?

The reaction continued until at least one of the reactants was consumed completely.

2. Two identical pieces of iron are sealed in identical containers. One container is placed in a room held at 25 °C, and the other is placed outside on a hot day (35 °C). Which piece of iron do you think will rust the most?

The piece of iron placed outside would likely rust the most because the hotter air would cause a higher number of collisions between oxygen molecules and iron atoms.

Multiple Choice Questions

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

1. The rate of reaction is

- **A. A measure of the speed at which a reaction occurs**
- **B.** An equation showing the products and reactants of a chemical reaction
- **C.** A chemical reaction that changes reactants into new products with new properties
- **D.** An element or compound that enters into a chemical reaction

2. A liquid is

- **A. A state of matter that has no fixed shape but has a definite volume**
- **B.** The process where reactants change to form products
- **C.** Formulas and symbols used to show what happens during a chemical reaction
- **D.** One of the original substances before a chemical reaction takes place

3. A product is

- **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. A solid is

- **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. A reactant is

- **A.** The process where substances change to form products
- **B. An 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. A reaction is

- **A.** Matter that has a definite shape and takes up a definite amount of space
- **B. A chemical process that 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 has a definite volume

7. A chemical equation is

- **A.** A substance formed by a chemical reaction
- **B.** A state of matter that has no fixed shape but has a definite volume
- **C.** A chemical reaction changes reactants into new products with new properties
- **D. A formula with symbols used to show what happens during a chemical reaction**

8. A gas is

- **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 list of randomly ordered words in the Key Term Challenge Word Bank.

1. Iron and oxygen change into iron oxide during the **chemical** reaction we know as rusting. Carbon dioxide is a **product** of the chemical reaction between vinegar and baking soda. Matter can be a **solid**, a liquid, or a gas, and chemical reactions can happen in each **phase**. The rate of a chemical **reaction** is the time required for a given quantity of **reactants** to be changed to products.

Extended Inquiry Suggestions

Investigate the reaction rate when there is more surface area (many particles of smaller 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?

12. Endothermic or Exothermic Chemical Reactions

Objectives

Students recognize that chemical reactions require or release energy. They also:

- Recognize that heat—the transfer of energy—can be evidence of a chemical reactions
- Classify reactions as endothermic (energy is absorbed) or exothermic (energy is released)

Procedural Overview

Students investigate endothermic and exothermic reactions while they:

- Measure the temperature change to the surroundings as energy is transferred by different chemical reactions.
- Interpret information about the thermal energy generated during chemical reactions by exploring a temperature versus 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
- Interpret information about the reactant (oxygen) in the exothermic chemical reaction by exploring a pressure versus time graph

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Fast response temperature sensor
- Absolute pressure sensor
- Erlenmeyer flask, 250-mL
- Graduated cylinder, 100-mL
- Quick-release connector[1]
- Barbed Tubing connector[1]
- Tubing, 20 to 30 cm[1]
- Stopper, 1-hole, for Erlenmeyer flask
- Beaker or clear plastic cup, 250-mL
- 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:

- ♦ Temperature measurement and temperature measurement scales
- ♦ 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

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Evidence of a Chemical Reaction
- ♦ Percent Oxygen in Air
- ♦ Phase Change
- ♦ Temperature versus Heat

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- ♦ 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)
- ♦ Measuring the difference between two points in a graph �(9.2)

- ♦ Displaying multiple graphs �(7.1.11)
- ♦ Saving your experiment �(11.1)

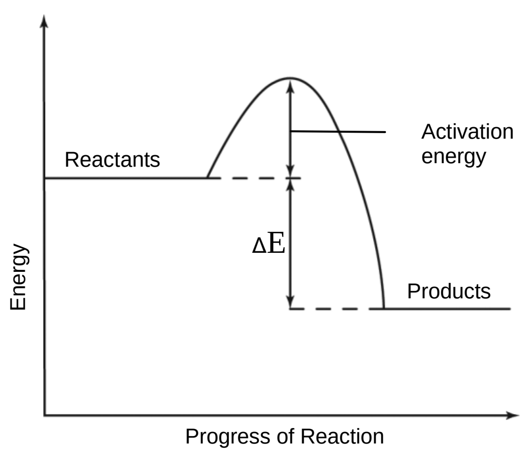
Background

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 release or absorption of heat.

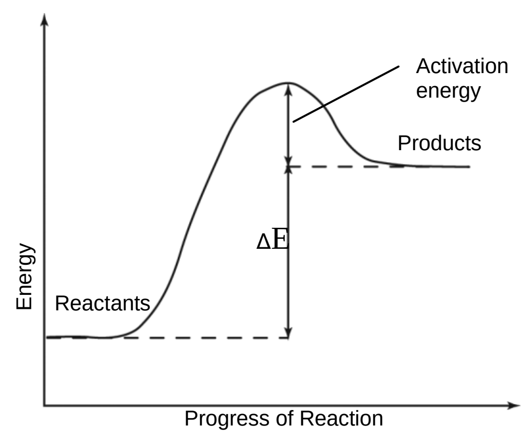
While the formation or disappearance of a substance, or a change in color, are relatively easy for students to observe, a change in thermal energy is apparent only if students are able to handle the vessel in which the reaction is occurring—and if the change is significant enough to be perceived. However, a temperature sensor can be used to measure any change in temperature and provides an excellent means of obtaining evidence for students to make quantitative observations as well as qualitative observations.

The change in temperature is used to determine the energy of reaction, which is the energy released or absorbed during a chemical reaction. In a chemical reaction, the amount of energy stored in the reacting molecules is rarely the same as the amount of energy stored in the product molecules. Depending on which is the greater, energy is either released to or absorbed from the surroundings.

Exothermic Chemical Reaction



Endothermic Chemical Reaction



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.

However, activation energy must be added to the system to start the reaction. For example, mixing propane gas into the air does not usually cause a reaction, but if a spark is added to provide the activation energy, the combustion reaction occurs and will continue until one of the reactants is used up.

Most disposable (one-use) chemical hot-packs contain chemicals that react with air. The reactants include iron, salt (a catalyst), water, and oxygen. The oxygen is obtained from the air, and 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 it does on the undersides of cars where winter roads are salted. Hot-packs have other ingredients as well, including carbon (often in the form of charcoal) to disperse the flow of thermal energy, and a 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:

1. What are the indications that a chemical reaction has taken place?

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)

2. Have students identify different chemical reactions that they observe in a typical day.

Answers will vary; collect and discuss all answers at the front of the room. Add the associated indication to each reaction that you discuss. For example, for the reaction rusting, the indication would be a change of color.

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).

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."

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

Lab Preparation

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

1. Each lab group will need 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.

2. 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 2, while they wait for the hot-pack reaction to occur in the closed flask.

3. Temperature sensor options

Fast response temperature sensor: 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.

Stainless steel temperature sensor: 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.

4. 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.

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.

3	1	2	4
Place two Alka-Seltzer tablets into a beaker of distilled water.	Measure 100 mL of distilled water to be added to a beaker.	Begin recording temperature data	Find the difference between the initial and final temperature.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Is the reaction of Alka-Seltzer and water endothermic or exothermic?

Set Up

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

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

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

4. ☐ Measure 100 mL of distilled water and pour it into the 250-mL beaker.

5. ☐ Place the temperature sensor in the water in the beaker.

6. ☐ Predict whether the reaction of Alka-Seltzer and water is exothermic (energy released, temperature increases) or endothermic (energy absorbed, temperature decreases).

Answers will vary; however, the reaction is endothermic.

Collect Data

7. ☐ Begin data recording. �(6.2)

8. ☐ Drop two Alka-Seltzer tablets into the water.

9. ☐ Continue recording data until the Alka-Seltzer tablets are completely dissolved and the temperature data is no longer changing.

10. ☐ Stop data recording. �(6.2)

Analyze Data

11. ☐ 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)

12. ☐ What did you observe on the graph?

The temperature decreases during this reaction.

13. ☐ Measure the difference between the initial and final temperature on your graph. �(9.2)

14. ☐ Record the difference between the initial and final temperature in Table 1 in the Data Analysis section, and identify the reaction as endothermic or exothermic.

15. ☐ Save your experiment. �(11.1)

Part 2 – What happens when a hot-pack reacts with the air?

Set Up

16. ☐ Predict whether the reaction of the disposable hot-pack is exothermic (energy released) or endothermic (energy absorbed).

Students are likely to predict correctly that this reaction will be exothermic because they know it will get hot.

17. ☐ Predict what will happen to the air pressure in a flask when the reaction of the disposable hot-pack is placed in a flask and sealed.

Answers will vary. As the iron oxidizes, the oxygen is consumed and the absolute pressure decreases.

18. ☐ Open the hot-pack and shake it gently to expose the chemicals within its pouch to the surrounding air.

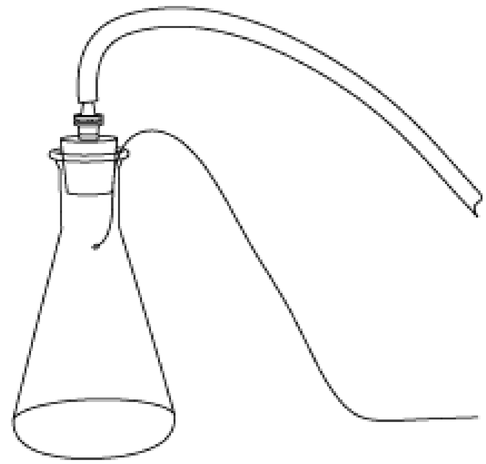
Note: You will need to let the hot-pack's chemicals react with the air for several minutes.

19. ☐ 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 between the mouth of the flask and the stopper.



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 �(7.1.11) —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.

23. ☐ Change the sampling rate to take a measurement every 2 seconds. �(5.1)

24. ☐ 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 mix air into the chemicals.

25. ☐ Why do you think it is important to shake the hot-pack?

Answers may vary, but the chemical reaction that makes the hot-pack hot requires oxygen. Shaking the hot-pack allows more oxygen to come in contact with the chemicals in the hot-pack.

26. ☐ Gently place the hot-pack into the flask.

27. ☐ Arrange the temperature sensor in the flask so it is touching the hot-pack.

28. ☐ How would the results differ if the temperature sensor was not touching the hot-pack?

If the temperature sensor does not touch the hot-pack, students would be measuring the temperature of the air above the hot-pack instead of the actual temperature of the hot-pack itself.

Collect Data

29. ☐ Begin data recording. �(6.2)

30. ☐ Observe the temperature graph for 2 to 3 minutes before closing the flask.

31. ☐ Place the stopper, with the pressure sensor tube, into the mouth of the flask, sealing it tightly and holding the temperature sensor in place.

32. ☐ Why is it important to make sure the stopper tightly seals the temperature sensor in the flask?

If the Erlenmeyer flask is not sealed, the air will leak in or out and the pressure data will not be correct.

33. ☐ Continue recording temperature and pressure data until there are no further changes.

34. ☐ Stop data recording. �(6.2)

Analyze Data

35. ☐ What do you observe on your graphs of temperature versus time and pressure versus time?

The temperature increases and then stabilized at about 36 °C. The pressure decreased, but stopped decreasing when the temperature stabilized, possibly indicating the oxygen in the flask had been used up.

36. ☐ Measure the difference between the initial and final temperature on your graph. �(9.2)

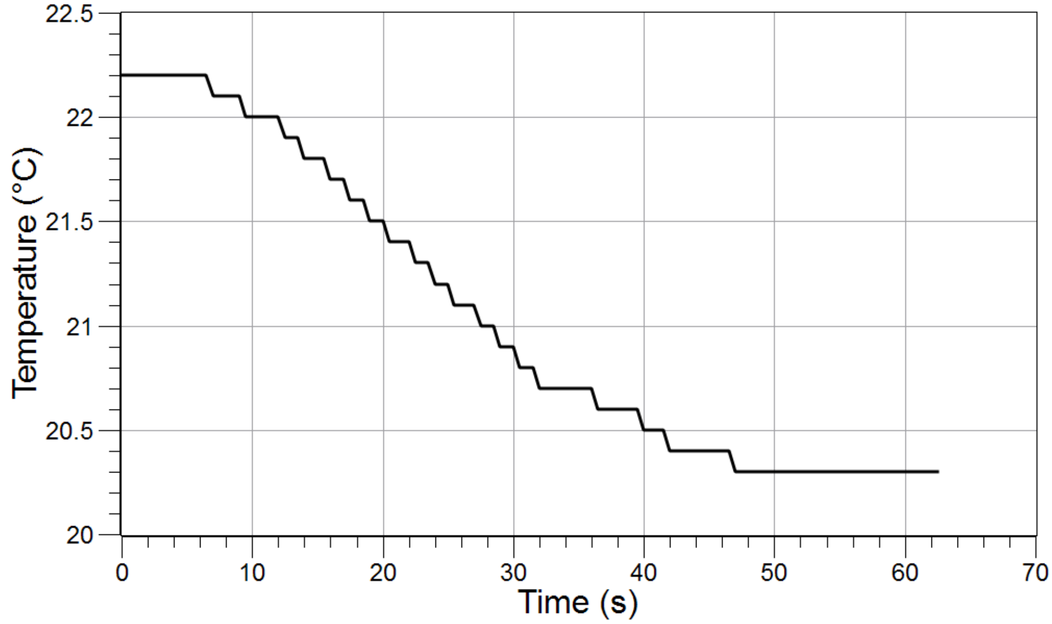
37. ☐ Record the difference between the initial and final temperature in Table 1 in the Data Analysis section, and identify the reaction as endothermic or exothermic.

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

Data Analysis

Part 1 – Is the reaction of Alka-Seltzer and water endothermic or exothermic?

Alka-Seltzer data



Part 2 – What happens when a hot-pack reacts with the air?

Hot-pack data

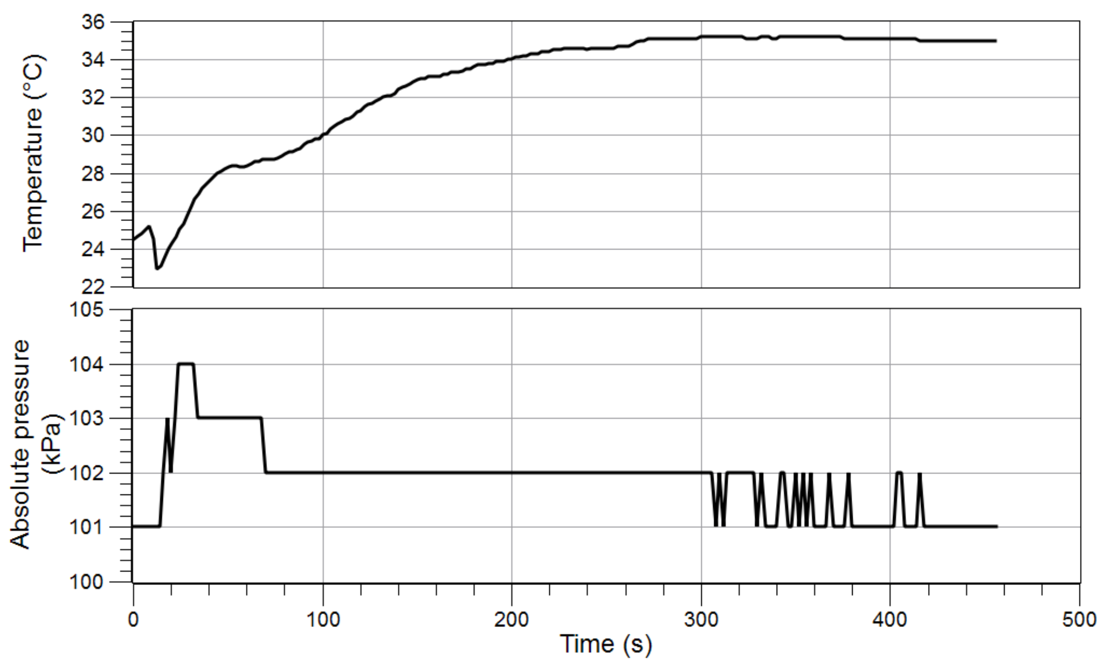


Table 1: Temperature change

Reaction	Temperature Difference (°C)	Type of Reaction
Alka-Seltzer	–1.9	Endothermic
Hot pack	10.5	Exothermic

Analysis Questions

1. How did your predictions of the "type of reaction" compare to your results in Part 1 and Part 2?

Answers will vary, as they are predictions. The Alka-Seltzer reaction is endothermic and the hot-pack reaction is exothermic.

2. How did your prediction of the air pressure change compare to your results in Part 2?

Answers will vary. Students may have predicted that the pressure in the flask would increase due to the increase in temperature, but as the oxygen is consumed, the air pressure decreases.

3. The chemical reaction between the hot-pack and the air required oxygen. What evidence do you see in your data that oxygen from the air in the flask was used for the reaction?

The air pressure decreased, providing evidence that the hot-pack used the oxygen in the flask (in the "Percent of Oxygen in Air" activity, students determine that about 20% of air is oxygen). After that, it could not react any more and the temperature of the hot-pack stopped increasing.

Synthesis Questions

Use available resources to help you answer the following questions.

1. When an automobile engine starts up, is this an endothermic or exothermic reaction? How can you tell?

The spark plug provides the activation energy that ignites the gasoline. This burning of gasoline is an exothermic reaction, which we know because the engine (the container of the reaction) gets warm.

2. 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 causes its surroundings to get warmer it is giving off energy as heat and is called an exothermic reaction. When a chemical reaction causes its surroundings to get colder it is taking in energy by absorbing heat, and is called an endothermic reaction.

Multiple Choice Questions

Select 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. A reaction that gives off heat is classified as:

- **A.** An endothermic reaction
- **B.** A phase change
- **C.** **An exothermic reaction**

4. Pressure is measured in SI units known as:

- **A.** Newtons
- **B.** **Pascals**
- **C.** Joules

5. Suppose you mix two colorless and 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.

6. 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.**

7. Consider the scenario in Question 5 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

8. 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.**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Chemical reactions may be accompanied by changes in **energy**, often in the form of **heat**. Chemical processes that absorb heat from their surroundings are **endothermic**, while those that release heat into their surroundings are **exothermic**. The heat released or absorbed by chemical reactions usually results in a change in temperature.

Extended Inquiry Suggestion

Students may find it interesting to measure and compare their results from Part 2 of this activity with a graph of the temperature change of the hot-pack without limiting the air supply.

How could this experiment be changed or modified to illustrate Charles' law?

Investigate the temperature change of chemical reaction of ammonium nitrate and water.*

Investigate the temperature change of chemical reaction of hydrochloric acid and magnesium ribbon.*

*For these investigations, use the stainless steel temperature sensor.

Physics

13. Position: Match Graph

Objectives

This activity introduces students to the concept of representing motion as a change of position in a graphical form. Students:

- ♦ Understand the difference between distance and position
- ♦ Experience motion as a change of position
- ♦ Interpret a position versus time graph

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Measuring the position of an object using a motion sensor
- ♦ Tracking the change of position of an object using a graphical representation
- ♦ Interpreting a graphical representation of position versus time

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Object to hold (textbook, basket ball) (optional)
- ♦ Motion sensor
- ♦ Rod stand for motion sensor (optional)

Concepts Students Should Already Know

Students should be familiar with the following concept:

- *x-y* graphing

Related Labs in This Guide

Labs conceptually related to this one include:

- Speed and Velocity
- Acceleration

Using Your Data Collection System

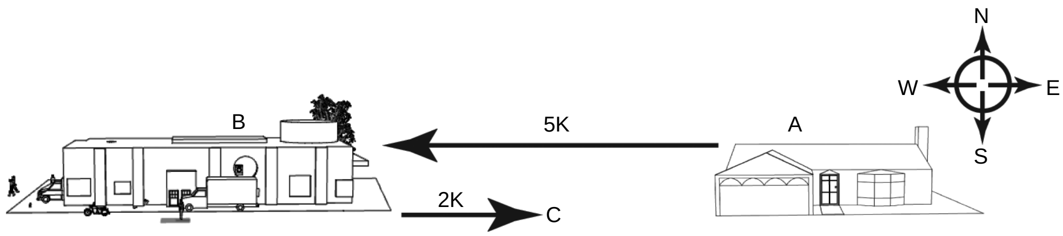
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions 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 and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Measuring the distance between two points in a graph �(9.2)
- Adding a note to a graph �(7.1.5)
- Saving your experiment �(11.1)

Background

The terms distance, position, and distance traveled are often used interchangeably in everyday language. We also describe a fourth term in science, displacement. Displacement is the vector quantity describing a change in position. 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 (distance and direction) of an object relative to a specific frame of reference.

To reiterate, position includes both direction and distance from a frame of reference. For example, if you tell someone the distance to your house from the mall, you might say, "five kilometers" (5 km). However, if you tell someone the position of your house (point A), you might say, "5 kilometers east of the mall (point B)."



In this description, the distance is 5 km, the direction is east, and the frame of reference is the mall. The distance traveled is the total distance required to get from one position to another.

Assuming 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 (point C). Your total distance traveled is then 7 km (5 km + 2 km), but your position is 3 km (5 km – 2 km) west of your house. In this example, the distance is 3 km, the direction is west, and the frame of reference is your house.

Therefore, in this example, your displacement is the vector sum of 5 km away from your house and 2 km toward your house, resulting in a displacement of 3 km west of your house. Frame of reference refers to the location of the observer while measurements are made of position, motion, or both.

For this activity, the motion sensor serves as the point of reference. All motion is relative to the face of the motion sensor, with the motion away from the sensor being the positive direction.

Pre-Lab Discussion and Activity

Depending on your students' math proficiency, it may be necessary to review basic *X-Y* graphing. Lay out a tape measure or other distance measuring device next to the path you will walk to represent the *y*-axis. The motion sensor uses echolocation to determine the distance to an object. Use a digits display (projected if possible) to show the distance to near-by objects (the floor, the ceiling, or a nearby student). Next use your hand to show how distance changes when an object moves toward and away from the sensor. Also, move your hand side to side to demonstrate what happens when the sensor looses track of an object. This is a good time to reinforce the difference between position, distance, distance traveled, and displacement.

Teacher Tip: When using a motion sensor, it is most common to set the sensor in a fixed position and have the student or object move relative to the sensor. In some instances, it is more appropriate to move the sensor relative to a fixed position, such as a wall. Both methods are completely viable, but you must clarify with students what they will use as a fixed frame of reference.

1. What does the value on the screen represent?

The distance between the motion sensor and the hand

2. How do I make that a position?

Give it a direction and frame of reference (0.5 meters in front of the face of the motion sensor on my desk).

3. If I moved my hand back and forth five times, 0.2 meters away, and then 0.2 back, what is the total distance my hand travelled?

0.4 meters per round trip, five round trips, means my hand traveled approximately 2 meters.

4. If my starting position is 0.5 meters away from the face of the motion sensor, and I move to a final position 1.5 meters from the face of the motion sensor, what is my displacement?

1.0 meters in the positive direction.

Note: In the background it is noted that the direction away from the motion sensor is the positive direction.

Next bring up a graph of Position versus Time. Ask your students to do the following predictions.

Teacher Tip: When using a motion senor to measure a person's movement, it is sometimes easier to have the person hold a target object like a textbook or a basketball. Because the sensor is using an ultrasonic pulse, sound-dampening surfaces like a soft sweater can be difficult for the sensor to track.

5. What do you think the graph will look like if I stand in front of the sensor and collect data for 10 seconds? Sketch your prediction.

The distance will remain constant, and time will increase from 0 to 10 seconds. The graph is a straight line parallel to the *x*-axis.

Stand between one and two meters from the sensor, and have your students estimate your distance from the sensor. Then, collect 10 seconds. of data. Discuss for a moment those predictions that are similar and those that are different.

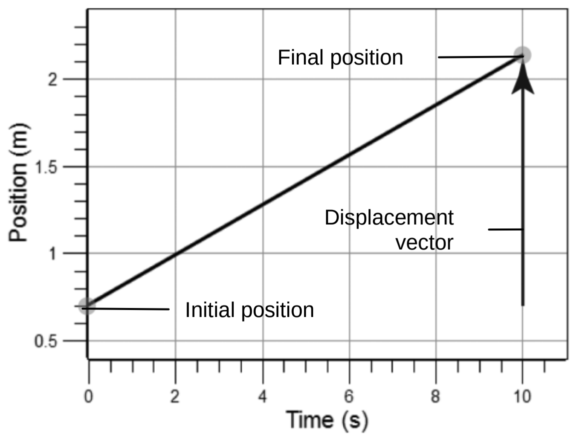
Teacher Tip: If someone willingly shares a significantly different prediction, this can be a good time to work through misconceptions, and review time as the independent variable (*x*-axis) and position as the dependent variable (*y*-axis).

6. What do you think the graph will look like if I move away from the sensor for 10 seconds? Sketch your prediction.

The graph will be a roughly straight line starting at time zero and your initial position with a positive slope.

Stand about one meter from the sensor and have your students estimate your distance from the sensor, then collect 10 seconds. of data while you move slowly and steadily away from the sensor. Briefly discuss those predictions that are similar and those that are different. Then review the key features of the graph.

Teacher Tip: You may want a volunteer to start and stop data collection.



Teacher Tip: Some instructors prefer to start with the Match Graph Challenge available as an EZscreen with Data Studio Software to get students excited about the idea of data collection.

Teacher Tip: Some Instructors prefer to use a cart and track rather than having students acting as the object in motion to reduce the amount of "extra motion" some students bring to the experiment.

Lab Preparation

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

1. Be sure to space the motion sensor stations around the room, and offset the sensors so that they do not directly face each other. The motion sensor will respond to the strongest signal it receives.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Make sure you have at least 2 meters of space in front of the motion sensor.

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.

4	2	1	3
Match the different types of motion you experienced with the different parts of your Position versus Time plot.	Position yourself in front of the motion sensor, and ensure you have adequate space to move.	Connect the motion sensor to the data collection system.	Carefully move and observe Position versus Time graph as you match the motion described.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 - Moving away from the motion sensor

Set Up

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

2. ☐ Connect the motion sensor to the data collection system, and make sure the motion sensor switch is in the far or “person” position. �(2.1)

3. ☐ Place the motion sensor on a table or rod stand such that you have at least two meters of clear space in front of the sensor and the face of the sensor is level with your midsection.

4. ☐ If you held the motion sensor and pointed it at a fixed position, like a wall, would it change the experiment significantly? Explain?

No, although the wall would now be the fixed position, and therefore the frame of reference, the distance measured would be the same. The fact that, "moving away from the wall is the positive direction," would be the same.

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

6. ☐ What are the independent and dependent variables on your graph?

The *x*-axis is the independent variable time, and the *y*-axis is the dependent variable position.

Collect Data

7. ☐ Position yourself approximately 40 cm in front of the motion sensor. You may want to hold a book or ball in front of you as a more easily controlled target.

8. ☐ Have your lab partner start recording a run of data. �(6.2)

9. ☐ Stand completely still for 2 seconds, and then carefully move backwards as smoothly as possible (away from the motion sensor) for a few seconds.

10. ☐ Stand still for 2 more seconds, and then have your lab partner stop recording data. �(6.2)

Analyze Data

11. ☐ Sketch your graph of Position versus Time in the Data Analysis section.

12. ☐ Annotate your graph in the Data Analysis section with descriptions of your motion at different parts of data collection.

Note: If you will be turning in an electronic document only, you can add notes to the graph on your data collection system �(7.1.5)

13. ☐ Find the difference between your initial and final position. �(9.2)

$$\text{final - initial} = 1.8\text{ m} - 0.5\text{ m} = 1.3\text{ m}$$

Part 2 - Moving away from and then toward the motion sensor

Set Up

14. ☐ Use the same set up as in Part 1.

Collect Data

15. ☐ Position yourself approximately 40 cm in front of the motion sensor. You may want to hold a book or ball in front of you as a more easily controlled target.

16. ☐ Have your lab partner start recording a run of data. �(6.2)

17. ☐ Carefully move backwards as smoothly as possible (away from the motion sensor) for a few seconds, then stand still for 2 seconds.

18. ☐ Carefully move approximately half way back toward the motion senor, and then have your lab partner stop recording data. �(6.2)

Analyze Data

19. ☐ Add this second data run to your graph of Position versus Time in the Data Analysis section.

20. ☐ Annotate your graph in the Data Analysis section with descriptions of your motion at different parts of data collection.

21. ☐ Find the difference between your initial and final position. �(9.2)

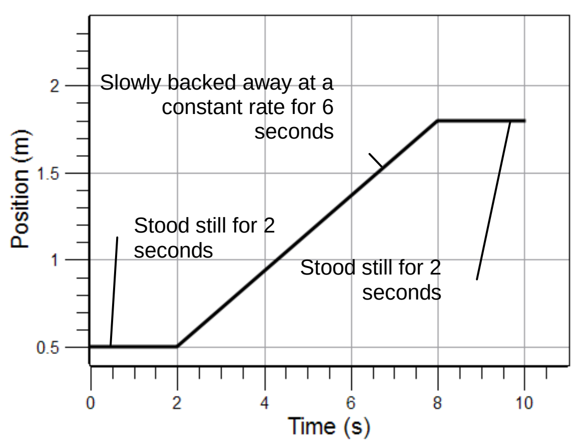
final - initial = 0.9 m - 0.5 m = 0.4 m

22. ☐ Add a note to your graph with value of the difference. �(7.1.5)

23. ☐ Save your data as described by your teacher. �(11.1)

Data Analysis

Graph 1: Position versus Time



Analysis Questions

1. From the first data run on your sketch in the Data Analysis section, identify your initial position and your final position?

Initial position was 0.5 meters in front of the motion sensor, and the final position was 1.8 meters in front of the motion sensor (using the sample graph above).

2. For the first run, what was the distance you travelled?

1.3 meters.

3. For the first run what was your displacement?

1.3 meters away from the motion sensor

4. From the second data run on your sketch in the Data Analysis section, identify your initial position and your final position?

Initial position was 0.5 meters in front of the motion sensor, and the final position was 1.2 meters in front of the motion sensor.

5. For the second run, what was the distance you travelled?

1.8 meters, 1.25 meters away from the sensor and .55 meters back toward the sensor.

6. For the second run what was your displacement?

0.7 meters away from the motion sensor.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If you were using a motion sensor to measure the motion of a cart on a track, and the graph of the motion was a straight line starting at 0.2 meter at zero seconds and ending at 1.1 meter at 4 seconds, what is the displacement of the cart?

The displacement of the cart is 0.9 meter away from the motion sensor.

2. At a field meet, a runner in a 2 kilometer event runs on a circular track that is exactly 2 kilometers in circumference so he only has to run one lap. What was his distance traveled in meters, and what was his displacement at the end of the lap?

The runner traveled 2000 meters, but his displacement is zero because he started and stopped at the same point.

3. A graph of Position versus Time of a car travelling down a straight road that starts at a driveway and ends at the post office shows the car travelling 5 miles away from the driveway in 15 minutes, and then 2.5 mile toward the driveway in 5 minutes. What distance did the car travel, and what was the car's final position?

The car travelled 7.5 miles, and its final position is 2.5 miles from the driveway in the direction of the post office.

4. An ant follows a straight chemical trail that starts at its nest to a piece of bread 23 centimeters away. At the end of the day it delivers 10 piece of bread to the nest. What was the total distance the ant travelled in meters, its initial position, and its final position?

The ant travelled 4.6 meters. Its initial position and its final position was the nest.

Multiple Choice Questions

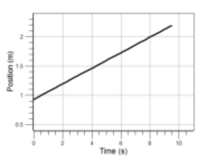
1. When trying to measure a soccer ball's displacement in real time when it is dropped from a height of 1.8 meters, what is the best tool to use?

- **A.** Force sensor
- **B.** **Motion sensor**
- **C.** Meter stick
- **D.** Acceleration sensor

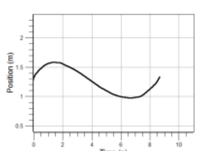
2. A fellow student tells you that her daily walk to school is 6 km. What is this measurement?

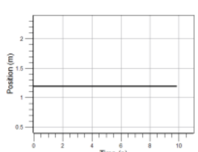
- **A.** Initial position
- **B.** Final position
- **C.** Displacement
- **D.** **Distance travelled**

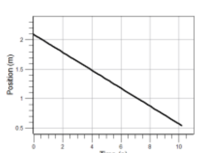
3. Which graph best represents an object moving away from a motion sensor at a constant speed?

A. 

[correct]

B. 

C. 

D. 

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. Motion is defined as a change in **position** relative to a frame of reference. Distance refers to the length of a **path** between points. In other words, it is the scalar value of length. Position refers to the location (distance and direction) of an object relative to a specific **frame of reference**.

2. Position includes both direction and **distance** from a frame of reference. Frame of reference refers to the location of the observer while measurements are made of position and/or **motion**. The vector displacement only includes the distance and a **direction.**

3. A ranger **traveling** through the woods used a pedometer to determine that he had walked 10 miles along the woodland trails. When he checked his map, he found that he was only a mile and a half north of the point that he started. He had no idea when he started that the trail was so twisted and was surprised that his **distance traveled** could be 10 miles, but his **displacement** was only 1.5 miles north.

Extended Inquiry Suggestions

Competition: using the EZscreen software that comes with Data Studio, take the Match Graph Challenge. Using the first Match Graph, ask each student group do several runs, and then send the student with the highest score to the front of the class to compete against the other groups.

Other graphs: ask your students to try the other graphs available in the EZscreen match activity, and discuss with them the similarities and differences. This is also a good opportunity to introduce the idea that the slope of a Position versus Time graph is related to speed and velocity.

14. Speed and Velocity

Objectives

This experiment highlights the similarities and differences between the concepts of speed and velocity. Students predict how the speed and velocity of a cart will differ, and then test their predictions by analyzing graphs generated using a motion sensor.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Predicting how a velocity versus time and speed versus time graph will look for a cart travelling down a track and back
- ♦ Assembling the equipment using a dynamics cart and track, as well as a motion sensor
- ♦ Measuring the actual speed and velocity using the motion sensor as the cart travels along a track
- ♦ Comparing the predicted graphs to the actual graphs

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Dynamics track
- ♦ Dynamics track end stop
- ♦ Motion sensor
- ♦ Dynamics cart

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Vector addition and subtraction
- ♦ 1-dimensional motion
- ♦ Basic graphical analysis techniques

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Acceleration
- ♦ Position: Match Graph

Using Your Data Collection System

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

- ♦ Starting a new experiment �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Changing the sample 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)
- ♦ Selecting data points in a graph �(7.1.4)
- ♦ Drawing a prediction �(7.1.12)
- ♦ Measuring the distance between two points in a graph �(9.2)
- ♦ Viewing statistics of data �(9.4)
- ♦ Creating calculated data �(10.3)

Background

When a police officer pulls someone over for driving too fast, it is not often that he or she is concerned about the velocity of the car, but rather, the speed at which it was traveling. A basic and important difference between speed and velocity is that velocity is a vector quantity, implying magnitude and direction, while speed is simply a scalar magnitude without direction.

Speed is defined as the change in distance, regardless of the direction of that displacement, divided by the change in unit time it took to travel that distance. This is otherwise thought of as how fast something is going:

$$\text{Speed} = \frac{\Delta\text{distance}}{\Delta\text{time}}$$

Velocity is generally defined as the unit displacement *in a specific direction* or change in position divided by the unit of time:

$$\text{Velocity}_x = \frac{\Delta\text{position}}{\Delta\text{time}}$$

It is important to understand how these two quantities are related. It is easy to think of the velocity of an object as simply the combination of the object's speed and its direction.

Pre-Lab Discussion and Activity

Students will need a concrete understanding of displacement and distance and how they differ before developing a good understanding of speed and velocity and how they differ. Here is a sample discussion that may better prepare students for this lab activity:

Begin by asking students about their interpretation of distance and how they would define the term mathematically. Many students will simply define the term as, "How far something travels," which is correct. Reinforce this idea by demonstrating with a student walking completely around the room. Make certain the student has returned to the same starting position in preparation for the next demonstration.

1. If the length of each wall is 35 ft, and the student has walked along all four walls, what is the distance he or she has traveled?

Answer: 35 ft × 4 = 140 ft

Now ask the student to walk around the room again, but ask the student to stop just before he or she has returned to the same starting position (several feet away).

2. Determine what the student's *displacement* is.

Commonly students will associate the two terms as being the same; however, the student's displacement is really the distance from his or her starting position to his or her final position.

Explain to students how speed is simply a metric for measuring how fast an object is moving, or rather, the amount of *distance* the object travels per unit of time. It is important that students know that speed is a scalar quantity that indicates magnitude and not direction.

Likewise, students must understand that velocity is a vector quantity that indicates both speed and direction. The formal definition of velocity involves the *displacement* (change in position) of an object rather than the distance the object travels.

Another way of distinguishing between the two is to say, “If you drove to San Francisco from Roseville, and back, how many miles did you put on the car?” (Answer: about 240 miles, if it is 120 miles one way). “But what is your displacement at the end of the trip?” (Answer: zero). That is the difference between distance and displacement.

Lab Preparation

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

This lab does not require any special setup other than having the equipment readily available for student use.

Safety

Add these important safety precautions to your normal laboratory procedures:

- The cart carries speed and momentum, so be careful not to pinch fingers between the moving cart and the end stop when catching it.
- The plunger on the dynamics cart may release accidentally, so be careful not to hold the cart near anything breakable when the plunger is loaded.

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.

5	1	3	4	2
Find the average velocity for the trip toward the bumper.	Draw your prediction on your data collection system.	Start data collection.	Gently push the cart toward the bumper.	Assemble the equipment with the Dynamics cart just over 15 cm from the motion sensor.

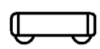
Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

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

2. ☐ Attach the motion sensor to one end of your track with the sensor's sensing element pointing down the length of the track. Make certain that the switch on the top of the motion sensor is set to the cart icon. 

3. ☐ Connect the end stop to the other end of the track.

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. ☐ The concept behind this setup is to push the cart so that it moves away from the motion sensor, increasing its position relative to the motion sensor, until it collides with the end stop and returns, measuring the position, velocity, and speed of the cart the entire time. If you or your lab partners aren't touching the cart as it travels, what do you think a graph of its Position versus Time will look like? Use the data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

7. ☐ What would happen to the cart if there were no bumper on the track?

The cart would roll off the end of the track.

8. ☐ Prepare the following calculation on the data collection system: �(10.3)

   Speed = abs(Velocity)

   where Velocity is the velocity measurement from the motion sensor.

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

10. ☐ Given the motion described above, what do you think a graph of its Speed versus Time will look like? Use your data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

11. ☐ As was mentioned in the background section, velocity is a vector quantity that implies direction. If the motion sensor measures 2.5 m/s as the velocity of a constant speed cart moving away from the sensor, what would the sensor measure if the same cart was moving towards the sensor? Justify your answer.

It would measure –2.5 m/s because the speed is the same but the direction is opposite, which implies a negative velocity of the same magnitude.

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

13. ☐ Given the motion described above, what do you think a graph of Velocity versus Time will look like? Use the data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

14. ☐ Return to the graph of Position versus Time.

15. ☐ Ensure that the sampling rate of the data collection system is at least 20 samples per second. �(5.1)

Collect Data

16. ☐ Place the cart on the track slightly more than 15 cm from the motion sensor such that either the magnets or extended plunger are facing the bumper so that the cart will rebound from the end of the track.

    Note: If you are not using the plunger to collide with the end stop, it is best to press the plunger all the way in and lock it in place so it is out of the way.

17. ☐ Start data collection. �(6.2)

18. ☐ Give the cart a push to start it moving toward the bumper.

19. ☐ Allow the cart to travel down the track, collide with the bumper and return, but catch it before it reaches its initial position.

20. ☐ Stop data collection. �(6.2)

21. ☐ Sketch your Position versus Time, Speed versus Time, and Velocity versus Time graphs on the blank graph axes provided in the Data Analysis section.

Analyze Data

22. ☐ On the Position versus Time graph, select a point just after you released the cart and another point just before the cart collides with the bumper. �(7.1.4)

23. ☐ Use the data collection system to find the difference between the data points you have selected. �(9.2)

24. ☐ Identify the points you used on your sketch of Position versus Time in the Data Analysis section.

25. ☐ Record the difference in time and the difference in position in Table 1 in the Data Analysis section.

26. ☐ From our definition of speed, calculate the speed for this leg of the journey, and record it in Table 1 in the Data Analysis section.

27. ☐ Describe the shape of the data plot in the interval you have selected.

The data plot is linear in the selected interval.

28. ☐ On the graph of Speed versus Time, select the same region you selected on the Position versus Time graph using the time values as your guide. �(7.1.4)

29. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

30. ☐ On the graph of Velocity versus Time, select the same region you selected on the Position versus Time graph using the time values as your guide. �(7.1.4)

31. ☐ Find the average value for velocity for the data you selected, and record it in the table in the Data Analysis section. �(9.4)

32. ☐ On the Speed versus Time graph, select a point just after the cart collides with the bumper and another point just before you catch the cart. Use the data collection system to select this part of the data plot. �(7.1.4)

33. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

34. ☐ Identify the points you used on the sketch of Speed versus Time in the Data Analysis section.

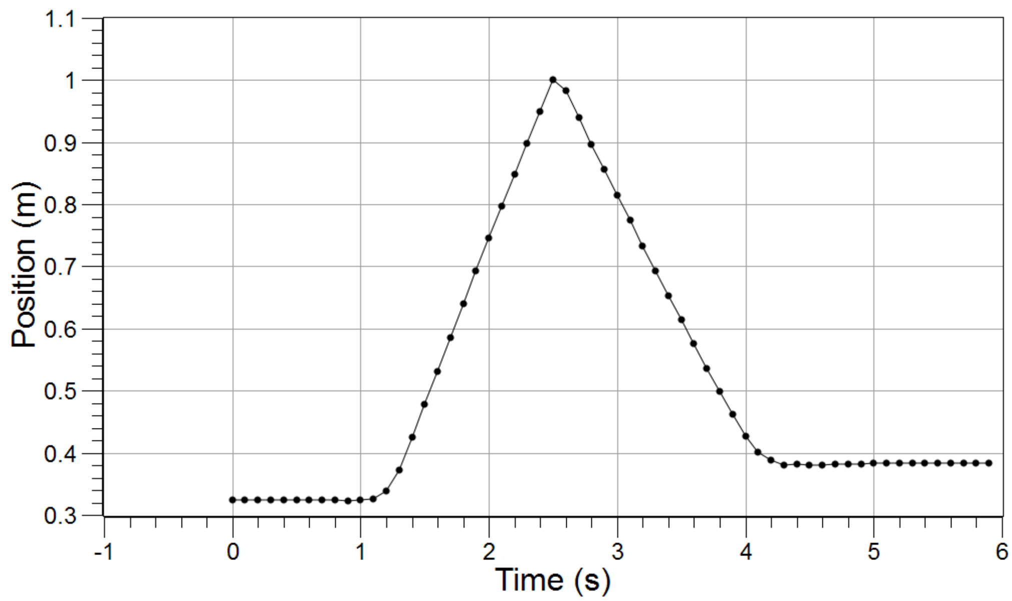
35. ☐ On the graph of Velocity versus Time, select the same region you selected on the speed graph using the time values as your guide. �(7.1.4)

36. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

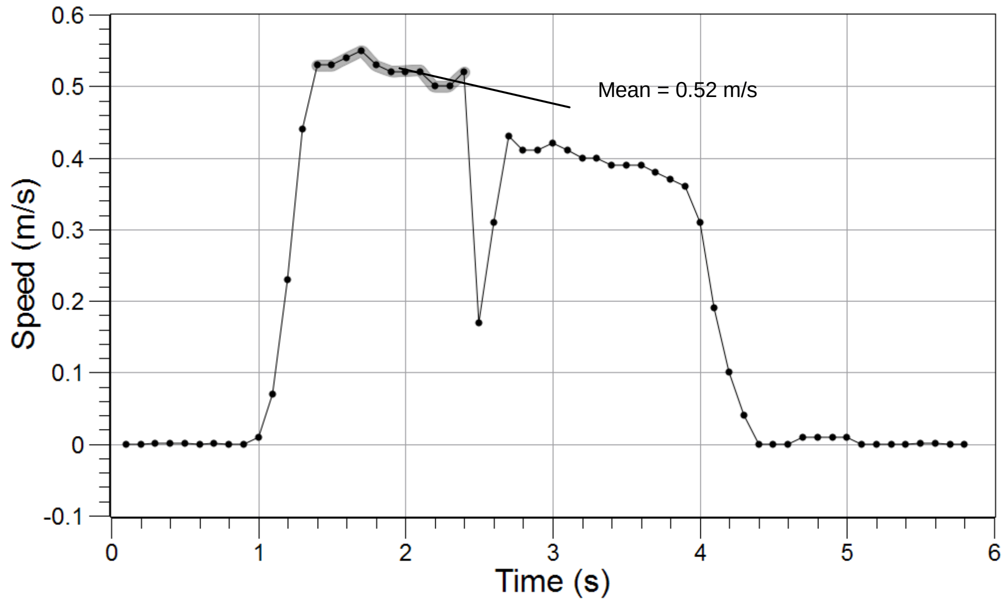
Data Analysis

1. ☐ In the first three spaces provided, sketch your prediction graphs of Position versus Time, Speed versus Time and Velocity versus Time for one trip down the track and back.

