Advanced Environmental Science And Earth Science

Teacher Guide

Contributors

PASCO Development Team

- Freda Husic, *Director of Education Solutions, Program Manager*
- Korey Champe, *Product Manager, Earth and Environmental Science, and Co-Lead Author*
- Sunny Bishop (*SB Tech Communications), Co-Lead Author*
- Patricia MacEgan*, Co-Lead Author*

Contributing Authors

- Aida Awad*, Department Chair, Environmental Science*
- Craig Bouma*, Teacher, Biology; Physics; AP Environmental Science*
- Jennifer Chambers*, Teacher, Biology*
- Jason Cochrane, *Teacher, Biology, Chemistry, Physical Science*
- Deborah Dogancay, *Teacher, Environmental Science; IB Chemistry; Honors Chemistry*
- Steve Engelmann, *Teacher, AP Environmental Science*
- Brad Horton, *Teacher, AP Biology*, *Biology, Environmental Science, Physics*
- Roger Palmer, *Teacher, Chemistry, Physics, Environmental/Field Science*
- Frank Rutherford, *Teacher, AP Environmental Science*
- David Tucker, *Teacher, Physics, Chemistry*
- Richard Wellbeloved-Stone, *Teacher, Environmental Science, Ecology, Earth Science*
- Ryan Reardon, *Teacher, AP Biology, AP Environmental Science, Biotechnology*

Editors

- Janet Miller, *Lead Editor*
- Nancy Clarke, *Editor*
- Marty Blaker, *Editor*
- Jim Collins, *Editor*
- Chuck Jaffe*, Editor*

PASCO Production Team

- Tommy Bishop, Design and Production *Specialist*
- Brynn Lacabanne, *Research Assistant*
- Susan Watson, *Production Specialist*

Student Activity Testers

- Brandon Giles, *Lead Student Tester*
- Josh Schmidt, *Student Tester*
- Kevin Branderhorst, *Student Tester*
- Joselyn Del Cid, *Student Tester*
- Milos Spasic, *Student Tester*

Advanced Environmental Science And Earth Science

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 978-1-886998-20-9
Printed in the United States of America
Catalog Number: PS-2979

Contents

Introduction

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

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

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

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

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

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

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

About the PASCO 21st Century Science Guides

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

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

The Data Collection System

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

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

Getting Started with Your Data Collection System

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

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

Teacher and Student Guide Contents

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

Lab Activity Components

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

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

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

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

TEACHER INFORMATION	STUDENT INQUIRY WORKSHEET
Objectives	Driving Questions
Procedural Overview	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 accompanying this manual contains the following:

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

International Baccalaureate Organization (IBO*) Support

IBO Diploma Program

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

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

Using these Labs with the IBO Programs

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

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

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

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

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

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

About Correlations to Science Standards

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

Global Number Formats and Standard Units

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

Reference

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

Master Materials and Equipment List

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

Teachers can conduct some lab activities with sensors other than those listed here. For assistance with substituting compatible sensors and probes 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	**Determining Soil Quality** Use a carbon dioxide gas sensor, a pH sensor, and a conductivity sensor to analyze the capacity of soil to support plant growth by examining the physical, chemical, and biological characteristics of different types of soil.	Data Collection System	1
		PASPORT Carbon Dioxide Gas Sensor and sampling bottle	1
		PASPORT pH Sensor	1
		PASPORT Conductivity Sensor	1
		PASPORT Sensor Extension Cable	1
		Beaker, 100-mL	4
		Beaker, 50-mL	1
		Digging tool	1
		Dissecting microscope	1
		Distilled or deionized water	300 mL
		Graduated cylinder, 100-mL	1
		Labeling tape	1 roll
		Microscope slides and cover slips	3
		Microscope with magnification up to 400x	1
		Microwave oven	1 per class
		Permanent marker	1
		pH calibration standard solution, pH 4	25 mL
		pH calibration standard solution, pH 7 or 10	25 mL
		Pipet, disposable, 1-mL	1
		Plastic bags	4
		Soil samples (from 3 different locations)	3
		Stirring rod	1
		Wash bottle containing distilled or deionized water	1
		Waste container	1
		White household vinegar	4 mL