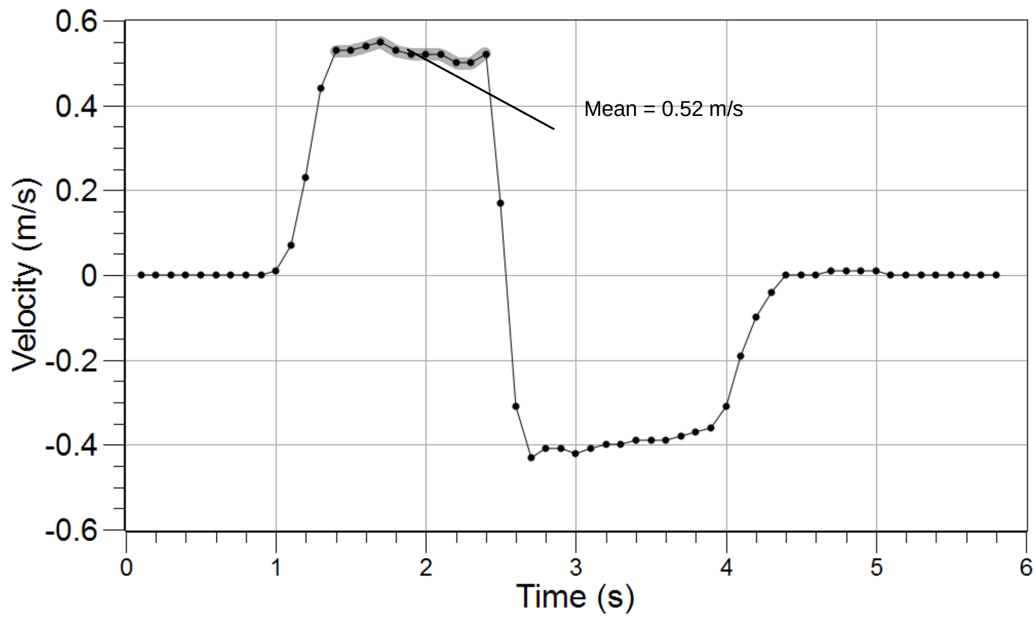
Position versus Time Prediction



Speed versus Time Prediction

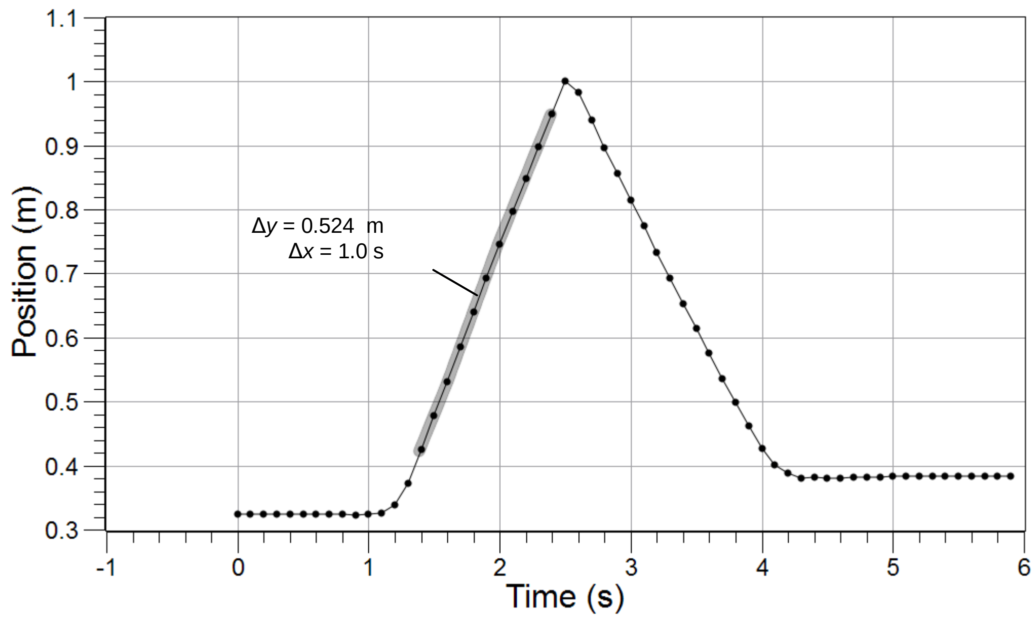


Velocity versus Time Prediction

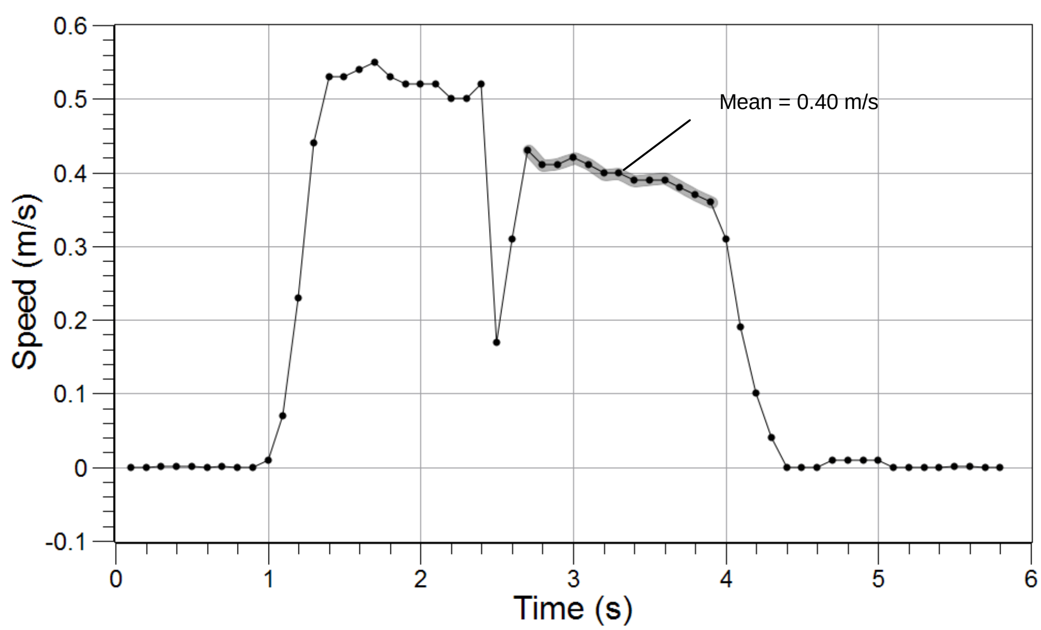


2. ☐ In the next three spaces provided, sketch your data from your graphs of Position versus Time, Speed versus Time and Velocity versus Time for one trip down the track and back.

Position versus Time



Speed versus Time



Velocity versus Time

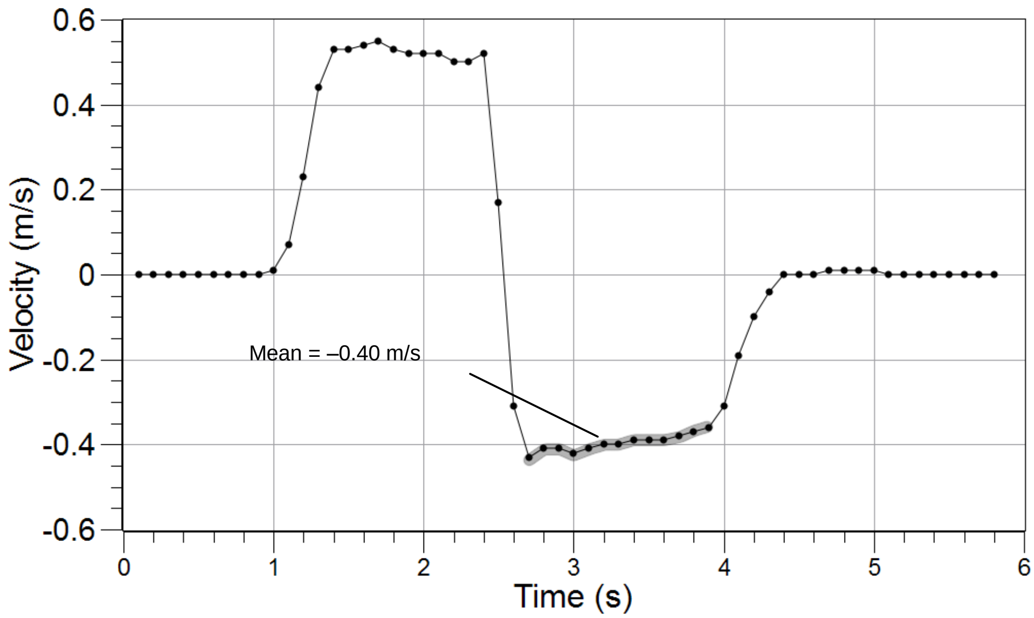


Table 1: Cart motion data

Parameter	Values
Difference in position moving away from the motion sensor	0.524 m
Difference in time moving away from the motion sensor	1 s
Calculated speed moving away from the motion sensor	0.524 m/s
Average speed moving away from the motion sensor	0.52 m/s
Average velocity moving away from the motion sensor	0.52 m/s
Average speed moving toward from the motion sensor	0.40 m/s
Average velocity moving toward from the motion sensor	–0.40 m/s

Analysis Questions

1. How does the value you calculated for speed moving away from the motion sensor compare to the value of the average speed over the same interval?

The values are nearly the same.

2. How do your values of speed and velocity moving away from the motion sensor compare to your values of speed and velocity moving toward the motion sensor?

The value for speed moving away from the motion sensor is nearly the same as the value for speed moving toward the motion sensor. However, the value for velocity moving toward the motion sensor was the opposite of the value of Velocity moving away from the sensor.

3. How does your prediction graph of Position versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?

Answers will vary, major differences may include a change in sign or an inversion of the graph.

4. How does your prediction graph of Speed versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?

Answers will vary, major differences may include a negative speed in the prediction.

5. How does your prediction graph of Velocity versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?

Answers will vary, major differences may include a change in sign, or a significant slope on the prediction.

6. Describe some of the major differences between your graph of Speed versus Time and Velocity versus Time, and explain why those differences exist.

The major difference is that the velocity graph has both positive and negative values, while the speed graph does not. This is because the cart changed direction when it collided with the bumper. So rather than traveling in the positive direction, it is traveling in the negative direction.

7. Describe how you think the Velocity versus Time graph would be different if the cart had an initial speed that was twice as large as the initial speed used in your experiment.

The shape of the graph would be identical, but the starting point of the graph would be twice as high.

8. You may have noticed that the speed of the cart slightly decreased as the cart moved along the track, both moving away from the motion sensor and moving toward the motion sensor. What do you thing would account for this decrease?

Friction between the wheels and the track, and also between the cart's wheels and its axle.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Imagine you are in a car driving on a highway and notice that the speedometer was constant at 65 miles per hour for several miles. Would this indicate that the speed of the car was constant during that distance, or the velocity of the car was constant? Justify your answer.

This would indicate that the speed was constant not velocity. A car can travel at the same speed but change direction; however, a car cannot change direction without changing velocity.

2. Two trains pass each other on opposing tracks; one train is traveling north at 105 km/hr while another train is traveling south at 85 km/hr. What is the difference between their velocities? What is the difference between their speeds? Show your work.

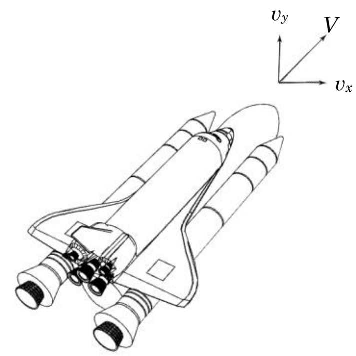
The difference between velocities is:

$$\mathbf{v}_2 - \mathbf{v}_1 = 105\ \text{km/hr} - (-85\ \text{km/hr}) = 190\ \text{km/hr}$$

The difference between speeds is:

$$|\mathbf{v}_2| - |\mathbf{v}_1| = 105\ \text{km/hr} - 85\ \text{km/hr} = 20\ \text{km/hr}$$

3. When a space shuttle is launched, it approaches the upper atmosphere at a very specific angle to help it safely reach orbit. At the point it reaches orbit, the shuttle is traveling at some speed *s*, which can be determined from the sum of the shuttle's two component velocity vectors, v_x and v_y. If v_x = 15,768 km/hr and v_y = 11,149 km/hr, what is the shuttle's speed *s*?



$$s = |\mathbf{v}| = \sqrt{|\mathbf{v}_x|^2 + |\mathbf{v}_y|^2} = \sqrt{(15{,}768)^2 + (11{,}149)^2} = 19{,}311\ \text{km/hr}$$

4. The average velocity of an object is defined as the total displacement of an object (from its original position) divided by the time elapsed during that displacement.

$$\overline{\mathbf{v}} = \frac{\textit{final displacement}}{\textit{total time}}$$

a. If a car drives all the way around a city block at 30 mi/hr and ends 10 minutes later at the same point it began, what is the average velocity of the car?

$$\mathbf{v} = 0$$

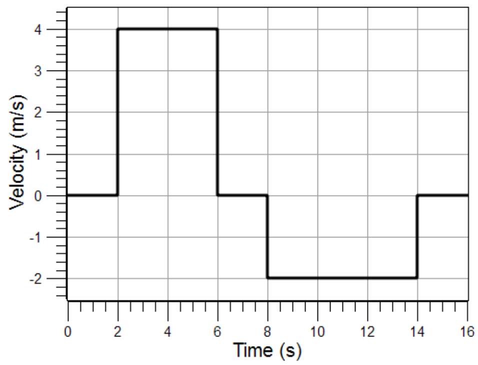
b. If a car drives north at 65 mi/hr for 48 minutes, turns right and drives east at 45 mi/hr for 23 minutes; and then turns right again and drives south at 30 mi/hr for an hour and 44 minutes, and stops. What was the car's average velocity during that that trip?

$$\mathbf{v} = \frac{\mathbf{d}_1 + \mathbf{d}_2 + \mathbf{d}_3}{t + t_2 + t_3} = \frac{52\ \text{mi (north)} + 17.25\ \text{mi (east)} - 52\ \text{mi (south)}}{0.8\ \text{hr} + 0.383\ \text{hr} + 1.73\ \text{hr}} = 6\ \text{m/hr (east)}$$

Multiple Choice Questions

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

1. The graph below shows the velocity of a particle as a function of time. Assume that the particle is traveling in a straight line. Use the graph to determine the particle's total displacement and average velocity.



- **A. 4 m; 0.25 m/s**
- **B.** –4 m; –0.25 m/s
- **C.** 26 m; 2.60 m/s
- **D.** 26 m; 1.63 m/s

2. Average speed is defined as the total distance an object travels divided by the time it took to travel that distance. If a jet flies 2,000 miles from San Francisco to Chicago in 5 hours, refuels for an hour, and then flies 700 miles from Chicago to Washington DC in 2 hours, what was the average speed of the jet for the entire trip?

- **A.** 386 mi/hr
- **B.** 443 mi/hr
- **C.** 250 mi/hr
- **D. 338 mi/hr**

3. What is wrong with this statement?

"A highway patrol officer traveling east with a constant speed of 70 mi/hr passes a speeding motorist traveling west at 110 mi/hr. To catch the speeder, the officer must first travel 0.25 miles to the next highway exit, turn around, and get back on the freeway then drive at a constant speed of –150 mi/hr for 58 seconds to catch-up with the motorist."

- **A.** The officer will pass the speeder if he/she travels at 150 mi/hr for 58 seconds.
- **B.** The officer's original constant velocity should be negative.
- **C. Speed cannot be negative.**
- **D.** There is nothing wrong with the statement.

Key Term Challenge

Instructions: Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Although **speed** and velocity are often used in the same context, the two terms are very different. Speed is a **scalar** quantity while velocity is a **vector** quantity. Velocity values specify **magnitude** as well as **direction** while speed simply specifies magnitude. If the speed of an object is known, it is impossible to determine the object's **velocity** without knowing the direction the object is traveling.

2. When discussing **average** speed and average velocity, one must first understand the difference between distance and displacement. If a boomerang follows a circular 42 meter **path** in 10 seconds and ends at the same point it was thrown, its **distance** traveled is 42 meters but its total **displacement** is zero. Furthermore, the boomerang's average **speed** was 4.2 meters/second, and its average **velocity** is zero.

3. If a ball is initially at **rest** (not moving), its **speed** and velocity are both zero. If the ball is thrown straight up in the air, it will eventually fall back down to the same **position** it was tossed from, at which point its final **velocity** is **equal** and **opposite** to its initial velocity.

Extended Inquiry Suggestions

The graph tools can be used to introduce mathematical concepts like limits. Return to the first leg of the Position versus Time graph. Ask your students to select smaller and smaller intervals for the linear curve fit around a central point. Have them compare the progression of results to the value from the Velocity versus Time graph for the same time, or the slope from the Slope Tool at the central point. This is an opportunity to point out the difference between instantaneous velocity and average velocity.

Follow-up Questions

Continue with the speeding analogy. One way to highlight the difference between average and instantaneous velocity is to ask:

1. Which type of velocity the police officer measures when the officer writes you a citation: instantaneous or average velocity?

Instantaneous

2. What about when the officer points the radar gun at your car as you pass by?

Still instantaneous

3. In some states where toll roads are common (like the New Jersey Turnpike) you can actually get a speeding ticket if you cover the distance between toll booths in too short a time period. Which velocity are they calculating if they give you a ticket in this case?

Average velocity

4. When airplanes are used to track speeding drivers, they use large "mile markers" signs along the road so the airplane can measure how long it took you to travel the distance between mile markers. Which type of velocity are they using in that case?

Average.

This is also a great opportunity to introduce the idea of linear fits. Go back to the idea of change in position over change in time, and tie this back to the mathematical idea of a slope of a line. Ask your students to return to their Position versus Time graph, and apply a linear fit to that first segment of the graph they chose. Then compare the slope to the calculated and average values of velocity in their tables.

A natural progression to this lab is to begin discussions about acceleration as a change in velocity, just as velocity is a change in position. You can discuss with your students the basis of acceleration and how it affects moving object. Then discuss with students what accelerations were present, such as the push to get the cart started and the collision with the bumper. Ask them to look again at the small change in velocity that occurs at each leg of the trip, and apply a curve fit to one of the segments to see what the slope of that line might reveal.

If acceleration is introduced graphically here, it is good to mention that changes in the Velocity versus Time graph are often shown as sudden changes in slope, but in reality, *any* change in velocity must happen over a time interval, otherwise you have infinite acceleration (which no moving object can possibly have). When students see a sudden change in slope on a Velocity versus Time graph, keep in mind that this is theoretical, and in reality that changes in Velocity have a gradual transition from one slope to the next.

15. Acceleration

Objectives

This activity introduces students to the concept of representing acceleration as a change of velocity in a graphical form. This activity allows students to:

- Understand that average acceleration over a given time is the change in velocity divided by the change in time
- Describe acceleration properly as the change in velocity with respect to time
- Interpret a velocity versus time graph

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the velocity of an object using a motion sensor
- Tracking the change of velocity of an object using a graphical representation
- Interpreting a graphical representation of velocity versus time

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dynamics track
- Dynamics cart
- Rod stand
- Motion sensor
- Dynamics track pivot clamp
- Dynamics track end stop

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Velocity consists of speed and direction
- Interpreting a position versus time graph for different situations

Related Labs in This Guide

Labs conceptually related to this one include:

- Position: Match Graph
- Speed and Velocity
- Newton’s First Law
- Newton’s Second Law

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Displaying multiple variables on the *y*-axis �(7.1.10)
- Finding the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)

Background

The definitions of velocity and acceleration are often presented similarly and therefore are easily confused. It is critical that students remember that velocity tells us how much an object's position has changed and acceleration tells us how much the object's velocity has changed. A graph of position versus time for an object can be used to determine the object's velocity: the slope of a graph of position versus time is equal to the velocity.

A graph of velocity versus time for an object can be used to determine the object's acceleration: the slope of a graph of velocity versus time is equal to the acceleration. It is especially important for the students to note the direction of the acceleration as an object increases or decreases its velocity. Students will have heard of the concept of "deceleration," and you should help them realize that this is *not* a different concept than acceleration. It is just acceleration in a different direction.

Acceleration is the rate at which the velocity of an object changes.

$$\text{acceleration} = \frac{\text{velocity}_{\text{final}} - \text{velocity}_{\text{initial}}}{\Delta\text{time}}$$

Because velocity is the speed and direction of an object's motion, acceleration can mean speeding up, slowing down, or changing direction.

A car can have a positive acceleration when it is speeding up and a negative acceleration when it is slowing down, depending on its direction of travel.

When a car is speeding up, its acceleration is in the same direction as its velocity: both acceleration and velocity are positive or negative. When a car is slowing down, its acceleration is in the opposite direction of its velocity: velocity and acceleration have opposite signs.

Constant, non-zero acceleration means that an object's velocity is changing at a uniform rate. For example, when you throw a ball into the air, it experiences a velocity change of 9.8 m/s every 1 second. Since the acceleration's direction is pointing toward the earth, the ball will decelerate (slow down) when moving up and accelerate (speed up) when falling down.

Note: In this activity, the direction away from the motion sensor is the positive direction, so down the track will be the positive direction. This is a good time to review frame of reference with you students.

Pre-Lab Discussion and Activity

We commonly use the term acceleration when an object is speeding up. Most of us probably experienced this when someone steps on the gas pedal in the car (even called the accelerator). But if we want to be able to compare objects that are accelerating under different conditions, then we need to have a very precise definition of the term acceleration. We will define acceleration using the data we collect as the slope of the Velocity versus Time graph. This will allow us to see how much the velocity of the object changes in one second.

For a demonstration station:

- Data collection system
- Dynamics track (2)
- Constant velocity cart
- Motion sensor (2)
- Fan cart
- Projection system

1. Set the tracks on a flat table side by side.

2. Connect a motion sensor to each track pointing in the same direction.

3. Place the fan cart and the constant velocity cart each on one track just over 15 cm from the motion sensors with the carts set to move away from the sensor.

4. Connect the motion sensors to the data collection system. �(2.2)

5. Create a Velocity versus Time graph with both sensors on the same graph. �(7.1.10)

6. Ask a student to catch the carts at the opposite end of the track.

7. Start collecting data, and send the carts down the track. �(6.2)

8. Stop collecting data just before the student catches the carts. �(6.2)

Challenge your students to describe the motion of each cart, and identify the one that is accelerating. You may want to show a Position versus Time graph at the same time to tie back to earlier position and velocity discussions.

Lab Preparation

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

1. Remind students that they need sufficient distance between the motion sensor and the cart both when the cart is moving toward the motion sensor and when they start the cart moving away from the motion sensor (greater than 15 cm). The motion sensor will respond to the strongest signal it receives.

2. Be sure that students do not have too steep a slope for the data collection using the dynamics track. This will allow for a more gradual motion and collecting more data points.

Safety

Follow all standard laboratory procedures.

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.

3	4	2	1
Repeat the data collection procedure this time pushing the cart up the incline away from the motion sensor.	Determine the acceleration of each trial from the slope of the graphed data.	Release the cart from the elevated end of the track to produce a Velocity versus Time graph.	Assemble the inclined track with the end stop at one end and the motion sensor at the opposite end.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

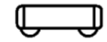
1. ☐ Start a new experiment on the data collection system. �(1.2)

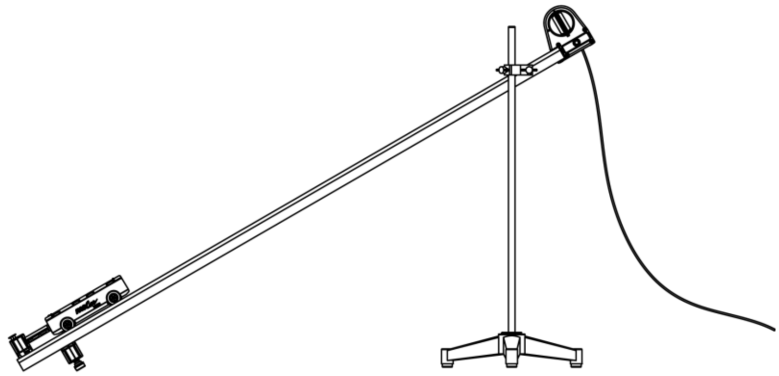
2. ☐ Connect a motion sensor to the data collection system. �(2.1)

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

4. ☐ When a car's acceleration is negative but its velocity is positive, what is the car doing?

Slowing down, or decelerating.

5. ☐ Ensure that your sampling rate is set to at least 20 samples per second. If your motion sensor has a selector switch, ensure that it is in the cart or near setting. �(5.1) 



6. ☐ Attach the end stop to the lower end of the dynamics track.

7. ☐ Mount the track to your rod stand using the pivot clamp, slightly inclining the track at one end.

8. ☐ Attach the motion sensor to the elevated end of the track with the face of the sensor pointed down the length of the track.

Collect Data

9. ☐ Set the cart at the top of the inclined end of the track, holding it just over 15 cm from the motion sensor.

10. ☐ Start data collection, and release the cart allowing it to roll down the track. �(6.2)

11. ☐ Catch the cart at the bottom of the inclined track just before it hits the end stop, and stop data collection. �(6.2)

12. ☐ Set the cart at the bottom of the inclined end of the track.

13. ☐ Start data collection, and give the cart a quick push with your hand up the track. �(6.2)

14. ☐ Allow the cart to roll back down the track, and catch the cart at the bottom of the inclined track just before it hits the end stop, and stop data collection. �(6.2)

Analyze Data

15. ☐ Sketch both runs of data in Velocity versus Time Graph in the Data Analysis section.

16. ☐ Use your data collection system to apply a linear fit to each run (applied only to the data while the cart was in motion), and record the slope in Table 1 in the Data Analysis section. �(9.6)

17. ☐ Save your data as instructed by your teacher. �(11.1)

Data Analysis

Velocity versus Time

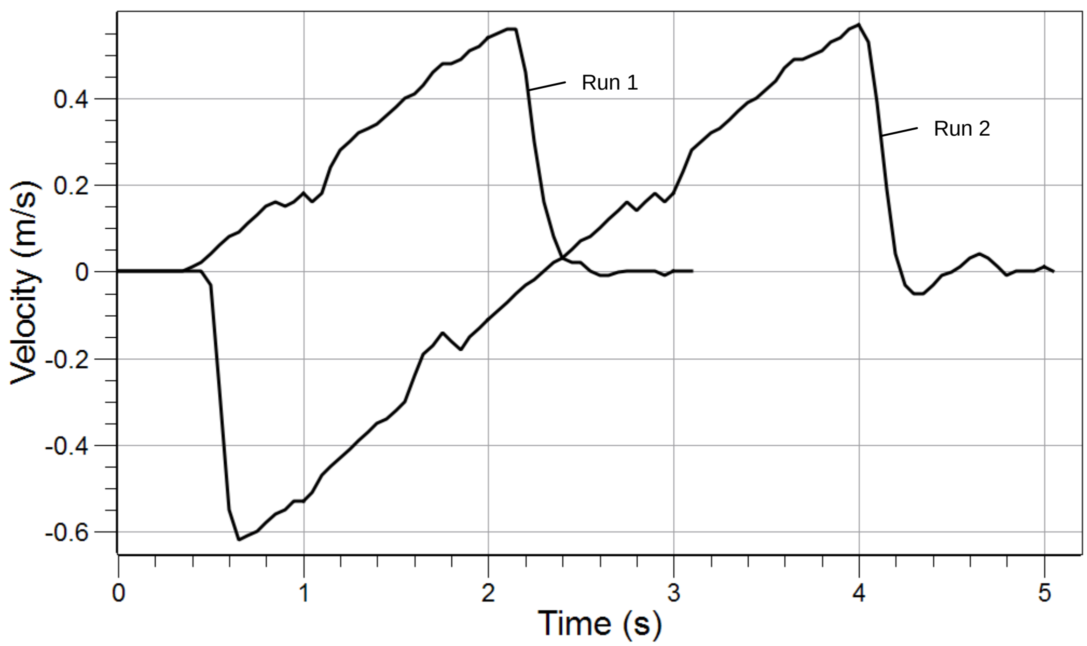


Table 1: Slope of Velocity versus Time

Run	Slope
Run 1	0.778 m/s^2
Run 2	0.738 m/s^2

Analysis Questions

1. During the period when the cart was in motion, are the Velocity versus Time graphs straight lines? Refer to the previous page if necessary. How is the acceleration of the cart changing if your Velocity versus Time graphs are straight lines?

The Velocity versus Time data plots are straight lines. The acceleration is constant if the Velocity versus Time data plot is a straight line.

2. Although the paths of the cart in both trials were different, the slopes of the Velocity versus Time graphs for each trial are the same (during the period in which the cart was in motion). Why is this the case? Justify your answer.

The slopes are the same because the cart is subject to the same acceleration in both trails.

3. Looking at the Velocity versus Time graph, what would a negative slope tell you about the cart's acceleration? What would a positive slope tell you?

A negative slope tells us that the acceleration is negative. A positive slope tells us that the acceleration is positive. Because moving away from the motion sensor, down the track, is the positive direction, the acceleration is positive.

4. What was causing the cart to accelerate after releasing it from rest at the top of the track? Was that acceleration constant?

Gravity. The acceleration was constant because the slope of velocity versus time stayed the same.

5. Describe the motion of an object that has a velocity versus time graph that is a horizontal straight line (a slope of zero).

The velocity of the object is constant, or the object moves at a constant speed in a constant direction. No change in velocity means no acceleration.

Synthesis Questions

Use available resources to help you answer the following questions.

1. The term "acceleration" is used in our everyday lives and language, but is often used in a non-physical context. Now that you have developed a physical definition of "acceleration," give an example of where the physical definition matches the "everyday" definition. Give an example where they are different.

An example where the definitions are similar is how a car accelerates. The car experiences a change in velocity due to acceleration

An example where the definitions are different is when a doctor describes the accelerated heart rate of a patient. Although the rate at which the heart is beating has increased, the actual position of the heart has not changed, thus there is no real velocity and no acceleration.

2. Modern aircraft carriers use a steam powered catapult system to launch jets from a very short range. These catapults can provide a constant acceleration to bring jets up to speed in only 2 seconds. If each jet requires a minimum take-off speed of 82.3 m/s, how much acceleration must the catapult supply so the jet can take off?

$$a = \frac{v_f - v_i}{\Delta t}$$

$$a = \frac{82.3\text{ m/s} - 0.00\text{ m/s}}{2\text{ s}}$$

$$a = 41.2\text{ m/s}^2$$

3. How many different devices in a car help to accelerate the vehicle? What are they?

Three. The throttle, the brakes, and the steering wheel all cause a change in velocity.

Multiple Choice Questions

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

1. If the acceleration due to gravity is –9.8 m/s^2, which of the following choices would best describe the acceleration of a 0.5 kg frictionless block sliding down the track used in our experiment?

- **A. 3.5 m/s^2 down the ramp**
- **B.** 3.5 m/s^2 up the ramp
- **C.** 0 m/s^2
- **D.** Indefinable

2. A cart with an initial velocity of zero and a final velocity of 12 m/s after 2 s will have an acceleration of?

- **A.** 4 m/s^2
- **B. 6 m/s^2**
- **C.** 8 m/s^2
- **D.** 12 m/s^2

3. A race car starting from rest accelerates uniformly at a rate of 5 m/s^2. What is the car's speed after it has traveled for 5 s?

- **A.** 5 m/s
- **B.** 10 m/s
- **C.** 20 m/s
- **D. 25 m/s**

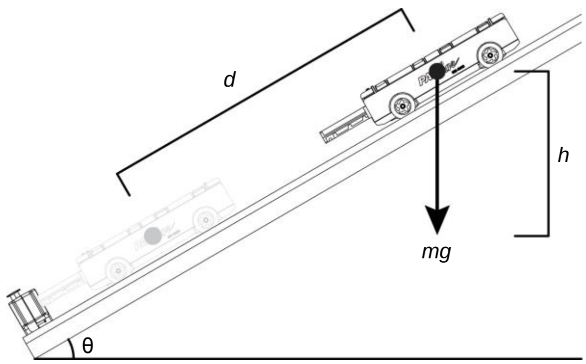
Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. Acceleration is defined as the change in velocity over time. If an object is sitting still or moving at a constant **velocity**, it has an acceleration of zero. If an object has a constant, non-**zero**, acceleration, the velocity of the object is **continuously** changing at the same rate. In common usage, an object with a positive velocity and a negative acceleration is said to be **decelerating**, and an object with a positive velocity and a positive acceleration is said to be accelerating.

Extended Inquiry Suggestions

Ask your students to measure the angle of their track and use trigonometry to determine the acceleration due to gravity based on the component they measured.



Review the answer to Synthesis Question 3. Elaborate on the use of a steering wheel as a means of changing velocity. This can be a tough concept for students to grasp and is a natural lead-in to discussing circular motion.

16. Introduction to Force

Objectives

This lab introduces students to the concept of forces. Primarily, they will measure and experience contact forces, but there will be some inclusion of non-contact forces in relation to gravity. Through direct measurement and experience, students develop the foundations of understanding the vector nature of forces that will carry through to Newton's laws and kinematics, and re-enforce their understanding of units of measure of force and mass.

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring force using a data collection system
- Differentiating between units of mass and units of force
- Differentiating between contact forces and non-contact forces
- Creating free body diagrams of force

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Objects (textbook, ball, carts, et cetera)
- Short rod
- String, 1 m
- Rod stand
- Masses (at least three different values)
- Balance (1 per classroom, optional)
- Right angle clamp

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The nature of vectors and scalars
- Acceleration

Related Labs in This Guide

Labs conceptually related to this one include:

- Archimedes' Principle
- Newton's First Law
- Newton's Second Law
- Newton's Third Law

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- Put ting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- Starting and stopping data recording � (6.2)
- Starting a new data set in manual sampling mode, recording data points, and stopping the data set �(6.3)
- Displaying data in a graph�(7.1.1)
- Changing the variable on the x- or y-axis �(7.1.9)
- Viewing statistics of data �(9.4)
- Finding the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)

Background

Generally speaking, when someone thinks of a force, they think of a physical push or pull, also known as contact forces. Contact forces are all around us. When you kick a ball, when you pull on a rope, or when you push someone on a swing, you are exerting or experiencing contact forces. Non-contact forces, or action-at-a-distance forces, are forces that can influence an object without touching it. The most prevalent example of this in everyday life is gravity.

Students will use a force sensor to measure some pushes and pulls. The force sensor uses strain gauges attached to a beam to measure very small deflections caused by pushing or pulling. For best results, students should push or pull in a straight line along the axis of the sensor. The idea of using different objects is to expose students to different force versus time plots, so try to use objects of different size, shape, mass, and composition.

Pre-Lab Discussion and Activity

Discuss these questions with your students.

1. What do you think a force is?

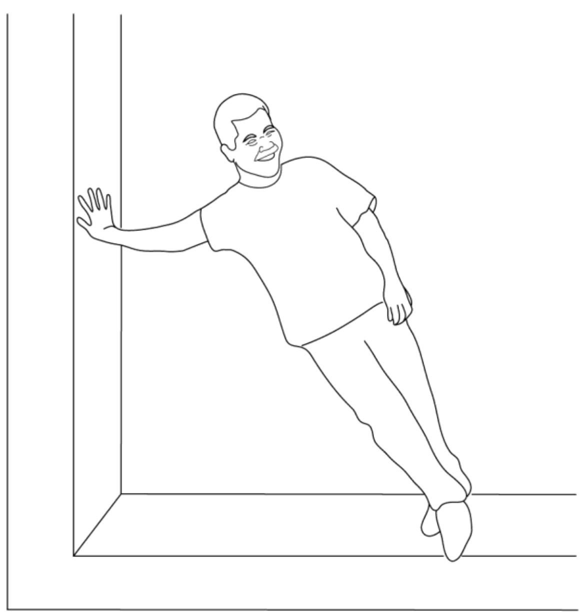
Use a white board (or equivalent) to collect student ideas to review and reference as you go through the discussion.

Use a simple set of objects (ball, book, cart, and track) to show the consequences of pushing or pulling on the objects. Emphasize that these are contact forces that result in motion. If you have a projector and a force sensor, show a graph of Force versus Time, to show the forces that you apply to the objects.

Push on both sides of an object to show that forces are present, but the object does not move. This is because the forces balance, or the net force is zero.

If you have a force platform and a projector, use it to show the actual force being applied to the wall and to the floor in the next section.

Carefully lean against a wall and ask the next questions.



2. Am I applying a force to the wall?

Yes, the force is toward the wall.

3. What kind of force?

This is a contact force.

4. Does applying this force result in motion?

No (hopefully).

5. Is the wall applying a force to my hand?

Yes. The wall applies a force to the hand to balance the applied force.

6. What direction is that force?

The force the wall applies to you is pointed out from the wall as a normal force.

The normal force is the component of the contact force with a surface that is perpendicular to the surface.

7. What would happen if the wall were made of tissue paper?

The force you apply to the wall will exceed the normal force that the surface can exert back, and there will be motion.

Reassert that this is a contact force that does not result in motion.

Stand on a solid low chair, and ask the following questions:

Teacher Tip: The same effect can be accomplished by simply holding an object up with a flat hand then moving your hand out from under the object quickly.

8. Am I applying a force to the chair?

Yes, a force that is proportional to your mass.

9. What direction is that force?

Down, more specifically, a line from my **center of mass** toward the center of mass of the Earth.

10. Is the chair applying a force to me?

Yes, a force that balances the force you are exerting on the chair. This and the force the wall was applying to you are *normal forces.*

11. What happens if the force that the chair is applying is removed?

The force pulling you down is no longer balanced by a force pushing up and you move downward.

Step off the chair.

12. **What force is pulling me down?**

Gravity

Identify this as a non-contact force because it was pulling you down even when you were not in contact with anything.

Lab Preparation

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

- Provide a collection of objects for students to push and pull.

Safety

Follow all standard laboratory procedures.

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.

1	4	2	3
Connect the force sensor to your data collection system.	Record the value of the slope of the best-fit line.	Once the reading has stabilized, record the value for force in your data table.	Find the best-fit line using the linear curve fit tool for Force versus Mass.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Pushing

Set Up

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

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

3. ☐ Attach the rubber bumper to the force sensor.

4. ☐ With the force sensor flat on the surface that you will be pushing and pulling across, press the "zero" button.

5. ☐ Select three objects from the pool of objects available to you, and record your selected items in Table 1 in the Data Analysis section.

6. ☐ Which item do you think will require the greatest force to move, and which item will require the least? Explain.

Answers will vary based on the objects selected.

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

Collect Data

8. ☐ Start data collection. �(6.2)

9. ☐ Use the force sensor to push an object about 20 cm.

10. ☐ Stop data collection. �(6.2)

Analyze Data

11. ☐ Describe the relationship between the contact of the force sensor and the object, the force plot, and the motion that resulted from the applied force.

Answers will vary depending on the objects chosen.

12. ☐ Find the maximum force applied by the sensor to the object on the Force versus Time graph. �(9.4)

13. ☐ Record the value in the Table 1 in the Data Analysis section.

14. ☐ Repeat data collection for each object.

Part 2 – Pulling

Set Up

15. ☐ Remove the rubber bumper from the force sensor, and replace it with the hook.

16. ☐ Set up your objects to be pulled the same 20 cm distance. Use the string if necessary.

17. ☐ Which item do you think will require the greatest force to move, and which item will require the least? Explain.

Answers will vary based on the objects selected.

Collect Data

18. ☐ Start data collection. �(6.2)

19. ☐ Use the force sensor to push an object about 20 cm.

20. ☐ Stop data collection. �(6.2)

Analyze Data

21. ☐ Describe the relationship between the contact of the force sensor and the object, the force plot, and the motion that resulted from the applied force.

Answers will vary depending on the objects chosen.

22. ☐ Find the maximum force applied by the sensor to the object on the Force versus Time graph. �(9.4)

23. ☐ Record the value in the Table 1 in the Data Analysis section.

24. ☐ Repeat data collection for each object.

25. ☐ Save your experiment. �(11.1)

Part 3 – What is a Newton?

Set Up

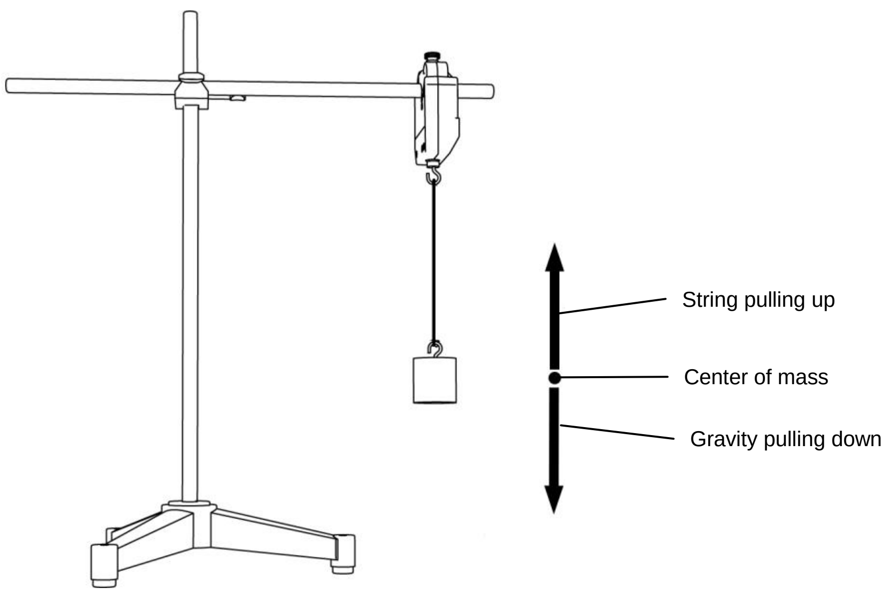
26. ☐ Connect the force sensor to the rod stand using the short rod and the right angle clamp.

27. ☐ Push the “zero” button on the force sensor.

28. ☐ Set up the data collection system to manually collect a force value for each mass value in a table, where mass is the user entered data in units of kg. �(5.2.1)

Collect Data

29. ☐ Hang a mass from the force sensor.



30. ☐ Start a manually entered data set with the first mass, collect a force value for each value of user-entered mass (switching masses between each value you keep), and stop collecting data when you have a force value for each mass. �(6.3)

31. ☐ Copy your values of force and mass to Table 2 in the Data Analysis section. �(9.6)

32. ☐ What two forces are acting on the mass? What kind of forces are they? Sketch them on the setup diagram above.

Gravity, a non-contact force, is pulling the object down, and the string attached to the hook of the force sensor is providing a contact force pulling up that prevents the object from falling.

33. ☐ What is the net force on the mass?

Zero

Analyze Data

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

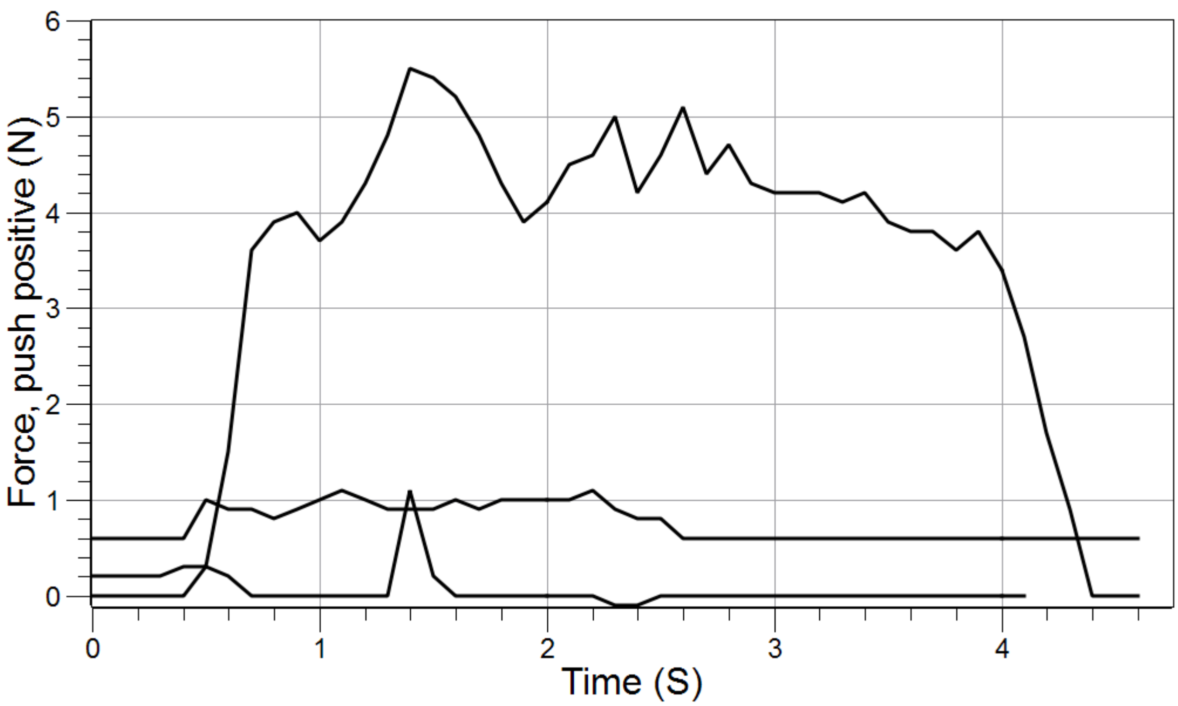
35. ☐ Change the *x*-axis from Time to Mass. �(7.1.9)

36. ☐ Find the slope of the best-fit line to the data using the linear fit tool. �(9.6)

37. ☐ Save your experiment �(11.1)

38. ☐ Sketch your plot of Force versus Mass in the Data Analysis section, and annotate it with the slope from your best-fit line.

Sample Data



Data Analysis

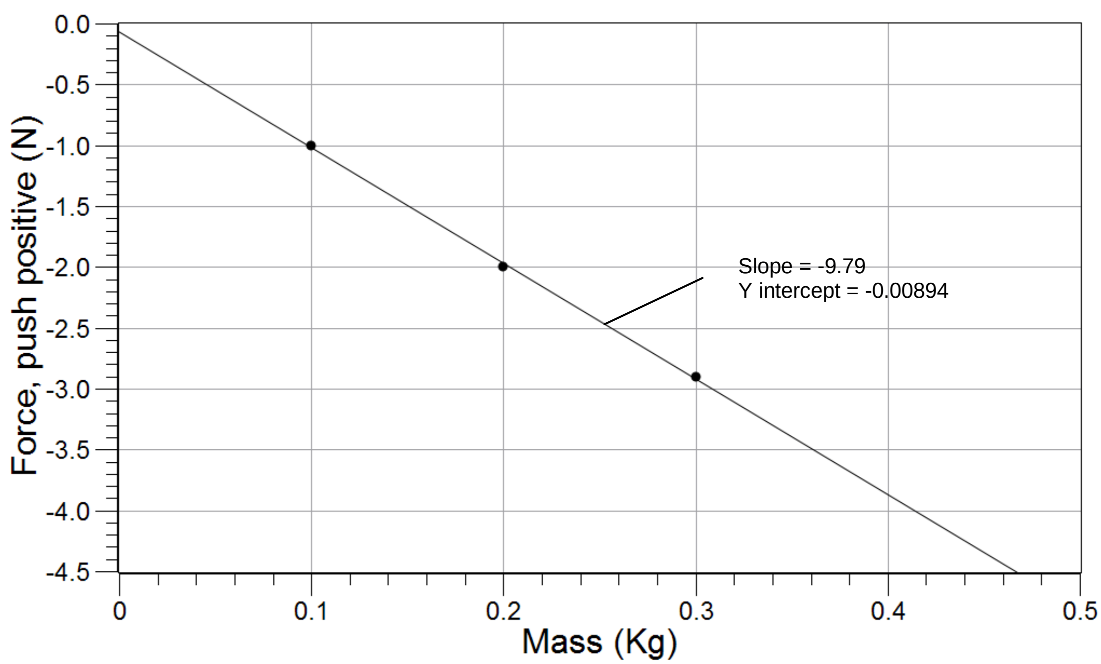
Table 1: Objects and forces

Object	Maximum Push Force	Maximum Pull Force
Book	5.5 N	–6.0 N
Roll of tape on its side	1.0 N	–0.8 N
Ball	1.1 N	–0.9 N

Table 2: Mass and force

Mass (kg)	Force (N)
0.1	–1.0
0.2	–2.0
0.3	–3.0

Force versus Mass



Analysis Questions

1. What is the slope of the best-fit line?

—9.8 N/kg

2. Does the value of the slope of the line represent a physical quantity? What are the units of this quantity?

Yes, 9.81 N/s^2 is the acceleration due to gravity at the surface of the earth (g), and 9.8 N/s^2 is remarkably close to this value. The force sensor was set to measure "push is positive," so the pull of the string was in the negative direction. The units of acceleration are m/s^2

3. Given that the force divided by the mass yields a physical quantity with its own units, what units make up a newton?

$$\frac{kg \cdot m}{s^2}$$

Synthesis Questions

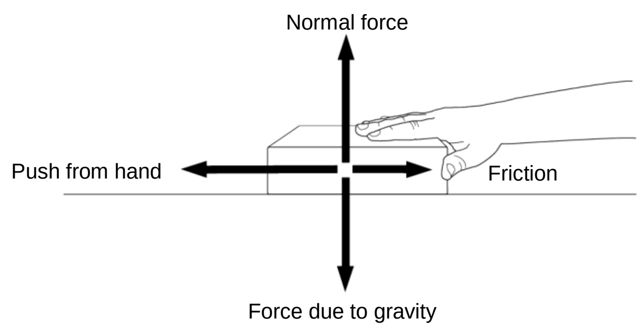
Use available resources to help you answer the following questions.

1. If a car has a mass of 1,000 kg that is evenly distributed to its four tires, how much force does each tire apply to the road?

2,452.5 N

2. If you push a book across a table, what are the forces on the book? Draw the forces on the diagram below.

The forces involved are: the push of my hand, the resistance of the friction between the book and table, the force of the book pushing back against my hand, the force of gravity pulling the book down, and the Normal force of the table pushing back.



Multiple Choice Questions

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

1. If an object is pushed north with 15 N of force, and friction between the object and the ground pulls back in the opposite direction at 2 N, what is the net force on the object?

- **A.** 17 N north
- **B.** 17 N south
- **C.** **13 N north**
- **D.** 13 N south

2. If a boat on a river is pushed west with 4 newtons of force by the wind, and pulled south by the current with a force of 3 newtons, what is the net force on the object?

- **A.** **5 N 37 degrees south of west**
- **B.** 7 N south
- **C.** 5 N 37 degrees west of south
- **D.** 1 N west

3. A book sitting on a table experiences a force due to gravity of 20 N when a student pushes down on the book with a force of 90 N. What is the magnitude of the net force on the book ?

- **A.** 110 N
- **B.** 70 N
- **C.** 1800 N
- **D.** **0 N**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. When two **forces** of equal **magnitude** but opposite direction are applied to the same object, they **balance,** and the net force is zero. If a force is applied to an object that is greater than any opposing forces, the **net force** is not zero, and the object moves. Because forces are **vectors** with both direction and magnitude, we represent them as arrows with lengths proportional to their magnitude in free body **diagrams**.

Extended Inquiry Suggestions

This lab serves as a lead-in to Newton's laws, but it can be used to discuss the idea of impulse. Return to a graph of Force versus Time from the first part of the lab. Ask your students describe in detail the amount of contact between the object and the force sensor, and the resulting motion. Ask them to look at the area under the Force versus Time curve as a way of introducing the idea of momentum.

17. Archimedes' Principle

Objectives

Students explore the relationship between the volume of fluid that a submerged object displaces and the buoyant force experienced by that submerged object. Through this process, students discover:

- The sum of the forces equals zero if the object is not accelerating
- Water provides an upward buoyant force on submerged objects
- That forces are responsible for some objects sinking and other objects floating

Procedural Overview

Students gain experience conducting the following procedures:

- Using a force sensor to measure the net downward force on the object submerged in air and submerged in water
- Measuring the volume of water displaced by the object by using a spill-can
- Calculating the weight of the displaced water using a scale or knowledge of the density of water

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Rod stand
- Short rod
- Overflow can
- Objects to submerge
- Small cup to add water to the overflow can
- Cup or beaker to catch water from overflow can
- Balance (1 per class)
- Right angle clamp
- String, 25 cm
- Water, 500 mL
- Ruler
- Graduated cylinder, 25-mL (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Force
- Density
- Volume
- Mass

Related Labs in This Guide

Labs conceptually related to this one include:

- Introduction to Force
- Newton's Second Law
- Newton's Third Law

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- Monitoring live data without recording �(6.1)
- Displaying data in a digits display �(7.3.1)

Background

Archimedes (287 B.C. to 211 B.C.) lived in Syracuse, on the island of Sicily, and is considered to be one of the greatest mathematicians of all time. Archimedes is widely credited as the principle reason for the failure of the Romans in their first attempt to capture Syracuse. According to several accounts, Archimedes applied his considerable talent to the defense of the city, and he invented several novel machines to repel the Roman siege engines.

Archimedes' most famous discovery was that an object submerged in a fluid is buoyed up by a force equal to the weight of the liquid the object displaces. This law is called Archimedes' Principle.

Pre-Lab Discussion and Activity

Engage the students in the following discussion and demonstration.

Ask a student why a boulder sinks but a ping-pong ball floats in water. You will likely get a response, "because the boulder is 'heavier' than the ping-pong ball." Ask the student why a log floats, and you might get a response, "because it is made of wood." Finally, ask the student why a nail sinks, and the student is likely to say, "because it is metal."

Continue with the following questions:

1. Which is heavier, a wooden chair or a steel nail?

The wooden chair.

2. Which is denser, a steel nail or a wooden chair?

The steel nail.

3. Which is denser, aluminum or iron?

Iron.

4. Demonstrate the following: submerge an empty aluminum can upside down under water. Does it float? Explain the reason for what you observe.

If the can is submerged upside down such that it traps a lot of air, the can will float because the overall density of the can would be less than that of water.

5. Demonstrate the following: submerge an empty aluminum can right-side up under water. Does it float? Explain the reason for what you observe.

If the can is submerged right-side up such that the can fills with water, then the can would sink because the overall density of the can would be more than that of water.

6. An object is both heavy and made of a dense material. Will the object float or sink in water?

The object will sink if it is solid. It might float if the overall density of the object is less than water's density.

7. Steel sinks in water. Ships are made of steel. Why do ships float in water?

Ships are not solid, and have air pockets, making their overall density less than water's density, so ships do float.

The general idea with this line of discussion is to shift student focus from what something is made of to an object's overall density. It helps to show objects sinking and floating to the whole class. You may want to use large clear container like a fish tank.

An alternate demonstration is to place a diet soda and a regular soda in a large transparent tub filled with water. The diet soda floats while the regular soda sinks. Few people know this, and they're usually quite amused. Sugar is a much more dense substance than aspartame. Hence, the same volume of fluid will sink because it is a much more dense fluid inside the can.

Lab Preparation

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

Teacher Note: Make sure students fill the water level of the spill can past full and allow the water to slowly drain out of the can via the spill tube before inserting the mass. This will yield more accurate volume results than filling the overflow can to the point of "almost full" due to the large surface tension of water. Water surface tension can also be reduced by adding a drop of detergent to the water.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Remind students to keep water away from all electronic equipment.

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.

3	1	4	2
Calculate the force due to gravity on the volume of displaced water (weight in N).	Completely submerge an object in water, collecting the volume of water displaced by the object.	Show that the change in net force on the object before and after submersion is equal to the weight of displaced water.	Measure the net force acting on the submerged object.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

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

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

3. ☐ Display force (pull positive, or inverted) in a digits display. �(7.3.1)

4. ☐ Attach the force sensor to the rod stand using a short rod and the right angle clamp.

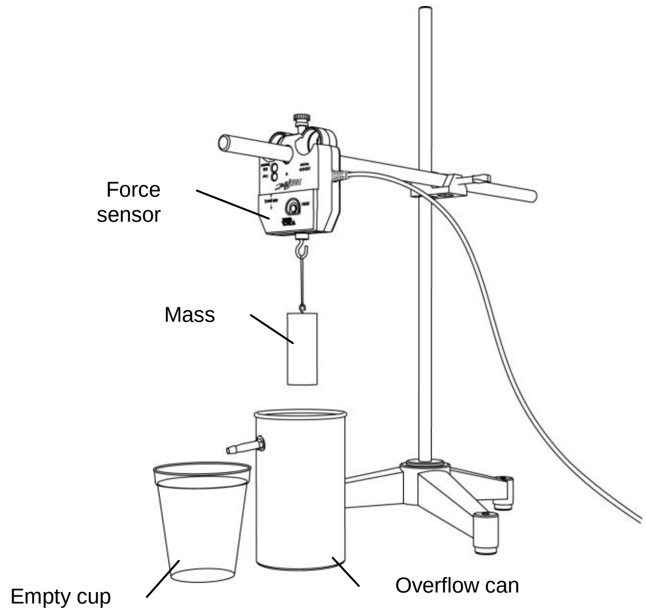
5. ☐ Press the "zero" button on the force sensor.

6. ☐ Why do you think it is important to press the "zero" button on the force sensor?

We are interested in the force on the object hanging from the force sensor, so the sensor should read zero before the mass is added.

7. ☐ Place the overflow can below the force sensor.

8. ☐ Tie a loop of string to the object, long enough to allow the object to be submerged completely in the overflow can when hung and lowered from the force sensor.



9. ☐ Place a dry cup (catch basin) under the spout of the overflow can.

10. ☐ Fill the overflow can with water to the limit.

Note: To reach the fill limit of the can, overfill the can allowing the excess water to pour from the spout. When the spout has stopped dripping, the can will be completely filled. Be sure to empty the catch basin after doing this.

11. ☐ Why is it important to fill the water to the point that it begins to run out of the spout of the overflow can?

This ensures that we capture all the water that is displaced by the mass.

Collect Data

12. ☐ Use the balance to measure the mass of the empty cup (catch basin) in kg, record the mass of the cup in Table 1, and then replace the cup in its original position.

13. ☐ Why is it important to measure the mass of the empty cup?

This ensures that we can get an accurate measurement of the amount of water displaced by the hanging mass.

14. ☐ Measure the mass of the object you will submerge in the water in kg, and record the mass of the object in Table 1.

15. ☐ Use your ruler to measure the dimensions of your object, use your knowledge of geometry to calculate its volume, and then record the volume in Table 1.

16. ☐ Begin monitoring force with your data collection system. �(6.1)

17. ☐ Use the string loop to hang the object from the force sensor hook. Make certain the object is not swinging before recoding data, and then record the force exerted by gravity on the object in Table 1.

18. ☐ Loosen the thumbscrew that holds the right angle clamp to the rod stand, and slowly lower the object into the overflow can. Displaced water from the overflow will pour into the empty cup (catch basin).

19. ☐ Tighten the thumbscrew to hold the object fully submerged, but not touching the bottom of the can.

20. ☐ Record the new “resultant” force measurement in Table 1.

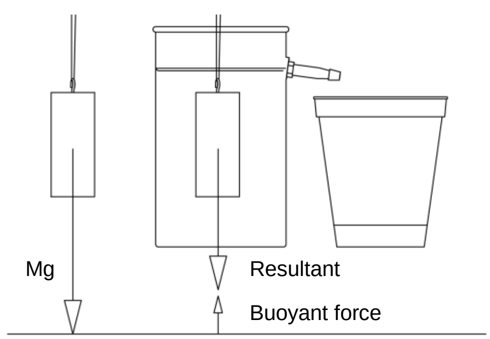
21. ☐ Use the balance to measure the mass of the cup (catch basin) and water that has overflowed from the can, and record the mass in Table 1.

22. ☐ Use the graduated cylinder to measure the volume of the water that has overflowed from the can, and record the volume in Table 1.

Note: If you are not using a graduated cylinder, use the mass of the water calculated in the next step and the conversion of 1,000 cm^3/kg for water to determine the volume.

Analyze Data

If the mass of the object does not change when it is submerged, but the net force does, we must be observing the action of a second force on the object. This force is called Buoyant Force. The force on the submerged object is the resultant of the vector addition of the force of gravity and the buoyant force acting on the object.



23. ☐ Calculate the mass of the displaced water in kilograms by subtracting the mass of the empty cup from the mass of the displaced water and cup together, and record the mass in Table 1.

0.029 kg – 0.006 kg = 0.23 kg

24. ☐ Calculate the weight of the water in newtons by multiplying the mass of the water by the acceleration of gravity (9.81 m/s^2), and record the weight in Table 1.

0.023 kg × 9.81 m/s^2 = 0.23 N

25. ☐ Calculate the buoyant force by subtracting the force on the submerged object from the force due to gravity, and record the force in Table 1.

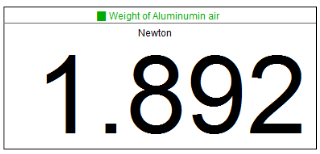
1.598 N – 1.823 N = –0.225 N If gravity, a downward force, is positive then this force must be upward.

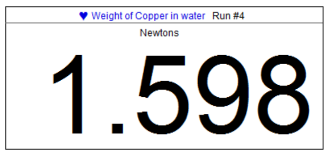
26. ☐ Calculate the density of your object from the measured mass and volume, and record the mass in Table 1.

0.189 kg/21.2 cm^3 = 0.00877 kg/cm^3

27. ☐ Repeat the Collect Data and Analyze Data steps for a second object that has a different mass and record the results in Table 1.

Sample Data





Data Analysis

Table 1: Object buoyancy data

Parameters	Object 1	Object 2
Object	Copper	Aluminum
Mass of the empty cup (kg)	0.006 kg	0.006 kg
Mass of the object (kg)	0.186 kg	0.193 kg
Volume of the object (cm^3)	21.2 cm^3	73.7 cm^3
Force of gravity on the object (N)	1.823 N	1.892 N
Resultant force on submerged object (N)	1.598 N	1.156 N
Mass of cup and water displaced by the object (kg)	0.029 kg	0.081 kg
Volume of water displaced by the object (cm^3)	22.9 cm^3	75.0 cm^3
Mass of the water displaced by the object (kg)	0.023 kg	0.075 kg
Weight of the water displaced (N)	0.225 N	0.736 N
Buoyant force (N)	–0.225 N	–0.736 N
Density of water (kg/cm^3)	0.001 kg/cm^3	0.001 kg/cm^3
Density of the object (kg/cm^3)	0.00877 kg/cm^3	0.00262 g/cm^3

Analysis Questions

1. Compare the mass of the object to the mass of the displaced water.

The mass of the object is greater than the mass of the water it displaces.

2. Compare the volume of the object to the volume of the water displaced.

The volume of water is equal to the volume of the object.

3. Compare the buoyant force to the weight of the water displaced.

The buoyant force is equal to the weight of the water displaced by the object.

4. Compare the density of your object to the density of water.

The density of the object is greater than the density of the water.

5. What do you think is the greatest source of error in your measurements, and why?

Student answers will vary, but most will find measuring the volume of the object the greatest source of error.

6. If you neglected to subtract the mass of the cup in your measurements what would be the percent error due to the cup in the mass of water measurement?

Answers will vary based on the materials used in the experiment. In this example of copper above, the mass measurement of water would be high by 26%.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What would a submerged object do if the buoyancy force were greater than the weight of the object?

The object would float to the surface.

2. Imagine a person in a deep pool. What happens if the person:

a. Lets the air out of their lungs? Why?

They sink. The person weighs a little less because they are "filled" with less air, but the amount of water that is displaced is also less. Thus, the force of buoyancy is also less. The weight of a volume of air compared to the same volume of water is much less.

b. Takes a deep breath and hold it? Why?

They float. The person weighs a little more because they are "filled" with more air, but the amount of water that is displaced is also more. Thus, the force of buoyancy is also more. The weight of a volume of air compared to the same volume of water is much less.

Multiple Choice Questions

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

1. A completely submerged object displaces its own:

- **A.** Density of fluid.
- **B.** Weight of object.
- **C.** **Volume**.
- **D.** Weight of the fluid in the container.

2. What is the buoyant force acting on a 20-ton ship floating in the ocean?

- **A.** **20 tons**.
- **B.** Less than 20 tons.
- **C.** More than 20 tons.
- **D.** Depends on the density of seawater.

3. A lobster crawls onto a bathroom scale submerged at the bottom of the ocean. Compared to its weight above the surface, the lobster will have an apparent weight under water that is:

- **A.** **Less**.
- **B.** The same.
- **C.** More.
- **D.** Depends on the density of seawater.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. The weight of an object acts downward, and the **buoyant** force provided by the displaced fluid acts upward. If these two forces are equal, the object does not sink. **Density** is defined as mass per unit of volume. If the density of an object exceeds the density of water, the object will **sink**.

2. **Archimedes'** most famous discovery was that an object submerged in a fluid is buoyed up by a force equal to the **weight** of the liquid the object **displaces**. This law is called "Archimedes Principle."

Extended Inquiry Suggestions

Ask your students to repeat the lab for a second object of different density to compare and contrast them.

Submarine buoyancy

Whether a submarine is floating or descending depends on the ship's buoyancy. Buoyancy is controlled by the ballast tanks, which are found between the submarine's inner and outer hulls.

A submarine resting on the surface has positive buoyancy, which means it is less dense than the water around it and will float. At this time, the ballast tanks are mainly full of air.

To submerge, the submarine must have negative buoyancy. Vents on top of the ballast tanks are opened. Seawater coming in through the flood ports forces air out the vents, and the submarine begins to sink.

The submarine, with ballast tanks now filled with seawater, is denser than the surrounding water. The exact depth can be controlled by adjusting the water to air ratio in the ballast tanks. Submerged, the submarine can obtain neutral buoyancy. That means the weight of the submarine equals the weight of water it displaces. The submarine will neither rise nor sink in this state.

To make the submarine rise again, compressed air is simply blown into the tanks, forcing the seawater out. The submarine gains positive buoyancy and becomes less dense than the water and rises.

A fun way to show this is to make a Cartesian diver. Fill a clear plastic bottle nearly to the top with water. A 2-liter soda bottle works well. Take a small medicine or eye dropper. Draw in just enough water into the dropper so that it barely floats when inserted into the clear plastic bottle. You'll probably have to try this several times before getting the amount of water just right. With the dropper barely floating, screw on the cap tightly. Increase the pressure inside the bottle by squeezing the bottle. Water will enter the dropper as the air inside the dropper becomes compressed. The dropper will "dive." Reduce the pressure inside the bottle by squeezing less. The air inside the dropper will expand, thus driving water out of the dropper. The dropper will then rise to the surface.

Buoyancy without water

To extend the idea of buoyancy beyond water, add the following demonstration. Obtain a Mylar® helium balloon and wait a few days until enough helium has leaked out that it loses some buoyancy and is roughly the same density as the room’s air. Blowing hot air (from a blow dryer) on the balloon heats and expands the remaining gas in the balloon, and it will rise to the top of the classroom. As it cools, the balloon falls slowly down again, where you can heat it again with the blow dryer to repeat the effect. Buoyancy can be easily calibrated with a few paperclips tied to the bottom of the balloon.

18. Newton's First Law

Objectives

This experiment investigates the concepts surrounding Newton's First Law of Motion. Students observe a simple cart and track system to determine the influence of force in the motion of an object, and how the absence of an external force means an objects motion is unchanged.

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the velocity of a cart while it undergoes three different forms of motion: constant zero velocity, constant non-zero velocity, constant non-zero acceleration.

- Comparing the velocity associated with each form of motion to determine whether a net force is acting on the cart.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Motion sensor
- Dynamics cart
- Dynamics track with feet
- Dynamics track end stop
- Mass and hanger set
- Super pulley with clamp
- String, 1 m

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Kinematics/motion in 1-dimension
- ♦ Acceleration

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Position: Match Graph
- ♦ Speed and Velocity
- ♦ Acceleration
- ♦ Newton's Second Law
- ♦ Newton's Third Law

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- ♦ Recording a run of data �(6.2)
- ♦ Displaying data in a graph �(7.1.1)

Background

Aristotle (384 BC to 322 BC) believed that the natural state of an object was to be at rest and therefore all objects in motion will eventually come to a stop. Serious arguments arose between early philosophers and scientists regarding the motion of objects. In the 17th century, Sir Isaac Newton formalized his three laws of motion.

His first law of motion, explored in this activity, states: An object will maintain its state of rest or uniform motion unless acted upon by an external unbalanced force. This became known as the "law of inertia."

Newton's first law implies that an object traveling with constant velocity will maintain that constant velocity unless otherwise acted upon by a net force. In addition, objects at rest (zero velocity) will stay at rest unless otherwise acted upon by a net force. In other words, if the net force on an object is zero, its acceleration is also zero.

We will investigate this concept by exploring the measured velocities associated with different types of motion of a cart.

Pre-Lab Discussion and Activity

For the demonstration station:

- Rubber ball
- Text book
- Large flat piece of wood (or other rigid material), Dimensions ≈ 1 m × 1 m

It is important, for now, that students focus on the idea that an object, "...continues to do what it is doing unless acted on by an outside agent."

It is advised that a discussion of inertia not occur in conjunction with these lab experiences. This discussion can occur later on as students investigate the concept of force further.

Begin with the piece of wood laying flat on the demonstration table. Place the ball on the wood near one edge (the ball should remain stationary in place). Inquire with students:

1. What is the ball's velocity?

Zero

2. Is the ball's velocity changing?

No

3. What forces are acting on the ball?

Gravitational and normal force

4. Was there a net "unbalanced" force acting on the ball?

No

Now have students pay close attention as you give the ball a small push slowly rolling it across the piece of wood in straight line. Stop the rolling ball before it rolls off the piece of wood. Inquire with students:

5. Was the ball's velocity equal to zero while it was rolling?

No

6. Ignoring friction, was the ball's velocity changing?

No, its speed and direction remained constant.

7. What forces were acting on the ball while it was rolling?

Gravitational and normal force

8. Was there a net "unbalanced" force acting on the ball while it was rolling?

No

Place the text book under one end of the piece of wood elevating that end slightly. Place the ball on the wood at the elevated edge, holding it in place. Have students predict what how the balls' motion will change when you release it.

Release the ball allowing it to roll down the piece of wood and catch it before it rolls off the far edge. Inquire with students:

9. Was the ball's velocity equal to zero while it was rolling?

No

10. Ignoring friction, was the ball's velocity changing?

Yes, its direction remained constant, but its speed was increasing.

11. What forces were acting on the ball while it was rolling?

Gravitational and normal force

12. Was there a net "unbalanced" force acting on the ball while it was rolling?

Yes, gravitational force was greater than the normal force, thus a net force.

For the final demonstration, leave the text book under one end of the piece of wood elevating that end slightly. Place the ball in the middle of either of the angled edges holding it in place. Tell students, "In this demonstration I will give the ball a slight horizontal push, of the same magnitude as the first demonstration, towards the other angled edge allowing it to roll freely." Have students predict what how the balls' motion will be different from the first demonstration where you gave the ball a slight push on the flat board.

Give the ball a slight push, horizontally, towards the other angled edge of the piece of wood allowing it to roll freely. Students should see the ball roll with the same horizontal speed as the first demonstration, but the ball's direction should change as it rolls across the piece of wood. Catch the ball before it rolls off the piece of wood. Inquire with students:

13. Was the ball's velocity equal to zero while it was rolling?

No

14. Ignoring friction, was the ball's velocity changing?

Yes, its speed and direction were changing

15. What forces were acting on the ball while it was rolling?

Gravitational and normal force

16. Was there a net "unbalanced" force acting on the ball while it was rolling?

Yes, gravitational force was greater than the normal force, thus a net force

17. If we were in space and the force from gravity was negligible, how would the ball's motion be different than we just saw?

Its speed and direction would have stayed constant.

Lab Preparation

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

Safety

Add this important safety precaution to your normal laboratory procedures:

- Keep water away from electronic equipment.

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.

3	2	4	1
Measure the velocity of a cart as a hanging mass acts on the cart.	Measure the velocity of a cart at rest on a flat track before setting the cart in motion.	Use velocity data to determine if any net forces are acting on the cart.	Set up the dynamics track with the super pulley at one end and the motion detector at the opposite end.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

1. ☐ Start a new experiment with your data collection system. �(1.2)

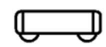
2. ☐ Connect the motion sensor to the data collection system. �(2.1)

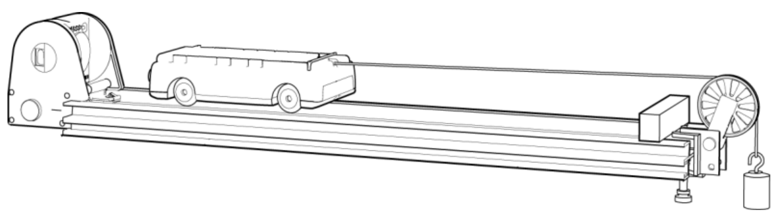
3. ☐ Display Velocity on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

4. ☐ Set the dynamics track on the lab table with one end of the track aligned with the edge of the lab table (or slightly hanging over the edge).

5. ☐ Attach the end stop and then the super pulley with clamp to the end of the track near the edge of the table.

6. ☐ Attach the motion sensor to the opposite end of the track with the face of the sensor pointed toward the super pulley. Be sure the switch on the sensor is set to the cart position.





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

8. ☐ Set the cart onto the track, and then adjust the level of the track using its adjustable feet so that the cart remains stationary when left at rest.

9. ☐ Cut a piece of string approximately 1 m long in preparation for data collection.

10. ☐ What will happen to an object at rest if no force is applied?

The object will remain at rest in this frame of reference.

11. ☐ What is required for an object to maintain motion at a constant velocity?

An object will maintain a constant velocity unless it is acted on by a force.

12. ☐ What will happen to an object if there is a constant net force applied to it?

The velocity of the object will increase in the direction of the force

Collect Data

13. ☐ With the cart stationary in the middle of the track, start data recording. �(6.2)

14. ☐ After approximately 5 seconds, stop data recording. �(6.2)

15. ☐ Now place the dynamics cart on the track approximately 15 cm in front of the motion sensor.

16. ☐ Start data recording. �(6.2)

17. ☐ Give the cart a soft push towards the super pulley, then catch the cart just before it hits the super pulley at the end of the track.

18. ☐ Stop data recording. �(6.2)

19. ☐ For the final data run, tie one end of your 1 m piece of string to the front of the dynamics cart, and tie the other end to the mass hanger.

20. ☐ Run the string over the pulley with the mass hanger hanging freely below the pulley.

21. ☐ Hold the cart in place approximately 15 cm in front of the motion sensor, and then attach 20 g of mass to the hanger. Continue to hold the cart.

22. ☐ Start data recording. �(6.2)

23. ☐ Release the cart, and allow it to freely roll down the track.

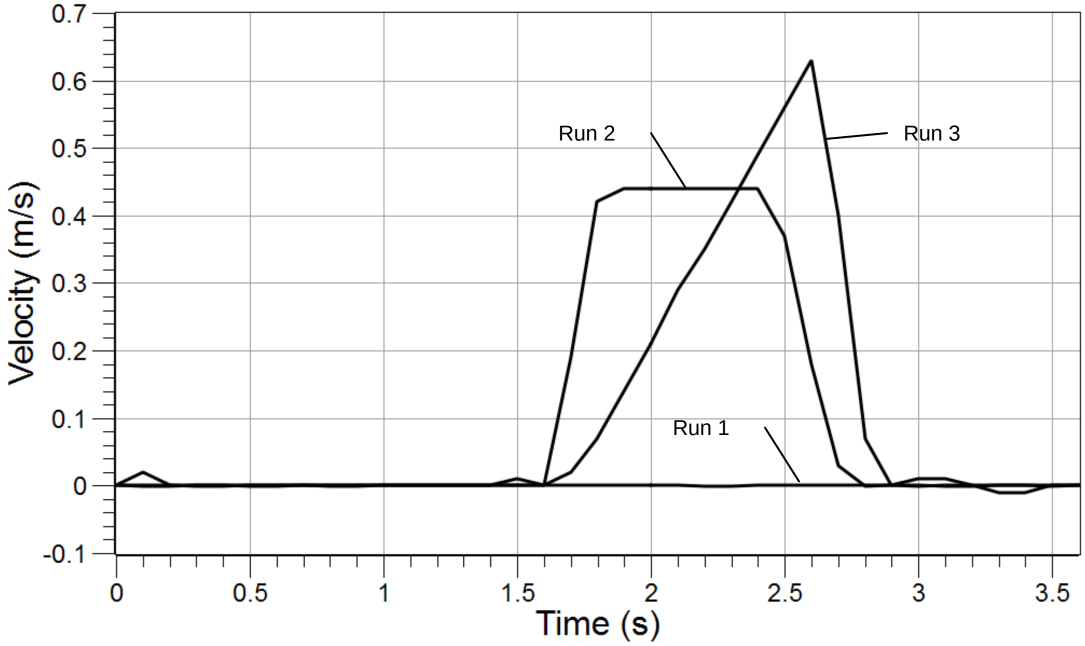
24. ☐ Catch the cart just before it hits the super pulley at the end of the track.

25. ☐ Stop data recording. �(6.2)

Analyze Data

26. ☐ Sketch your graph of Velocity versus Time in the Data Analysis section, and label each run.

Data Analysis



Analysis Questions

1. How was the velocity of the cart in Run 1 changing? Was there a net force acting on the cart? If yes, what is that force caused by?

The velocity of the cart in Run #1 is not changing. There is no net force acting on the cart.

2. Explain how you could tell how the cart's position was changing from a Velocity versus Time graph rather than directly from a Position versus Time graph.

We can determine how the position of the cart was changing from the Velocity versus Time graph because the velocity was zero, which means that the cart's position is not changing.

3. How was the velocity of the cart in Run 2 changing? Was there a net force acting on the cart? If yes, what was that force caused by?

The velocity of the cart in Run #2 is constant. Other than giving the cart a push, there was no net force acting on the cart while it was rolling. Some students may note a slight decrease in velocity due to friction.

4. How was the velocity of the cart in Run 3 changing? Was there a net force acting on the cart? If yes, what was that force caused by?

The velocity of the cart in Run #3 is constantly increasing. There was a force due to gravity experienced by the mass that was in turn pulling on the cart.

5. What evidence from the Velocity versus Time graph for Run 3 indicated there was a net force acting on the cart?

The slope of the Velocity versus Time curve was non-zero, which indicated that there was a net force acting on the cart.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What happens to the velocity of an object if it never experiences an unbalanced force?

The velocity will remain constant and never change.

2. How do forces affect the motion of objects? (Think of a force as a push or pull acting on an object.)

Forces affect motion by pushing or pulling the object out of its constant motion either by speeding up the object, or slowing it down, or changing its direction.

3. Is it possible for an object to experience a net force without physically touching another object? If yes, give an example.

Yes, gravity is an example of a force that acts on freefalling objects, but the objects might not be physically touching the surface of the Earth.

4. An object's resistance to change in motion is called "inertia". What property of matter gives an object inertia? Give an example of something with a relatively large amount of inertia, and something else with a relatively small amount.

Inertia is related to an object's mass. Student examples will vary. An example of an object with large inertia is a wrecking ball made of steel. An example of an object with small inertia is a balloon.

5. What would happen to a ball if you threw it in deep space where there were no forces acting on it? Describe its motion during the time you are in contact with it and then after you release it.

If you threw a ball in deep space, it would speed up while it was in your hand, stop speeding up after you released it, and maintain a constant velocity from then on because there are no forces in deep space to produce a net force on the ball.

Multiple Choice Questions

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

1. You slide a box across the floor at a constant velocity. Which of the following statements is true?

- **A. Your pushing force exactly equals the resisting force of friction.**
- **B.** Your pushing force must be greater than the force of friction.
- **C.** Your pushing force is less than the force of friction.
- **D.** Once you let go of the box, it will immediately come to a stop.

2. If you continue to push with the same force after the box slides onto a surface with less friction, which of the following statements is true?

- **A.** The box will speed up until it reaches a faster velocity and then continue at that velocity.
- **B.** **The box will speed up continuously as long as you continue to push with the same force.**
- **C.** The box will continue to slide at its original speed.
- **D.** If you let go of the box it, will continue to move indefinitely.

3. If an object experiences a constant net ___________, it will have a constant_______. However, if no force interacts with an object, that object will maintain a constant __________ indefinitely.

- **A.** Acceleration, force, velocity.
- **B.** Velocity, acceleration, force
- **C.** **Force, acceleration, velocity**
- **D.** Force, velocity, acceleration

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. **Inertia** is a term that refers to an object's resistance to a change in motion. Objects that are more **massive** are harder to accelerate. If an object experiences a constant net **force,** it will have a constant **acceleration**. However, if nothing interacts with an object, it will maintain a constant **velocity** indefinitely. **Nothing** is required for an object to maintain a constant speed in a straight line.

Extended Inquiry Suggestions

In addition to being the first of Newton's three laws of motion, this lab can branch out to investigations of friction and continued discussions around defining reference frames. Something at rest on the surface of the Earth is moving around the axis of the Earth as it rotates and moves around the sun as it orbits.

Aristotle observed that objects did seem to slow down and stop, as one might conclude today based on their experiences. What are the clues that Aristotle might have used to revise his ideas? Challenge your students to come up with ways to separate the general ideas of motion (Newton's laws) from the specifics of our everyday experience (friction).

19. Newton's Second Law

Objectives

Students investigate the relationship between the net force applied to an object, the acceleration of the object, and the object's mass.

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the applied force and resultant motion using a force and motion sensor
- Interpreting graphs of force and motion to outline the relationships that exist between mass, acceleration, and net force in the system

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	25 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Motion sensor
- Force sensor
- Dynamics track
- Dynamics cart
- Dynamics track end stop
- Super pulley with clamp
- Mass and hanger set
- Balance (1 per classroom)
- String, 1.5 m

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Acceleration due to gravity
- ♦ Tension forces

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Acceleration
- ♦ Introduction to Force
- ♦ Newton’s First Law
- ♦ Newton’s Third Law

Using Your Data Collection System

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

- ♦ Starting a new experiment with the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data acquisition device �(2.2)
- ♦ Changing the sampling rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Selecting data points on a graph �(7.1.4)
- ♦ Changing the variable on the *x*- or *y*-axis of a graph �(7.1.9)
- ♦ Displaying data in a digits display �(7.3.1)
- ♦ Viewing statistics of data �(9.4)
- ♦ Saving your experiment �(11.1)

Background

Often, several forces act on an object simultaneously. In such cases, it is the net force, or the vector sum of all the forces acting, that is important. Newton's first law of motion states that if no net force acts on an object, the velocity of the object remains unchanged. Newton's second law states that the acceleration of an object is directly proportional to the net force acting on that object and in the same direction as the net force.

$$\mathbf{F}_{net} = m\mathbf{a}$$

Like Newton, we will observe a simple system to look for a relationship between net force and motion. From earlier studies, we know that a mass hung from a string experiences a force due to gravity and a tension force from the string. In equilibrium, the two forces are equal and opposite. When one of the two forces is greater, causing a non-zero net force, motion begins. We will investigate how this net force is related to the motion of the system.

Pre-Lab Discussion and Activity

Start with a quick review of a force as a push or a pull. Hold the force sensor, using the finger loops, to show the class that indeed when you push or pull on the hook of the force senor, a digits display does in fact register newtons of force. �(7.3.1) Hold the sensor with the hook pointed toward the floor.

Teacher Tip: Be sure to zero the sensor before proceeding.

Teacher Tip: Use a mass that is known and can be dropped on the floor without damage, like a beanbag.

1. What do you think will happen when I hang this mass from the force sensor?

Once there is consensus, hang the mass and show the resulting force.

2. What if the force sensor wasn't here to hold the mass in place?

Take a moment to remind your students of the acceleration experiment. Then, drop the mass to the floor so the mass accelerates in the direction the force is applied. This is consistent with past experience. We know that if we apply a small force, an object accelerates a small amount.

Push an object on the desk, a student volunteer, or a cart on a track. Give the same object a harder push. If we apply a larger force, the object accelerates more. Therefore, we say that force and acceleration are proportional and related to the motion of an object.

Lab Preparation

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

1. Remind students that the motion sensor has a minimum distance that it can measure (about 15 cm).

2. If the motion sensor has a sensitivity switch, make sure it is in the "cart" position.

3. Point the motion sensor at the cart so other objects, like books or other students, will not interfere.

4. Set the sampling rate high enough to capture the motion of the mass (at least 20 samples per second). �(5.1)

Safety

Follow all standard laboratory procedures.

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	3	4	1
Release the cart and collect position, velocity, acceleration, and force data.	Plot net force measured by the force sensor versus acceleration.	Use the data to determine the relationship between the net force and acceleration .	Connect the motion sensor, force sensor, cart, pulley, and hanging mass to the dynamics track.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

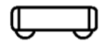
1. ☐ Start a new experiment on the data collection system. �(1.2)

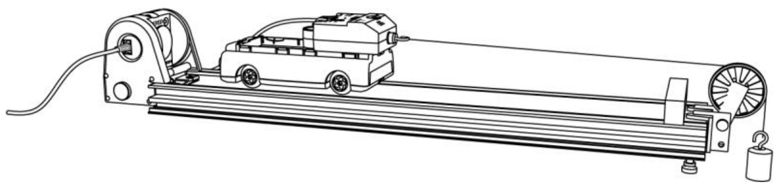
2. ☐ Connect a force and a motion sensor to the data collection system. �(2.2)

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

4. ☐ Why is a “Measurement versus Time” graph chosen to view the data? What is another way to view the data?

The position is continuously changing. To compare a matched force and acceleration value, they must be aligned in time. Because we are interested in comparing different parameters, we could plot one versus the other: Position versus Acceleration.

5. ☐ Set the sampling rate to at least 20 samples per second, and if your motion sensor has a selector switch, set it to the cart or near setting. �(5.1) 



6. ☐ Connect the force sensor to the top of the cart and attach the motion sensor to the end of the dynamics track.

7. ☐ Attach the end stop and the pulley to the other end of the track so the pulley hangs over the edge of the table and the bumper prevents the cart from colliding with the pulley.

8. ☐ Use the string to hang the mass from the force sensor, over the pulley, so the mass hanger is just below the pulley when the cart is 15 cm away from the motion sensor on the track.

9. ☐ Adjust the height of the pulley to make the top of the pulley equal to the height of the force sensor hook.

10. ☐ To zero the force sensor, remove the string and mass hanger from the force sensor, and press the “zero” button on the force sensor.

11. ☐ Why is it important to zero the force sensor with no hanging mass before collecting data?

We are interested in the *net force* on the object. When standing still on the track, the net force is zero.

12. ☐ Placing the cart 15 cm from the motion sensor, re-hang the mass from the force sensor over the pulley.

Collect Data

13. ☐ Start data recording. �(6.2)

14. ☐ Release the cart and allow it to travel the length of the track.

15. ☐ Stop data recording and catch the cart before the cart collides with the end stop. �(6.2)

16. ☐ Save your experiment as directed by your teacher. �(11.1)

Analyze Data

17. ☐ Display Velocity on the *y*-axis and Time on the *x*-axis of a graph. �(7.1.9)

18. ☐ Display Acceleration on the *y*-axis and Time on the *x*-axis of a graph. �(7.1.9)

19. ☐ Display Force, pull positive on the *y*-axis and Time on the *x*-axis of a graph. �(7.1.9)

20. ☐ Sketch all four graphs in the Data Analysis section.

21. ☐ Compare the four graphs. Which two seem the most alike?

Students should be able to identify that both force and acceleration appear to remain constant while the cart is in motion and are the most alike. Although velocity and position are both increasing with time, the velocity increases linearly, while the position is increasing in a non-linear fashion.

22. ☐ Find the average acceleration while the cart was in motion:

a. Select the data points on your Acceleration versus Time graph that represent the cart in motion. �(7.1.4)

Note: Use the Time values to insure that you are using the same range of data for each graph.

b. Find the average acceleration while the cart was in motion on your graph of Acceleration versus Time. �(9.4)

c. On the graph of Acceleration versus Time you sketched, highlight or otherwise indicate the data points used to obtain the average acceleration.

d. Record the average acceleration in Table 1 of the Data Analysis section.

23. ☐ Find the average force while the cart was in motion:

a. Select the data points on your Force versus Time graph that represent the cart in motion. �(7.1.4)

b. Find the average force while the cart was in motion on your graph of Force versus Time. �(9.4)

c. On the graph of Force versus Time you sketched, highlight or otherwise indicate the data points used to obtain the force acceleration.

d. Record the average force in Table 1 of the Data Analysis section.

24. ☐ Use the balance to find the mass of the cart and the mass together then record the mass in Table 1 of the Data Analysis section.

25. ☐ Clean up according to your teacher's instructions.