Lab	Title	Materials and Equipment	Qty
2	**Insolation and the Seasons** Use a stainless steel temperature sensor to measure the temperature of a solar panel positioned at different angles relative to the sun in order to determine how the earth's tilt and rotation around the sun is related to climate and the seasons.	Mobile Data Collection System	1
		PASPORT Stainless Steel Temperature Sensor	1
		Black construction paper, 15 x 15 cm	1
		Cardboard, 15 x 15 cm	1
		Drinking straw	1
		Glue, bottle	1
		Protractor	1
		Scissors	1
		Small Tripod Base and Rod	1
		Tape	1 roll
		Three-fingered clamp	1
3	**Investigating Specific Heat** Use fast-response temperature probes and stainless steel temperature sensors to determine and compare the specific heat of water to that of sand, as a model of land, and consider the effects of these differences on global weather and climate.	Data Collection System	1
		PASPORT Stainless Steel Temperature Sensor	2
		PASPORT Fast Response Temperature Sensor	2
		Beaker, glass, 500-mL	1
		Beakers, glass, 250-mL	2
		Buret clamp	2
		Disposable insulated cup (2) and lid	2
		Heat lamp or 150 W incandescent lamp	1
		Hot plate	1
		Mass balance or scale	1 per class
		Sand, 200 g	200 g
		Small tripod base, and rod	1
		Stirring rod	1
		Test tube, glass, 18 x 150-mm (large)	1
		Tongs	1
		Water	650 mL
4	**Monitoring Microclimates** Use a weather/anemometer sensor to identify factors that affect measurements for reporting weather and climate information.	Mobile Data Collection System	1
		PASPORT Weather/Anemometer Sensor	1
		Cardboard box, (20 cm)3 or larger	1
		Marking pen	1
		Scissors	1

Lab	Title	Materials and Equipment	Qty
5	**Sunlight Intensity and Reflectivity** Use a light sensor, a fast-response temperature probe, and a stainless steel temperature probe to explore the concept that air temperatures near the earth's surface result largely from the interplay of the sun's incoming energy and the absorption, reflection, and radiation of that energy by materials on the earth's surface.	Mobile Data Collection System PASPORT Light Sensor PASPORT Fast Response Temperature Sensor PASPORT Stainless Steel Temperature Sensor PASPORT Sensor Extension Cable *Dark rock* *Dark sand* *High intensity incandescent lamp* *Large disposable plate* *Marking pen* Mass balance *Paper* Rod and clamp *Scissors* *Small cardboard box, (20 cm)3 or larger* *Tape* *Three-finger clamp* *Tripod base and support rod* *White rock* *White sand*	1 1 1 1 1 500 g 500 g 1 1 1 1 per class 1 piece 1 1 1 1 roll 1 1 500 g 500 g
6	**Tracking Weather** Use a weather/anemometer sensor to determine how variations in temperature, humidity, barometric pressure, dew point, wind speed, and sky conditions relate to each other and produce specific weather conditions.	Mobile Data Collection System PASPORT Weather/Anemometer Sensor *Brick or block to lift sensor off ground (optional)* *Weather data for comparison* *Weather shield*	1 1 1 1
7	**Earth’s Magnetic Field** Use a magnetic field sensor to visualize the magnetic field lines surrounding Earth.	Data Collection System PASPORT Magnetic Field Sensor Degree wheel template Magnetic field demonstrator plate, 2-D Map of Earth template *Bar magnet* *Clear plastic cup* *Pin* *Sewing needle* *Small cork (or a bit of polystyrene)* *Water, 500 mL*	1 1 1 4 1 1 1 1 1 1 500 mL
8	**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 (stainless steel or fast response) *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

Lab	Title	Materials and Equipment	Qty
9	**Seafloor Spreading and Plate Tectonics** Use a magnetic field sensor to explore the movement of Earth's crustal plates and the evidence that is used to support the theory of plate tectonics.		
	Station 1	*Strip of paper, 10 cm × 28 cm* *Cardboard or card stock, 15 cm × 20 cm* *Colored pencils or markers, red and green* *Scissors* *Tape*	1 1 Several 1 1 roll
	Station 2	Data Collection System PASPORT Magnetic Field Sensor *Bar magnet*	1 1 1
	Station 3	Data Collection System PASPORT Magnetic Field Sensor *Basalt, hand size specimen* *Magnetite, hand size specimen*	1 1 1 1
	Station 4	Data Collection System PASPORT Magnetic Field Sensor *Seafloor spreading model*	1 1 1
10	**Modeling an Ecosystem** Use a variety of sensors to explore the use of terrariums as a closed system for environmental studies, designing ways to explore the interrelationships of biotic and abiotic structures in ecosystems.	Data Collection System Sensors (some of the sensors that can be used): PASPORT Oxygen Gas Sensor PASPORT Carbon Dioxide Sensor PASPORT Temperature Sensor* PASPORT pH Sensor PASPORT Conductivity Sensor PASPORT Weather Sensor PASPORT Sensor Extension Cable PASCO EcoZone™ System PASPORT Water Quality Colorimeter and sample vials (nitrate and ammonia recommended) *Compost or soil (quantity determined by student design)* *Different types of living organisms* *Plant seeds or seedlings, or moss* *Pollution sources (depends on students' design):* *Detergent (10 mL liquid soap)* *Fertilizer (10 g)* *HCl or white vinegar (16.6 mL)* *Strong incandescent or full-spectrum fluorescent light source* USB hub (depending on data collection system) *Water, dechlorinated (quantity determined by student design)*	1 or more 1 or more 1 Several Several 1 1 1 1

Lab	Title	Materials and Equipment	Qty
11	**Photosynthesis and Primary Productivity** Use a dissolved oxygen sensor to determine the primary productivity of an aquatic plant.	Data Collection System	1
		PASPORT Dissolved Oxygen Sensor or PASPORT Water Quality Sensor	1
		Black cloth, opaque, 50 cm x 50 cm	1
		Dechlorinated tap water	1 L
		Elodea sp. plant	Several
		Lamp, 100 W or high-intensity	1
		Magnetic stirrer and stir bar	1
		Photosynthesis Tank	1
		Rubber stopper, #3 (included with Photosynthesis Tank)	1
		Alternative to the photosynthesis tank:	
		Erlenmeyer flask, 250-mL	1
		Large base and support rod	1
		Mineral oil	1
		Shallow pan or dish, large	1
		Three-finger clamp	1
12	**Photosynthesis and Cell Respiration in a Terrarium** Use an oxygen sensor, a carbon dioxide sensor, and a temperature sensor to demonstrate that a terrarium, as a closed system, is an excellent tool for conducting environmental studies and to design additional investigations on photosynthesis and cellular respiration.	Data Collection System	1
		PASPORT Oxygen Gas Sensor	1
		PASPORT Carbon Dioxide Gas Sensor	1
		PASPORT Temperature Sensor*	1
		PASPORT Sensor Extension Cable	1
		PASCO EcoChamber	1
		Fast-growing, small, potted plant	1
		Opaque cloth, about 1 m^2	1
		Strong incandescent or full-spectrum fluorescent light source	1
		USB hub (depending on data collection system)	1
13	**Cellular Respiration and Carbon Cycle** Use a carbon dioxide sensor to compare the respiration of dormant bean sees with germinating bean seeds, and to observe the contribution of cellular respiration to the global carbon cycle.	Data Collection System	1
		PASPORT Carbon Dioxide Gas Sensor	1
		PASPORT Sensor Extension Cable	1
		Dissecting microscope or magnifying glass	1
		Dry bean seeds	22
		Knife or scalpel	1
		Parafilm® for Erlenmeyer flask	1
		Sampling bottle or Erlenmeyer flask, 125-mL	2