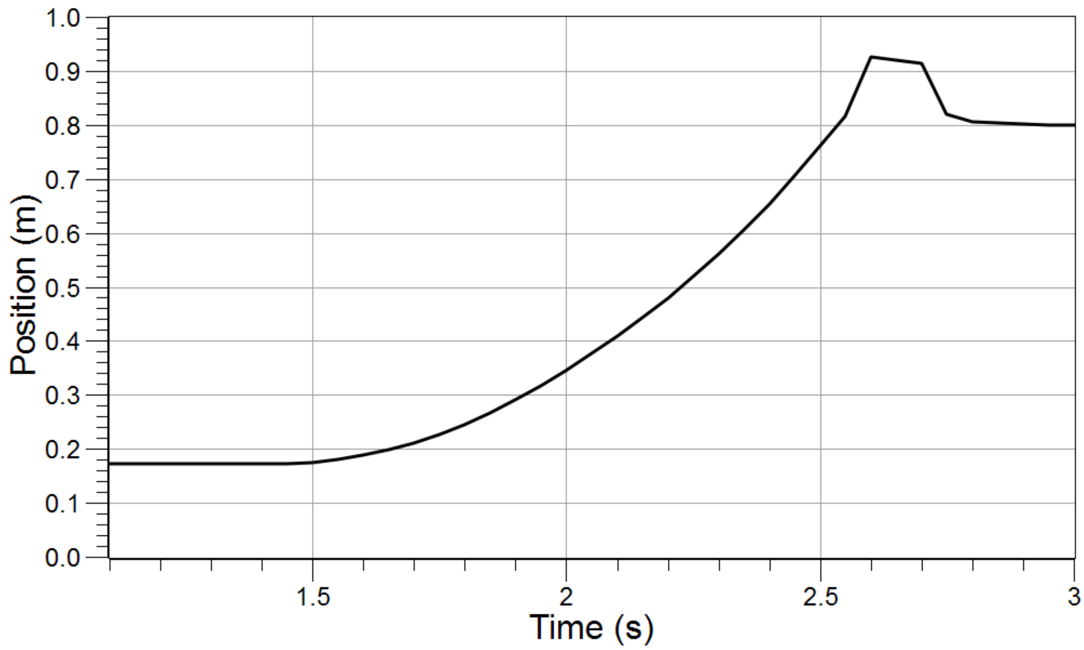
Data Analysis

For each of the 4 graphs:

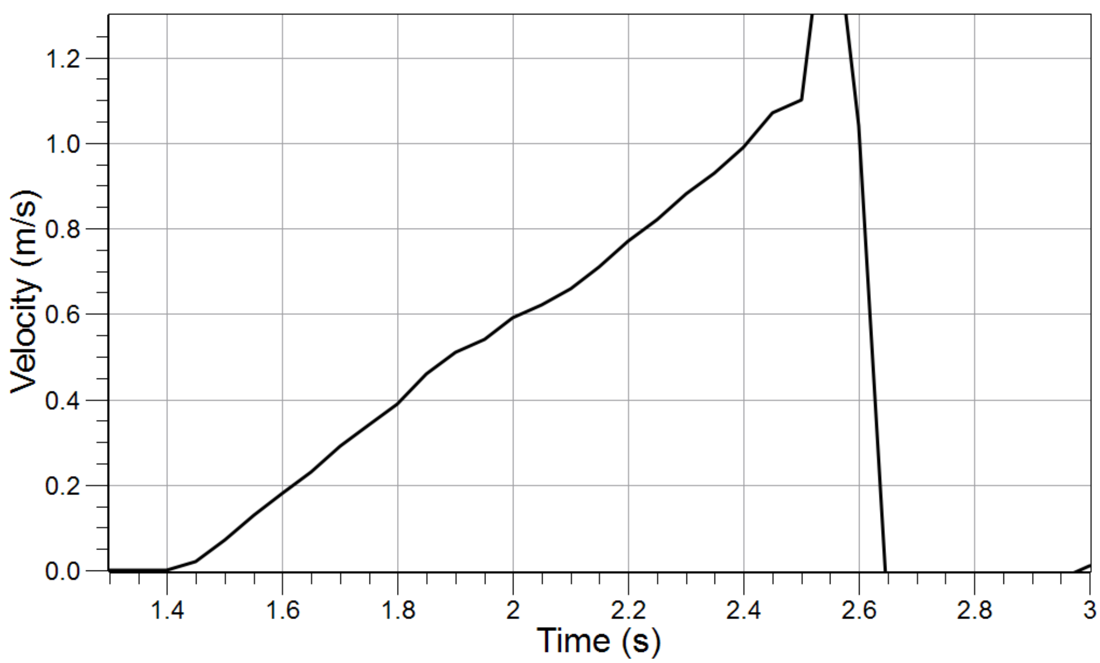
1. ☐ Label the overall graph, the *x*-axis and *y*-axis, and include units on the axes.

2. ☐ Create a shape or color or both for each data run in the Key. Then draw graphs of your data for a single data run in order to compare force with position, velocity and acceleration as they change over time.

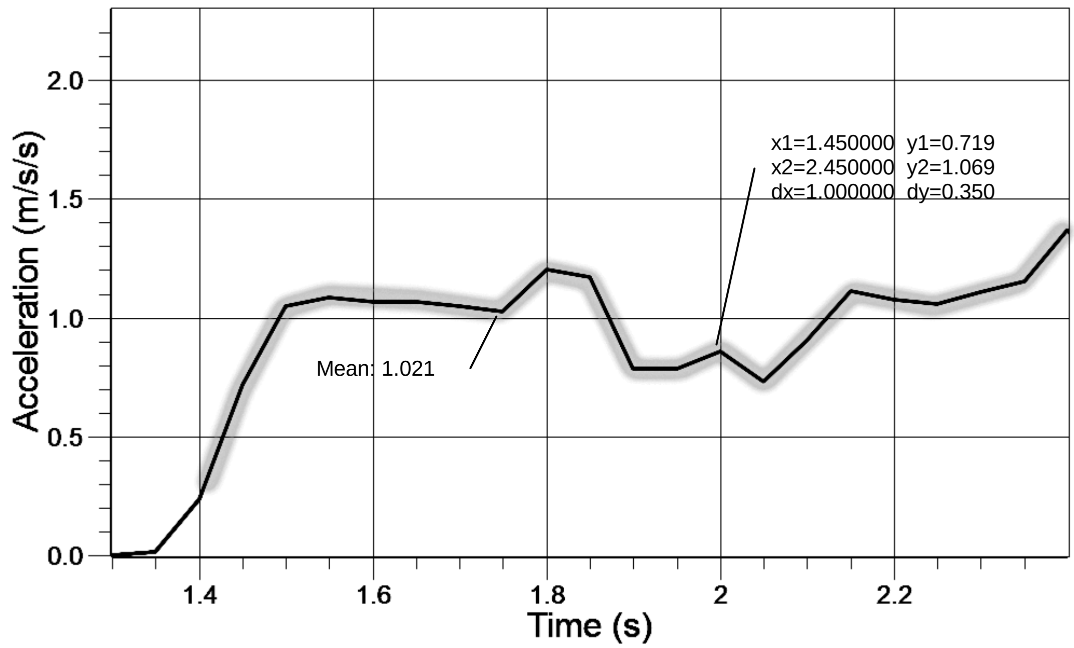
Position versus Time



Velocity versus Time



Acceleration versus Time



Force versus Time

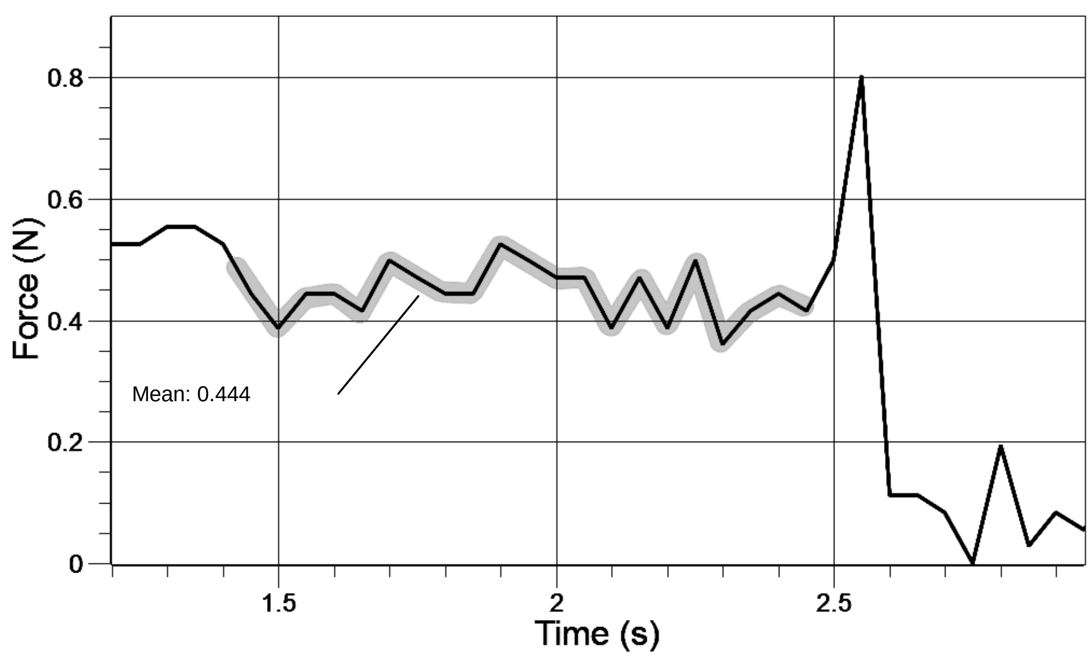


Table 1: Cart motion measurements

Parameters	Values
Average acceleration (m/s^2)	1.021
Average force (N)	0.444
Mass (kg)	0.418

Analysis Questions

1. Divide the average force by the average acceleration. Is the resulting value similar to any other parameter of the experiment?

$\frac{0.444 \text{ N}}{1.021 \text{ m/s}^2} = 0.435$ kg; The value should be very similar to the combined mass of the cart and hanging mass.

2. Write your calculation in the form of an equation.

$$\frac{\mathbf{F}}{\mathbf{A}} = m$$

3. How would you describe the relationship between force and acceleration in words, based the equation you wrote?

Force is proportional to acceleration, and the proportionality constant is the mass of the system.

4. Do the units of the equation balance?

Yes, $N = kg \times m/s^2$

5. What is the percent difference between the mass of the system and the average force divided by the average acceleration?

$$\frac{\text{mass} - \text{value}}{\left(\frac{\text{mass} + \text{value}}{2}\right)} \times 100 = \frac{0.418 - 0.435}{\left(\frac{0.418 + 0.435}{2}\right)} \times 100 = 3.99\%$$

6. What would you do to verify this relationship?

Student answers will vary, but should include something like: Perform additional trials with the same parameters, changing one variable at a time to determine if the relationship holds true.

Synthesis Questions

Use available resources to help you answer the following questions.

1. We know from experience that the harder we throw a ball (apply more force), the faster it will be moving (greater initial velocity resulting from acceleration).Assume the velocity of the object leaving your hand is proportional to the acceleration experienced by the object. If you throw a 1 kg softball as hard as you can, and it is traveling at 20 m/s when it leaves your hand, how fast would a 5 kg shot put be traveling with the same throw?

Assuming the “same throw” means that the applied force is equal in both cases, the shot put should be traveling at 4 m/s, or 1/5 the final speed of the softball.

2. We say that force is proportional to acceleration. Based on the relationship discovered in this experiment between force, mass, and acceleration, how would you describe the relationship between acceleration and mass?

They are inversely proportional.

3. If we launch a rocket that has been designed to produce a constant force, will the acceleration at initial launch be the same as the acceleration just before the fuel is completely expended? Explain your answer.

Because fuel has mass, the acceleration will be greater when most of the fuel is consumed.

Multiple Choice Questions

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

1. Which statement is true if two potatoes of different mass are launched from a potato launcher that applies the same force to each one?

- **A.** The heavier potato will be traveling faster than the lighter one.
- **B**. **The lighter potato will be traveling faster than the heavier one.**
- **C.** Regardless of their mass, they will be traveling at the same velocity.
- **D.** There is not enough information to draw a conclusion.

2. A roller coaster is designed to deliver a 3g acceleration at the bottom of a dip. The mass of the cart is 500 kg. and the rider is 100 kg. The track at this point is designed to withstand 15,000 N of force without buckling. Will the cart and rider make it through the dip?

- **A.** **No, this ride will likely end in disaster.**
- **B**. Yes, the cart and rider will easily make it past the dip.
- **C.** Yes, but a second rider of equal size would not make it through.
- **D.** There is not enough information to draw a conclusion.

3. If a 1,000 kg rocket is launched straight up with its engine producing a force of 39,240 N, what is its acceleration?

- **A.** 9.81 m/s^2
- **B**. 39.24 m/s^2
- **C.** 1000 m/s^2
- **D.** **29.43 m/s^2**

4. The acceleration of an object is

- **A.** Proportional to the mass of the object and the force being applied.
- **B**. Proportional to the mass of the object and inversely proportional to the force being applied.
- **C.** **Proportional to the net force being applied and inversely proportional to the mass of the object.**
- **D.** Always perpendicular to the force of gravity.

5. The net force on an object is

- **A.** Proportional to the force of gravity.
- **B. The vector sum of the individual forces acting on the object.**
- **C.** Always balanced by the normal force.
- **D.** Both A and C.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Newton's **second** law predicts the following relationship between **acceleration**, force, and mass: The acceleration of an object is directly **proportional** to the net force and will always be in the same direction as the net **force**. Acceleration will be inversely proportional to the **mass** of the object, meaning that more massive objects will have less acceleration if subjected to the same net force.

Extended Inquiry Suggestions

Ask your students to repeat the experiment using different masses for the cart and the hanging mass to determine if the relationship holds true.

This is a great time to introduce Atwood Machines.

20. Newton's Third Law

Objectives

Students analyze the relationship between an action force and the resulting reaction force and recognize that for every action there is an equal and opposite reaction. Toward this end they investigate that:

- Forces occur in pairs, commonly referred to as "action" and "reaction"
- Action and reaction forces never act on the same body
- Action and reaction forces are always equal in magnitude and opposite in direction

Procedural Overview

Students gain experience conducting the following procedures:

- Determining the force exerted on an object as well as the reaction force exerted by the object
- Interpreting graphs of Force versus Time

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor, with hook and rubber bumper (2)
- Short rod (optional)
- Large table clamp (optional)
- Rubber band

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Free-body diagram
- Newton’s first law
- Newton’s second law

Related Labs in This Guide

Labs conceptually related to this one include:

- Introduction to Force
- Newton's First Law
- Newton's Second Law
- Acceleration

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 multiple sensors to the data collection system �(2.2)
- Recording a run of data �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Adding a note to a graph �(7.1.5)
- Displaying multiple graphs �(7.1.11)
- Showing and hiding data runs in a graph �(7.1.7)
- Finding the coordinates of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

When one object exerts a force on another object, the second object exerts a force of equal magnitude and opposite direction on the first object—sometimes stated as, "for every action there is an equal and opposite reaction." Newton's third law can be both remarkably clear and perplexing to students, but a clear understanding of Newton's third law will make it much easier for a student to draw free-body diagrams and to analyze situations requiring an understanding of Newton's second law.

It is important to recognize that forces are like shoes—they occur in pairs. It is impossible to have a single force; for example, one can’t have an action force without having a reaction force. Students frequently find it difficult to understand that inanimate objects, like walls and floors, can exert forces. They may also find it preposterous to believe that walls and floors exert a gravitational force on the earth that is equal in size to the force the earth exerts on them. The pre-lab discussion and activities address some of these issues. At the end of this activity, students should realize that for every action there is an equal and opposite reaction, without exception.

Pre-Lab Discussion and Activity

Select any number of activities for discussion here based on the time and equipment you have available.

Forces occur in pairs

Suspend a 1-kg mass from a large stand using a string and pendulum clamp. Give the mass a small push with your finger so that it begins to swing. Ask students:

1. In which direction did I exert a force on the mass?

In the direction it began to move.

2. Did the mass exert a force on me?

Yes.

3. If so, in which direction was it?

Toward your finger.

4. How could I tell that it exerted a force on me?

By the pressure on your finger tip.

Inanimate objects can exert forces 1

Hold a meter stick with a small mass on the end and deflect it. Ask the following questions:

1. How can you tell that I am exerting a force on the meter stick?

It is distorted in shape.

2. Is the meter stick exerting a force back on me?

Yes, but accept all student answers and discuss until consensus is reached.

Release the meter stick by sliding your finger off the end to show the light mass projected into the air.

Inanimate objects can exert forces 2

Place a small mirror on the floor, and shine a laser pointer on it so that the reflected beam strikes the ceiling. Always direct the laser away from eyes. Now ask a student to walk past the mirror, stepping near it, as the other students watch the reflected beam. Ask the question,

1. What does the behavior of the reflected beam tell you about the floor?

The fact that the spot on the ceiling moves means the floor was slightly distorted as the student walked past the mirror.

Objects exert gravitational forces on each other

Ask the questions:

1. What evidence is there that leads us to believe that the earth exerts a gravitational force on the moon?

The moon orbits the earth.

2. What evidence is there that leads us to believe that the moon in turn exerts a gravitational force on the earth?

The moon causes tides. On the side of the earth nearest the moon, the water bulges towards the moon.

3. Why does the gravitational force of the earth on the moon have a much greater effect on the moon's motion than does the gravitational force of the moon on the earth have on the earth's motion?

The earth is much more massive than the moon.

Lab Preparation

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

Safety

Follow all standard laboratory procedures.

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	4	3	1
Before pushing or pulling, predict which student will push or pull the hardest.	Determine which student pushed or pulled the hardest and how that relates to Newton's third law.	Two students record the force applied as they first push the sensors against each other and then pull them from each other.	Connect 2 force sensors to the data collection system. Zero both force sensors before recording data.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Pushing

Set Up

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

2. ☐ Connect the force sensors to the data collection system. �(2.2)

3. ☐ Display two graphs simultaneously, the first with Force, push positive on the *y*-axis and Time on the *x*-axis, the second with Force, pull positive on the *y*-axis and Time on the *x*-axis. �(7.1.11)

Note: Your force sensor may use the measurements "force" and "force (inverted)" rather than "push positive" and "pull positive."

4. ☐ Why do you think one sensor uses "push positive" and the other uses "pull positive"?

When the sensors face each other, they will be pointed in opposite directions.

5. ☐ Attach the force sensor's rubber bumper attachment to the front of each force sensor.

6. ☐ Decide which sensor will be held by Student A and which will be held by Student B.

Teacher Note: Alternatively, if you do not want students pushing and pulling one another, one of the sensors can be mounted to a lab bench with the table clamp and small rod.

7. ☐ If Student A and Student B push the force sensors against each other, bumper to bumper, which student will exert the larger force?

Student answers will vary largely depending on misconceptions regarding stronger or larger students exerting more force, but the forces are equal and opposite.

8. ☐ Student A should face Student B with the force sensors held level in front of each student, using the finger loops.

9. ☐ Press the zero button on each force sensor, and then position the force sensors so their bumpers touch.

Collect Data

10. ☐ Start data recording. �(6.2)

11. ☐ Pushing procedure:

- **a.** Student A pushes Student B's force sensor while Student B tries to hold the sensor in place for 5 to 10 seconds.
- **b.** Student B pushes Student A's force sensor while Student A tries to hold the sensor in place for 5 to 10 seconds.
- **c.** Both Student A and Student B push at the same time for 5 to 10 seconds.

12. ☐ Stop data recording. �(6.2)

Analyze Data

13. ☐ Adjust the scale of the graphs to include all three peaks and align the Time axes of both graphs. �(7.1.2)

14. ☐ Find the peak force for each force sensor at each stage and record the peak values in Table 1 in the Data Analysis section. �(9.1)

15. ☐ Annotate the peaks of each graph to show which student was pushing at each peak. �(7.1.5)

16. ☐ Sketch your graphs of Force versus Time in the "Force versus Time – Pushing" blank graphs in the Data Analysis section.

Part 2 – Pulling

Set Up

17. ☐ Remove the rubber bumpers from the force sensors and attach a hook to each sensor.

18. ☐ Student A and Student B face each other again. Hold the sensors level and press the zero buttons.

19. ☐ Connect a rubber band between the two hooks.

20. ☐ To avoid confusion, hide all previous runs of data on your graph. �(7.1.7)

21. ☐ Will Student A or Student B exert more force when pulling away from each other?

Student answers will vary largely depending on misconceptions regarding stronger or larger students exerting more force, the forces are equal and opposite.

Collect Data

22. ☐ Start data recording. �(6.2)

23. ☐ Pulling procedure:

a. Student A pulls Student B's force sensor while Student B tries to hold the sensor in place for 5 to10 seconds.

b. Student B pulls Student A's force sensor while Student A tries to hold the sensor in place for 5 to 10 seconds.

c. Both Student A and Student B pull at the same time for 5 to 10 seconds.

Note: Be careful not to break the rubber band.

24. ☐ Stop data recording. �(6.2)

Analyze Data

25. ☐ Adjust the scale of your graphs to show all three peaks of the Force versus Time graph, and align the Time axes. �(7.1.2)

26. ☐ Find the peak force for each force sensor at each stage, and record the peak value in Table 2 in the Data Analysis section. �(9.2)

27. ☐ Annotate the peaks of each graph to show which student was pushing at each peak. �(7.1.5)

28. ☐ Sketch the graphs of Force versus Time in the "Force versus Time – Pulling" blank graph in the Data Analysis section.

29. ☐ How accurate were your predictions?

Answers will vary. In all cases, though, the force was the same magnitude but opposite in direction.

30. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Table 1: Maximum force applied while pushing

Condition	Student A	Student B
Student A pushing (N)	–28.7	28.1
Student B pushing (N)	–41.1	39.1
Student A and Student B pushing (N)	–51.4	53.8

Force versus Time – Pushing

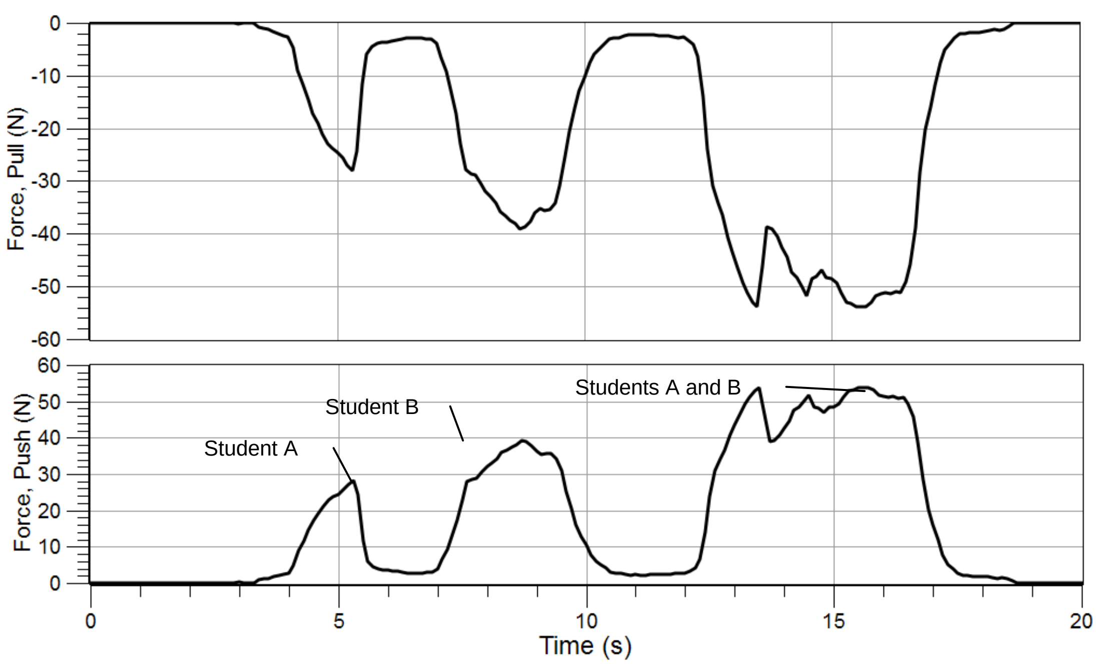
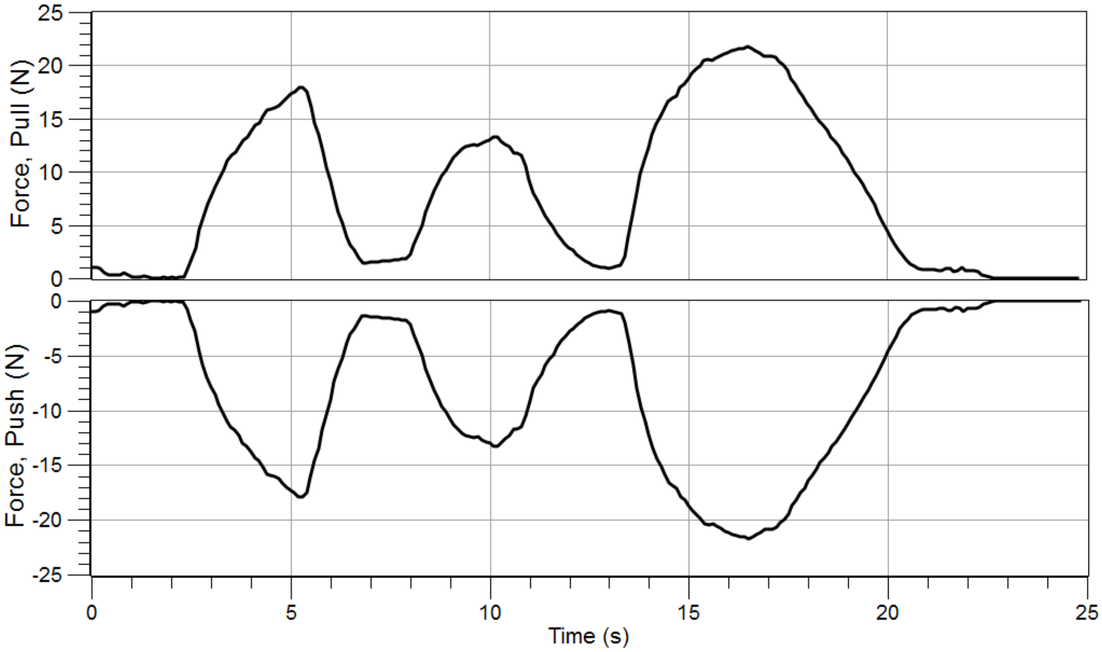


Table 2: Maximum force applied while pulling

Condition	Student A	Student B
Student A pulling (N)	17.8	–17.9
Student B pulling (N)	13.2	–13.3
Student A and Student B pulling (N)	21.8	–21.8

Force versus Time – Pulling



Analysis Questions

1. If you look at all of the interactions studied in this activity, how would you summarize the results in a single sentence?

For every action there is an equal and opposite reaction. Or: When Student A exerts a force on Student B, Student B exerts a force on Student A equal in size and opposite in direction.

2. It is likely that the results from pushing are not as consistent as the results from pulling? Can you think of reasons that this might be true? What might you do to improve the consistency of the pushing part of the Procedure, if this is the case?

The sensors tend to self-align along the axes of the sensors when pulling, but pushing the force sensors against each other has a higher potential to be off-axis. If the sensors were mounted on carts on a track, or some other form of force alignment was used, the results would be more consistent.

Synthesis Questions

Use available resources to help you answer the following questions.

1. **A 65.0 kg Olympic diver dives from a 10 m high tower. Consider the instant that the diver is in the air 1 m above the platform. Draw a free-body diagram showing the forces acting on this diver at this instant. In the table below, describe these forces in the "Action" column. Give the size and direction of the force as well as stating what exerts the force. In the "Reaction" column, give a similar detailed description of the reaction force. Assume that the gravitational field strength is 9.80 N/kg.**

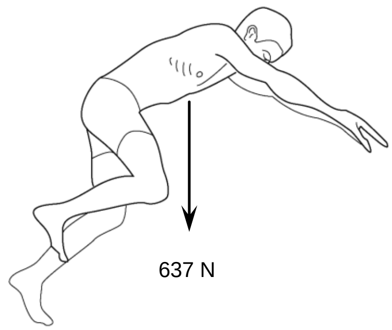


Table 3: Forces acting on the diver

Action	Reaction
A gravitational downward force of 637 N is exerted by the earth on the diver.	A gravitational upward force of 637 N is exerted by the diver on the earth.

2. **A 65.0 kg tourist is standing in line waiting to get into a theatre. Draw a free-body diagram to show the forces acting on the tourist. In the table below, describe these forces in the "Action" column. In each case, give the size of the force, show its direction, and specify what exerts the force. In the "Reaction" column, describe the reaction for each of the action forces again, giving size, direction, and the object that exerts the force.**

Table 4: Forces acting on the tourist standing in line

Action	Reaction
A gravitational force of 637 N down is exerted by the earth on the tourist.	A gravitational force of 637 N up is exerted by the tourist on the earth.
A force of 637 N up is exerted by the ground on the tourist.	A force of 637 N down is exerted by the tourist on the ground.

3. A parent pulls a sled with children at a constant velocity of 0.8 m/s across a level snow covered lawn by exerting a force of 225 N to the west. The mass of the sled and children is 85.0 kg. Draw a free-body diagram to show the forces acting on the loaded sled. In the table below, describe these forces in the "Action" column. In the "Reaction" column, give the size of the force, show its direction, and specify what exerts the force. Assume that the gravitational field strength is 9.80 N/kg.

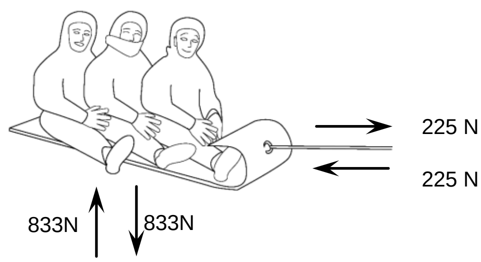


Table 5: Forces acting on the sled

Action	Reaction
A downward gravitational force of 833 N is exerted on the sled by the earth.	An upward gravitational force of 833 N is exerted by the sled on the earth.
A westward force of 225 N is exerted by the man on the sled.	An eastward force of 225 N is exerted by the sled on the man.
An eastward frictional force of 225 N is exerted by the snow covered lawn on the sled.	A westward frictional force of 225 N is exerted by the sled on the snow covered lawn.
An upward force of 833 N is exerted by the snow covered lawn on the sled.	A downward force of 833 N is exerted by the sled on the snow covered lawn.

4. A horse that is hitched to a stationary cart begins to pull on the cart. If the force exerted by the cart on the horse is always equal in size and opposite in direction to the force exerted by the horse on the cart, how can the horse move the cart?

The force exerted by the horse on the cart and the force exerted by the cart on the horse act on two different bodies, namely the cart and the horse. Consider the cart. If the horse exerts a force that is greater than the force of friction acting on the cart, then the cart will begin to move.

5. A student holds a force sensor from which a 500-g mass hangs. Suddenly, the force sensor slips out of the student's hand and falls to the floor. What reading does the force sensor show as it falls to the floor?

The force sensor would show a value of 0 N. Earth's gravitational field accelerates the sensor downward at the same rate as the mass so it is impossible for the mass to exert a downward force on the sensor.

Multiple Choice Questions

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

1. A student attaches a force sensor to a large block on a level surface. The student gradually increases the horizontal force exerted by the force sensor on the block until the block begins to move. If the force sensor records a value of 23.5 N the instant the block begins to move, what is the value of the size of the force exerted by the block back on the force sensor?

- **A.** Less than 23.5 N
- **B.** **23.5 N**
- **C.** More than 23.5 N
- **D.** Either more than 23.5 N or less than 23.5 N depending on the amount of friction present

2. The earth exerts a downward gravitational force on an automobile. The reaction to this force is:

- **A.** The upward force of the ground on the automobile
- **B.** The downward force of the automobile on the ground
- **C.** **The upward gravitational force of the automobile on the earth**
- **D.** None of the above

3. A soccer player exerts a force of 86 N on a 300 g soccer ball by kicking it. The force exerted by the soccer ball on the player's foot is:

- **A.** 0 N
- **B.** 29.4 N
- **C.** 43 N
- **D.** **86 N**
- **E.** 170 N

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

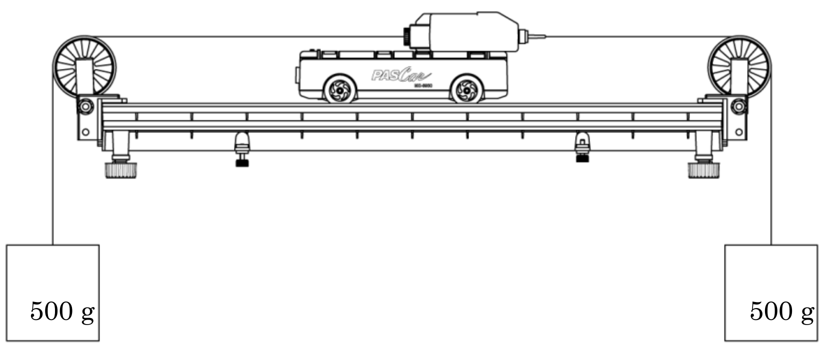
1. If a quarterback exerts a **force** of 150 N [to the south] on a football, then the **reaction** force is a force of 150 N [to the north] exerted by the football on the quarterback. If the quarterback is in the air when he makes the throw, the ball will move toward the south and the quarterback will move to the north. The **motion** of the ball will be much more significant because the **mass** of the ball is much less than that of the quarterback.

2. Newton's **third** law is commonly stated as: To every **action** there is an equal and opposite reaction. These forces always occur in **pairs** that are equal in **magnitude** but opposite in **direction**.

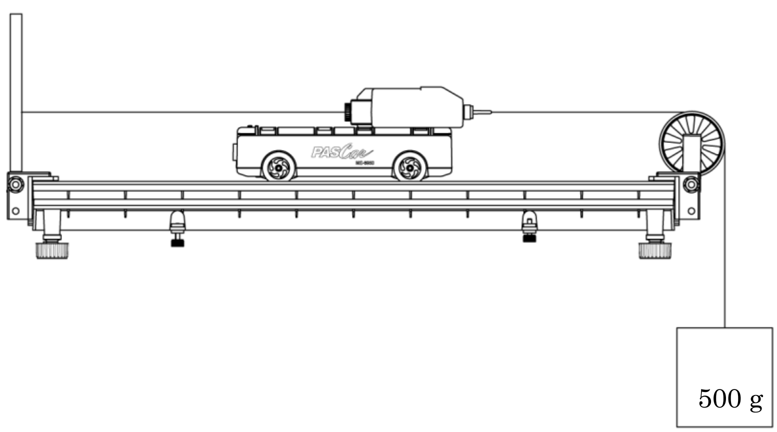
Extended Inquiry Suggestions

The diagram below shows two different setups using a dynamics system, super pulley, force sensor, and 500-g mass. The purpose of the cart is to support the force sensor and ensure that friction is negligible. Assuming that g = 9.80 N/kg, have students predict what the reading the force sensor will record in each of the two situations. Teachers might want to first set up arrangement A, and ask students make a prediction. Then, after predictions are made, the arrangement can be switched to B. Again, ask students to make a prediction. At this point, some students may want to change their prediction for arrangement A. After giving predictions and discussing reasons for the predictions, the measurements can be made.

A



B



In each case, the force sensor will record a reading of 4.9 N. In situation B, the rod pulls to the left with a force of 4.9 N on the force sensor just as the 500 g mass on the left did in situation A.

21. Boyle's Law

Objectives

Students observe changes in pressures and volumes of gases as they apply to Boyle's Law. At the end of this lab, students:

- ♦ Understand the relationship between volume and pressure of an enclosed gas at constant temperature.
- ♦ Are able to graph this relationship and derive an equation relating pressure and volume of an enclosed gas
- ♦ Apply the equation to predict gas behavior using Boyle's Law

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Decrease the volume of the gas in a closed system causing pressure to increase.
- ♦ Enclose gas with a 20ml syringe and pressure sensor and decrease the volume increasing pressure
- ♦ Linearization of data to determine the nature of a relationship between to variables.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Absolute pressure sensor
- ♦ Barbed quick-release connector[1]
- ♦ Syringe[1], 20 mL
- ♦ Tubing[1]

[1] Included with PASCO Pressure Sensors

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Temperature, pressure, and volume of a gas
- Graphing Basics, including inverse and direct relationships

Related Labs in This Guide

Labs conceptually related to this one include:

- Temperature versus Heat
- Percent Oxygen in Air

Using Your Data Collection System

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

- Starting a new experiment with the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Manual Sampling mode with manually entered data �(5.2.1)
- Starting a manually sample 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)
- Changing the variable on the x- or y-axis �(7.1.9)
- Applying a curve fit �(9.5)
- Creating calculated data �(10.3)
- Saving data files �(11.1)

Background

If you take an isolated system like a Mylar® balloon filled with helium and place it in a cooler environment, it will contract. If you put it in the sun or blow hot air on it with a blow dryer, it will expand and rise due to its increased buoyancy. But what if you held the temperature constant? What changes if only pressure and volume vary while temperature isn't changed at all?

If you squeeze (decrease the volume of) an enclosed gas, the pressure of the gas increases. Boyle and his colleague Robert Hook built vacuum syringes to study the relationship between pressure and volume and found that at a constant temperature, the absolute pressure times the volume of the gas was always the same and can be represented as

$$PV = k \qquad \text{(Eq. 1)}$$

Another way of writing this relationship is:

$$P_1V_1 = P_2V_2 \qquad \text{(Eq. 2)}$$

Eq. 2 is related to the ideal gas law: $PV = nRT$ where n is the number of gas molecules, T is the temperature of the gas, and R is the ideal gas constant. If n and T are held constant, then nRT becomes a constant and the equation can be rewritten as Eq. 1 or Eq. 2: $P_1V_1 = P_2V_2$, which is the most fundamental of all the gas laws.

Pre-Lab Discussion and Activity

A great discussion about Boyle's Law starts with scuba divers. Scuba divers breathe atmospheric air from a canister that is a constant shape and volume, yet it must be filled up and does get empty after a while. How does air get inside a scuba tank? Through pressure, air is packed into the scuba tanks by a compressor, which takes in air from the atmosphere and forces it into the small canisters. Because all that air is crammed into a small space, it's under tremendous pressure. As the air is let out, it expands, and the pressure in the canister decreases as it empties.

1. What is the basic relationship stated in Boyle's Law?

Gas pressure is inversely related to its volume.

2. What mathematical relationship best represents Boyle's Law?

$PV = k$ or $P_1V_1 = P_2V_2$

3. If you double the volume, what would happen to the absolute pressure on an ideal gas?

It would be half the original pressure.

4. What if you decreased the volume to one half its original value?

The absolute pressure would double from its original value.

Connect an absolute pressure sensor to a syringe as you would for the experiment, and then connect the absolute pressure sensor to a data collection system set up to project Pressure to the class. Wrap your hand around the syringe, and show the change in pressure.

Remind the class that we want to observe the relationship between pressure and volume, so keep the system isothermal. Keep the syringe away from heat sources, and hold the syringe so that you are not changing its temperature.

Lab Preparation

Although this activity 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:

♦ To minimize the risk of injury or damage to the equipment, avoid over-compressing the air in the syringe.

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.

3	2	4	1
Compress the gas in the syringe by pushing the plunger. Record the volume and pressure each time.	Configure the data collection system to measure pressure for various volumes.	Graph Pressure versus Volume for at least 6 data points. Determine the relationship between pressure and volume.	Connect a syringe to the absolute pressure sensor.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

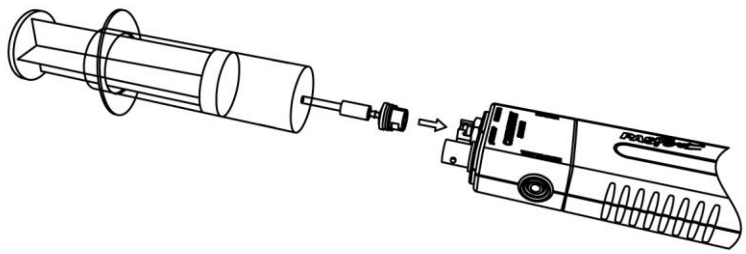
Set Up

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

2. ☐ Connect the absolute pressure sensor to the data collection system. �(2.1)

3. ☐ Set up your data collection system to collect manually entered data in a table with Volume in mL as the user entered measurement. �(5.2.1)

4. ☐ Set the syringe to 20 mL, and connect it to the absolute pressure sensor using the shortest piece of tubing possible and the barbed quick-release connector.



Collect Data

5. ☐ Begin recording a set of manually sampled data starting with the plunger at 20 mL. �(6.3.1)

6. ☐ Record the first manually sampled data point at 20 mL. �(6.3.2)

7. ☐ Squeeze the plunger compressing the volume inside the syringe to 18 mL, then record the next manually sampled data point. �(6.3.2)

8. ☐ Repeat the previous step compressing the volume by an additional 2 mL each time until you have reached a final volume of 10 mL.

9. ☐ Stop recording data. �(6.3.3) Copy the values to Table 1 in the Data Analysis section.

Analyze Data

10. ☐ Use your data collection system to create a graph of Pressure versus Time. �(7.1.1)

11. ☐ Change the x-axis to the manually entered measurement Volume. �(7.1.9)

12. ☐ Sketch your graph of Pressure versus Volume in the Data Analysis section.

13. ☐ Look at your graph of Pressure versus. Volume. Is it a linear or curved relationship?

It's a curved relationship, so it's nonlinear.

14. ☐ What simple mathematical relationship do you think this type of curve represent?

The asymptotic curve shows an inverse relationship, where as the *x*-component gets large, the *y*-component goes to zero. Conversely, as the *x*-value goes to zero, the *y*-value goes to infinity.

15. ☐ Try applying different curve fits until you find the one that best represents the trend of the data. �(9.5)

16. ☐ Which curve fit best represented the data trend?

Inverse

17. ☐ How could you manipulate the data (by squaring, doubling, inverting, or taking the square root) to plot a new variable that would give a linear graph with pressure?

If you could plot Pressure versus (1 / Volume), it would yield a linear graph.

18. ☐ Create the following calculation: VolumeInv = 1/[volume] �(10.3)

19. ☐ Change the *x*-axis from Volume to VolumeInv on the graph of Pressure versus Volume on your data collection system. �(7.1.5)

20. ☐ Sketch your graph of Pressure versus VolumeInv in the Data Analysis section.

21. ☐ Apply a Linear curve fit to your plot of Pressure versus VolumeInv. �(9.5)

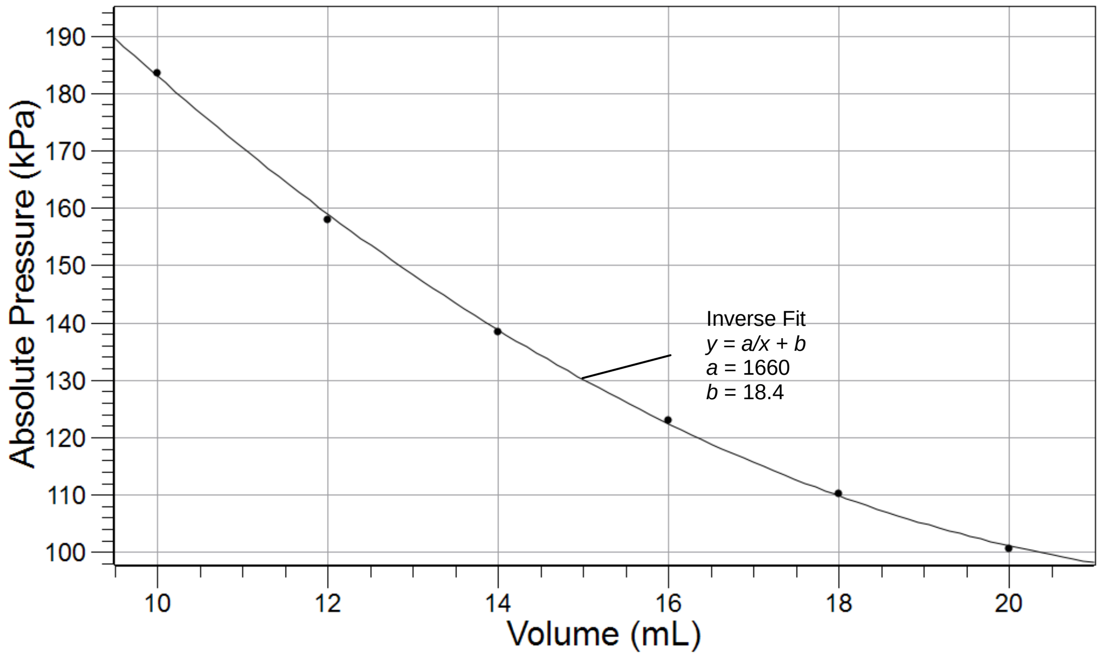
22. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

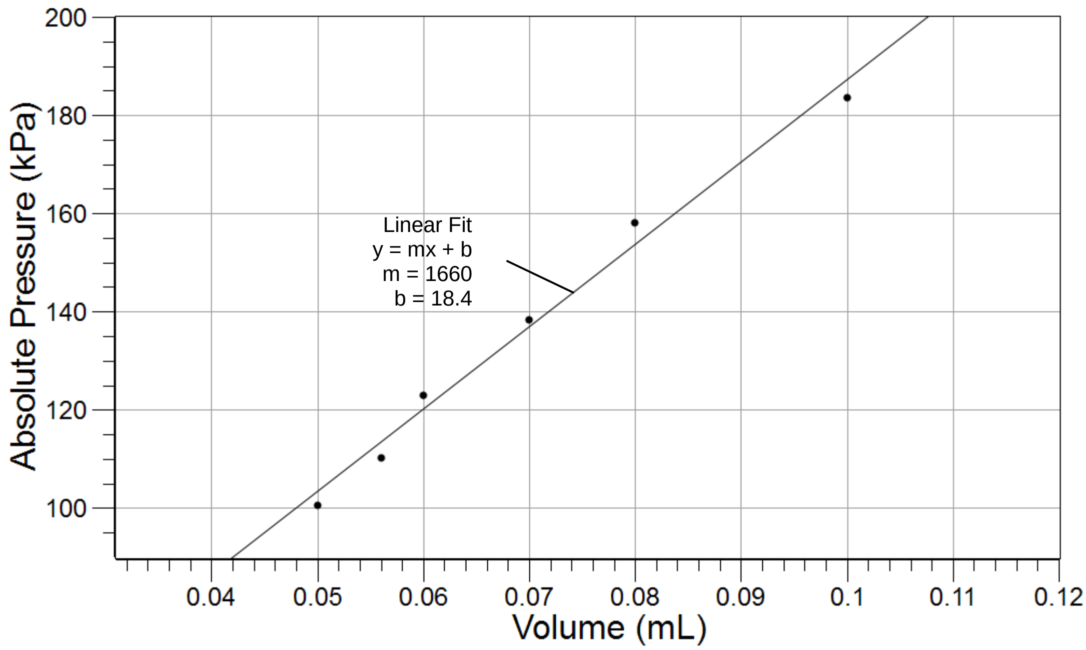
Table 1: Volume and pressure

Volume (mL)	Pressure (kPa)
20	100.62
18	110.30
16	123.02
14	138.36
12	158.00
10	183.56

Pressure versus Volume



Pressure versus 1/Volume



Analysis Questions

1. Look at your graph of Pressure versus VolumeInv. How well does the linear curve fit represent the trend of this data? What does this mean?