Lab	Title	Materials and Equipment	Qty
14	**Energy Content of Food** Use a fast response temperature sensor to investigate and compare the energy content of four different food items: marshmallow, popcorn, peanut, and cashew.	Mobile Data Collection System	1
		PASPORT Fast Response Temperature Sensor	1
		Aluminum pie pan	4
		Aluminum soda can	4
		Cardboard box, large	1
		Electronic balance	1 per class
		Food samples: marshmallow, popcorn, peanuts, cashew	1 each
		Graduated cylinder, 100 mL	1
		Large base and support rod	1
		Marking pen	1
		One-hole rubber stopper, ~1 1/2" top diameter	4
		Paperclip, large	5
		Plastic straw	1
		Rod and clamp	1
		Tape	1 roll
		Water	200 mL
		Wooden matches (or starter wand)	Several
15	**Weather in a Terrarium** Use a weather sensor and light sensor in a terrarium to conduct and design an investigation of weather, using this closed system to help identify independent variables, dependent variables, and controlled variables.	Data Collection System	1
		PASPORT Light Sensor	1
		PASPORT Weather Sensor	1
		PASPORT Sensor Extension Cable	2
		PASCO EcoChamber	1
		Fast-growing, small, potted plant	1
		Strong incandescent or full-spectrum fluorescent light source	1
16	**Yeast Respiration** Use a dissolved oxygen sensor, a carbon dioxide sensor, and the EcoChamber™ to analyze aerobic and anaerobic respiration by yeast cells.	Data Collection System	1
		PASPORT Dissolved Oxygen Sensor	1
		PASPORT Carbon Dioxide Gas Sensor	1
		PASCO EcoChamber	1
		Activated baker's yeast, 7-g packet	1
		Beaker, 1 L	1
		Graduated cylinder, 500-mL or 1-L	1
		Hot plate with magnetic stirrer and stir bar	1
		Magnetic stir plate with stir bar	1
		Microscope slide and cover slip	1
		Microscope with 400x magnification	1
		Pipet, disposable	1
		Sugar	100 g
		Water	1 L

Lab	Title	Materials and Equipment	Qty
17	**Properties of Water** Use a stainless steel temperature sensor to explore how the properties of water can be explained by the molecular structure of water.	Data Collection System	1
		PASPORT Stainless Steel Temperature Sensor	1
		Beaker, 100-mL	1
		Beaker, 600-mL	1
		Crushed ice	300 mL
		Eyedropper or disposable pipet	1
		Foam tray	1
		Hot pads or mittens	1
		Hot plate	1
		Other materials to test	
		Paper towel	1
		Ring stand	2
		Utility clamp	1
		Water	50 mL
		Waxed paper	1
		Data Collection System	1
18	**Air Pollution and Acid Rain** Use a pH sensor to investigate chemical reactions important in the formation of acid rain to understand the relationship between man-made emissions, acid rain, and problems arising from acid rain.	Data Collection System	1
		PASPORT pH Sensor	1
		1 M HCl	15 mL
		1-hole rubber stopper for flask	1
		Beaker, 40-mL	1
		Erlenmeyer flask, 50-mL	1
		Flexible Teflon® tubing to fit glass tubing	20 cm
		Glass tubing for rubber stopper	1
		Graduated cylinder, 50- or 100-mL	1
		Graduated pipet, 4-mL and pipet bulb	1
		Sodium bicarbonate	5 g
		Sodium bisulfite	5 g
		Sodium nitrite	5 g
		Wash bottle containing distilled or deionized water	1
		Water or deionized wate	1 L
19	**Monitoring Water Quality** Use a water quality sensor, turbidity sensor, and weather/anemometer sensor to monitor the pH, dissolved oxygen content, conductivity, and turbidity of a natural body of water, determining how water quality changes in response to changes in environmental factors.	Mobile Data Collection System	1
		PASPORT Water Quality Sensor	1
		PASPORT Turbidity Sensor	1
		PASPORT Weather/Anemometer Sensor	1
		PASPORT GPS Position Sensor (optional)	1
		Sensor User Guides with calibration instructions and tables	Several
		Chemical test kit (optional)	1
		Duct tape, roll	1
		Long-handled sampling device	1
		Scissors	1
		Wading boots (optional)	1 pair
		Wash bottle containing distilled or deionized water	1
		Wide-mouth sampling jar or small plastic bucket with a handle	1

Lab	Title	Materials and Equipment	Qty
20	**Toxicology Using Yeast** Use a carbon dioxide gas sensor and a pH sensor to evaluate the role of pH in toxicity and the role of cell culture in toxicology studies.	Data Collection System	1
		PASPORT Carbon Dioxide Gas Sensor	1
		PASPORT pH Sensor	1
		PASPORT Sensor Extension Cable	1
		PASCO EcoChamber	1
		Beaker, 100-mL (for vinegar)	1
		Beaker, glass, 2-L	1
		Erlenmeyer flask, 125-mL	1
		Graduated cylinder, 1-L or 500-mL	1
		Graduated cylinder, 25-mL or 10-mL	1
		Household bleach, half-strength	50 mL
		Magnetic stir plate and stir bar	1
		Rapid-rise activated baker's yeast (7-g packet)	1
		Rubber stopper for Erlenmeyer flask	1
		Stirring rod	1
		Sugar	100 g
		Water	1 L
		White vinegar	50 mL
21	**Water Treatment** Use pH, conductivity, and turbidity sensors to demonstrate how water treatment processes such as filtration, flocculation, and sedimentation improve water quality.	Data Collection System	1
		PASPORT Water Quality Sensor (or PASPORT pH and PASPORT Conductivity Sensors)	1
		PASPORT Turbidity Sensor	1
		Activated charcoal	2 g
		Balance	1 per class
		Beaker, 150-mL	4
		Beaker, 50-mL	1
		Beaker, large ("wastewater" container)	1
		Graduated cylinder, 100-mL	1
		Graduated pipet, 50-mL, and bulb	1
		Lint-free lab tissue	box
		Paper napkins, dinner, white, smooth	12
		Paper towels, white	4
		Soda bottle, empty, 500-mL	1
		Stirring rod	1
		Swimming pool water clarifier solution, 4%	2 to 4 mL
		Test tube, 18-mm OD or greater	1
		Wash bottle containing water	1
		Wastewater sample (made from coffee, soil, and kitty litter if the soil has a low clay content)	500 mL
		Water	300 mL

Lab	Title	Materials and Equipment	Qty
22	**Greenhouse Gases** Use a fast response temperature sensor and an EcoChamber to determine the effect of a man-made organofluorine compound, a greenhouse gas, on the trapping of heat in an isolated system.	Data Collection System PASPORT Fast Response Temperature Sensor EcoChamber with stoppers Balance *Canned keyboard duster (fresh)* *Dark aquarium rocks or dark sand* *Heating lamp* *Heavy-duty tape* *Ring stand* *Size 5 or 5 1/2 solid stoppers*	1 2 1 1 per class 1 ~200 g 1 1 1 2

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

Calibration Materials

To calibrate various sensors, you will need the following:

pH Sensor

Item	Quantity	Activity Where Used
Buffer solution, pH 4 Buffer solution, pH 7 or 10 Beaker, small Wash bottle with deionized or distilled water	25 mL 25 mL 3 1	1, 10, 18, 20, 21