The linear curve fit strongly represents the trend of the data, which means the original data of Pressure versus Volume is an inverse relationship.

2. What does this mean in general for finding the mathematical relationship of different types of data plots?

A mathematical relationship can be applied to a data set, and if the resulting *x-y* plot is linear, then the mathematical relationship that was applied is a good representation of the trend of the original data plot.

3. How would you describe the relationship between Pressure and Volume in words?

Pressure is proportional to the inverse of volume.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Does the shape of the graph make sense, knowing the common behaviors of gases, volumes, and pressures? Explain why or why not.

The graph makes good sense. Squeezing the gas by applying force to the plunger of the syringe causes the volume to decrease, and the pressure of the gas to increase. Likewise, if a gas is allowed to expand, it will increase its volume so as to decrease its pressure.

2. Volume and pressure of an ideal enclosed gas at a constant temperature are inversely related. What happens if:

a. You cut the volume in half, what would happen to the absolute pressure?

It would double.

b. What if you cut the volume in half again, how would the final pressure relate to the original pressure before you first moved the syringe in part a) above?

It would be four times the original pressure.

3. The surrounding air pressure at high elevations (like in the mountains) is much less than at sea level. Explain how this affects the appearance of a sealed bag of potato chips that you take from sea level to high elevations.

The bag becomes noticeably larger in volume because of lower pressure on the outside of the bag. The pressure inside the bag is fixed, so less pressure on the outside means a higher volume for the bag.

Multiple Choice Questions

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

1. Boyle's Law states that, for an enclosed gas,

- **A.** Pressure is inversely related to volume.
- **B.** Pressure increases as volume increases.
- **C.** (Pressure × volume) equals a constant at a given temperature.
- **D.** Volume increases as temperature decreases.
- **E. Both A and C are correct.**

2. According to Boyle's Law, what must happen to the size of bubbles as they rise to the top of a carbonated beverage?

- **A.** The bubbles stay the same size.
- **B.** The bubbles expand as they rise because the pressure on them is greater.
- **C.** The bubbles contract as they rise because the pressure on them is greater.
- **D.** The bubbles contract as they rise because the pressure on them is lower.
- **E. The bubbles expand as they rise because the pressure on them is lower.**

3. A container of 2.5 Liters of air is under pressure of 85 kPa. What is its volume after the pressure is increased to 105 kPa?

- **A.** 0.494 L
- **B. 2.02 L**
- **C.** 3.09 L
- **D.** 0.324 L
- **E.** none of these

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. If a gas is enclosed and held at constant temperature, **Boyle's Law** states that the absolute pressure of the gas is **inversely** proportional to its volume. This means that if the number of gas particles is held **constant** at the same **temperature**, cutting the **volume** in half will double the pressure of the gas. Similarly, if the **pressure** were to be decreased by one-half the volume would have to expand to **double** its original amount.

2. Applications of Boyle's Law are all around us. Scuba divers have to **exhale** the air from their lungs as they **rise** to the surface of the water, because the air in their lungs **expands** greatly as the fluid pressure **decreases** when they near the surface. In fact, since one **atmosphere** of pressure represents the increase for every 10.3 meters of water depth, a scuba diver at a depth of about **21** meters would be at a pressure of 2 atmospheres. This means the air in his lungs would expand to about grow about **2 times** the volume if he did not exhale the air as he rose to the surface.

Extended Inquiry Suggestions

Instructors can follow this lab with a discussion of atmospheric pressure and sealed containers: what do sealed containers do when you take them from sea level to higher elevations? Mention how Boyle's Law leads quickly to Charles' Law, the volume-temperature law, and of course the ideal gas law. Be sure to list exceptions to the ideal gas law. Lastly, instructors can focus on the vast amount of scientific study going on at the time that Boyle published his work (with the assistance of Robert Hooke). French Physicist Edme Mariotte discovered the same gas law working independently of Boyle and Hooke just 4 years after Boyle published his work.

Instructors can quickly combine Boyle's Law with Charles' Law to get the combined gas law, and again combined with Avogadro's Law to get the ideal gas law. It is advantageous for both instructors and students to see Boyle's Law (and the other gas laws) present in the ideal gas law.

22. Temperature versus Heat

Objectives

Students establish a fundamental understanding of the relationship between heat transfer and temperature changes in substances. This activity is designed to provide students with an understanding of:

- How dissimilar objects have the capacity to transfer different amounts of heat to a solution although they start at the same temperature.
- How the temperature of dissimilar solutions changes with an identical amount of heat transferred to each solution.
- The ability of a solution or object to transfer heat, and how that transfer is related to increases/decreases in temperature.

Procedural Overview

In this investigation, your students will gain experience with the following tools and techniques:

- Identifying and controlling the correct variables in an experiment
- Measuring the change in temperature of a system from a graph
- Defining the relationship between temperature and heat based on data

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor (2)
- Beaker, 600-mL
- Hot plate
- Calorimetry cup (2) [1]
- Copper mass (2), 200-g [1]
- Aluminum mass (2), 200-g [1]
- Balance (1 per classroom)
- Vegetable oil, 500 g
- Water, 500 g
- String, 15 cm (4)
- Paper clip, (2)

[1] Part of the Basic Calorimetry Set

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Kinetic energy
- Conservation of energy
- Temperature
- Heat

Related Labs in This Guide

Labs conceptually related to this one include:

- Phase Change
- Specific Heat of Sand versus Water

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 multiple sensors to the data collection system� (2.2)
- Monitoring live data without recording � (6.1)
- Starting and stopping data recording � (6.2)
- Adjusting the scale of a graph � (7.1.2)
- Displaying multiple variables on the *y*-axis of a graph � (7.1.10)
- Viewing statistics of data � (9.4)
- Saving your experiment � (11.1)

Background

Matter, whether liquid, solid, or gas, is made of moving particles. The average kinetic energy of these particles is related to temperature. Because the kinetic energy of each of the individual particles cannot be directly measured, temperature scales, like the Celsius and Fahrenheit scales, are employed on the macroscopic level to measure temperature.

The thermal energy, or internal energy, of a material includes the kinetic energy of the atoms or molecules as well as the potential energy between the atoms and molecules. Heat is a measure of the energy transferred from a hotter material to a cooler material. Heat will continue to flow from hot materials to cold materials until the temperature of the materials is equal.

Pre-Lab Discussion and Activity

Engage your students by connecting temperature, thermal energy, and heat concepts to their real world experiences.

Prior to beginning the demonstration, fill a gallon-sized clear container and a cup-sized clear container with water and allow them to settle to room temperature. Use a temperature sensor to measure the room temperature. Then ask the students the following questions:

1. When I measure the temperature of the room, what am I actually measuring?

The average kinetic energy of the particles of air.

2. Is it possible for a cup of water and a gallon of water to have the same temperature?

Yes.

Use two temperature sensors (if you have them) to show that both the gallon and the cup have the same (room) temperature.

3. If so, do they have the same amount of thermal energy? Why?

No, because the gallon of water has more particles with energy.

Note: An analogy to this is kinetic energy. Two objects can have the same velocity, but the one with more mass will deliver more kinetic energy.

4. If so, can they transfer the same amount of heat? Why?

No, because the gallon of water has more internal energy to transfer because it has more particles with energy.

5. Which has more thermal energy: an iceberg or a cup of water? Why?

The iceberg has more thermal energy because it contains significantly more particles with energy; albeit on average a lower amount of energy.

6. Which can transfer more heat: an iceberg or a cup of water?

The iceberg can transfer more heat because it contains more thermal energy.

Create three digits displays of temperature, one for each scale (Fahrenheit, Celsius, and Kelvin).

7. Which scale have we been using so far?

Celsius.

8. In a room like this (at one atmosphere of pressure), what happens to water at 0 °C, and 100 °C?

Water freezes into ice (becomes a solid) or boils (becomes a gas).

9. So this scale is based on common experience. What do you suppose happens when the temperature reaches zero K?

This is when particles have zero kinetic energy.

Lab Preparation

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

1. Place water and vegetable oil in containers located next to each other in the same area of the lab.

Note: Some insulated cups can allow oils to seep through. Do not use the insulated cups for long term storage.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not directly touch hot items like the hot plate, beaker, and water.
- Keep the boiling water away from other electrical equipment like a computer.
- Wear an apron, goggles, and gloves as recommended by your teacher.

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	5	3	4
Put the heated, different metal samples in calorimeters containing the same room-temperature fluid.	Measure the mass of different metal samples, heat them in boiling water.	Put the heated, same-metal samples in calorimeters with different fluids and compare the temperature changes.	Determine the temperature change of the fluid caused by different metals placed in calorimeters with the same liquid.	Now measure the mass of two samples of the same metal; heat them in the boiling water.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Different materials in the same fluid

Set Up

1. ☐ Measure and record the mass of a copper sample and an aluminum sample in the Data Analysis section.

2. ☐ Why do you think it is important that the mass is similar for the copper and aluminum samples?

The mass of the samples is one of variables being controlled.

3. ☐ Tie approximately 15 cm of string to each of the metal masses.

4. ☐ Carefully place the masses into the 600-mL beaker with the string hanging over the lip of the beaker.

5. ☐ Cut the excess string leaving just enough string so that the masses can be safely lifted out later.

6. ☐ Pour just enough water into the beaker to submerge the masses.

7. ☐ Place the beaker on the hot plate, and then plug-in and turn on the hot plate.

8. ☐ Place the same amount of water in each calorimetry cup.

Note: Make the water level high enough so that the metal sample will be completely submerged when it is placed into the cup; but not so high that the water will overflow.

9. ☐ Use paper clips to attach a temperature sensor to each calorimeter cup so that the tip of each sensor is submerged in water but not touching the wall of the cup.

10. ☐ Why do you think it is important that the mass of water is the same?

The mass of the liquid is one of variables being controlled.

11. ☐ Why do you think it is important to use foam calorimetry cups for this experiment?

We are trying to minimize (control) the amount of heat lost to the environment.

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

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

14. ☐ Display both temperature measurements on the *y*-axis of a graph with Time on the *x*-axis. � (7.1.10)

15. ☐ What is a good method of making sure the temperature of the water is the same in each cup?

Pour water back and forth from one cup to the other.

16. ☐ Make sure the temperature of the water in the calorimetry cups is the same temperature.

17. ☐ Why do you think it is important that the temperature of the water is the same?

The temperature of the liquid is one of the variables being controlled.

Note: Remember to make sure the mass of the water in each cup is the same when done.

Collect Data

18. ☐ When the water bath starts boiling, start data recording. � (6.2)

Note: Keep the water bath hot for Part 2.

19. ☐ Carefully transfer the masses from the water bath to the calorimetry cups. One mass in each cup

20. ☐ After a few minutes, when the Temperature versus Time plot levels off, stop data recording. � (6.2)

Analyze Data

21. ☐ For each metal sample, find the initial water temperature (minimum) and the final water temperature (maximum), and record them into Table 1 in the Data Analysis section. � (9.4)

Part 2 – Similar materials in different fluids

Set Up

22. ☐ Measure and record the mass of two samples of the same metal in the Data Analysis section.

23. ☐ Why do you think it is important that the samples are made of the same materials and have the same mass?

For this part of the lab, the type of material and mass are variables being controlled.

24. ☐ Tie approximately 15 cm of string to each of the metal masses.

25. ☐ Carefully place the masses into the 600 mL beaker filled with hot water with the string hanging over the lip of the beaker.

26. ☐ Cut the excess string leaving just enough string so that the masses can be safely lifted out later.

27. ☐ Turn up the hot plate so that the water will return to a boil.

28. ☐ Place vegetable oil in one of the calorimetry cups, and place the same mass of water as vegetable oil in the other calorimetry cup.

Note: Make the fluid level high enough so that the sample will be completely submerged when it is placed into the cup; but not so high that the fluid overflows.

29. ☐ Use paper clips to attach a temperature sensor to each cup so that the tip of each sensor is submerged in fluid but not touching the wall of the cup.

30. ☐ Monitor the temperature in the cups without recording. � (6.1)

31. ☐ Why do you think it is important that the mass of fluid is the same?

In this part of the lab, the mass of the fluid is one of variables being controlled.

32. ☐ What is a good method of making sure the temperature of the fluid is the same in each cup?

Use water and vegetable fluid that have been sitting in the same location of the room for several hours, or add small amounts of hot or cold water until the water matches the vegetable oil.

33. ☐ Adjust the temperature of the water to match that of the vegetable oil.

34. ☐ Why do you think it is important that the temperature of the fluids is the same?

The temperature of the fluids is one of the variables being controlled.

35. ☐ Stop monitoring live data, and return to your graph display.

Collect Data

36. ☐ When the water bath starts boiling, start recording data. � (6.2)

37. ☐ Turn off the hot plate.

38. ☐ Carefully transfer the masses from the water bath to the calorimetry cups, one mass in each cup.

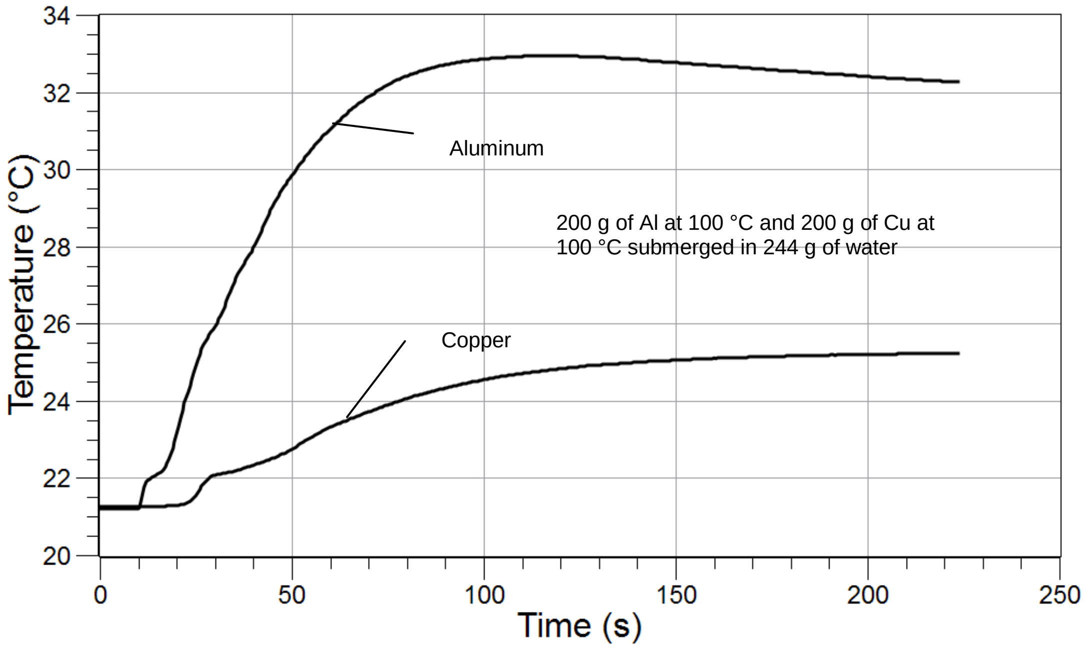
39. ☐ After a few minutes, when the Temperature versus Time plot levels off, stop data recording. � (6.2)

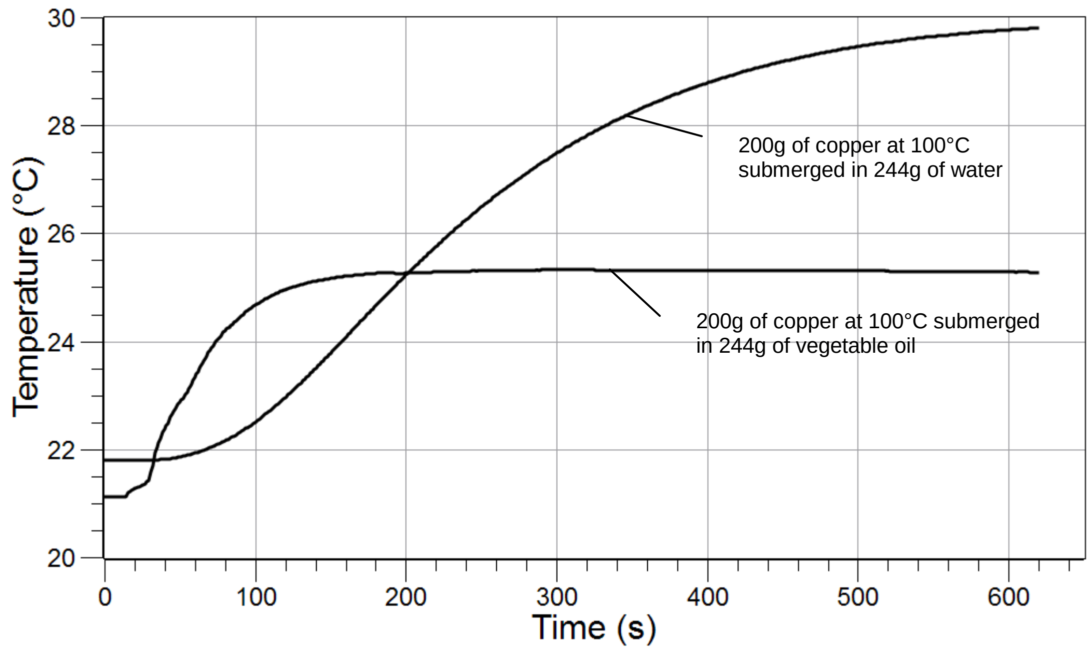
Analyze Data

40. ☐ For each liquid sample, find the initial temperature (minimum) and the final temperature (maximum), and record those values into Table 3 in the Data Analysis section. � (9.4)

41. ☐ Save your experiment as instructed by your teacher. � (11.1)

Sample Data





Data Analysis

Part 1– Different materials in the same fluid

Mass of Aluminum: 200 g   Mass of Copper: 200 g

Table 1: Change in temperature, same fluid

Metal Sample	Initial Temperature (°C)	Final Temperature (°C)
Water with Aluminum	21.2	32.9
Water with Copper	21.3	25.2

1. ☐ Calculate the change in temperature for each sample, and enter the change in Table 2.

32.9 – 21.2 = 11.7; 25.2 – 21.3 = 3.9

Table 2: Change in temperature, same fluid

Metal Sample	Temperature Change (°C)
Water with aluminum	11.7
Water with copper	3.9

Part 2– Similar materials in different fluids

Mass of Sample 1: 200 g   Mass of Sample 2: 200 g

Table 3: Change in temperature, different fluids

Fluid	Initial Temperature (°C)	Final Temperature (°C)
Vegetable oil	21.8	29.8
Water	21.1	25.3

2. ☐ Calculate the change in temperature for each sample, and enter the change in Table 4.

29.8 – 21.8 = 8.0; 25.3 – 21.1 = 4.2

Table 4: Change in temperature, different fluids

Fluid	Temperature Change (°C)
Vegetable oil	8.0
Water	4.2

Analysis Questions

1. In each case where you started with a metal that was hot and a liquid at room temperature, what happened to the temperature of the liquid? What does this tell you about the flow of heat?

In each case the temperature of the liquid increased, indicating that its internal energy had increased. Therefore, heat must be flowing from the hot metal sample to the cold liquid.

2. How does the change in water temperature compare for the different metals submerged in the same amount of water?

The change in temperature for the water with the aluminum sample is approximately three times as much as the change in temperature for the water with the copper sample (based on the sample data).

3. The temperature change of the water represents the change in the water's internal energy. Compare the amount of heat delivered by the different metal samples submerged in water. Explain your answer.

Because heat is the amount of energy transferred, and temperature is related to the amount of energy in a material, then more heat was transferred in the aluminum-water system than the copper-water system.

4. The initial temperature of the metal samples was the same, and the initial temperature of the water in the cups was the same. Because the final temperature of the water in the different cups is different, what does this tell you about internal energy of the metal samples when they are at the same temperature in the water bath? Explain?

The aluminum was able to deliver more energy to the water, so it must have more internal energy than copper even though they started at the same temperature.

5. What does the answer from the previous question tell you about the temperature and heat of two different metals?

Two different metals of the same mass can have the same temperature but different internal energies and different capacities to deliver heat.

6. How does the change in temperature compare for the same metal submerged in different fluids?

The change in temperature for the vegetable oil is three times as much as the change in temperature for the water but took much longer (based on the sample data).

7. The copper samples are the same material at the same temperature initially. Therefore, they must start out with the same internal energy. Compare how the heat from the metal samples affects the liquids they are submerged in. Explain your answer.

The same amount of energy coming from the copper causes the oil to increase its temperature more than the water, so different liquids have different capacities to absorb heat.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What is the difference between heat and temperature?

Heat is the amount of energy given off from a warm object to a cold object; whereas, temperature is a measure of the amount of heat in an object.

2. Imagine you have two copper samples, one that is 100 g and one that is 200 g, each at a temperature of 85 °C. If each sample is placed into a cup of room-temperature water, which cup will be the hottest after they both reach equilibrium? Explain.

The 200 g sample will be hotter because it has twice as much heat to deliver to the water. The 200 g sample has twice as much mass; therefore, the amount of heat stored in the 200 g mass will be twice as much as the 100 g sample.

Multiple Choice Questions

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

1. A 200 g mass of copper at 150 °C is placed on top of a 400 g mass of aluminum at 20 °C. The internal energy of the aluminum increases because

- **A.** Heat transfers from the aluminum to the copper.
- **B. Heat transfers from the copper to the aluminum.**
- **C.** The average kinetic energy of the copper increases.
- **D.** It begins to melt.

2. Which of the following best describes heat?

- **A.** The amount of translational kinetic energy in a material
- **B.** The average kinetic energy in a material
- **C.** The total energy in a material
- **D. The transfer of energy from one material to another without work being done**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Two common temperature scales used in science are the **Kelvin** and **Celsius** scales. Temperature is related to the average **kinetic energy** of the particles in a material. Kinetic energy depends upon the mass and **velocity** of particles. The particles move in different ways. Some particles may have **translational** or straight-line motion, while others may vibrate or even spin.

2. The word "heat" is loosely used in common language. However, in science it specifically relates to the **transfer** of energy from one material to another. Sometimes the term "heat" is used interchangeably with the term "thermal energy." Thermal energy is in fact the total amount of **energy** contained in a material. Heat transfers spontaneously from a **hot** object to a **cold** object.

Extended Inquiry Suggestions

Consider these variations of this activity:

- Use lead masses instead of copper and aluminum masses.
- Use different amounts of each mass; for example, 100 g or 400 g masses instead of 200 g masses.
- Use different amounts of each fluid.

23. Voltage: Fruit Battery/Generator

Objectives

This activity introduces students to voltage. The activity explores both the chemical and physical production of a potential difference and allows students to:

- ♦ Produce a potential difference
- ♦ Understand the construction of a battery
- ♦ Understand the similarities and differences of batteries and generators

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Using probeware to measure discrete voltages
- ♦ Constructing a simple fruit battery
- ♦ Comparing voltages of batteries in series
- ♦ Comparing voltages of batteries in parallel

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	25 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Voltage sensor
- ♦ Piece of copper[1]
- ♦ Piece of zinc[2]
- ♦ Series/parallel battery holders
- ♦ Batteries, "D" cell (3)
- ♦ Alligator clips (one red, one black)
- ♦ Variety of fruit (minimum of 1 piece per student group)

[1]Heavy gauge, solid bare copper wire works well
[2]Galvanized nails work well

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Charge and units of charge
- ♦ Electric fields
- ♦ Potential Energy

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Faraday's Law of Induction

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- ♦ Monitoring live data without recording �(6.1)

Background

Voltage, also known as electric potential or electromotive force (EMF), measures the potential of an electric field to cause charge to move and is measured in volts. Just as with gravitational potential energy, electric potential can be converted into other forms of energy, such as heat or motion.

When we create an electric potential, the potential difference is measured between two reference points (e.g. the potential indicated on a battery is between the two terminals of the battery, usually marked + and –). Because charges can be both positive and negative, electric potentials can be both positive and negative.

There are different ways to create electric potential. As one can learn from studying charges, we can physically move charge from one object to another and give rise to an imbalance in charge, thus producing an electric potential.

Count Alessandro Giuseppe Antonio Anastasio Volta (1745–1827) was a physicist known especially for the development of the electric cell. In 1800, he invented the voltaic pile, an early electric battery which produced a steady electric current. Volta had determined that the most effective pair of dissimilar metals to produce electricity was zinc and silver. He first experimented with individual cells, each cell being a glass filled with brine into which the two dissimilar electrodes were dipped. The electric pile replaced the glasses with cardboard soaked in brine. The battery made by Volta is credited as the first electrochemical cell. For this experiment we replace brine-soaked cardboard with the electrolytes of a piece of fruit.

Michael Faraday (1791–1867) discovered the operating principle of electromagnetic generators. The principle, later called Faraday's law, states that a potential difference is generated between the ends of an electrical conductor that moves perpendicular to a magnetic field. He also built the first electromagnetic generator, called the Faraday disc, using a copper disc that rotated between the poles of a magnet. It produced a small DC voltage and large amounts of current.

Pre-Lab Discussion and Activity

For the Demonstration Station:

- Data collection system
- Voltage sensor
- Projection system
- Series/parallel circuit board
- Hand crank generator

Set Up

1. Start a new experiment on the data collection system. �[1.2]

2. Connect the voltage sensor to the data collection system. �[2.1]

3. Connect the terminals from the hand crank generator to the voltage terminals on the voltage sensor.

4. Configure the data collection system to monitor live data without recording. �[6.1]

Demonstration

Have the display from your data collection system projected in front of the class. Review the idea of charges, and the fields between like and dissimilar charges. You may want to simply rub a balloon on your hair and stick it to a wall to show that there are actual forces involved.

Select a student volunteer and have the student volunteer give the crank a few turns to show that a voltage is being produced by the generator.

Connect the terminals from voltage sensor and generator in parallel across one of the small light bulbs on the Series/Parallel Circuit Board (parallel mode).

Ask your volunteer to begin to turn the crank so that the light bulb is clearly lit.

1. **What kind of energy is being converted?**

The mechanical energy is being converted into electrical energy and the electrical energy is being converted into light and heat.

2. Ask the volunteer which was easier, before or after the bulb was added?

Before the bulb.

3. The generator is creating a potential difference across the "load" (the light bulb). Do you think it will be easier or harder to turn the crank on the generator if we double the load?

It will get harder.

Add the second bulb to the circuit, in parallel to the first. Have the volunteer now turn the crank on the generator with two bulbs in parallel.

4. Which was easier, one or two bulbs?

One bulb

Explain to your students that continuous energy must be provided to the system to maintain the potential across the load. This is essentially what happens at the opposite end of the power sockets on the wall, but on a much larger scale.

Explain to students, "As you might imagine, it would be nice to have other ways to make this kind of energy and store it until it is needed, i.e. batteries."

Lab Preparation

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

1. Provide a variety of fruits so each group will be able to try three different types.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ The fruit should not be consumed after use in this lab.

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.

4	2	1	3
Record the voltage produced by a second piece of fruit and compare it with the first.	Insert the copper and the zinc electrodes into your piece of fruit.	Ensure the copper and zinc electrodes are clean and free of corrosion.	Record the voltage value.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Electrochemical cells

Set Up

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

2. ☐ Connect your voltage sensor to the data collection system. �(2.1)

3. ☐ Configure the data collection system to monitor live data without recording. �(6.1)

4. ☐ What happens to two "like" charges (positive and positive, or negative and negative) when they are near each other?

Two like charges will repel each other.

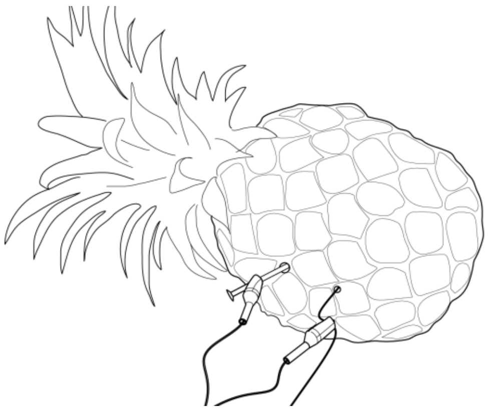
5. ☐ Mount the red and black alligator clips on the voltage sensor's 4 mm banana connector leads.

6. ☐ Choose the first piece of fruit.

7. ☐ Push the copper wire and the zinc-coated nail into the fruit about 5 cm apart. Leave about 2 cm of each electrode exposed.

8. ☐ Connect the red alligator clip to the copper wire.

9. ☐ Connect the black alligator clip to the zinc-coated nail.



10. ☐ As the electrolytic solution decreases the number of positive charges on one of the metal electrodes, is the number of negative charges changing on that same electrode? Is that electrode now positively charged or negatively charged?

The number of negative charges is not changing, but the net charge is now negative, making the electrode negatively charged.

Collect Data

11. ☐ Let the voltage value stabilize, and then record the voltage value and fruit (cell) type in Table 1 in the Data Analysis section.

12. ☐ Remove the electrodes from the fruit, clean them off, and insert them into the next piece of fruit.

13. ☐ Let the voltage value stabilize, and then record the voltage value and fruit (cell) type in Table 1 in the Data Analysis section.

14. ☐ Remove the electrodes from the fruit, clean them off, and insert them into the next piece of fruit.

15. ☐ Let the voltage value stabilize, and then record the voltage value and fruit (cell) type in Table 1 in the Data Analysis section.

16. ☐ Detach the leads of the voltage sensor from the alligator clips.

17. ☐ Hold the red lead to the positive end of a battery and the black lead to the negative end. Let the voltage value stabilize, and then record the voltage value and fruit type (D-cell battery) in Table 1 in the Data Analysis section.

Part 2 – Multiple cells

Set Up

18. ☐ Place three batteries in individual battery holders.

19. ☐ Connect the voltage sensor across the terminals of one of the batteries, red to positive and black to negative.

Collect Data

20. ☐ Record the voltage value of one cell in Table 2 in the Data Analysis section.

21. ☐ Connect a second battery holder to the first so that the positive terminal of the first is connected to the negative terminal of the second (connected in series).

22. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

23. ☐ Record the voltage value for two cells in series in Table 2.

24. ☐ Connect a third battery holder to the first two so that the positive terminal of the first two is connected to the negative terminal of the third (connected in series).

25. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

26. ☐ Record the voltage value for three cells in series in Table 2.

27. ☐ Disconnect the batteries and connect one of the batteries to the voltage sensor again, and enter the voltage value for one cell in Table 3.

28. ☐ Connect a second battery holder to the first so that the positive terminal of the first is connected to the positive terminal of the second and the negative terminal of the first is connected to the negative terminal (connected in parallel).

29. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

30. ☐ Record the voltage value for two cells in parallel in Table 3.

31. ☐ Connect a third battery holder to the first two so that the positive terminal of the second is connected to the positive terminal of the third (connected in parallel), and the negative terminal of the second is connected to the negative terminal of the third.

32. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

33. ☐ Record the voltage value for three cells in parallel in Table 3.

Data Analysis

Table 1: Fruit and voltage

Fruit	Voltage (V)
Lemon	0.97
Tomato	0.91
Pineapple	0.93
"D" Battery	1.54

Table 2: Connected in series

Number of Cells	Voltage (V)
1	1.54
2	3.01
3	4.52

Table 3: Connected in parallel

Number of Cells	Voltage (V)
1	1.54
2	1.51
3	1.51

Analysis Questions

1. How does the voltage of the first piece of fruit compare to the voltage of the second piece of fruit? Why do you think they are different or similar?

The voltage produced by the fruits were similar because the strength of the electrolyte solution in each piece of fruit was about the same.

2. How does the voltage of either piece of fruit compare to the voltage of the D-Cell battery? Why do you think they are different or similar?

The difference in voltage between the fruit and the battery was over 0.5 volts, more than 50% greater than the fruits. This was due to the strong electrolyte solution (acid) inside the battery.

3. What is one thing that might increase the voltage from the piece of fruit?

One thing that might increase the voltage is using a fruit with a stronger electrolyte solution inside it.

4. Could you light the bulb from a flashlight with the voltage of a piece of fruit? Why or why not?

No, because although the fruit battery produces a sufficient voltage, it can't provide a sufficient current to light the bulb.

Synthesis Questions

Use available resources to help you answer the following questions.

1. An electrochemical cell made from a piece of fruit may supply a sufficient voltage to power some small electrical devices. However, its total charge on each electrode and the rate at which the net charge is produced is not sufficient to produce a proper current for these devices. What is one way to fix this problem using several electrochemical cells?

One way to fix this problem would be to attach several fruit batteries together at once in parallel.

2. What would happen to the voltage measurement from your fruit battery if the two electrodes accidentally touched each other? Justify your answer.

If the electrodes accidentally touched each other, the voltage would drop to zero because the charges would jump across the electrode, equilibrating the net charge on each.

Multiple Choice Questions

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

1. What are two key parts of any electrochemical cell?

- **A.** Copper and zinc
- **B.** **Electrodes and electrolyte**
- **C.** Fruit juice and copper sulphate
- **D.** Unknown

2. If you measured the voltage across two pieces of metal, and that voltage was zero, which of the following statements is true?

- **A.** Each piece of metal has zero charges on it.
- **B.** There are more positive charges on one piece of metal than the other.
- **C.** **Each piece of metal has the same net charge on it.**
- **D.** There are more negative charges on one piece of metal than the other.

3. If you connected the electrodes from two identical fruit batteries together (zinc to zinc and copper to copper), the voltage would be:

- **A.** Twice as much as one fruit battery
- **B.** Half as much as one fruit battery
- **C.** Zero
- **D.** **The same as one fruit battery**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. We have found many ways to turn **generators**. Wind power, hydro power, burning fossil fuels, and splitting atoms have all been used to ultimately turn a generator and provide a **voltage** to the various appliances we use in our everyday life. The need for consistent reliable **electromotive** force to move **charge** across the ever growing consumer **load** has given rise to a global, multi-billion dollar power generation industry.

2. Most electronic devices that have rechargeable batteries use a combination of smaller **cells** connected in **series** to provide just the right voltage required for each device. The manufacturers must balance how long a device will last on a single charge with how much space and weight the **battery** can have when deciding how many cells they can connect in **parallel**.

3. The electric **potential** between the terminals of a battery causes charge to flow in a conductor when it is connected to the **terminals**. If one of the terminals is connected to the Earth, it is said to be grounded. A large potential **difference** can cause charge to flow through things that are not very **conductive**, like a dramatic lightning discharge in air.

Extended Inquiry Suggestions

If the appropriate materials are available, this is a good time to introduce the idea of a changing voltage (AC) and why it is important for power transmission.

This is also a natural time to lead into the idea of current as moving charge.

1 ampere = 1 coulomb per second

If connecting batteries in series gives you more voltage, why do you think it is important to connect batteries in parallel?

This provides more current, or longer battery life.

24. Faraday's Law of Induction

Objectives

In this experiment, students observe the electromotive force generated by passing a magnet through a coil. Students will explore the relationship between:

- ♦ The number of turns in the coil and the magnitude of the electromotive force
- ♦ The rate of change of the magnetic flux by virtue of the size of the magnetic field in motion and the magnitude of the electromotive force
- ♦ The rate of change of the magnetic flux by virtue of the speed of the magnet field in motion and the magnitude of the electromotive force

Procedural Overview

Students gain experience measuring a continuously changing voltage for a very short duration. This lab pays particular attention to the scientific method of isolating a variable. In each of three parts, students isolate and change a single variable to determine the effect it has on the outcome.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Voltage sensor
- ♦ Coils (3), 200-, 400-, and 800-turn
- ♦ Magnets (3), different strengths
- ♦ Rod stand
- ♦ Three-finger clamp
- ♦ Paper
- ♦ Tape
- ♦ Pen or pencil
- ♦ No-bounce pad (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Voltage or electromotive force
- ♦ Current
- ♦ Magnetic fields
- ♦ Acceleration due to gravity

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Voltage: Fruit Battery/Generator

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 your data collection system �(2.1)
- ♦ Changing the sample 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 in a graph �(7.1.3)
- ♦ Adding a note to a graph �(7.1.5)
- ♦ Drawing a prediction �(7.1.12)
- ♦ Saving your experiment �(11.1)

Background

Michael Faraday (1791–1867) discovered a relationship between a changing magnetic flux Φ (magnetic field strength), and the potential within a conductor ε:

$$\varepsilon = -N \frac{\Delta\Phi}{\Delta t} \qquad \text{(Eq. 1)}$$

Known as Faraday's Law, this relationship summarizes how a voltage (potential ε) may be generated by a change in the electromagnetic environment (such as changing the magnetic field strength). It is defined by two key elements: the number of turns in a coil N, and the change in magnetic flux Φ. The negative sign indicates that the induced electromotive force (emf) always opposes the change in magnetic flux. Magnetic flux is related to the strength of the magnetic field B, the area enclosed by the wire loop A, and the angle between them θ.

$$\Phi = BA\cos\theta \qquad \text{(Eq. 2)}$$

Because the size of the coil used in this activity is fixed and students will be dropping the magnet through the coil perpendicular to the plane of the wire loops in the coil (for which the cosine θ term in Eq. 2 equals 1) we can say that the flux is proportional to the strength of the magnetic field B.

Students will investigate the rate of change of flux by using magnets of different strength and increasing the rate at which the magnet passes through the coil. We will use three different coils to see what effect the different number of turns in a coil has on the induced electromotive force.

Pre-Lab Discussion and Activity

For the demonstration station:

- Data collection system
- Voltage sensor
- 800-turn coil
- Projection system recommended
- Magnet
- DC voltage supply
- Magnetic field sensor
- Patch cord, 4-mm banana plug (2)

Connect the DC power supply directly to the coil using the banana plug patch cords. Demonstrate with a magnetic field sensor that, when the power is "off," the magnetic field strength is zero, and when the power is "on," a field is present and stable. Use the magnetic field sensor to show that a stable field is also present around your magnet.

Connect the voltage sensor directly to the coil. Place the magnet in the center of the coil and hold it in place. Begin collecting or monitoring voltage data and show that the voltage produced by the static magnetic field is zero. This can also be accomplished with a demonstration multi-meter or voltmeter.

Challenge your students to predict what will happen when you pull the magnet out of the coil.

Teacher Tip: Accept all answers, and write ideas on the board or overhead projector, keeping them displayed during the activity.

Quickly pull the Magnet out of the coil, and discuss the result relative to the student predictions.

Lab Preparation

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

Although this activity 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:

- Be careful with magnets. Strong magnets can disrupt electronic devices and severely pinch any skin that comes between them.
- Especially keep magnets away from computer hard drives, USB drives, or videotapes.

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.

1	3	5	4	2
Connect the Voltage Sensor to the Data Collection System.	Drop the magnet through the coil, and then stop data collection.	Compare the voltage produced by the 200-turn coil to that produced by the 400 turn coil on the graph.	Remove the 200-turn coil and replace it with the 400 turn coil.	Begin collecting data with your Data Collection System.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – As the coil turns: same magnet, different coils

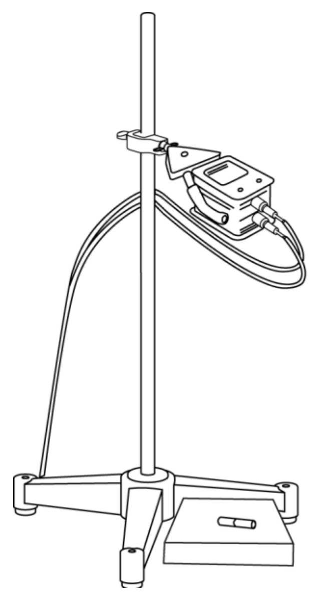
In the first part of this lab, we determine if passing a magnet through a coil of wire gives rise to a voltage (or electromotive force), and whether the number of turns in the coil *N* has any effect on the amount of voltage as predicted in Faraday's equation.

Note: For the best comparison, always be sure to use the same orientation of the magnet when dropping it through the coil.

Set Up

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

2. ☐ Mount the 200-turn coil to the rod stand using the three-finger clamp, approximately 40 cm above the lab table.



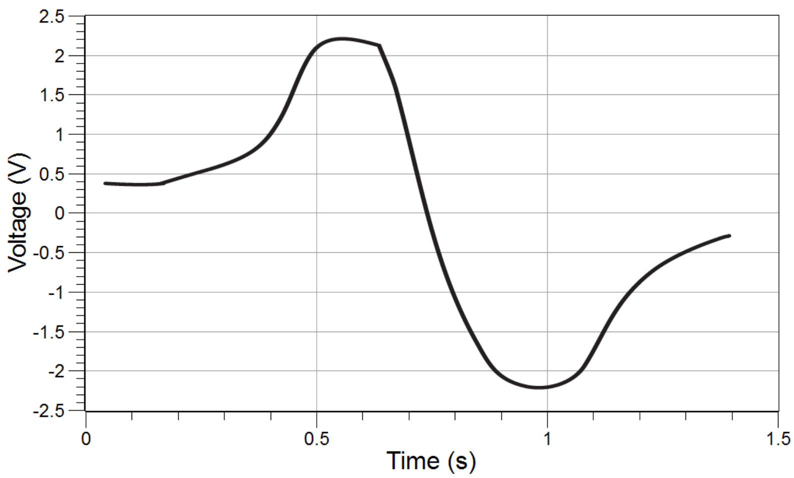
3. ☐ Connect the voltage sensor to the coil. If you are using a no-bounce pad, place it below the coil.

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

5. ☐ Display a graph of Voltage versus Time data on your data collection system. �(7.1)

6. ☐ Set the sampling rate of your data collection system for at least 1000 samples per second. �(5.1)

7. ☐ Given the bipolar nature of a magnet, try to predict the shape of the Voltage versus Time curve using the data collection system, and sketch your prediction on the graph below. �(7.1.12)



8. ☐ If a changing magnetic field causes charges to move in a conductor, and charges moving in a conductor give rise to a magnetic field, what do you think the orientation of the induced magnetic field would be relative to the original changing magnet field?

The new field should have the opposite orientation of the changing magnetic field.

Teacher Tip: This could also be expressed as resisting or opposing the change of the original field.

Collect Data

9. ☐ Hold the magnet just above the coil opening.

10. ☐ Start collecting data with the data collection system. �(6.2)

11. ☐ Drop the magnet through the coil, and then quickly stop collecting data. �(6.2)

12. ☐ Annotate your data run with the number of turns in the coil you used. �(7.1.5)

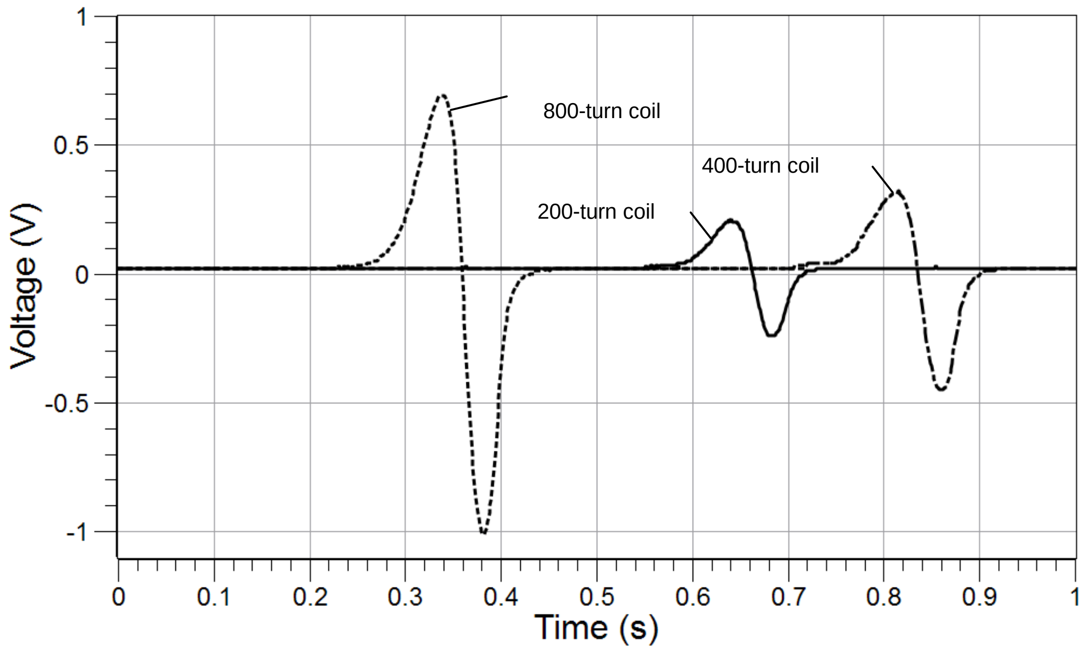
13. ☐ Replace the coil with the next in the series, and repeat the data collection steps for each coil.