Dissolved Oxygen Sensor

Item	Quantity	Activity Where Used
Clean electrode storage bottle Distilled water	1 5 mL	11, 16, 19

Oxygen Gas Sensor

Item	Quantity	Activity Where Used
Sampling Bottle (included with the sensor)	1	10, 16

Carbon Dioxide Gas Sensor

Item	Quantity	Activity Where Used
Sampling Bottle (included with the sensor)	1	1, 10, 12, 16, 20

Turbidity Sensor

Item	Quantity	Activity Where Used
100 NTU Standard	1	19

Water Quality Colorimeter

Item	Quantity	Activity Where Used
Calibration Ampule	1	10

Activity by PASCO Equipment

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

Items Available from PASCO	**Qty**	**Activity Where Used**
Data Collection System	1	1, 3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22
Mobile Data Collection System	1	6, 14, 19
PASCO EcoChamber	1	12, 15, 16, 20
PASCO EcoZone System	1	10
PASPORT Carbon Dioxide Gas Sensor	1	1, 10[1], 12, 16, 20, 22
PASPORT Conductivity Sensor	1	1, 10[1]
PASPORT Fast Response Temperature Sensor	1	3, 5, 22
PASPORT GPS Position Sensor	1	19 (optional)
PASPORT Light Sensor	1	5, 15
PASPORT Magnetic Field Sensor		7, 9
PASPORT Oxygen Gas Sensor	1	10[1],12
PASPORT pH Sensor	1	1, 10[1], 18, 22
PASPORT Stainless Steel Temperature Sensor	2	3
PASPORT Stainless Steel Temperature Sensor	1	2, 5
PASPORT Temperature Sensor[2]	1	8, 10[1], 12, 14
PASPORT Turbidity Sensor	1	19, 21
PASPORT Water Quality Colorimeter and sample vials	1	10[1]
PASPORT Water Quality Sensor	1	19, 22
PASPORT Weather Sensor	1	15, 10[1]
PASPORT Weather/Anemometer Sensor	1	4, 19
PASPORT Sensor Extension Cable	1	5

[1] The actual quantity of these items is determined by the student design of the activity.

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

Normal Laboratory Safety Procedures

Overview

PASCO is concerned with your safety and because of that, we are providing a few guidelines and precautions to use when exploring the labs in our Advanced Environmental 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 or drink or chewing gum is allowed in the lab.
- Wear protective equipment (for example, safety glasses, gloves, apron) when appropriate.
- Do not touch your face with gloved hands. If you need to sneeze or scratch, take off your gloves, wash your hands, and then take care of the situation. Do not leave the lab with gloves on.
- Wash your hands after handling samples, 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 2 or more in case of trouble and help is needed.
- Keep the work area neat and free from any unnecessary objects.

Water Related Safety Precautions and Procedures

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

Chemical Related Safety Precautions and Procedures

- Consult the manufacturer's Material Safety Data Sheets (MSDS) for instructions on handling, storage, and disposing of chemicals. Your teacher should provide the MSDS 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 the 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.
- Be sure that all acids and bases are neutralized before being disposed of down the drain.
- Wear eye protection, lab apron, and protective gloves when handling acids. Splash-proof goggles are recommended. Either latex or nitrile gloves are suitable. Use nitrile gloves if you have latex allergy.
- Read labels on all chemicals and pay particular attention to Hazard icons and safety warnings.
- When handling any bacterial species, follow aseptic techniques.
- Wash your hands before and after a laboratory session.
- If any solution comes in contact with skin or eyes, rinse immediately with a copious amount of running water for a minimum of 15 minutes.
- Follow the teacher's instructions for disposing of chemicals, handling substances.
- Check the label to verify it is the correct substance before using it.
- Never point the open end of a test tube containing a substance at yourself or others.
- Use a wafting motion when smelling chemicals
- Do not return unused chemicals to their original container.
- Keep flammable chemicals from open flame.