Analyze Data

14. ☐ Display all three data runs on the graph on your data collection system. �(7.1.3)

15. ☐ Adjust the axis of your graph to focus on the portions of the graph where the greatest change in voltage takes place. �(7.1.2)

16. ☐ Sketch your graph below, and be sure to indicate which run corresponds to which coil.



17. ☐ Describe one of the major differences between the data runs.

The peak voltage increases as the number of turns in the coil increases

18. ☐ Describe the relationship between the number of turns in the coils and the peak voltages you observed.

The peak voltage appears to be proportional to the number of turns in the coil.

Part 2 – More magnets: same coil, different magnets

The second part of Faraday's equation refers to the rate of change in magnetic flux. From our observations of magnets, different types of material produce different strengths of magnetic field. Try at least three magnets of different strengths to see if the strength of the magnet makes a difference. Use only one of the coils, and drop the magnets from the same height each time.

Set Up

19. ☐ Use the same set up for this part as in Part 1, but use only the 200-turn coil.

Collect Data

20. ☐ Hold the first magnet just above the coil opening.

21. ☐ Start collecting data with the data collection system. �(6.2)

22. ☐ Drop the first magnet through the coil, and then quickly stop collecting data. �(6.2)

23. ☐ Annotate your data run with the identifier for the magnet you used. �(7.1.5)

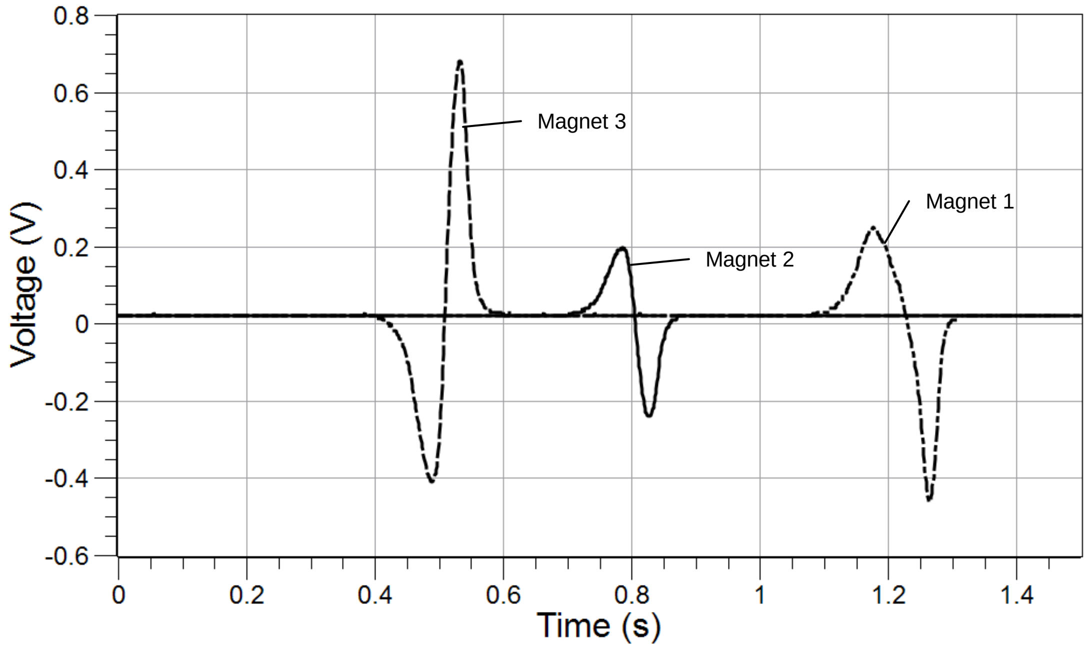
24. ☐ Repeat the data collection steps for each of the magnets, dropping the magnets from the same height each time.

Analyze Data

25. ☐ Display all the data runs on the graph on your data collection system. �(7.1.3)

26. ☐ Adjust the axis of your graph to focus on the portions of the graph where the greatest change in voltage takes place. �(7.1.2)

27. ☐ Sketch your graph below, and be sure to indicate which run corresponds to which magnet.



28. ☐ Describe one of the major differences between the data runs.

The peak voltage increases with stronger magnets.

29. ☐ Describe the relationship between the strength of the magnets used and the peak voltages you observed. What would you measure to better understand the relationship?

The peak voltage appears to be proportional to the strength of the magnet used, but measuring the strength of the magnets would give a better understanding of the relationship.

Part 3 – The faster the flux: one magnet, one coil, and different speeds

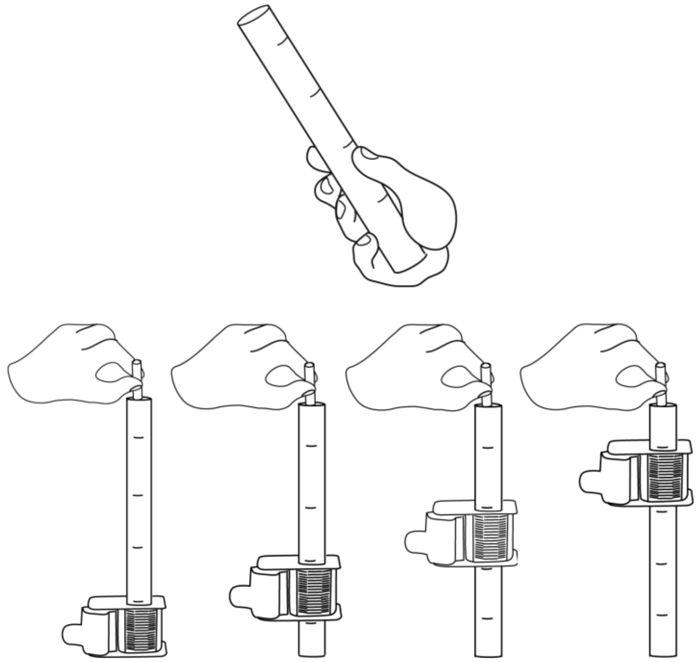
If the strength of the magnet affects the change in flux, how about the speed at which the magnet passes through the coil? The farther an object falls in a gravitational field, the faster it travels. If the magnet passes through the coil faster, it is reasonable that the magnetic flux in the coil is changing faster. Use one of your coils to find out.

Set Up

30. ☐ Use the same set up for this part as Part 1, but using only the 200-turn coil and a single magnet.

31. ☐ Roll up a piece of paper into a tube, and tape it securely. The tube should be wide enough to allow your magnet to pass through freely, but narrow enough to fit inside the coil.

32. ☐ Mark four equally spaced positions on the tube and slide the tube into the coil so that the first mark is showing just above the coil opening.



Collect Data

33. ☐ Hold the magnet just above the tube opening.

34. ☐ Start collecting data with the data collection system. �(6.2)

35. ☐ Drop the magnet through the tube/coil, and then quickly stop collecting data. �(6.2)

36. ☐ Annotate your data run indicating the height from which the magnet was dropped (for example,1st Mark)

37. ☐ Slide the tube down into the coil until the next mark on the tube is just above the opening of the coil.

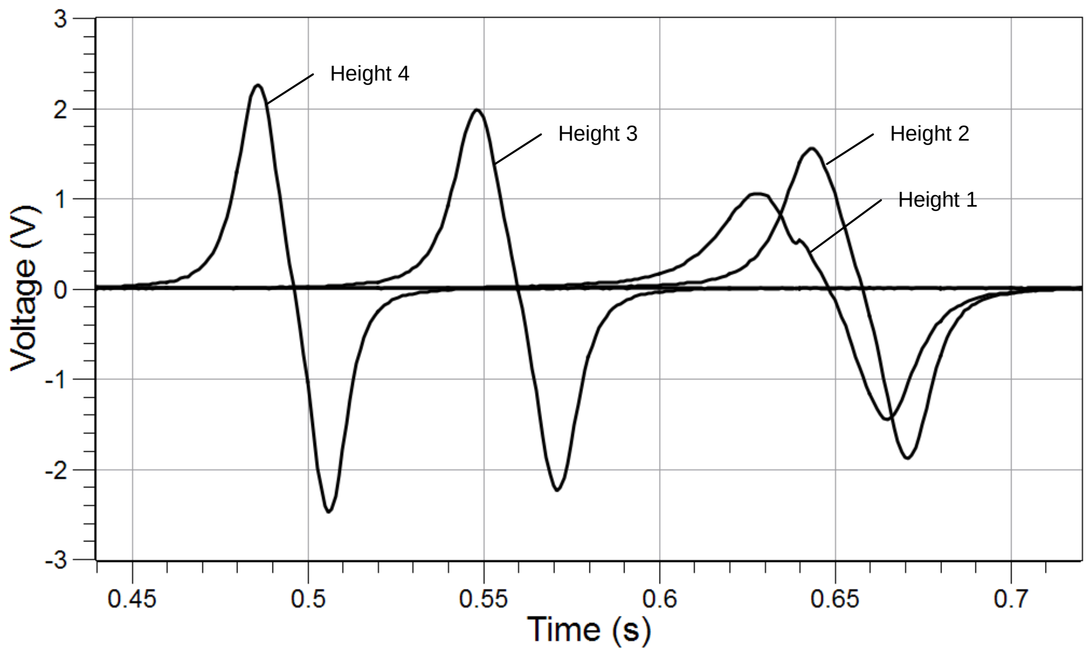
38. ☐ Repeat the data collection steps for each mark on the side of the tube.

Analyze Data

39. ☐ Display all the data runs on the graph on your data collection system. �(7.1.3)

40. ☐ Adjust the axis of your graph to focus on the portions of the graph where the greatest change in voltage takes place. �(7.1.2)

41. ☐ Sketch your graph below, and be sure to indicate which run corresponds to which height.



42. ☐ Describe one of the major differences between the data runs.

The peak voltage appears to increase with the speed of the magnet through the coil

43. ☐ Describe the relationship between the height at which the magnet fell above the coil and the peak voltages you observed. What would you measure to better understand the relationship?

The peak voltage appears to be proportional to the speed the magnet travels through the coil, but measuring the speed of the magnet as it passes through the coil would give a better understanding of the relationship.

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

Analysis Questions

1. How does your prediction compare to the actual Voltage versus Time graph?

Answers will vary.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Based on your observations in this lab, describe the characteristics of an electric coil generator that you would optimize to get the most electromotive force out?

To produce the largest electromotive force, the generator would need to have as many coil turns as possible, have the strongest magnets available, and move as fast as possible.

2. You may have noticed that the second peak of the voltage curve is always in the opposite direction of the first peak. However, you may not have noticed that it is also a slightly higher peak. Can you describe why that might be?

The peak was higher because the magnet is speeding up as it falls, making the top part of the magnet travel faster as it passes through the coil.

Multiple Choice Questions

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

1. The electromotive force (emf) produced from dropping a magnet through a coil is a form of energy transformation. What kind of transformation is it?

- **A.** Thermal energy is transformed into electrical energy.
- **B.** Mechanical energy is transformed into thermal energy.
- **C.** **Kinetic energy is transformed into electrical energy.**
- **D.** Electrical energy is transformed into thermal energy.

2. If a generator with a 200-turn coil produced 120 V of electromotive force, how much would it produce if it was upgraded to an 800-turn coil?

- **A.** 40 V
- **B.** **480 V**
- **C.** 220 V
- **D.** There is not enough information to draw a conclusion.

3. The equation for Faraday's Law includes a negative sign on one side. What does it represent?

- **A.** Magnetism is an inherently negative force.
- **B.** Opposites attract.
- **C.** The emf generated seeks to reinforce the change in magnetic field.
- **D.** **The emf generated seeks to oppose the change in magnetic field.**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Faraday's Law defines the relationship between the number of turns in a **coil** *N*, and the rate of change in **magnetic flux** Φ. Magnetic flux is related to the strength of the magnetic field, the area enclosed by the wire loop, and the angle between them. Because of the geometry of the experiment, we can say that the flux is proportional to the strength of the magnetic **field**.

Extended Inquiry Suggestions

Project: Build a Generator

Provide your students with raw parts (such as magnets, wire, etc.), and have them build a small generator. In groups of 3 to 5 students, ask them design and build a generator. Ask them to present their work to the class and include a live demonstration of the device.

Introducing area under a curve

Ask your students to repeat the experiment using one magnet and one coil of their choosing. On the graph of Voltage versus Time, have them use their data collection system to explore the area under the curve. �(9.7)

What are the units for the area under the curve?

Volt-seconds (v•s)

What does this represent?

The volt-second is also known as the weber and is a unit of magnetic flux

Demonstration

Use a hand-cranked generator to show how physical motion can be used to produce an electromotive force, and induce current to power a circuit.

Also, a discussion of electrical transformers could help here. You can discuss the electrical grid and how voltages are adjusted for domestic use and long-distance transmission. A great demo to enhance this discussion would be a "Jacob's Ladder," which transforms voltage from 120 V AC up to 10,000 V AC which is then high enough to jump a small gap and form the infamous "rising spark" so common to old sci-fi movies.

Other relevant applications worth mentioning are:

How does a "hybrid" car save so much money on gas?

Induced current from mechanical braking sets up an induced current that recharges electrical batteries, which becomes usable energy.

Earth Science

25. Radiation Energy Transfer

Objectives

Students determine the effect the color of a container has on the temperature of water in the container as it is heated using radiant energy. Through this investigation, students:

- Describe radiant energy
- Describe the relationship between an object's color and its ability to absorb energy
- Explain that different surfaces on Earth absorb different amounts of radiant energy

Procedural Overview

Students gain experience conducting the following procedures:

- Graphing temperature versus time data as water, in different colored cans (black and silver), is heated using radiant energy from a light bulb
- Comparing the change in the temperature of water in the black container to the water in the silver container

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activities	30 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor (2)[1]
- Graduated cylinder, 100-mL
- Heat lamp (or 150-W lamp)[2]
- Radiation can (2), 1 black, 1 silver[3]
- Insulated pad (2)
- Ring stand
- Water, room temperature, 0.5 L

[1] Use two of the same type of temperature sensors (either stainless steel or fast response).

[2] An inexpensive 150-W shop light, available in hardware stores, works well in this activity.

[3] The radiation cans need to be the same size.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The difference between radiation, conduction, and convection
- The difference between heat and temperature

Related Labs in This Guide

Labs conceptually related to this one include:

- Insolation and the Seasons
- Temperature versus Heat
- Specific Heat of Sand versus Water

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sampling rate �(5.1)
- Recording a run of data �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple variables on the *y*-axis �(7.1.10)
- Finding the values of a point in a graph �(9.1)
- Measuring the difference between two points in a graph �(9.2)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

Uses of incoming solar radiation

The Earth receives an enormous amount of radiant energy from the sun. This energy is used in many ways. Some of the energy drives processes in the atmosphere that cause wind and waves. Some of it is converted to chemical potential energy through the process of photosynthesis and some is absorbed as thermal energy by the oceans and continents. The radiant energy that becomes trapped in our atmosphere is what keeps Earth the perfect temperature for life to exist and thrive.

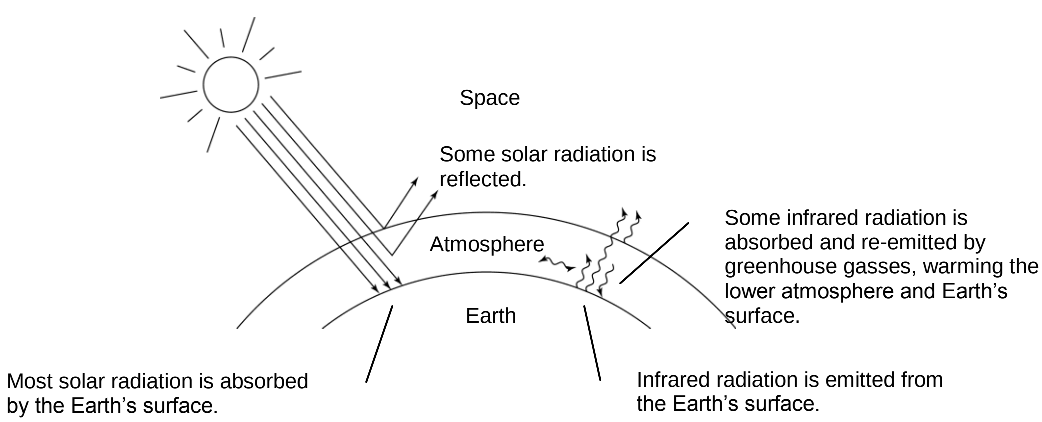
Electromagnetic spectrum

Solar radiation is made up of the entire spectrum of electromagnetic waves. Visible light, the light that we can see, is only a tiny part of this spectrum. Other types of electromagnetic radiation produced by the sun include infrared radiation (thermal energy), microwaves, radio waves, ultraviolet light, X-rays, and gamma rays.

All electromagnetic radiation travels at about 300,000 kilometers per second in a vacuum. Although velocity is constant for all forms of light energy, electromagnetic radiation varies inversely in wavelength and frequency: the higher the frequency of the wave, the shorter the wavelength. Radio waves have very long wavelengths, ranging to tens of kilometers and correspondingly low frequencies. Gamma rays have very short wavelengths that are less than one billionth of a centimeter, with extremely high frequencies.

What happens to incoming solar radiation?

Incoming solar radiation is scattered, reflected, or absorbed by the atmosphere or the Earth's surface. Earth's atmosphere protects us from most X-rays, gamma rays, and ultraviolet radiation by reflecting these wavelengths of light back into space. The light that travels through our atmosphere is either reflected or absorbed by Earth's surface. Different surfaces absorb and reflect differing amounts of solar radiation.



When radiant energy reaches a surface on Earth some of the energy is absorbed and some of it is reflected. The percentage of radiation absorbed depends on the properties of the surface it hits. Dark and rough surfaces absorb more radiation and reflect less radiation. Light, smooth, shiny surfaces reflect more radiation and absorb less. The term albedo is used to compare the degree to which different surfaces reflect incoming solar radiation. Surfaces with high albedo reflect more radiation than surfaces with low albedo. Surfaces with low albedo absorb more radiant energy than they reflect.

When surfaces absorb radiant energy they become warmer. This in turn increases their thermal energy, or total internal energy. Likewise, cooling decreases thermal energy. The total amount of energy the Earth receives is in equilibrium with the total amount of energy the Earth loses and is called Earth's energy budget.

Pre-Lab Discussion and Activities

Materials and Equipment for Pre-lab Activities

- Data collection system
- Light sensor
- Fast-response temperature sensor
- Black paper, same size as the white paper
- White paper, same size as the black paper
- Sunlight

Personal Experience with Color and Heat

Engage the students in a discussion about their experiences with the affect of color on the absorption of heat.

1. On a hot summer day, if you want to keep from getting overly warm, would you prefer to wear a dark colored shirt or a light colored shirt? Why?

Students would prefer to wear a light colored shirt because it feels cooler. Darker clothes absorb more heat and are therefore feel hotter.

2. Do you expect the temperature inside of light colored car and a dark colored car that were both parked in the direct sun for one hour to be the same or different? How do you know?

Students would expect the dark colored car to be hotter inside. They know this from personal experience.

3. Would you prefer to walk barefoot on a blacktopped playground or on a cement sidewalk?

Students would prefer to walk on the sidewalk because it is cooler and their feet won't burn.

Absorption and Reflection of Radiation

Show the students two pieces of paper of equal size, one black and one white, sitting in the sunlight. Have the students predict which paper reflects the most sunlight. Then measure the light being reflected using a light sensor. Have the students explain what happens to light that is not reflected and discuss how to measure light that is absorbed.

4. How will the light reflected from each piece of paper compare?

The white paper will reflect more radiant energy than the black paper.

5. What data can we collect to determine the answer to the question above?

Use a light sensor to determine the radiant energy being reflected off each paper.

6. What do the results indicate?

The results show that white paper reflects more sunlight (1,852 lux) than black paper (1,320 lux).

7. Is the same amount of radiant energy (sunlight) hitting each piece of paper?

Yes, the two papers are right next to each other and there are not filters or object blocking the light.

8. What happens to the radiant energy that is not being reflected?

It is being absorbed by the paper.

9. How could we measure the amount of solar radiation absorbed by an object? Why would this work?

Measure the temperature of each object. This will work because when an object absorbs radiant energy the total thermal energy in the object increases causing it to get warmer.

10. What piece of paper do you expect to have a higher temperature? Why?

Students will expect the black paper to have a higher temperature. According to the data collected earlier, less radiant energy is being reflected from the black paper (than the white paper) so it must be absorbing more energy and thus have a higher temperature.

11. Were your predictions correct?

Yes, the black paper had a warmer temperature (36.4°C) than the white paper (35.1°C).

Lab Preparation

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

1. Allow approximately 500 mL of water per group to sit in the room overnight before starting this activity.
2. Mount the heat lamp (or 150-W lamp) on a ring stand. Set up one lamp and ring stand for each group of students.

Safety

Follow all standard laboratory procedures.

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	4
Place one temperature sensor into each can of water.	Obtain one black radiation can and one silver radiation can and fill each can with 200 mL of water.	Turn on the heat lamp and collect Temperature versus Time data for 20 minutes.	Compare the Temperature versus Time data collected for the two cans of water.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

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

2. ☐ Label one temperature sensor “1” and the second temperature sensor “2”.

3. ☐ Connect temperature sensor 1 to the data collection system. �(2.1)

4. ☐ Connect temperature sensor 2 to the data collection system.

Note: Temperature 2 will be displayed on the data collection system as Temperature$_2$.

5. ☐ Set the data collection system so that both temperature sensors are collecting data once every five seconds. �(5.1)

6. ☐ Display a graph with Temperature 1 and Temperature 2 on the *y*-axis and Time on the *x*-axis. �(7.1.10)

7. ☐ Confirm that you know how each temperature sensor is displayed on your device. Explain below how you confirmed this.

Students may collect data while holding temperature sensor 1 in their hand and leaving temperature sensor 2 on the table. Temperature 1 on the data collection system should increase while temperature 2 should stay at room temperature.

8. ☐ Place each radiation can on an insulated pad. Keep the cans away from drafts.

9. ☐ Why are you asked to place each radiation can on an insulated pad and to keep the cans away from drafts?

Putting the radiation cans on an insulated pad and keeping the cans away from drafts are both done to maximize the amount of heat gained by the water in the containers by limiting heat loss.

10. ☐ Fill each can with 200 mL of room-temperature water (the cans should be the same size so that the water level in both is the same).

11. ☐ Put temperature sensor #1 into the water in the black can and temperature sensor #2 into the water in the silver can.

12. ☐ Place the heat lamp so it is about 20 cm in front of the two cans. Make sure the lamp is the same distance from each radiation can to ensure even heating.

13. ☐ How do you think the change in water temperature in the black can will compare to that of the silver can? Explain your reasoning.

The water temperature in the black can will show a greater change than the water temperature in the silver can. This will occur because dark colors absorb more radiation and thermal energy than lighter colors.

Collect Data

14. ☐ Turn on the lamp and start data recording. �(6.2)

15. ☐ Continue recording data for 20 minutes.

Note: If necessary, adjust the scale of the graphs to show all data. �(7.1.2)

16. ☐ How will you know which can absorbed the most radiation?

The can that absorbs the most radiation will have the greatest change in temperature.

17. ☐ What surfaces on Earth could the black can represent?

The black can represents dark surfaces on Earth such as asphalt, rocks, and dark colored soil.

18. ☐ What surfaces on Earth could the silver can represent?

The silver can represents light surfaces on Earth such as snow, ice, and light colored sand.

19. ☐ Stop data recording. �(6.2)

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

Data Analysis

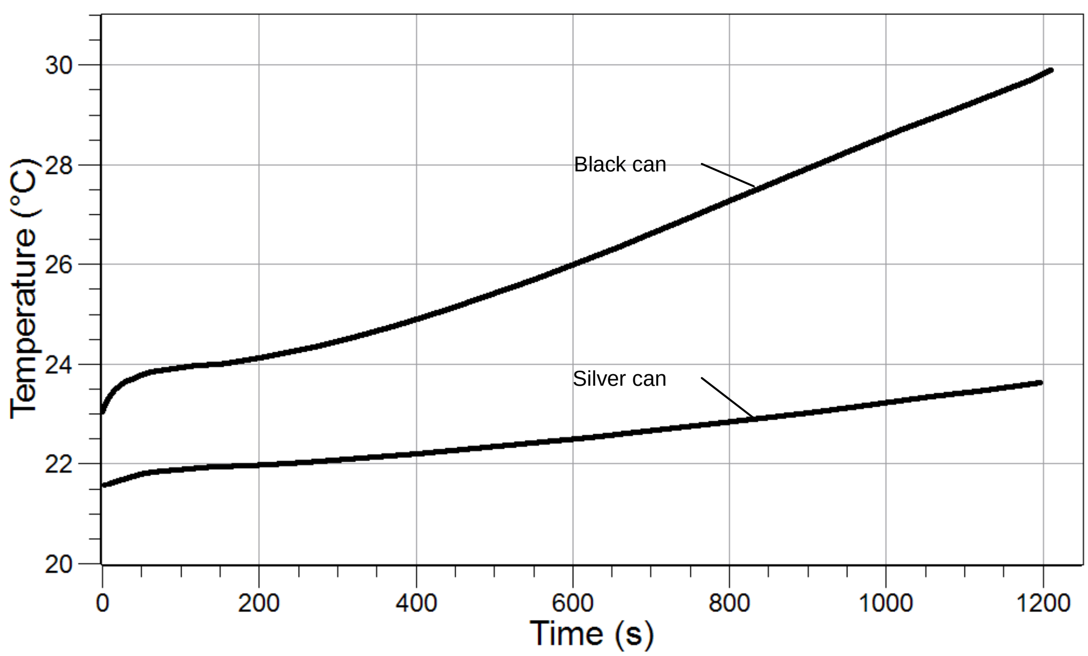
1. ☐ Use the graph of Temperature versus Time to determine the initial temperature, final temperature, and change in temperature for each radiation can and record the answers in Table 1. �(9.1) (9.2)

Table 1: Recorded and calculated temperatures

Type of Can	Initial Temperature (°C)	Final Temperature (°C)	Change in Temperature (°C)
Silver	18.8	21.2	2.4
Black	19.3	29.2	9.9

2. ☐ Sketch or print a copy of the graph of Temperature versus Time. Include the data for both radiations on the same set of axes. Label each trial as well as the overall graph, the *x*-axis, the *y*-axis, and include numbers on the axes. �(11.2)

Using Radiant Energy to Heat Water in a Black Radiation Can and a Silver Radiation Can.



Analysis Questions

1. Examine your Temperature versus Time graph and Table 1. Which can absorbed more radiant energy? Use your data to support your answer.

The black can absorbed more radiant energy than the silver can. In the 20 minutes that the experiment ran, the change in temperature for the black can was 9.9 °C, while the change in temperature for the silver can was 2.4 °C. This represents a rate of heating that is 4 times greater for the black can.

2. Compare the slope of data collected for the black can to the slope of the data collected for the silver can. What does this tell you about the efficiency of the black can's ability to absorb radiant energy?

The slope of the black can is greater than the slope of the silver can. This shows that the black can absorbs radiant energy at a faster rate than the silver can. This shows that the black can is more efficient at trapping heat than the silver can.

3. What is the relationship between the color of an object and the object's ability to absorb heat?

Darker objects absorb more heat than lighter objects.

4. Does radiant energy affect all Earth's surfaces equally? Use your data to support your answer.

Radiant energy does not affect all of Earth's surfaces equally. Darker surfaces on Earth absorb more energy than lighter surfaces in the same way that the black can absorbed more energy than the silver can.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Suppose you had to choose a roof color for a new house and were given two choices: dark grey or light grey. Which would you choose to keep the house cooler in the summer? Why?

Students may choose the light grey rather than the dark grey roof to keep their house cooler in the summer because it would absorb less radiation from the sun and consequently radiate less heat into the house.

2. On a sunny summer day would you expect an asphalt street or a cement driveway to feel hotter? Explain.

The asphalt on the street feels hotter in the summer compared to a cement driveway because the cement is a lighter color and does not absorb as much radiation from the sun.

3. Would you expect the albedo of a mountain range to change after the first snowfall? Explain.

The albedo of a mountain range is greater when snow is covering the ground. Snow is white and therefore reflects more radiation than rock or dirt does in summer months.

Multiple Choice Questions

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

1. **What is the Earth's source of radiant energy?**

- **A.** Earth's moon
- **B.** The oceans
- **C.** **The sun**
- **D.** Electricity
- **E.** None of the above

2. **What happens to incoming solar radiation when it reaches Earth?**

- **A.** It is reflected.
- **B.** It is absorbed.
- **C.** It is scattered.
- **D.** **It is reflected, absorbed, and scattered.**
- **E.** None of the above.

3. **What surface has the highest albedo?**

- **A.** Dark colored rocks
- **B.** Grass
- **C.** Soil
- **D.** **Snow**
- **E.** Pavement

4. **What color radiation can you expect to absorb the most radiant energy?**

- **A.** **A blue can**
- **B.** An orange can
- **C.** A green can
- **D.** A yellow can
- **E.** A white can

5. **What process causes an objects temperature to increase the most?**

- **A.** Scattering radiant energy
- **B.** Reflecting radiant energy
- **C.** **Absorbing radiant energy**
- **D.** Emitting radiant energy
- **E.** Transferring radiant energy

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank

1. The sun gives off radiant energy in the form of **electromagnetic** waves or small disturbances in space that carry energy much like waves in the ocean carry gravitational energy. These waves travel at the speed of light (300 million m/s) in straight lines until they are scattered, reflected, or **absorbed.** Smooth, metallic, and lightly colored surfaces tend to **reflect** light and have a high **albedo**. Rough, dark objects tend to absorb light and have a **low** albedo. When a surface absorbs light its **thermal energy** increases causing their temperature to increase.

2. While some energy from the sun is **emitted** in all the colors of the spectrum, the sun also emits energy with shorter and longer wavelengths than our eyes can see. Some of these are familiar to us. **Ultraviolet** radiation causes our skin to burn if we receive too much sunlight. Because of **infrared** radiation the pavement heats up during the day and windows get hot to the touch in sunlight. The Earth receives far more energy as **solar** radiation than is used to keep the Earth warm. Some of this excess solar energy is reflected off the atmosphere, and some is simply re-emitted back into space as **terrestrial** infrared radiation. In the end, the total amount of solar radiation the Earth receives remains in **equilibrium** with the total amount of radiation the Earth loses.

Extended Inquiry Suggestions

Use a light sensor to determine the amount of light reflected from different colored surfaces.

Compare the effect of tinted windows versus clear windows for a car parked in a sunny location.

The use of solar water heating systems has increased in recent years. Learn how solar water heaters are made and describe their efficiencies.

Another extension would be an inquiry into the wavelengths of light that actually impart the energy into the water. Students may want to prismatically separate the light before it falls on the water bottle to determine which wavelength of light actually heats the water. Alternatively, see if you can find several types of bulbs of the same power (watts) that have different colors such as soft white verses hard white light. Soft white has more reds and oranges while harder white light has more blues to violets.

26. Insolation and the Seasons

Objectives

Determine the effect the angle of the sun has on the temperature of a given surface. Through this investigation, students:

- Define the term insolation.
- Deduce how the earth's tilt affects seasonal temperature variations.

Procedural Overview

Students gain experience conducting the following procedures:

- Constructing a solar energy collection panel
- Going outside and aligning the solar energy collection panel to receive sun rays at three different angles (90°, 60°, and 30°).
- Measuring the temperature of the solar energy collection panel for five minutes at each of the three different angles
- Comparing the change in temperature to the angle of insolation.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	75 minutes

Materials and Equipment

For each student or group:

- Mobile data collection system
- Fast response temperature sensor
- Base and support rod
- Three-finger clamp
- Protractor
- Scissors
- Cardboard, 15 × 15 cm
- Black construction paper, 15 × 15 cm
- Drinking straw
- Tape
- Glue
- Sunlight

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Seasons
- Planetary elliptical revolution
- Energy
- Temperature

Related Labs in this Guide

Labs conceptually related to this one include:

- Temperature versus Heat
- Radiation Energy Transfer
- Specific Heat of Sand versus Water

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Showing and hiding data runs in a graph �(7.1.7)
- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

Insolation

Insolation is the intensity of *in*coming *sol*ar radi*ation* that strikes a given surface on Earth at a given time. This incoming solar energy is by far the most important factor influencing climate on Earth. Equatorial regions on Earth are hot because they receive intense solar radiation. Polar regions are cold because they receive less solar radiation. In addition to extreme climate differences, seasonal temperature variations can also be explained by changes in insolation. What causes these variations in the solar radiation received at different times and locations on Earth?

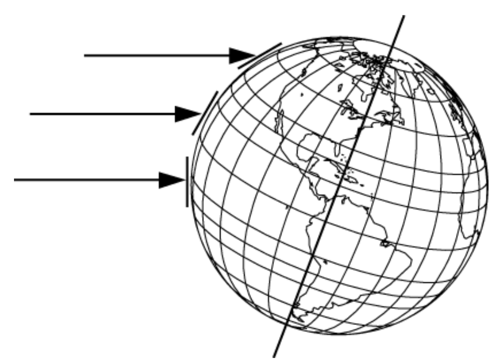
Earth's elliptical orbit around the Sun, Earth's rotation on its axis, and the tilt of Earth's axis all affect the intensity of solar radiation striking the Earth. The distance of Earth from the Sun varies as the Earth revolves around the Sun. The intensity of solar radiation is strongest when Earth is closest to the Sun (147 million kilometers). This position is called the perihelion and occurs around January 4th each year. The intensity of solar radiation is the weakest when Earth is farthest from the Sun (152 million kilometers). This position is called the aphelion and occurs around July 4th each year.

The change in solar intensity due to the distance of the Earth from the Sun is very small because the distance from the Earth to the Sun varies by such a small amount (5 million kilometers). Greater differences in solar intensity can be explained by Earth's tilt as it revolves around the Sun.

Angle of insolation and the seasons

The Earth spins daily around its axis (axis of rotation), which is tilted to approximately 23.5 degrees relative to its orbit around the sun. The rotation of Earth causes night and day while the tilt of the Earth is the primary cause of our seasons. Earth's tilt causes seasonal temperature variations because the solar radiation strikes Earth's surface at different angles. In this activity the students will investigate how the angle of insolation affects the temperature on a given surface.

The angle of insolation changes throughout the year because Earth's tilt stays the same as Earth orbits the Sun. When the Earth is near its perihelion, it is winter in the Northern Hemisphere and summer in the Southern Hemisphere. This is because the tilt of the Earth causes the Southern Hemisphere to receive direct (90°) solar radiation while the solar radiation that reaches the Northern Hemisphere is less intense because it strikes at an angle less than 90°. This causes the Northern Hemisphere to be colder and have shorter days while the Southern Hemisphere is warmer and has longer days. These seasonal differences are due to the angle of insolation.



The seasons are marked by four days in Earth's orbit around the Sun. In the Northern Hemisphere the summer solstice marks the first day of summer (June 21 or 22) and the winter solstice marks the first day of winter (December 21 or 22). Halfway between these dates are the equinoxes. Equinoxes occur when the solar radiation directly hits the equator and creates days and nights of equal length. In the Northern Hemisphere the autumn equinox occurs on September 22 or 23 and the spring equinox occurs on March 21 or 22. In the Southern Hemisphere all the dates are the same, but the seasons are reversed.

Pre-Lab Discussion and Activity

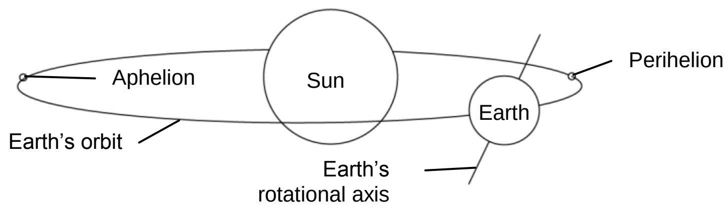
Materials and Equipment for Pre-lab Activities:

- Globe
- Spherical object to represent the sun (basketball)
- Graph paper
- Flashlight

The Earth and Its Seasons

Ask your students to consider why temperatures tend to be cooler in the winter and warmer in the summer. Explain that the earth is physically closer to the sun in January and farther from the sun in July. Point out that the tilt of the axis of rotation means that the Northern Hemisphere is tilted toward the sun during summer and that it is tilted away from the sun during winter.

Which factor—distance from the sun or tilt of the earth relative to the sun would seem to be responsible for warm temperatures in the summertime?



Use a globe and another spherical object, such as a basketball (sun) to model and demonstrate the orbit of the earth around the sun.

1. Make sure the globe is tilted to about 23.5°. Place the basketball in the middle of a large table to model the sun. Put the globe in its perihelion position at the December solstice (closest to the sun with the North Pole tilted away from it). Point out that now the North Pole is pointed towards the sun.

What time of the year is it?

December solstice, December 20 or 21, the shortest day of the year in the Northern Hemisphere and the longest day of the year in the Southern Hemisphere, the beginning of winter in the Northern Hemisphere, the beginning of summer in the Southern Hemisphere.

2. Model the orbit of the earth around the sun as follows. Move the globe in a 90° clockwise arc around the basketball. Make sure the tilt and direction of the axis stays constant. Point out that now the North and South Poles are the same distance from the sun.

What time of the year is it?

March equinox, March 20 or 21, the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres, the beginning of spring in the Northern Hemisphere, the beginning of fall in the Southern Hemisphere.

3. **Move the globe in another 90° arc around the sun to the aphelion position at the June solstice (furthest from the sun, with the North Pole tilted towards it). Make sure the tilt and direction of the axis stays constant. Point out that now the North Pole is pointed towards the sun.**

What time of the year is it?

June equinox, June 20 or 21, the longest day of the year in the Northern Hemisphere and the shortest day of the year in the Southern Hemisphere, the beginning of summer in the Northern Hemisphere, the beginning of winter in the Southern Hemisphere.

4. **Move the globe in another 90° arc around the basketball, making sure that the tilt and direction of the axis stays constant. Point out the equivalent distance from the sun of the North and South Poles.**

What time of the year is it?

September equinox, September 22 or 23, the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres, the beginning of fall in the Northern Hemisphere, the beginning of spring in the Southern Hemisphere.

5. **When do the warmest temperatures in the summer and the coldest temperatures in the winter usually occur?**

During the next few months after the solstices.

6. **Why do the warmest temperatures in the summer and the coldest temperatures in the winter usually occur after the summer and winter solstices?**

Although the greatest amount of insolation occurs at the summer solstice, the earth absorbs much of this energy, which is then radiated it back into the atmosphere during the next two or three months. The cumulative effect of both the sun's energy and the heat energy radiating from the earth in the months after the summer solstice result in warmer temperatures after the date of the summer solstice.

Conversely, the least amount of insolation occurs at the winter solstice, but because the earth retains heat energy, much of which is subsequently radiated to the trophosphere, it stays warmer, with the coldest surface temperatures occurring during the next two or three months as the radiated heat dissipates.

Angles of Light and Light Intensity

Engage the students in a series of predictions about how the shape of a beam of light changes when the light is shined at different angles. Tape a sheet of graph paper to the board and shine a light at it from a 90 degree angle and then again from a 45 degree angle. Analyze and discuss the results. Conclude the discussion by shining the flashlight on the globe at different angles and having the students suggest how the angle of sunlight affects the temperature on different regions on Earth.

7. **What shape will this flashlight's beam have when it hits the graph paper at a 90 degree angle?**

Answers will vary, but the light beam will be circular.

8. **What shape will this flashlight's beam have when it hits the graph paper from a 45 degree angle?**

Answers will vary, but the light beam will be oblong (egg-shaped).

9. Will the beam of light take up the same area when it is pointed at a 90 degree angle and a 45 degree angle?

Answers will vary, but the light striking straight on will take up a smaller area than the light shined at a 45 degree angle.

10. How do the results compare to our prediction?

Answers will vary based on what the students predictions were, but the beam of light shined at 90 degrees will be circular shaped and take up less area. The beam of light shined at a 45 degree angle will take up more space and be oblong in shape.

11. Does the amount of light coming out of the flashlight change based on the angle the light is held at?

No, the same amount of light is released.

12. How does the intensity of light in the beam compare at 90 degrees versus 45 degrees? Why?

The intensity of light is stronger at 90 degrees than at 45 degrees. The same amount of light is in each beam, but the beam of light is spread out over more space and is therefore less intense when the light is shined at a 45 degree angle.

13. Does the angle that light hits Earth's surface affect the temperature of that region on Earth? Explain.

Students should be able to observe the same characteristic change from a circle to an ellipse on the globe. The goal of the experiment is to address this question.

Lab Preparation

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

Safety

Add this important safety precaution to your normal laboratory procedures:

- Do not look directly at the sun.

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.

4	2	1	3	5
Remove the solar panel to a shady location to allow it to cool and then repeat the experiment at 30°, and 60°.	Go outside. Set up the solar panel so it is perpendicular (90°) to the sun's incoming rays.	Construct a solar energy collection panel.	Measure the temperature while exposing the apparatus to the sunlight for 5 minutes.	Determine the change in temperature achieved in each of the 3 data runs and compare the results.

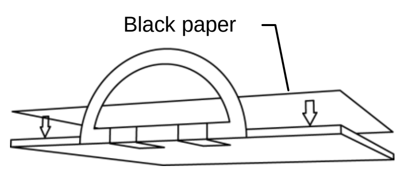
Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

1. ☐ Make a solar energy collection panel as follows:



a. Glue a piece of black construction paper to the surface of the cardboard.

b. Tape the protractor to it so it is perpendicular to the surface of the cardboard.

2. ☐ Tape the straw to the protractor so that it is perpendicular (90°) to the cardboard and the end of the straw is about 0.5 cm from the surface of the cardboard.

3. ☐ Tape the tip of the temperature sensor to the center of the solar energy collection panel.

4. ☐ You will be aligning your solar energy collection panel so that the sun rays strike it at 90°, 60°, and 30°. At each angle of insolation you will collect temperature data for 5 minutes. Will the angle of insolation affect its temperature after 5 minutes? Why?

The temperature of the solar energy collection panel will increase at all three angles because the black paper absorbs the sun rays. The change in temperature will increase as the angle of insolation increases because the incoming solar radiation is more intense. Therefore the solar energy collection panel at 90° will have the greatest change in temperature.

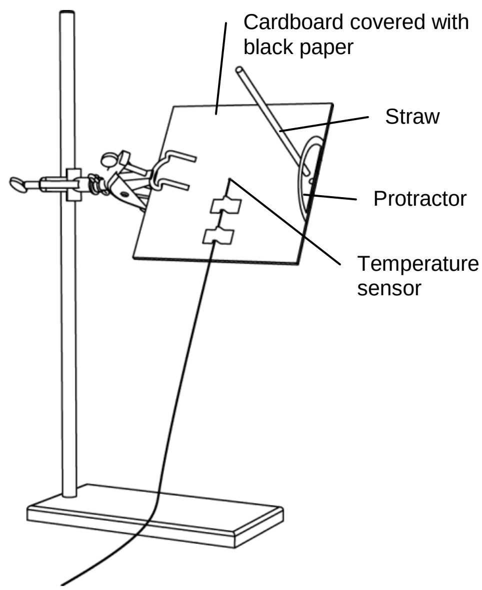
5. ☐ Why did you cover the surface of the cardboard with black paper?

The black paper absorbs more of the light energy than the plain cardboard. This energy is then radiated, so the temperature sensor can better detect differences in the amount of energy that has been absorbed at the various angles of insolation.

6. ☐ Take your solar energy collection panel with the temperature sensor attached, your data collection system, a three-finger clamp, and a base and support rod outside and find a sunny location that is sheltered from the wind.

CAUTION: Do not look directly at the sun when performing the next step.

7. ☐ Use the three-finger clamp and the base and support rod to position the solar energy collection panel so it is perpendicular (90°) to the sun and the straw is pointing at the sun. When the solar energy collection panel is perpendicular to the sun, the shadow cast by the straw will hardly be visible (just a small circle) and a focused spot of light will emerge through the end of the straw.



8. ☐ Start a new experiment on your data collection system. �(1.2)

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

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

Collect Data

11. ☐ Start data recording �(6.2)

12. ☐ Adjust the scale of the axes as necessary to see any temperature changes taking place. �(7.1.2)

13. ☐ Record data for 5 minutes.

14. ☐ Write your data run number here: __________

15. ☐ Stop data recording. �(6.2)

16. ☐ Remove the solar energy collection panel and take it to a shaded location to cool completely.

17. ☐ Remove the straw and tape it to the protractor at 60° from the surface of the solar collection panel,

18. ☐ The solar energy collection panel represents a given piece of Earth's surface. You are physically changing the angle of the solar energy collection panel to adjust the angle of insolation. What causes a given area of Earth's surface to receive a different angle of solar radiation?

A given area of Earth's surface will receive a different level of solar radiation at different times during the day and at different times of year (seasonal variation).

19. ☐ Fan the solar energy collection panel to increase the rate of cooling. When its temperature returns to approximately its original temperature, secure it to the base and support rod using the three-finger clamp.

20. ☐ Align the solar panel as before by watching the shadow cast by the straw until it is just a small circle and the focused sport of light can be seen through the straw.

CAUTION: Do not look directly at the sun.

21. ☐ Collect temperature data for five minutes. Follow the steps given above as needed.

22. ☐ Write your data run number here: __________

23. ☐ Remove the solar panel and take it to a shaded location to allow it cool down and to adjust the straw so that it is positioned at the 30° mark from the surface of the solar collection panel.

24. ☐ Secure the solar energy collection panel to the base and support rod and align it as you have done previously.

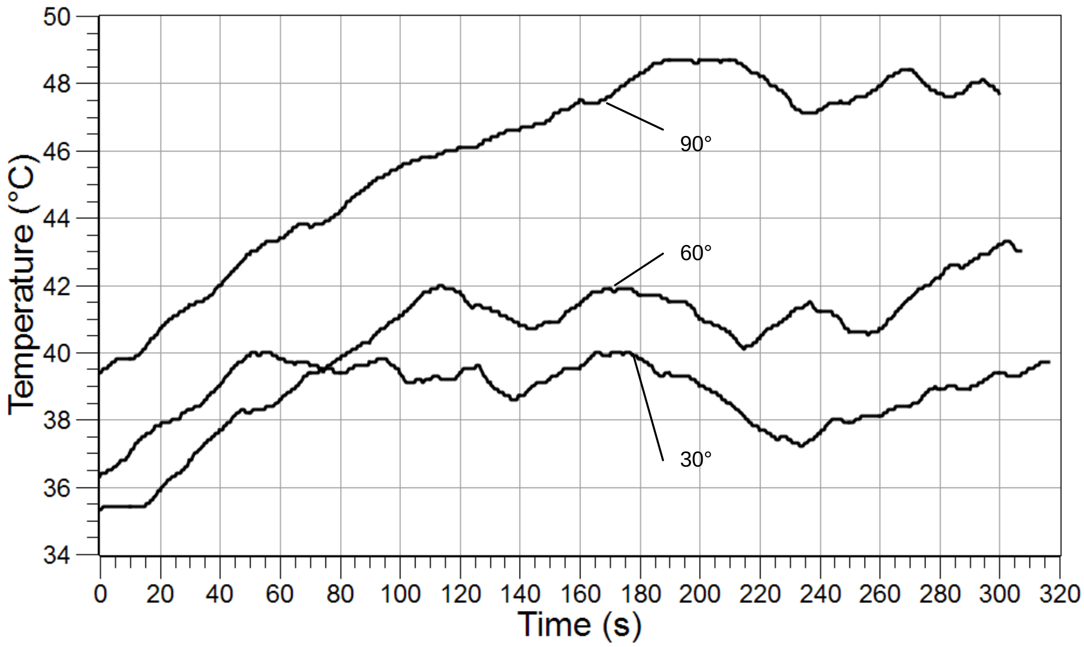
25. ☐ Collect temperature data for five minutes. Follow the steps given above as needed.

26. ☐ Write your data run number here: __________

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

Sample Data

Temperature of the solar energy collection panel at three angles of insolation



Data Analysis

1. ☐ Find the minimum and maximum temperatures for each run of data and record them in Table 1 below.

a. Display the run of data you want to analyze. �(7.1.7)

b. Use the statistics tool to find the minimum and maximum temperature. �(9.4)

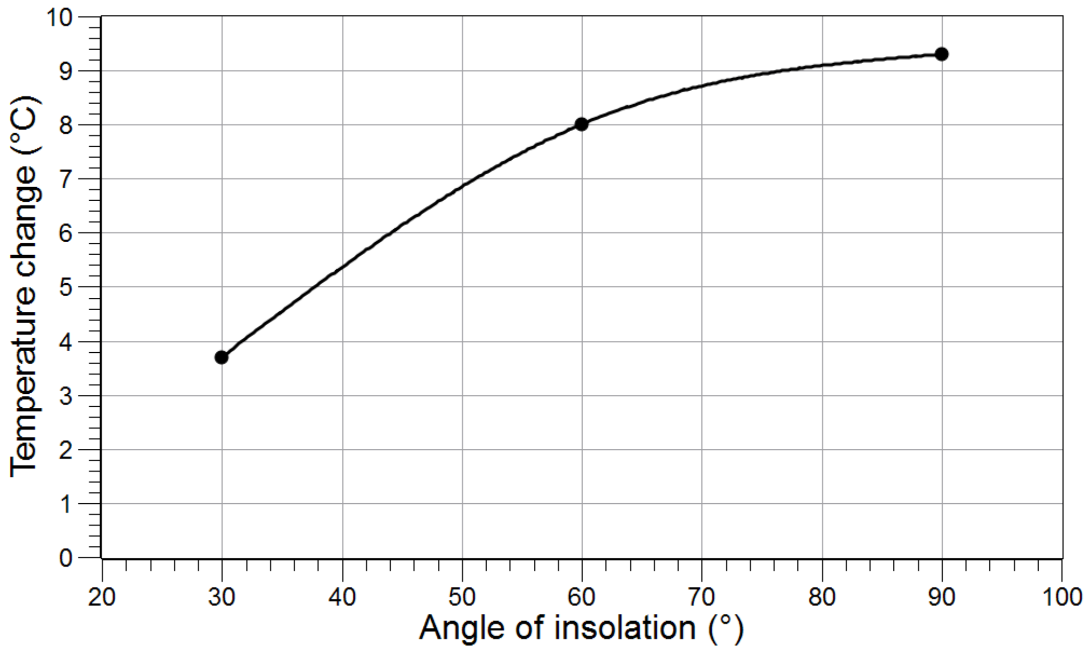
Table 1: Temperatures at 3 angles of insolation

Angle of Insolation	Minimum Temperature (°C)	Maximum Temperature (°C)	Change in Temperature (°C)
90°	39.4	48.7	9.3
60°	35.3	43.3	8.0
30°	36.3	40.0	3.7

2. ☐ Calculate the change in temperature for each run of data and enter the answers in Table 1 above.

3. ☐ Plot a graph of Temperature Change on the y-axis with Angle of Insolation on the x-axis. Label the overall graph the x-axis, the y-axis, and include a scale with units on the axes.

Temperature Change After Exposing a Solar Energy Collection Panel to Solar Radiation at Different Angles for Five Minutes



Analysis Questions

1. What effect did the angle of the sun have on the temperature of the solar energy collection panel? Use your data to support your answer.

The greater the angle of insolation was, the larger the change in temperature. At 90° the change in temperature was 9.3 °C, at 60° the change in temperature was 8.0 °C, and at 30° the temperature change was only 3.7 °C.

2. What is the independent variable and dependent variable in this experiment?

The independent variable was the angle of insolation. The dependent variable was the temperature of the solar energy collection panel.

3. How did the procedure in this lab simulate solar radiation received by cities with different latitudes?

The solar energy collection panel was aligned at different degrees of insolation which is similar to the way that cities at different latitudes receive solar radiation at different angles.

4. Would you expect the results of this experiment to change if you performed the lab six months from now? Why or why not?

The relationship between the angle of insolation and the temperature would not change because the lab procedure changes the angle of insolation by moving the solar energy collection panel which should always give the same results. The values of the temperatures (minimum, maximum, and change in temperature), however, would likely be different because data would be collected in a different season.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Mars is tilted 25.1° on its axis in relation to its path around the Sun. Given this information, predict whether or not you would expect Martian weather to be subject to seasonal variations.

Yes, Mars has seasons for the same reasons that Earth has seasons – different parts of the planet receive different angles of insolation at different times of year as the planet revolves about the sun.

2. Why are seasons more pronounced the further you move away from the equator?

The seasons are more pronounced the further you move away from the equator because the changes in the angles of insolation are more extreme as you move towards the poles.

Multiple Choice Questions

Select the best answer or completion to each of the question or incomplete statements below.

1. If you repeated the same experiment using the angles listed below, which one would you expect to see the greatest change in temperature?

- **A.** 20°
- **B.** 40°
- **C.** 60°
- **D.** **80°**
- **E.** 100°

2. Which of the following affect seasonal temperature changes the most?

- **A.** Distance of the Earth from the Sun
- **B.** **Tilt of the Earth on its axis**
- **C.** Rotation of the Earth on its axis
- **D.** Distance of the Moon from the Earth
- **E.** All of the above affect seasonal temperatures equally

3. At the Spring and Fall equinoxes, the earth's North Pole is

- **A.** Tilted towards the sun relative to the South Pole.
- **B.** Tilted away from the sun relative to the South Pole.
- **C.** **The same distance from the sun relative to the South Pole.**
- **D.** It depends on whether it is spring or fall.
- **E.** Both A and B are correct.

4. Which of the following terms refers to the intensity of incoming solar radiation that strikes a given surface on Earth at a given time?

- **A.** Insulation
- **B.** **Insolation**
- **C.** Intensity
- **D.** Perihelon
- **E.** Solstice

5. How do seasons in the Southern Hemisphere and Northern Hemisphere compare?

- **A.** They are the same and occur at the same time each year.
- **B.** **They are the same but occur at opposite times of year. When it is summer in the Northern Hemisphere it is winter in the Southern Hemisphere.**
- **C.** They are the same but are one season off. When it is summer in the Northern Hemisphere it is spring in the Southern Hemisphere.
- **D.** There are a completely separate set of seasons in the two different hemispheres.
- **E.** The Southern Hemisphere does not have winter, but they do have the other seasons.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Annual temperature changes or **seasons** on planets are controlled by the amount of **insolation** that reaches the planets. Insolation is defined as the intensity of incoming solar **radiation** that strikes a given surface on a planet at a given time. Two factors, the **distance** from the Sun and the tilt of the planet's **axis**, control the amount of insolation. On Earth, with its **elliptical** orbit, the distance from the Earth to the Sun varies by only 5 million kilometers (average distance from the Sun is about 150 million kilometers) over the course of one year. If distance were the main factor controlling the seasonal temperature variations, then when the Sun was the closest to the Earth during its orbit (called the **perihelion**) we would expect the amount of energy to be highest and lowest when it is furthest away (called the **aphelion)**. Earth is closest to the Sun around January 4th, which in the Northern Hemisphere is the middle of winter and furthest from the Sun in early July during the middle of the summer! Therefore, the second factor, the tilt of Earth's axis, must be the controlling factor.

2. At any point during the day, the amount of **energy** that a particular part of the Earth receives changes. The daily change is due to Earth's **rotation,** that is the spinning of Earth on an **imaginary** line called the **axis** of rotation. One half of the Earth receives sunlight, while the other half receives none. During rotation, the amount of sunlight reaching a specific location can vary due to terrain, **latitude**, and a multitude of other factors.

3. The December **solstice**, December 20 or 21, is the **shortest** day of the year in the Northern Hemisphere and the **longest** day of the year in the Southern Hemisphere. It is the beginning of **winter** in the Northern Hemisphere and the beginning of **summer** in the Southern Hemisphere. The June **solstice**, June 20 or 21, is the **longest** day of the year in the **Northern** Hemisphere and the shortest day of the year in the **Southern** Hemisphere. It is the beginning of **summer** in the Northern Hemisphere and the beginning of **winter** in the Southern Hemisphere. The March **equinox**, March 20 or 21, is the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres. It is the beginning of **spring** in the Northern Hemisphere and the beginning of **fall** in the Southern Hemisphere. The September equinox, September 22 or 23, is the day when there are 12 hours of daylight and 12 hours of night in both the Northern and Southern Hemispheres. It is the beginning of fall in the **Northern** Hemisphere the beginning of spring in the **Southern** Hemisphere**.**

Extended Inquiry Suggestion

Challenge students to use available resources to conduct a comparison of latitude and change in minimum and maximum temperatures of various cities worldwide. If you have *My World GIS* available, this would be a good query.

27. Specific Heat of Sand versus Water

Objectives

In this activity, students explore the effect energy has on the temperature of sand and water. Through this investigation, students:

- ♦ Determine the rate of heating and cooling of sand and water
- ♦ Explain how the specific heat of a substance describes the rate of cooling and heating of that substance
- ♦ Determine the specific heat of sand and compare it to the specific heat of water
- ♦ Consider the effects different specific heats of water and sand have on global weather and climate

Procedural Overview

Students gain experiences conducting the following procedures:

- ♦ Use temperature sensors to record the temperature of sand and water as they are heated by a light source and then cooled by turning off the light
- ♦ Compare rates of heating and cooling for sand and water
- ♦ Calculate the specific heat of sand and compare it to the specific heat of water

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	90 minutes (45 minutes for each part)[1]

[1]Refer to the Lab Preparation section for tips on ways to make this lab fit into one 45 minute lab period.

Materials and Equipment

For each student or group:

- Data collection system
- Stainless steel temperature sensor (2)[1]
- Beaker, glass, 500-mL
- Test tube, glass, 18-mm × 150-mm
- Beaker (2), glass, 250-mL
- Sand, dry, clean, 200 g
- Heat lamp or 150-W incandescent lamp
- Utility clamp (2)
- Insulated cup and lid (2), disposable
- Balance (1 per class)
- Water, 750 mL
- Tongs and hot pad
- Ring stand
- Hot plate

[1]A fast response temperature probe is not appropriate for Part 2 in this lab.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Conservation of energy
- Thermal energy transfer
- Difference between heat and temperature
- Determining ratios
- Rates can be determined from the slope of a line

Related Labs in This Guide

Labs conceptually related to this one include:

- Temperature versus Heat
- Radiation Energy Transfer
- Insolation and the Seasons

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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 multiple sensors to the data collection system �(2.2)
- Changing the sample rate �(5.1)

- Monitoring live data without recording �(6.1)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Selecting data points in a graph �(7.1.4)
- Displaying multiple variables on the *y*-axis �(7.1.10)
- Finding the coordinates of a point in a graph �(9.1)
- Applying a curve fit �(9.5)
- Finding the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

Specific Heat

The specific heat of a substance (also known as specific heat capacity) determines how quickly the temperature of that material will rise or fall when it gains or loses heat energy. The higher the specific heat, the more energy is necessary to raise the temperature of a substance and the more energy must be lost to decrease its temperature. Specific heat is an intrinsic property of a substance and is dependent on its molecular structure and phase.

Specific heat c refers to the amount of energy needed to raise the temperature of 1 gram of a substance 1 degree Celsius. This is expressed in units of joules per gram degree Celsius (J/(g·°C)). The specific heat of water, 4.186 J/(g·°C), is often represented as its own separate measure: the calorie.

Liquid water's specific heat is one of the highest of any substance. Therefore, liquid water requires more heat energy to increase its temperature than almost any other substance. Likewise, liquid water must lose more energy to decrease its temperature than almost any other substance.

Global Climate and the Specific Heat of Earth’s Surfaces

The high specific heat of water is fundamentally involved in moderating global climate, global weather patterns, and local weather patterns. Without water's high specific heat, the global surface and air temperatures would fluctuate through a much larger range, making life on Earth impossible or severely reducing the types of organisms that could live on Earth.

The high specific heat of liquid water allows the oceans to function as huge energy sinks that can transfer large amounts of energy from one area to another, moderating the climates of all regions of the globe. The high specific heat of water also allows water to remain liquid across a large range of air temperatures, as well as to change in temperature slowly, providing a reliable habitat for aquatic organisms. The temperature of air above large bodies of water also stays within a narrower range, greatly moderating the climate above and near these bodies of water.

Conversely, the low specific heat of dry ground causes its temperature to increase more rapidly in response to heating from the sun, and to decrease more rapidly when the sun goes down. This heating or cooling result in the air above the ground being heated or cooled accordingly. In regions having land areas close to large bodies of water, this difference in the heating and cooling rates of land and water results in air movement (wind). As air over land is heated, it rises and cooler air from over the water moves in to take its place. This is called a sea breeze (also known as an onshore breeze) The opposite, a land breeze (also known as an offshore breeze), occurs at night when the water is warmer than the land.

Pre-Lab Discussion and Activity

Introduction

Engage the students in a discussion about different by helping them to recall experiences when they were visiting an ocean beach or lake on a hot day and a cool night in the summer.

1. Give an example of when you have experienced a perceived temperature difference between water and the ground.

Students may recall running across a hot beach to reach the cool water on a hot, sunny day or the silky warmth of the water compared to the cool air temperature during a moonlight swim. Similarly students may have experience running across the hot cement to reach a swimming pool.

2. How do these temperature differences occur, given the fact that the Sun's energy is equally distributed on both land and water throughout the day and equally absent at night?

Land and water are made up of different substances that have different properties. One of the properties that can account for this difference is specific heat, which will be investigated in this lab.

Heat Energy

Review with the students the concepts of temperature, energy, and energy transfer.

3. Would you agree that boiling water has more energy in it than cold water? Where does this increased energy come from?

Boiling water has more energy in it than cold water. The additional energy comes from the heat source used to boil the water.

4. What happens to the energy in boiling water if we pour it into ice water?

The energy flows from the boiling water to the ice water and causes the ice to melt, and the cold water to increase in temperature.

5. How can we measure this transfer of energy?

The energy transfer cannot be measured directly, but the change in temperature can be measured and the heat transferred can be calculated using the equation $Q = mc\Delta T$ (Q is heat, m is mass, c is specific heat, and ΔT is change in temperature).

6. Would we get a different result if we did this in a closed container instead of an open one? Where would the energy go in each case, and what might be the difference in temperature?

The final temperature in a closed container would be higher than the temperature in an open container, since some heat energy will be lost to the surroundings in an open container. In the closed container, all the heat energy of the boiling water would be transferred to the ice water.

Lab Preparation

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

Teacher Tip: To save time, there are several ways you can have the students perform this lab:

- Do either Part 1 or Part 2 as a demonstration (such as in the Pre-Lab Discussion and Activity section) and have the students perform the other part.
- Have some groups do Part 1 and other groups do Part 2, and then share data.
- Have the students do Part 1 on one day and then do Part 2 in the next class period.
- If you plan to do both sections in one class period, advise students to set up the hot plate and beaker for part 2 in advance and begin heating the water while still doing part 1. This will ensure that the water is at a full rolling boil when they are ready to begin part 2 and save time.
- In Part 2, provide the students with hot or boiling water. This will reduce the amount of wait time.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Use care when handling hot objects.
- Keep electrical wires away from the hot plate.

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.

Part 1 –Heating and cooling of sand and water

- 1 — Measure 200 g of sand and 200 g of water in separate beakers.
- 2 — Place a temperature sensor in each beaker and display a graph of Temperature versus Time.
- 5 — Stop collecting data and then determine the rate of heating and cooling for the sand and water.
- 4 — Turn off the lamp and continue to collect data as the beakers are allowed to cool for 15 minutes.
- 3 — Start collecting data, turn on the lamp, and continue to collect data as the beakers are heated for 15 minutes.

Part 2 – Determining the specific heat of sand

- 5 — Calculate the specific heat of the sand and compare it to the specific heat of water.
- 3 — Start collecting Temperature versus Time data of the water in the calorimeter and carefully add the hot sand.
- 2 — As the sand is heating, fill a calorimeter with 70 g of water. Once the sand is heated, record the temperature of the hot sand.
- 1 — Fill a test tube with a known mass of sand and heat the sand in boiling water for five minutes.
- 4 — When the temperature of the water-sand mixture in the calorimeter stabilizes, stop collecting data.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Heating and cooling of sand and water

Set Up

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

2. ☐ Label one temperature sensor “1” and the second temperature sensor “2”.

3. ☐ Connect temperature sensor 1 to the data collection system. �(2.1)

4. ☐ Connect temperature sensor 2 to the data collection system. �(2.2)

Note: Temperature 2 will be displayed on the data collection system as “Temperature_2”.

5. ☐ Set the data collection system so that both temperature sensors are collecting data at a sample rate of 5 seconds. �(5.1)

6. ☐ Display a graph with Temperature 1 and Temperature 2 on the y-axis and Time on the x-axis. �(7.1.10)

7. ☐ Confirm that you know how each temperature sensor is displayed on your device. Explain below how you confirmed this.

Students may collect data while holding temperature sensor 1 in their hand and leaving temperature sensor 2 on the table. Temperature 1 on the data collection system should increase while temperature 2 should stay at room temperature.

8. ☐ Put 200 g of sand into a 250-mL beaker.

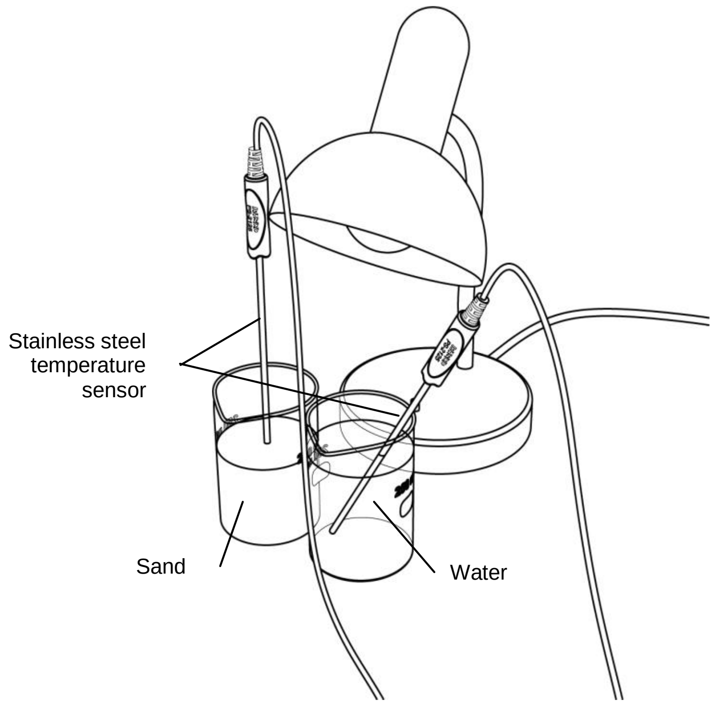
9. ☐ Put 200 g of water into another 250-mL beaker.

10. ☐ Put temperature sensor 1 in the beaker of sand so that the tip of the sensor is no more than 5.0 cm below the surface.

11. ☐ Put temperature sensor 2 in the beaker of water.

12. ☐ Place the heat lamp (turned off) directly above the beakers so that both beakers will receive the same amount of energy when the light is turned on.

13. ☐ Why is it important to heat both beakers equally?



It is important to heat both beakers equally so the water and the sand receive the same amount of energy from the light. Then the variable of heat added to the system will be equal for both materials.

14. ☐ Will the temperature of the sand and water increase at the same rate when the lamp is turned on? Explain your reasoning based on your personal experiences.

The temperature of the sand will increase at a faster rate than the water. On a hot summer day sandy surfaces become hotter than surfaces covered with water such as a pond.

Collect Data

15. ☐ Start data recording. �(6.2)

16. ☐ Adjust the scale of the graph as needed. �(7.1.2)

17. ☐ Record data for 30 seconds.

18. ☐ Turn on the light and record data for an additional 15 minutes (900 seconds). *Do not stop recording data!*

19. ☐ What surfaces on Earth does the sand represent?

The sand represents land or continents.

20. ☐ What surfaces on Earth does the water represent?

The water represents oceans, seas, and other bodies of water on Earth's surface.

21. ☐ How can the graph being created, as you collect temperature and time data, be used to compare the rate at which water and sand are heating? Why?

The slope of the data points can be used to determine the rate of heating. The slope can be used because slope represents the change in temperature divided by the total change in time.

22. ☐ Is the temperature of sand and water increasing at the same rate? Was your prediction correct? Explain.

The temperature of sand is increasing faster than the temperature of water. Students should state whether or not their prediction earlier was correct and explain any differences.

23. ☐ When the light is turned off do you expect that the temperature of sand and water will decrease at the same rate? Explain your reasoning.

The temperature of sand and water will decrease at different rates. Sand heated up faster than water and it should also cool down faster than water.

24. ☐ Turn the light off.

25. ☐ Continue recording data for 15 minutes.

26. ☐ If sand and water represent different surfaces on Earth what does the light bulb represent? What causes the light to be turned on and off?

The light bulb represents the sun and solar radiation. The rotation of the Earth on its axis causes the light to be turned on and off.

27. ☐ Is the temperature of sand and water decreasing at the same rate? Was your prediction correct? Explain.

The temperature of sand is decreasing faster than the temperature of water. Students should state whether or not their prediction earlier was correct and explain any differences.

28. ☐ Stop data recording. � (6.2)

29. ☐ Remove the temperature sensors from the sand and water, but leave them attached to the data collection system so they can be used in Part 2.

30. ☐ Name the data runs "Sand" and "Water". Temperature sensor 1 was placed in the sand and temperature sensor 2 was placed in the water. �(8.2)

31. ☐ Save your experiment. � (11.1)

Analyze Data

32. ☐ Determine the rate of heating and the rate of cooling for both the water and the sand. **Hint:** The heating rate is the slope of the line during heating and the cooling rate is the slope of the line while cooling.

a. Select the data points on the graph for the region of interest (heating or cooling). �(7.1.4)

b. Apply a linear fit to the selected region. �(9.5)

c. Determine the slope of the linear fit line. �(9.6)

d. Record the slope in Table 1.

Table 1: Rates of heating and cooling for water and sand

Substance	Rate of Heating (°C/s)	Rate of Cooling (°C/s)
Water	0.003	–0.001
Sand	0.021	–0.006

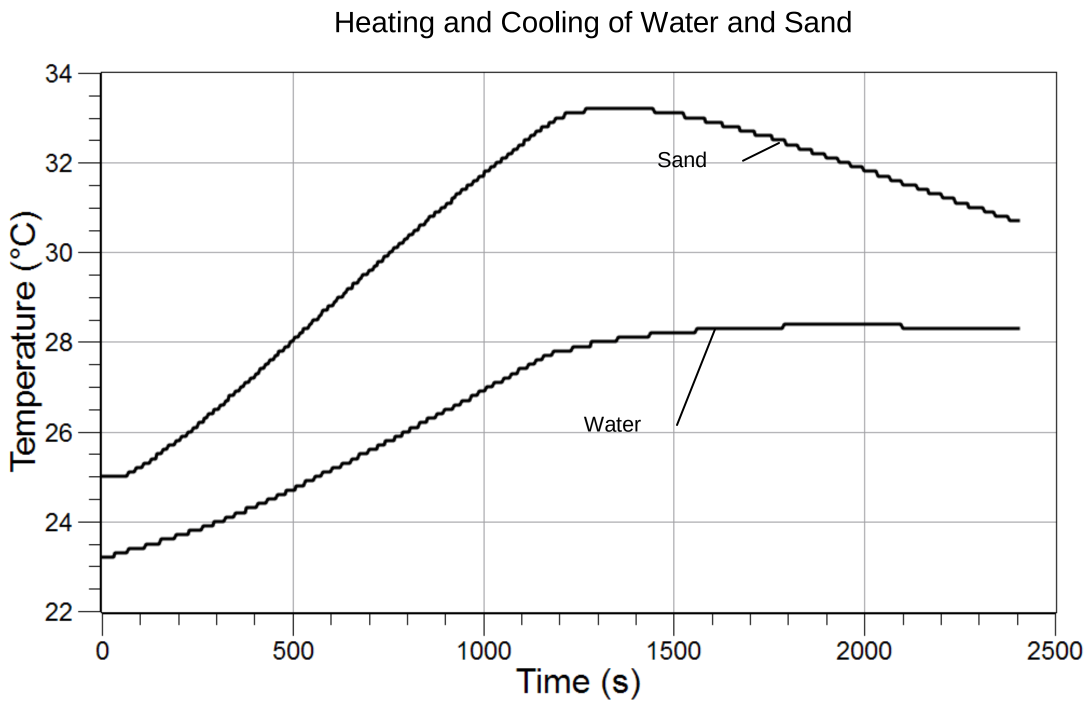
33. ☐ Calculate the ratio of the sand's rate of heating to the water's rate of heating. Describe what this ratio means.

The ratio of the rate of heating of sand to water is 0.021 to 0.003 or 7 to 1. This means that sand heats up seven times faster than water.

34. ☐ Calculate the ratio of the sand's rate of cooling to the water's rate of cooling. Describe what this ratio means.

The ratio of the rate of cooling of sand to water is 0.006 to 0.001 or 6 to 1. This means that sand cools down 6 times faster than water.

35. ☐ Sketch or print a copy of the graph of Temperature versus Time. Include the data for both sand and water on the same set of axes. Label each set of data as well as the overall graph, the *x*-axis, the *y*-axis, and include numbers on the axes.



36. ☐ Indicate on the graph above where the light was turned on and turned off.

Part 2 – Determining the specific heat of sand

Set Up

37. ☐ Fill the 500-mL beaker about 3/4 full with water.

38. ☐ Place the beaker on the hot plate, and turn it on to the highest setting. Continue with the rest of the Set Up procedure as you wait for the water to come to a boil.

39. ☐ How do you think the specific heat of sand will compare with the specific heat of water? Explain your reasoning.

The specific heat of sand will be lower than the specific heat of water. The specific heat of a substance measures the amount of energy that must be added to cause 1 g of a substance to increase 1 °C. In part 1 the data showed that the temperature of sand increased faster than that of water when the same amount of energy was added. Thus less energy is required to raise 1 g of sand 1 °C than is required to raise 1 g of water1 °C.

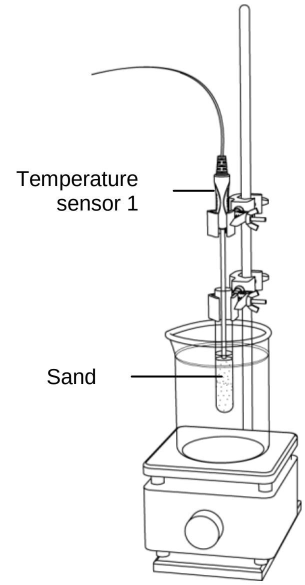
40. ☐ Measure the mass of the test tube.

Mass of the test tube (g): 20.9 g

41. ☐ Fill the test tube half full with sand.

42. ☐ Measure the mass of the sand and the test tube.

Mass of the test tube and sand (g): 40.7 g



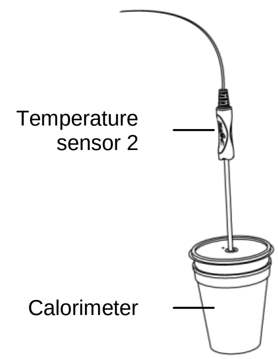
43. ☐ Use a utility clamp to secure the test tube half full with sand in the 500-mL beaker of hot water. Make sure the sand in the test tube is below the water level.

44. ☐ Ensure that you still have both temperature sensors plugged in and that you know which one is sensor 1 and which one is sensor 2. Refer to the Set Up section in Part 1 if necessary.

45. ☐ Use a utility clamp to secure temperature sensor 1 in the test tube of sand. Be sure that the tip of the sensor is in the middle of the sand and does not touch the bottom or sides of the test tube.

46. ☐ Why is it important to ensure that the tip of the temperature sensor is completely in the sand and not touching the side of the test tube?

This will ensure that that thermometer is reading the temperature of the sand and not the temperature of the glass of the test tube.



47. ☐ Place the two disposable insulated cups together to make a calorimeter.

48. ☐ Place the calorimeter on the balance and tare the balance.

49. ☐ Add 70.0 g of room-temperature water to the calorimeter and record the exact mass added below.

Mass of water added to the calorimeter (g): ____________________ 70.0 g

Collect Data

50. ☐ Display temperature 1 in a digits display and monitor live data. (6.1)

51. ☐ After heating the sand in the boiling water for 5 minutes, observe the temperature of the sand (temperature 1) and record it below.

Temperature of heated sand (T_{initial}) (°C): ____________________ 95.9 °C

52. ☐ Turn the hot plate off and remove the temperature sensor from the test tube.

53. ☐ Display Temperature 2 on the *y*-axis of a graph with Time on the *x*-axis.

54. ☐ Put the lid on the calorimeter and insert temperature sensor 2 through the hole in the lid and into the water.

55. ☐ Start data recording. �(6.2)

56. ☐ Adjust the scale of the graph as needed. �(7.1.2)

57. ☐ Work with a partner to carefully transfer the hot sand from the test tube into the calorimeter by following the steps below:

a. Hold temperature sensor 2 in the calorimeter with the lid of the calorimeter partially open and temperature sensor 2 still in the water but pulled off to one side.

b. Use tongs and a hot pad to remove the test tube of sand from the hot water and carefully pour the sand into the calorimeter without having the sand touch the temperature sensor and ensuring that the water in the calorimeter does not splash out.

c. Immediately cover the calorimeter and make sure that temperature sensor 2 remains in the water, but does not touch the sand.

58. ☐ Gently swirl the calorimeter to mix the water and the sand. Make sure that the temperature sensor does not touch the sand.

59. ☐ Continue to swirl and record data until the temperature levels off, and then stop recording data. �(6.2)

60. ☐ Why is it so important to make sure that the temperature sensor does not touch the sand in the calorimeter?

The calorimeter is designed to measure the change in temperature of the water due to the sand. Initially the sand is much hotter than the water and if the temperature sensor touches the sand, the temperature reading will spike due to the temperature of the sand, not the temperature of the water.

61. ☐ Name the data run "Calorimeter". �(8.2)

62. ☐ Save your experiment. �(11.1)

Analyze Data

63. ☐ Copy the mass of water and the initial temperature of sand recorded in the Procedure section into Table 2.

Table 2: Determining the specific heat of sand

Substance	Mass m (g)	T_{initial} (°C)	T_{final} (°C)	ΔT (°C)	Heat Energy Q Lost or Gained (J)	Specific Heat c (J/(g·°C))
Water	70.0	23.7	27.0	3.3	970	4.184
Sand	19.8	95.9	27.0	68.9	970	0.71

64. ☐ Calculate the mass of the sand alone and record it in Table 2.

65. ☐ Use the graph of Temperature versus Time to determine the initial temperature and final temperature of the water in the colorimeter. Record the values in Table 2. �(9.1)

66. ☐ The final temperature of water is also the final temperature of the sand. Record the final temperature of sand in Table 2.

67. ☐ Calculate the change in temperature (ΔT) for the water and the sand. Record these in Table 2.

68. ☐ Using equation 1, find the value of Q, the energy gained by the water as it was warmed by the added hot sand. Use the mass of the water in the cup, and the specific heat of water c (4.184 J/(g °C)). Record this in Table 2.

$$Q_{\text{water}} = m_{\text{water}} c_{\text{water}} \Delta T_{\text{water}} \qquad \text{(Eq.1)}$$

$$Q_{\text{water}} = (70.0\text{ g})\left(4.184\ \frac{\text{J}}{\text{g}\cdot{}^{\circ}\text{C}}\right)(3.3\ {}^{\circ}\text{C}) = 966.5\text{ J} = 970\text{ J}$$

69. ☐ Using equation 2, determine the amount of heat lost by the sand. Record this value in Table 2.

$$\left|Q_{\text{sand}}\right| = \left|Q_{\text{water}}\right| \qquad \text{(Eq.2)}$$

$$\left|Q_{\text{water}}\right| = 970\text{ J, therefore } \left|Q_{\text{sand}}\right| = 970\text{ J}$$

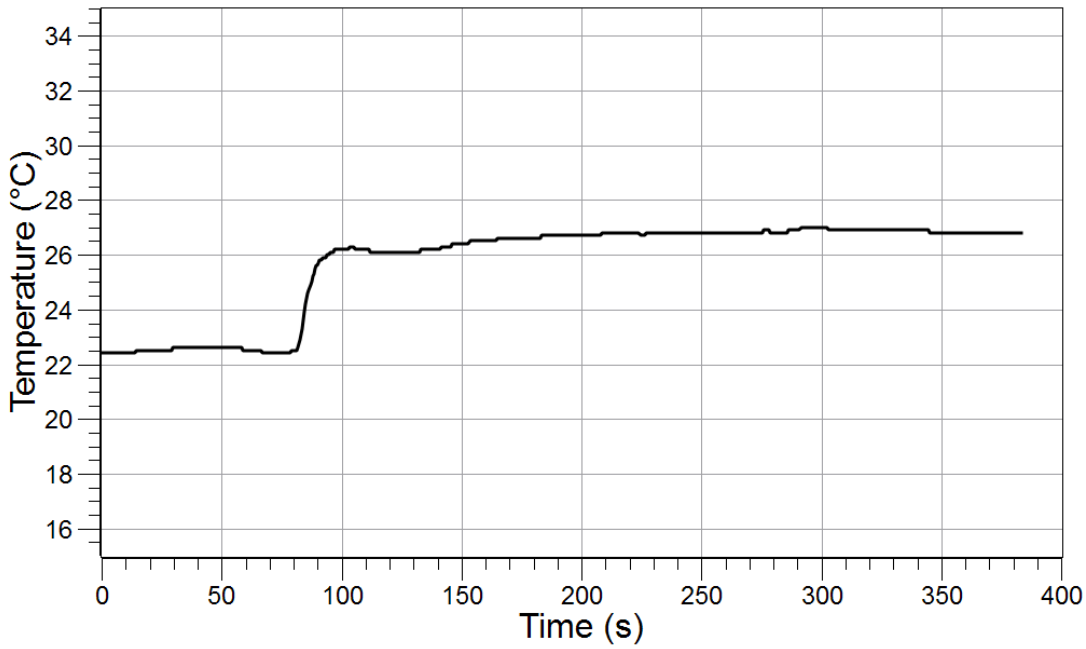
70. ☐ Using equation 3, find the specific heat (c) of sand. Record this in Table 2.

$$Q_{\text{sand}} = m_{\text{sand}} c_{\text{sand}} \Delta T_{\text{sand}} \qquad \text{(Eq.3)}$$

$$c_{\text{sand}} = \frac{Q_{\text{sand}}}{m_{\text{sand}}\Delta T_{\text{sand}}} \quad \frac{970\text{ J}}{(19.8\text{ g})(68.9\ {}^{\circ}\text{C})} = 0.71\ \frac{\text{J}}{\text{g}\cdot{}^{\circ}\text{C}}$$

Sample Data

Part 2 – Determine the specific heat of sand



Analysis Questions

1. In part 1, how did the rate of heating and cooling of sand compare to water? Were your predictions correct? Give a quantitative comparison.

The sand had a higher rate of heating and cooling than the water. The sand heated up 7 times faster and cooled down 5.7 times faster than water. The students should compare their results to what they predicted.

2. In part 2, how did the specific heat of sand compare to that of water? How do the results compare with your prediction?

The specific heat of sand is much lower (0.71 J/(g·°C)) than water (4.184 J/(g·°C)). The students should compare their results to what they predicted.

3. Explain how the specific heats of sand and water relate to their rate of heating and cooling. How can you generalize the relationship between a substance's specific heat and its ability to heat up and cool off?

Sand has a low specific heat and it heats up and cools off very quickly. Water has a high specific heat and a low rate of heating and cooling. In general, the higher a substance's specific heat, the slower it changes in temperature when the energy content of its environment changes.

4. In part 2, what does Q represent? Why is $|Q|$ the same for the water and the sand?

Q represents the amount of heat energy lost or gained by the system. The heat energy given up by the sand was transferred to the water (law of conservation of energy). By using a calorimeter to prevent heat loss to the environment, the amount of heat transferred from the sand was the equal to that gained by the water.

5. List some important sources of experimental error that might occur in each part of this activity.

In part one, the amount of energy added to each system might not be exactly the same. In part 2, an unknown amount of energy was lost to the environment. Some of the energy was absorbed by the calorimeter itself, some was lost through the calorimeter. Some heat energy was also lost when the sand was transferred into the calorimeter.

Synthesis Questions

Use available resources to help you answer the following questions.

1. The specific heat of dry soil is 0.80 J/(g·°C) and wet soil is 1.48 J/(g·°C). Using these values, predict which type of soil when exposed to sunlight would increase its temperature faster. Explain your prediction.

Dry soil will heat up faster to a higher temperature because it has a lower specific heat than wet soil. The lower a substance's specific heat, the faster it changes its temperature when exposed to an energy source.

2. Would you expect a city on the coast or a city in the desert to have higher afternoon temperatures? Explain your reasoning using the concept of specific heat.

A desert city would have higher afternoon temperatures. Sand has a lower specific heat (higher rate of heating) than the water. As temperatures of the land rise, the air above the ground will heat up. On the coast, marine air is very humid, and the specific heat of the water vapor will help to moderate the temperature of the air. Thus the air temperature in the city in a desert would likely be hotter than the air above a coastal city.

3. Explain how the proximity to a large body of water influences climate. Provide an example.

Proximity to a large body of water moderates the climate. Relative to areas inland from the water, the average summer temperatures are cooler and the average winter temperatures are warmer near the water. For example, the average temperatures in Brisbane, on the coast of Australia, in January and July respectively are 25 °C and 14 °C. Those for Alice Springs, in the interior of Australia at the approximately the same latitude and elevations, are 34 °C and 12 °C respectively.

Multiple Choice Questions

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

1. When exposed to the same amount of heat energy, how does the time it takes for water to increase 5 °C compare to that of an equal amount of sand?

- **A.** Water will heat up a little faster than sand.
- **B.** **Sand will heat up much faster than water.**
- **C.** Water will heat up much faster than sand.
- **D.** Sand and water will heat up at approximately equal rates.
- **E.** All of the above are correct.

2. If 5.0 grams of each of the following room temperature substances are placed in a freezer, which would you expect to drop its temperature by 10 °C the fastest?

- **A.** Asphalt (c = 0.92 J/(g·°C))
- **B.** **Gold (c = 0.13 J/(g·°C))**
- **C.** Stone (c =0.75 J/(g·°C))
- **D.** Plastic (c = 1.67 J/(g·°C))
- **E.** Impossible to tell from this information.

3. How quickly the temperature of a material will rise or fall when it gains or loses heat energy is called

- **A.** Temperature
- **B.** Endothermic
- **C.** **Specific heat**
- **D.** First law of thermodynamics
- **E.** Nonpolar molecules

4. The specific heat of sand is

- **A.** **Less than the specific heat of water**
- **B.** Greater than the specific heat of water
- **C.** Approximately the same as the specific heat of water
- **D.** Specific heat is only used to measure liquids
- **E.** Impossible to tell from this information

5. The high specific heat of water compared to that of land results in

- **A.** The small range of temperatures in the oceans compared to that on land
- **B.** Coastal climates that have smaller ranges of temperature compared to those of inland areas
- **C.** The ability of large fresh water bodies to stay in liquid phase when air temperatures drop below 0 °C
- **D.** **All of these are true**
- **E.** None of the above are true

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. How quickly the temperature of a substance heats up or cools down when a quantity of heat is added or lost is determined by its **specific heat**. Specific heat is defined as the amount of **energy** needed to raise the temperature of 1 gram of a substance 1 degree Celsius. Specific heat is expressed in units of **joules** per gram degree Celsius (J/(g·°C)). Specific heat of a substance depends on the molecular structure and **phase** of the substance. Compared to other substances, liquid water has an unusually **high** specific heat of 4.184 J/(g·°C).

2. Earth's different surfaces absorb different amounts of **solar** radiation. The longer a surface on Earth stays warm, the more effective it is at heating the **air** above it. During the day, the **land** heats more quickly to higher temperatures than **water**. During the night, the land **cools** more quickly to **lower** temperatures than water. These differences affect global weather and **climate**. Large bodies of water hold heat and **moderate** the climate above and near these bodies of water. Conversely, large land areas heat up quickly and cool off quickly causing **significant** temperature difference between the high and low temperatures in the region.

Extended Inquiry Suggestions

Have students conduct an Internet search to find the specific heat of various substances. Find the specific heat of common building materials. Challenge the students to relate these specific heats with the phenomenon of "heat islands" found in cities.

Determine the effect of humidity on air temperature. Compare the heat index in different cities such as Atlanta, Georgia and Phoenix, Arizona.

28. Soil pH

Objectives

Determine the pH of three different samples of soil. Through this investigation, students:

- Explain how the pH scale is used to measure the acidity and alkalinity of a soil sample
- Discuss why pH is one indicator of soil health

Procedural Overview

Students gain experience conducting the following procedures:

- Collecting soil samples and preparing them for measuring the soil pH
- Using a pH sensor to measure the pH of soil samples
- Drawing a bar graph that represents the soil pH at each soil sample location

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	90 minutes (45 minutes for each part)[1]

[1]For ideas on how to perform this lab in a 45 minute class period refer to the Lab Preparation section.