Dangerous or Harmful Substance Related Lab Safety Precautions

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

Outdoor Safety Precautions

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

Other Safety Precautions

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

Additional Resources

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

Earth Systems and Resources

1. Determining Soil Quality

Objectives

Students explore the requirements and capacity of soil to support plant growth by examining the physical, chemical, and biological characteristics of different types of soil.

Procedural Overview

Students gain experience conducting the following procedures on three soil samples:

- Using the carbon dioxide (CO_2) gas sensor to determine the soil respiration rate
- Using pH and conductivity sensors to measure the soil pH, salinity, and buffering capacity
- Using a dissecting microscope and a light microscope to analyze the physical and biological characteristics of the soil samples

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	90 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Carbon dioxide gas sensor and sampling bottle
- pH sensor
- Conductivity sensor
- Sensor extension cable
- Stirring rod
- Beaker (4), 100-mL
- Beaker, 50-mL
- Graduated cylinder, 100-mL
- Microscope with magnification up to 400x
- Dissecting microscope
- Microscope slides and cover slips (3)
- Microwave oven (1 per class)
- Pipet, disposable
- Digging tool
- Soil samples (from 3 different locations)
- pH calibration standard solution, pH 4
- pH calibration standard solution, pH 7 or 10
- White household vinegar, 4 mL
- Distilled or deionized water, 300 mL
- Wash bottle containing distilled or deionized water
- Plastic bags (4), sealable, about 1-L
- Waste container
- Permanent marker
- Labeling tape

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- When organisms oxidize food for energy under aerobic conditions, oxygen gas (O_2) is consumed and carbon dioxide gas (CO_2) is released as a byproduct.
- Soil is a complex mixture of inorganic material, organic material, and living organisms, most of which require a microscope to be seen.
- Salts are ionic compounds composed of cations (positively charged ions) and anions (negative ions) so that the product is electrically neutral (without a net charge). The most common salt is sodium chloride (NaCl), also known as table salt.
- Most cells function best within a narrow range of acidity.
- The pH scale ranges from 0 through 14. A pH of 7 is neutral. The further below 7, the more acidic a solution is. The further above 7.0, the more alkaline it is.

Related Labs in This Guide

Labs conceptually related to this one include:

- Air Pollution and Acid Rain
- Cellular Respiration and the Carbon Cycle
- Monitoring Water Quality

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)
- Calibrating a pH sensor �(3.6)
- Setting a conductivity sensor for a particular measurement range �(4.2)
- Monitoring live data without recording �(6.1)
- 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)

- Displaying data in a digits display �(7.3.1)

- Finding the values of a point on a graph �(9.1)

- Saving your experiment �(11.1)

Background

Soils are complex combinations of inorganic materials, organic materials, and living organisms. (*Organic* means carbon-based. *Inorganic* means not carbon-based.) Some combinations of materials yield soils that provide good support for plant growth. Others do not, or they only support certain types of plant growth.

Ideal soils for plant growth include the following characteristics:

- Being porous, to allow air and water to filter through them

- Being able to retain moisture

- Containing a substantial amount of humus (dead plant material)

- Having a pH in the neutral range from 6.0 to 7.5 and the ability to resist changes in pH

- Not containing too much salt or sodium

- Having a thriving population of decomposers

Decomposers, such as earthworms, ants, beetles, fungi, and bacteria, break down materials to the smallest building blocks that can be used by plants for growth.

Saline soils are high in salt content. Salt is a simple molecule essential to life, but it is quickly becoming a “silent killer” in the environment. In addition to common table salt (sodium chloride), other salts composed of various combinations of calcium, magnesium, potassium, sulfate, and nitrate, contribute to this dilemma. A high salt concentration results in movement of water from the root cells into the saline soil in an attempt to establish an osmotic equilibrium. The plant becomes stressed, wilts, and eventually dies.