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Beaker (2), 50-mL
- Beaker (3), 250-mL
- Graduated cylinder, 100-mL
- Stirring rod
- Wash bottle filled with distilled water
- Digging tool
- Plastic bag (3), sealable, small
- Buffer solution, pH 4, 25 mL
- Buffer solution, pH 10, 25 mL
- Distilled water, 400 mL
- Permanent marker
- Paper towels
- Waste container
- Soil sample (3)[1]

[1]In Part 1, students go outside and collect these three soil samples. See the Related Labs in This Guide section for additional labs that require soil samples.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Basic components of soil
- Plants absorb their nutrients from the soil

Related Labs in This Guide

Labs conceptually related to this one include:

- pH of Household Chemicals
- Air Pollution and Acid Rain

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file 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)
- Calibrating the pH sensor �(3.6)
- Monitoring live data �(6.1)
- Displaying data in a digits display �(7.3.1)

Background

Soil Components

Soil consists of minerals, water, air, and organic matter modified by weather, wind, water, and organisms. Minerals, the main component of soil, anchor plants and provide essential nutrients. The organic fraction of soils derives from dead leaves and branches, animal dung, remains of plants and animals, and microorganisms. Soils form from parent rock materials that are slowly broken down by biological, chemical, and physical weathering.

Soil formation continues as parent rock materials beneath already formed soil break down to add new soil. Regional and local landscapes influence soil types and soil formation. For example, steep slopes often have little or no soil cover because the soil and rock are constantly being moved by gravity. During decomposition, which is part of the nutrient cycle, bacteria and fungi decompose large organic molecules and convert them to small inorganic molecules including carbon dioxide, water, and nutrient minerals. Continued weathering of parent rock materials replaces some nutrient minerals lost by erosion or agriculture.

Soil pH

Most plants thrive in a narrow range of soil pH conditions. Deviating from that range can dissolve potentially toxic materials from rocks and compromise soil health, leading to a decline in plant growth. Soil pH affects plant growth because it affects the way plants absorb nutrients from the soil. This has a direct implication for agricultural crops, thus pH has become an invaluable tool for measuring soil fitness.

The pH range that crops can tolerate varies. For instance, a pH down to 5.5 for corn, cucumbers or cotton may be acceptable, but for beans, lettuce, or onions the low end of the tolerable pH range is 6.0. Because of the logarithmic pH scale, 5.5 is five times more acidic than 6.0. Similarly, a pH up to 7.0 works for cabbage, carrots, or spinach, but for peanuts, peppers, or strawberries the high end of the tolerable pH range is about 6.5. While a crop like alfalfa can tolerate a pH range between 5.2 and 7.8, a staple like potatoes only tolerates a range from 5.0 to 5.25.

Soil pH depends upon the chemical nature of the parent material, the indigenous plants, the agricultural history, and management practices (such as fertilizing and liming).

Acidic Soil

Problems arise when soils become too acidic. On the pH scale, any pH value less than 7 is considered acidic. A soil is considered too acidic when the pH of the soil is less than the lowest pH value in the acceptable range for a given plant. Acidic soil results from both natural and manmade events such as the use of some fertilizers, the removal of calcium by plants, the addition of carbon dioxide during soil respiration, and acid rain.

Symptoms of acidic soil include stunted plants, deformed young leaves, yellowed leaves, weak and stubby roots (instead of long and drought resistant), and poor crop yields.

Alkaline Soil

Soil that is too alkaline also causes problems. On the pH scale, any pH value greater than 7 is considered alkaline. A soil is considered too alkaline when the pH of the soil is higher than the highest pH value in the acceptable range for a given plant. Alkaline soil is mainly a result of the parent material of the soil (such as limestone). The main manmade cause of alkaline soil is through irrigation, especially with water that contains sodium bicarbonate. Symptoms of high alkalinity are generally associated with nutrient deficiencies.

Pre-Lab Discussion and Activity

Materials and Equipment for Pre-Lab Demonstration:

- Data collection system
- pH sensor
- Dirt sample in a clear container (2 different soils)
- Small containers (2), one of water, one empty of all but air
- Small rock samples, such as gravel or pulverized rock
- Organic matter (such as leaves and sticks)
- Living organisms such as earwigs, sow bugs, earthworms or any fungi

- Wash bottle filled with distilled water

Composition of Soil

Show the students a sample of soil in a clear container and guide the students in a discussion about the components of soil. Each time the students mention a component of soil provide a sample of that component isolated from the others.

1. What is soil made up of?

Soil is made up of rocks (minerals) that have been broken into small pieces, organic matter, air, water, and living organisms. (Provide samples of all as they are mentioned by students.)

2. Why does soil look so different in different locations? Are all soils made up of these same components?

Soils look different because they are made up of different types of rock and minerals (different parent material) and because they have varying amounts of soil components. Some soils may have lots of organic matter while other soils have less organic matter.

3. Why is the composition of soils important for plants?

Plants absorb all the nutrients they need to grow from soil. In order for a plant to be healthy it needs soil that can meet its needs.

Soil Health

Engage the students in a discussion about soil health by having the students predict the relative health of the two soils provided.

4. What in your opinion makes a soil "healthy"?

Accept all answers and make a list of their criteria.

5. What soil do you think is healthier?

Students should predict what soil is healthier and give their reasoning.

6. What characteristics of the soil can be measured to determine its health? Why?

Soil moisture, soil salinity, nutrients levels, and soil pH are among the characteristics that can be used to assess the health of a soil. These are important because they affect the way plants absorb the nutrients they need to grow.

7. How does the type of plant being grown relate to the “health” of a soil sample?

Different plants require different conditions in order to grow. Thus soil that is healthy for one type of plant may be unhealthy for another type of plant.

Soil pH

In this lab students will determine the pH of three soil samples. Guide the students in a discussion of pH, the pH scale, and demonstrate the use of the pH sensor.

8. What is soil pH?

Soil pH is a measure of the acidity and alkalinity of a soil sample.

9. What is the pH scale and what does it mean?

The pH scale is a numerical scale between 0 and 14 that compare the acidity and alkalinity of aqueous solutions. Substances with a pH of 7 are considered neutral, a pH of less than 7 is acidic, and a pH greater than 7 is alkaline.

10. The pH scale is a logarithmic scale. What does this mean?

A logarithmic scale is based on multiplication rather than addition. In a typical linear scale the difference between each point on the scale increases by the same amount (typically 1). So on a linear scale the difference between 1 and 2 is one and the difference between 1 and 3 is two (one plus one). In a logarithmic scale the difference between 1 and 2 is 10 and the difference between 1 and 3 is 100 (10 times 10). So a pH of 4 is 100 times more acidic than a pH of 6.

11. How can the pH of a soil sample be determined?

The pH of soil can be determined by mixing a soil sample with water and then measuring the pH of the water using a pH sensor.

12. How do you think the pH of these two soil samples compare?

Students will make their predictions.

Demonstrate the use of the pH sensor by testing the pH of the two soil samples. Demonstrate thorough mixing of the soil solutions: stir vigorously for 2 minutes; allow the mixture to sit for 5 minutes. Clean sensor with the distilled water between each test. Compare the results with the students' predictions.

Lab Preparation

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

Teacher Tip: To save time, there are several ways you can have the students perform this lab:

- ♦ Collect the soil samples (Part 1) for the students ahead of time and have the students use these samples to complete Part 2 of the lab.
- ♦ Have the students collect the soil samples (Part 1) as homework and then have the students use the soil samples to complete Part 2 of the lab.
- ♦ Have the students collect the soil samples (Part 1) in one class period and then measure the pH (Part 2) in the next class period.
- ♦ Have the students collect extra soil and then save the soil to be used in the two additional labs that require soil samples (see the Related Labs in This Guide section).

Teacher Tip: Students need to obtain permission before collecting soil samples from private property.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ To avoid health risks students should *not* collect soil samples in areas high in animal wastes.

♦ Students should avoid collecting samples at road cuts along busy streets.

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	5	3	4
Remove any rocks, sticks, or foreign objects from the soil samples and crush the soil into small, uniform pieces.	Obtain three different soil samples and describe the environment each soil sample was taken from.	Determine the pH of the remaining two samples. Be sure to clean the sensor between samples.	Combine 60 mL of distilled water with 60 mL of soil and mix thoroughly. Repeat this step for the other two soil samples.	Determine the pH of the first soil-water mixture.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Obtaining samples and initial observations

1. ☐ Look around the area and pick out three locations from which to collect soil samples. Select three areas that you think will exhibit a wide variety of pH. Record the selected areas in Table 1.

Table 1: Detailed observations of soil sample locations

Soil Sample	Soil Sample Location	Observations
1	PASCO parking lot	The soil is dry with minimal plant life. The nearby area contains scattered weeds.
2	Duck pond	Moist, lots of foot traffic The nearby area contains grass.
3	Next to a driveway	Moist, dark brown The nearby area contains shrubbery and small plants along the edge of the pavement and grass.

2. ☐ Why do you think these locations will have different pH readings?

The PASCO parking lot, the duck pond, and next to a driveway will have different pH readings because the soil looks different and there are different plants in each area.

3. ☐ Collect a soil sample from the first site using the following technique:

- **a.** Clean the digging tool.
- **b.** Clear away leaves and any other debris.
- **c.** With the digging tool, loosen the soil as deep as eight centimeters and dig up some of this loosened soil.
- **d.** Fill the plastic bag half-full with soil.
- **e.** Seal the bag to preserve moisture.
- **f.** Label the sample; for example, "Vacant lot", or "Hiking trail".

4. ☐ Record your observations about the location of soil sample 1. Your observations should include the following:

- ♦ The appearance of the soil and soil composition, including conditions such as arid or humid
- ♦ The appearance and types of plants and other organisms
- ♦ Animal tracks and the appearance of animals
- ♦ The terrain, holes in the ground, and the geological features of rocks
- ♦ Nearby buildings and whether nearby roads are asphalt, cement, gravel, or dirt
- ♦ Anything unusual about the area

5. ☐ Collect soil samples from the remaining two locations using the same technique described above and record your observations of each location in Table 1.

6. ☐ Why is it necessary to clean the digging tool before collecting each soil sample?

Cleaning the digging tool is necessary to prevent contamination from soil in one location to soil in another location.

Part 2 – Measuring the pH of the samples

Set Up

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

8. ☐ Connect a pH sensor to the data collection system.. �(2.1)

9. ☐ Display pH in a digits display. �(7.3.1.)

10. ☐ Place 25 mL of pH 4 buffer solution in a 50-mL beaker and 25 mL of pH 10 buffer solution in a second 50-mL beaker. Use these solutions to calibrate the pH sensor. �(3.6)

11. ☐ Label a 250-mLbeaker for each soil sample as you did with the sample bags.

12. ☐ Complete following steps for each soil sample:
    - **a.** Remove any rocks, sticks, or foreign objects from the soil.
    - **b.** Leaving the soil sample inside the plastic bag, crush the soil using with a clean digging tool.
    - **c.** Mix the crushed particulates thoroughly.
    - **d.** Use a clean 100-mL graduated cylinder to measure 60 mL of the soil sample.
    - **e.** Place the 60 mL of soil in the appropriately labeled beaker.
    - **f.** Add 60 mL of distilled water to the soil.
    - **g.** Use a stirring rod to mix the soil and water vigorously for 2 minutes.
    - **h.** Allow the soil-water mixture to sit for at least 5 minutes.
    - **i.** Clean the graduated cylinder and stirring rod.

13. ☐ Why do you need to crush the soil?

The soil needs to be pulverized to increase the surface area that is available, so when water is added, a representative sample of the minerals in the soil becomes dissolved.

14. ☐ Why are you adding water to the sample?

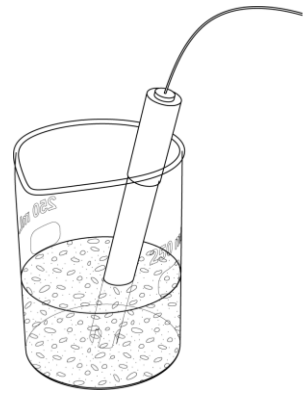
Measuring pH cannot be done with solids. Generally, water must be added to liberate the ions for measurement.

15. ☐ What is the independent variable and the dependent variable in this experiment?

The independent variable is the location of the soil collected. The dependent variable is the pH of the soil.

Collect Data

16. ☐ Rinse the pH sensor with distilled water.



17. ☐ Why is the pH sensor rinsed with distilled water before testing each sample?

Distilled water is used to prevent cross contamination from the other samples.

18. ☐ Place the pH sensor into the first soil sample.

19. ☐ Monitor live pH data in a digits display. �(6.1)

20. ☐ Stir the mixture gently with the pH sensor until the reading stabilizes.

21. ☐ Record the soil location and pH in Table 2.

Table 2: Stabilized pH readings for soil samples

Soil Sample	Soil Sample Location	pH
1	PASCO parking lot	6.7
2	Duck pond	6.4
3	Next to a driveway	7.0

22. ☐ Remove the pH sensor from the beaker and wash it thoroughly with distilled water.

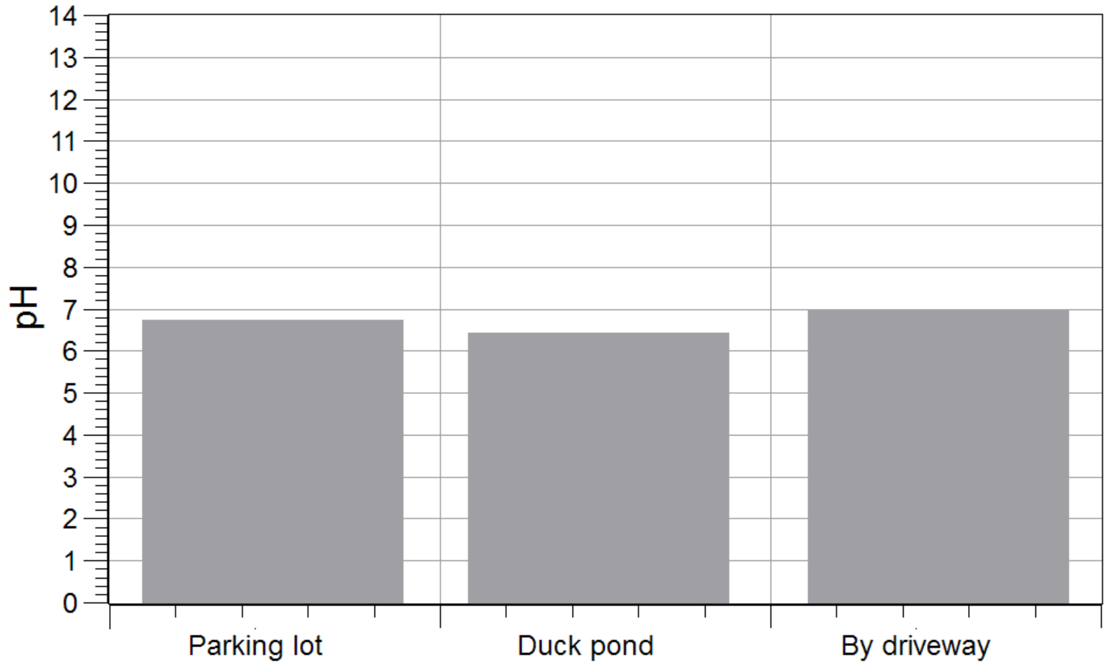
23. ☐ Rinse the pH sensor with distilled water, then repeat the Collect Data steps for the other two soil samples. Record the results in Table 2.

24. ☐ Clean up according to your teacher's instructions.

Data Analysis

1. ☐ Draw a bar graph that represents the pH recorded at each location. Label the axes as well as the overall graph.

Soil pH at Different Locations



Analysis Questions

1. What factors (variables) did you attempt to control in the three trials?

The factors that were controlled were method of soil collection, method of soil preparation, amount of soil used; type of water used; amount of water used; instrumentation variables (since the same instrument was used for all measurements and the measurement procedure was the same for all measurements; temperature during measurement.

2. List the soil location in order from most acidic to most alkaline.

Students' answers will vary. In this sample, the duck pond soil was the most acidic, then PASCO parking lot soil, and the most alkaline was the soil that was collected next to the driveway.

3. Which soil sample was the closest to being neutral? How do you know?

Students' answers will vary. The soil collected from beside the driveway was neutral because it had a pH of 7 which is considered neutral.

4. Based on the pH values measured, would you consider the soils you tested to be healthy? Explain.

All three of the soils tested were found to have pH values close to neutral (6.4 to 7), which means that based on pH the soils were all healthy and would support the nutrient needs of some plants.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Which of the soil samples might be able to effectively neutralize acid rain? Explain why.

Acid rain would be neutralized by alkaline soil. None of the soils sampled were alkaline so these locations would not neutralize acid rain very well.

2. How can you assess the overall quality of a soil sample?

The overall quality of a soil sample can be assessed by determining the pH of the soil, the nutrient content of the soil, soil moisture, and soil salinity. To truly know the health of a soil all of these components need to be measured.

3. What is the pH scale and what does it mean if my soil has a pH of 4.2?

The pH scale is a quantitative scale between 0 and 14 that measures of the acidity and alkalinity of an aqueous solution. A pH of 4.2 means that the soil is very acidic and many plants would not thrive in these soil conditions. The soil would need to be treated in order to make the soil conditions more conducive to plant growth.

Multiple Choice Questions

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

1. What does pH measure?

- **A. The acidity and alkalinity of soil**
- **B.** The water content of soil
- **C.** The salt content of soil
- **D.** The particle size of soil
- **E.** All of the above

2. A soil with a pH of 9.6 is considered to be _________________.

- **A.** Acidic
- **B. Alkaline**
- **C.** Neutral
- **D.** Moist
- **E.** Salty

3. A soil pH of ______________ means that the soil is neutral.

- **A.** 3
- **B.** 5
- **C.** **7**
- **D.** 10
- **E.** 12

4. What characteristics should be assessed to determine the health of soil?

- **A.** pH
- **B.** Salinity
- **C.** Nutrient content
- **D.** Moisture levels
- **E.** **All of the above**

5. How can the pH of soil be determined?

- **A.** A pH sensor can be inserted directly into the ground to measure the pH.
- **B.** **A pH sensor can be inserted into a solution of soil and water.**
- **C.** A thermometer can be inserted directly into the ground to measure the pH of the soil.
- **D.** Soil pH can be determined by rubbing the soil between your fingers.
- **E.** All of the above are correct ways to measure pH.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. **Soil** consists of minerals, water, air and **organic** matter. The **mineral** portion of soils is the main component, providing anchorage and essential nutrients for plants. The minerals in soil come from **parent** rock materials that are slowly broken down by biological, chemical, and physical weathering processes in a continuous process that involves interactions between Earth's spheres. The **organic** fraction of soils is derived from dead leaves and branches, animal dung, remains of plants and animals, and microorganisms. Different types of soil exist and some are **healthy** and promote plant growth, while other types of soil hinder plant growth.

2. Soil pH affects a plants ability to absorb **nutrients**. Most plants thrive in a **narrow** range of soil pH conditions. This means that slight changes in **pH** can have serious affects on plant life. Soil pH can be determined by collecting a soil sample, **crushing** it, and mixing it with **water**. A pH sensor is placed in the soil-water mixture and the pH is measured. In general, neutral soils have a pH near **seven**, while acid soils have a pH **less** than seven, and **alkaline** soils have a pH greater than seven. However, we say that a soil will be too **acidic** for a given plant if its pH is lower than the value known to be acceptable for that type of plant, even if that value is above 7.0. Soil pH is just one of several factors that can be used to assess the **health** of soil.

Extended Inquiry Suggestions

Can certain types of soils neutralize acid rain? Explain why or why not and then design an experiment to determine the answer.

How does soil type (sandy, loam, & clay) affect a soils pH?

How does soil pH affect the growth rate of plants?

How do famers adjust the pH of their soil for different crops?

What affect does fertilizer have on the pH of soil?

29. Air Pollution and Acid Rain

Objectives

Determine the effect air pollutants (CO_2, SO_2, and NO_2) have on the pH of water. Through this investigation, students:

- ♦ Describe the relationship between air pollutants and acid rain.
- ♦ Discuss the effect changes in the pH of water have on the environment.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Perform chemical reactions to generate three types of gases (CO_2, SO_2, and NO_2) that are common air pollutants.
- ♦ Graph pH versus Time data as each type of gas is bubbled through a beaker of water.
- ♦ Determine the overall change in pH for each gas tested and relate these finding to the causes and effects of acid rain.

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ pH sensor
- ♦ Erlenmeyer flask, 50-mL
- ♦ Beaker, 50-mL
- ♦ Graduated cylinder, 50- or 100-mL
- ♦ One-hole s topper to fit the flask
- ♦ Tubing connector [1]
- ♦ Tubing to fit the tubing connector, 20-cm
- ♦ Volumetric pipet with bulb, 10-mL
- ♦ Sodium bicarbonate ($NaHCO_3$), 5 g
- ♦ Sodium bisulfite ($NaHSO_3$), 5 g
- ♦ Sodium nitrite ($NaNO_2$), 5 g
- ♦ 1.0 M Hydrochloric acid (HCl), 15 mL [2]
- ♦ Water or deionized water, 60 mL
- ♦ Wash bottle containing distilled or deionized water
- ♦ Balance (1 per class)

[1]A piece of glass tubing can be substituted.

[2]To prepare using concentrated (12 M) or dilute (6 M) hydrochloric acid (HCl), refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Acids, bases, and pH
- ♦ Most organisms function best within a narrow pH range
- ♦ Human activities that cause air pollution

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Soil pH
- ♦ pH of Household Chemicals

Using Your Data Collection System

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

Note: There are no Tech Tips to list in this section as this activity does not use a data collection system.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to your 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)
- ♦ Showing and hiding data runs in a graph �(7.1.7)
- ♦ Naming a data run �(8.2)
- ♦ Viewing statistics of data �(9.4)
- ♦ Saving your experiment �(11.1)
- ♦ Printing �(11.2)

Background

The Creation of Acid Rain

Acid rain is not only rain, but any other form of precipitation that is acidic. As this acidic water flows over and through the ground, it affects a variety of plants and animals. The strength of these effects depends on many factors, including: 1) the acidity of the water, 2) the chemistry and buffering capacity of the soils involved, and 3) the types of fish, trees, and other living things that rely on the water.

Scientists discovered that sulfur dioxide (SO_2) and nitrogen oxides (including nitric oxide, (NO), and nitrogen dioxide (NO_2)), collectively known as NO_x, are the primary causes of acid rain. Acid rain results when these gases react in the atmosphere with water, oxygen, and other airborne chemicals to form various acidic compounds.

Sulfur dioxide and nitrogen oxides go through several complex pathways of chemical reactions in the atmosphere before they become the acids found in acid rain. One of the most important pathways involves the oxidation of sulfur dioxide (SO_2) to sulfur trioxide (SO_3) by ozone (O_3). Ultraviolet energy of sunlight increases the rate of most of these reactions by degrading ozone to oxygen gas (O_2) and an oxygen radical (O^-) that is a highly reactive oxidizer. The sulfur trioxide then reacts with water vapor to form sulfuric acid. These reactions are shown as follows:

$$2SO_2 + 2O^- \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4.$$

Dust or ice particles can transport this sulfuric acid through the atmosphere to settle on the ground as dry acid deposition. The sulfuric acid can also dissolve in rain or fog and settle on the ground as wet acid deposition. Scientists believe that sulfuric acid is primarily responsible for the formation of acid rain.

Sulfur dioxide also readily reacts with water to produce sulfurous acid. Students will explore this reaction of sulfur dioxide in this lab activity.

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

In the United States, about two-thirds of all SO_2 and one-quarter of all NO_x comes from electric power generation that relies on burning fossil fuels such as coal. Other sources include automobile exhaust, furnaces, paper pulp production, and metal smelters.

Carbon dioxide is also a source gas for acid rain. It produces a relatively weak acid, but still should be considered a source due to increased use of fossil fuels.

The Effects of Acid Rain

The effects of acid rain are widespread. Acid rain causes acidification of lakes and streams. It damages trees at high elevations, such as red spruce trees above 600 meters, damages sensitive forest soils, and accelerates the decay of building materials (such as limestone and marble), metals (such as bronze) and automotive paint and other coatings. The stressful and sometimes deadly fluctuations in water systems due to acid rain cause aquatic life to experience chemical "shock" effects. For example, as the pH drops to 5.5, plankton, certain insects, and crustaceans begin to die and trout eggs do not hatch well.

Acid rain reduces crop productivity and forest growth rates while accelerating the rate at which "heavy" metals, such as lead and mercury, and nutrient cations (such as Mg^{2+} and K^{+}) leach from soils, rocks, and water body sediments. Scientists believe that acid rain causes increased concentrations of methylmercury in bodies of water—methylmercury is a neurotoxic molecule that accumulates in fish tissues and can cause birth defects in populations that ingest high concentrations of affected fish.

Pre-Lab Discussion and Activity

Air Pollution

Engage your students in a discussion about the visual signs of air pollution and the causes of air pollution.

1. Where have you been that has bad air pollution? How did you know that the air quality was bad?

Air pollution tends to be bad in large, industrial cities. The air quality is bad when there is a brownish haze covering the city. Some people have a hard time breathing and may experience wheezing and coughing.

2. What are the main causes of air pollution?

Air pollution is caused by both man-made and natural processes. Man-made process of air pollution are mostly related to the burning of fossil fuels. This includes power plants, factories, furnaces, automobiles, and airplanes. Natural sources include volcanic eruptions, forest fires, and biological processes.

3. What are some common air pollutants?

Common air pollutants include sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds such as methane (CH_4), particulate matter such as dust, toxic metals such as lead, chlorofluorocarbons (CFCs), ammonia (NH_3), odors, and radioactive pollutants.

Air Pollution and Environmental Problems

Discuss the relationship between air pollutants the environment. Lead the discussion to determining if air pollutants are related to acid rain.

4. How do air pollutants affect the environment?

Humans can develop health problems and diseases from air pollution. Air pollutants cause stains and discoloration on buildings and statues.

5. Is there a relationship between air pollutants and acid rain?

Answers will vary. This is the objective of the lab and should not be answered here. Just get students thinking about it.

6. What is acid rain and how can the acidity of water be measured?

Acid rain is when rain water has a pH of 5.6 or lower. The acid content of water can be measured using a pH sensor. Review the pH scale as needed.

7. How can we determine the effect of air pollutants on the pH of water?

One type of air pollutant can be added to water over time, if the pH is measured as this process takes place the data will determine whether or not that specific air pollutant affects the pH of water.

8. Air pollutants are found mixed in the air. How can a source of a single air pollutant be generated?

Chemical reactions can be used to generate specific chemical compounds including air pollutants.

Chemical Reactions Performed In this Lab

Tell students that they will generate a small amount of CO_2, SO_2, and NO_2 to determine the effect of these pollutants on the pH of water.

Review the chemical reactions that produce the gases they will be studying:

Sodium bicarbonate + hydrochloric acid → sodium chloride + water + carbon dioxide gas

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

Sodium bisulfite + hydrochloric acid → sodium chloride + water + sulfur dioxide gas

$$NaHSO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + SO_2(g)$$

Sodium nitrite + hydrochloric acid → sodium chloride + nitrogen dioxide gas

$$NaNO_2(s) + HCl(aq) \rightarrow NaCl(aq) + NO_2(g)$$

Lab Preparation

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

Follow these safety procedures as you begin your preparations:

- ♦ Wear eye protection, lab apron, and protective gloves when handling acids. Splash-proof goggles are recommended. Either latex or nitrile gloves are suitable.
- ♦ If acid or base solutions come in contact with skin or eyes, rinse immediately with a copious amount of running water for a minimum of 15 minutes.
- ♦ Diluting acids and bases create heat; be extra careful when handling freshly prepared solutions and glassware as they may be very hot.
- ♦ Always add acids and bases to water, not the other way around, as the solutions may boil vigorously.
- ♦ Handle concentrated acids and bases in a fume hood; the fumes are caustic and toxic.

Prepare the following solution:

1. Prepare 100 mL of 1.0 M hydrochloric acid from either concentrated (12 M) or dilute (6 M) HCl. This is enough for 10 lab groups.

Starting with concentrated (12 M) HCl

a. Add approximately 50 mL of distilled water to a 100 mL beaker with a stir bar.

b. Slowly add 8.3 mL of 12 M HCl to the beaker with continuous stirring.

c. Allow the solution to cool, then carefully pour into a 100-mL volumetric flask and dilute to the mark with distilled water.

d. Cap and invert three times to ensure complete mixing.

Starting with dilute (6 M) HCl

a. Add approximately 50 mL of distilled water to a 100 mL volumetric flask.

b. Add 16.7 mL of 6 M HCl to the water and dilute to the mark with distilled water.

c. Cap and invert three times to ensure complete mixing.

Teacher Tips:

♦ Use tap water unless the water in your area has a high level of dissolved solids which can produce a significant buffering action (as is the case for some well water, for example). The pH of distilled and deionized water is highly susceptible to large changes as a result of minute contaminants.

♦ Because the pH measurements in this activity are relative only to measurements within this lab, it is not necessary to calibrate the pH sensor to obtain useful and meaningful data.

♦ If your classroom does not have good ventilation, students can generate the CO_2 part of the activity at their lab benches. The parts for SO_2 and NO_2 can be performed by one group or the teacher under the fume hood in the chemistry lab and the results presented to the class for analysis.

♦ For students generating CO_2 at their workbench, you can substitute household white vinegar if you do not have 1.0 M HCl.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Hydrochloric acid is a corrosive irritant. Avoid contact with skin and eyes.

♦ Work in a well ventilated room (or under a fume hood) when creating sulfur dioxide and nitrogen dioxide.

♦ Do not remove the stopper from the Erlenmeyer flask once the reaction has started.

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.

4	3	2	5	1
Repeat the gas generation and data collection for NO_2 and SO_2.	Dispose of the contents of the flask and beaker and thoroughly rinse out the flask, beaker, and tubing.	Collect pH versus time data for water as CO_2 gas is bubbled through it.	Determine the changes in pH for each gas.	Set up equipment. Open a graph display.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Making carbon dioxide (CO_2) gas and measuring its effect on the pH of water

Set Up

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

2. ☐ Connect the pH sensor to the data collection system. �(2.1)

3. ☐ Display pH on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

4. ☐ What do you think will happen to the pH of the water when you dissolve CO_2 gas in it? Why?

Answers will vary according the student predictions. Since CO_2 creates carbonic acid in the solution, the pH will be lowered. Carbonic acid is a weak acid and there for the expected change will be small.

5. ☐ Measure 20 mL of water using the graduated cylinder.

6. ☐ Pour the water into the 50-mL beaker.

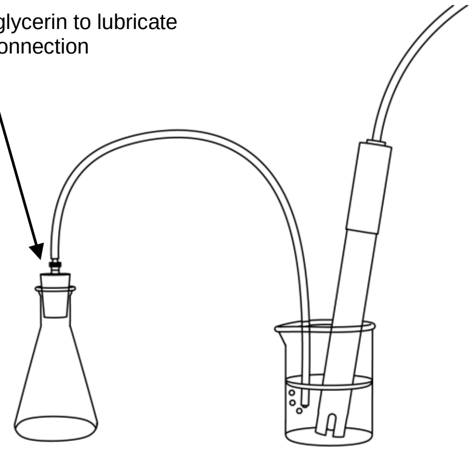
7. ☐ Obtain a sample of powdered sodium bicarbonate ($NaHCO_3$) from the teacher.

8. ☐ Measure 5 grams of $NaHCO_3$.

9. ☐ Place the measured $NaHCO_3$ in the 50-mL Erlenmeyer flask.

10. ☐ Connect the tubing to the stopper using the tubing connector. See the picture below.

Note: If necessary, use glycerin to lubricate the connection so that the connector is well seated in the stopper.



11. ☐ Thoroughly rinse the pH sensor with distilled water.

12. ☐ Hold the rinsed pH sensor and the free end of the tubing beneath the surface of water in the beaker.

Collect Data

13. ☐ Start recording data. �(6.2)

14. ☐ Pipet 4 mL of 1.0 M hydrochloric acid (HCl) into the Erlenmeyer flask, immediately stopper the flask, and place the free end of the tubing in the water in the beaker.

CAUTION: Hydrochloric acid is a strong acid. Handle with care. Flush any spillage with a lot of water.

Note: If necessary, adjust the scale of the graphs to show all data. �(7.1.2)

15. ☐ Record data for about 200 seconds (until the change in pH stops or stabilizes), then stop recording data. �(6.2)

16. ☐ Name your data run to reflect the sample type. �(8.2)

17. ☐ In this part of the lab you generated CO_2 gas by reacting HCl with $NaHCO_3$. What human-related and natural processes emit CO_2 gas into the atmosphere?

The main source of CO_2 gas emission into the atmosphere is the combustion of fossil fuels. This occurs in power plants, automobiles, and industrial factories. Natural processes such as respiration by plants and animals and volcanic eruptions also release CO_2 gas into the atmosphere.

18. ☐ Dispose of the contents of the flask and beaker as directed by your instructor.

19. ☐ Rinse the beaker, flask, and tubing with water.

Part 2 – Making sulfur dioxide (SO_2) gas and measuring its effect on the pH of water

20. ☐ What do you think will happen to the pH of the water when you dissolve SO_2 gas in it? Why?

Answers will vary according the student predictions. Since SO_2 creates sulfurous acid in the solution, the pH will be lowered. Sulfurous acid is a strong acid so the change in pH should be larger than the change observed using CO_2 gas.

21. ☐ Again measure 20 mL of water and repeat the steps in Part 1 using 5 g sodium bisulfite ($NaHSO_3$) instead of $NaHCO_3$.

22. ☐ In this part of the lab you generated SO_2 gas by reacting HCl with $NaHSO_3$. What human-related and natural processes emit SO_2 gas into the atmosphere?

The main source of SO_2 gas emission into the atmosphere is the combustion of fossil fuels. This occurs in power plants, automobiles, and industrial factories. Natural processes such as volcanoes and the biological decay of organic matter release SO_2 gas into the atmosphere.

Part 3 – Making nitrogen dioxide (NO_2) gas and measuring its effect on the pH of water

23. ☐ What do you think will happen to the pH of the water when you dissolve NO_2 gas in it? Why?

Answers will vary according the student predictions. Since NO_2 creates nitric acid in the solution, the pH will be lowered. Nitric acid is a strong acid and so the change in pH should be greater than that of CO_2.

24. ☐ Repeat the steps in Part 1 using 5 g sodium nitrite ($NaNO_2$) instead of $NaHCO_3$.

25. ☐ In this part of the lab you generated NO_2 gas by reacting HCl with $NaNO_2$. What human-related and natural processes emit NO_2 gas into the atmosphere?

The main source of NO_2 gas emission into the atmosphere is the combustion of fossil fuels. This occurs in power plants, automobiles, and industrial factories. Natural processes such as lightning discharges and biological process release NO_2 gas into the atmosphere.

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

Data Analysis

1. ☐ Determine the maximum and minimum pH values for each run of data and record them in Table 1 below.

a. Display the run of data you want to analyze. �(7.1.7)

b. Use the statistics tool to find the maximum and minimum pH of the data run. �(9.4)

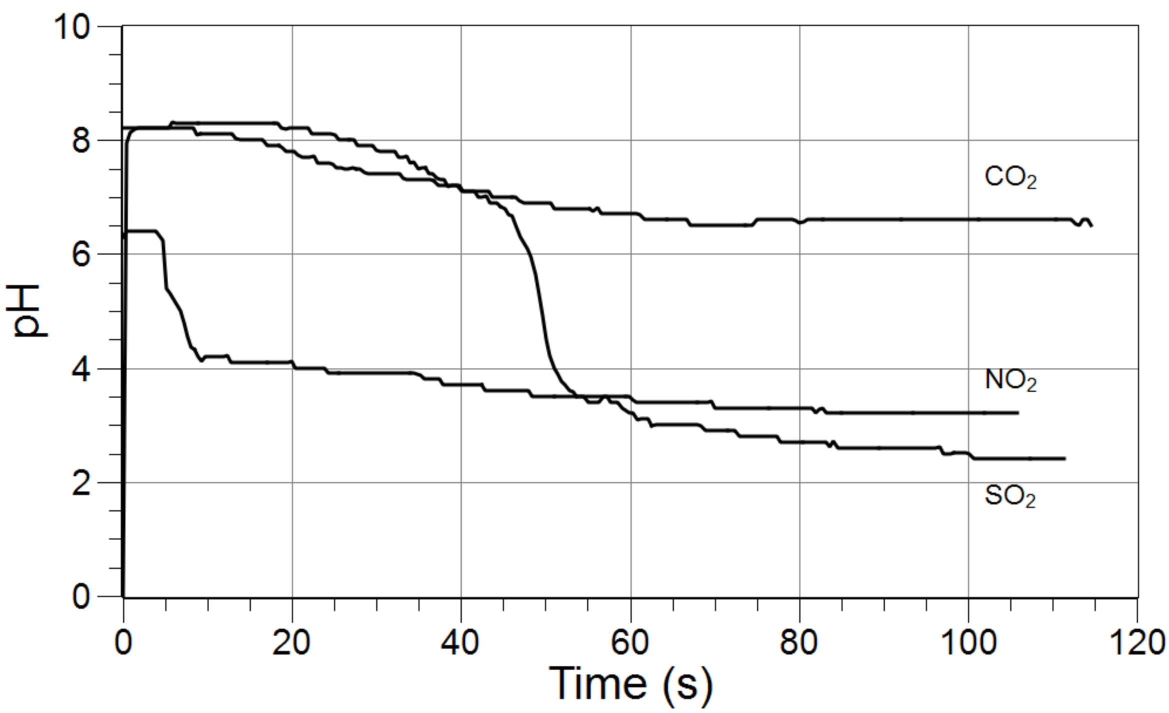
Table 1: pH change due to gases dissolved in water

Gas	Maximum pH	Minimum pH	Change in pH
Carbon dioxide	8.2	6.5	1.7
Sulfur dioxide	8.3	2.9	5.4
Nitrogen dioxide	6.4	3.2	3.2

2. ☐ Calculate the change in pH and record your answers in Table 1 above.

3. ☐ Sketch or print a graph of pH versus Time for all three gases on one set of axes. Be sure to label each run of data. Also label the overall graph, the *x*-axis, the *y*-axis, and include units on the axes. �(11.2)

Change in the pH of Water as CO_2, SO_2, and NO_2 Gasses Were Added



Analysis Questions

1. Were your three predictions about CO_2, SO_2, and NO_2 correct? Did the pH of the water change as you expected for each gas? Explain.

Answers will depend on what students predicted. They should briefly discuss why they were correct or not correct.

2. What effect do air pollutants (CO_2, SO_2, and NO_2) have on the pH of water? Use your data to support your answer.

The air pollutants tested, CO_2 SO_2, and $NO_{2,}$ all caused the pH of water to decrease. In all three cases the maximum pH was recorded before the gases had been added and the minimum pH was recorded after the gases had been added. This means that all the gases caused the pH of water to be lower.

3. Do all the gases you tested contribute equally to acid rain? Use your data to explain your answer.

SO_2 and NO_2 gases are stronger contributors to acid rain than CO_2 gas. SO_2 gas lowered the pH in water the most (a change of 5.4) which means it will create acid rain with the lowest pH. This was followed by NO_2 gas, which caused the pH of water to be lowered by 3.2 and will also rain to be quite acidic. Out of the three gases CO_2 gas had the smallest affect on the waters pH and only dropped it by 1.7 units.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Explain the relationship between air pollution and acid rain.

Air pollutants such as SO_2, NO_2, and CO_2 cause acid rain. These air pollutants cause acid rain by reacting with oxygen, water, and other chemicals in the atmosphere to form acidic compounds. The acid compounds formed cause the pH of rain to be lower than normal and result in acid rain.

2. How does acid rain affect aquatic ecosystems?

Acid rain causes the pH of lakes, streams, and other bodies of water to decrease. Aquatic organisms can only survive in water with a specific pH range. When the pH of the water decreases below this range the aquatic organisms can die. If the organisms themselves do not die, they can be affected in other ways. Their food sources such as plankton and small insects could die leaving them without food or their reproduction systems could be affected resulting in smaller numbers of offspring.

3. How does acid rain affect terrestrial ecosystems?

Acid rain causes the pH of soil to decrease. When soils become more acidic the minerals that plants need are more easily leached from the soil and washed away with rain. Crop productivity and forest growth rates are decreased. Animals that depend on these crops for survival are affected.

4. What are some ways to prevent the formation of acid rain?

The formation of acid rain can occur by reducing or eliminating man-made forms of air pollution. This can be done by: 1) using alternate forms of energy such as solar energy or wind energy instead of fossil fuels; 2) Install the use of technologies such as scrubbers on smoke stacks to reduce emissions; 3) Install catalytic converters in cars to convert nitric oxide gases to nitrogen gas; 4) Conserve energy. Using less energy will require burning less fossil fuels, which contain sulfur and nitrogen; 5) Develop more fuel efficient cars.

5. Coal from states in the western United States, like Montana and Wyoming, has a lower percentage of sulfur impurities than coal found in the eastern United States. How would the burning of low-sulfur coal change acid rain?

Burning low-sulfur coals would decrease the amount of acid rain by reducing the amounts of sulfur oxides emitted into the atmosphere.

Multiple Choice Questions

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

1. Which of the following is true about acid rain?

- **A.** Acid rain is linked to NO_2 and SO_2 molecules in the atmosphere.
- **B.** Acid rain can result in the death of many species of water-dwelling organisms when it causes the pH of lakes systems to move to a range outside their tolerance.
- **C.** Acid rain affects soil chemistry and the ability of plant roots to take in nutrients.
- **D. All of the above are true.**
- **E.** None of the above are true.

2. Which of the following play important roles in the formation of acid rain?

- **A.** Gases in the atmosphere
- **B.** Soil types
- **C.** Water in the atmosphere
- **D. A and C are correct**
- **E.** A, B and C are all correct

3. In general, rain exerts harmful effects on ecosystems when it falls below a pH of:

- **A.** 1.6
- **B.** 2.6
- **C.** 3.6
- **D. 5.6**
- **E.** 7.6

4. How do air pollutants (CO_2, SO_2, and NO_2) affect the pH of water?

- **A.** Air pollutants increase the pH of water.
- **B. Air pollutants decrease the pH of water.**
- **C.** Air pollutants either increase or decrease the pH of water.
- **D.** Air pollutants have no affect on the pH of water.
- **E.** Air pollutants only affect the pH of acidic water.

5. Significant sources of SO_2 and NO_2 in the atmosphere are:

- **A.** Sunshine and water moisture
- **B. Burning coal, auto exhaust, and factories**
- **C.** Photosynthesis and respiration
- **D.** Manure waste from cattle and sheep farms
- **E.** All of the above

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Many types of air **pollutants** are released into the atmosphere by factories, coal-burning power plants, **automobiles**, and furnaces. Among the pollutants are gases like sulfur dioxide (SO_2) and **nitrogen dioxide** (NO_2). These gas pollutants are the **primary** cause of acid rain. **Acid rain** occurs when these gases react in the **atmosphere** with water, oxygen, and other chemicals to form various acidic compounds. Rain with a pH of 5.6 or **lower** is considered to be acid rain.

2. Acid rain affects a variety of plants and animals. Some types of **organisms**, such as plankton, certain insects, crustaceans, and trout eggs are especially susceptible to damage due to **low** pH of the water. Acid ran can also accelerate the leaching of **metals** and nutrients found in soils and rock. It reduces crop **productivity** and forest growth rates. Acid rain may remove **protective** layers from plant leaves, causing the plants to be more susceptible to **disease**. Scientists believe that acid rain causes increased concentrations of toxic **methylmercury** dissolved in surface water. Acid rain can **damage** concrete, stone, and metal structures.

Extended Inquiry Suggestions

What is the pH of your local rainwater? Have students design a way to collect rainwater and then measure the pH of the sample using a pH sensor.

What is the pH of a local water system? Have students collect samples from a local pond, stream, lake, or river. Then, determine the pH of the samples using a pH sensor.

Visit a local cemetery and observe the wearing away of the headstones or other grave markers over time. Military cemeteries use limestone markers that are more easily affected by acid rain than the granite markers in some private cemeteries. Use the dates on the marker stones and the condition of the stones to determine which ones acid rain may have damaged. Remember that these materials would naturally deteriorate when exposed to the weather and rain (even clean rain). Acid rain would accelerate this damage.

Have students write, produce, and direct a special "weather special" segment for TV on the effect of weather patterns and the travel of acid rain over large distances. Contact the weather bureau or a local television station's weather department to ask about the wind patterns in your area. This information and data for your area may also be available on the Internet.

Have students contact a local natural resource specialist from your local zoo or park, Ask that person to tell you about the impact, if any, of both acid rain and dry acid deposition in the lakes.