The ions from dissolved salts flow in ground and surface water. Salt used to de-ice roadways is toxic to roadside vegetation. Ash water, a highly saline wastewater pollutant from power processing stations, is another contaminant. Saline soils might be found in areas where fertilizer is frequently added or the water table is high.

Sodic soils are those with an excess of sodium ions associated with clay particles. These soils are nonporous and become waterlogged. They cause stunting of plants due to poor water, air, and root penetration.

Although many plants thrive in slightly acidic soils, highly acidic soils may mobilize high levels of aluminum, manganese, nickel, and iron, which can be toxic to plants. In addition, these elements can interfere with the uptake of some essential nutrients, such as phosphorus, calcium, magnesium, and molybdenum.

Soils may become excessively acidic because of the addition of fertilizers, lack of buffers in the soil, addition of acidic water (for example, acid rain), and a number of other factors. Symptoms of acidic soil include stunting of plants, young leaves with deformities, yellowing of leaves, roots that are weak and stubby, and poor crop yields.

Alkaline soils usually have high salinity due to salts of sodium, magnesium, and calcium. Soils with a high pH (greater than 7.5) may hinder plant growth and cause yellowing, due to a lack of dissolved nutrients, such as iron.

Soils are a vital part of the ecosystem. Terrestrial plants comprise an important segment of primary productivity on which all living beings ultimately depend for food. Plants and decomposers are vital links in the global cycles of water, carbon, oxygen, nitrogen, sulfur, phosphorous, potassium, calcium, and other elements that are required for growth of living things. Being able to analyze soils and remedy poor soils are important skills for the good of humanity.

Pre-Lab Discussion and Activity

Engage your students by telling them that they will be collecting a variety of soil samples to analyze and to determine how well they would support plant life. Tell them they will be using three sensors, a dissecting microscope, and a regular microscope to analyze physical, chemical, and biological characteristics of the soil samples.

Distribute clean, sealable plastic bags—three per student or group. Instruct students to 1) collect soil samples from their home or neighborhood, 2) label the source of each soil sample, 3) seal the bag to preserve moisture, and 4) record the soil information as directed in the Data Analysis section. Caution them to be sure they have permission to take soil samples and to avoid samples containing animal waste.

If necessary, review the correct operation of a dissecting and regular microscope.

Briefly present background on measuring salinity with a conductivity sensor. Help students recall that salts dissolve in water to become electrically charged ions. The conductivity sensor records the concentration of these ions in water. The conductivity sensor records data in microsiemens/cm (μS/cm). The higher the conductivity value is, the greater the concentration of salt ions.

Note: Since the range of salinity tolerated by plants is large compared to the variation between conductivity sensors, it is not necessary to calibrate the conductivity sensor.

Discuss the method for calibrating the pH sensor and why calibration is important. Remind students that there are slight differences between pH sensors. Since the range of tolerated pH is narrow for plants, it is important that the pH measurement is as accurate as possible. Calibration should reduce the variability in measurement between different sensors.

Point out that an important duty of agricultural outreach workers is to be sure their instruments have been calibrated properly.

If necessary, review the pH scale and the concepts of acidity, alkalinity, and neutrality.

Lab Preparation

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

1. If you have access to some rich compost, include it as one of the samples to be analyzed, since it should provide excellent data for the biological investigations.

2. Consider the following schedule:

    - Part 1 can be assigned as pre-lab homework.

    - This lab can easily be split into two 50-minute sessions. Another way to accomplish the lab in less time is to assign groups to perform different parts of the lab on the same soil samples, sharing the data.

    - If you choose to have all groups do all parts of the lab, instruct students to do Parts 3 through 6 while they are collecting data for Part 2.

3. You may want to provide a copy of the user manual for the carbon dioxide gas, pH, and conductivity sensors.

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	5	1	3	4
First, explore the capacity of soil samples to exhibit cellular respiration (generate CO_2 gas).	Determine the effect of killing all the decomposers in the soil sample with the highest CO_2 generation.	Collect three different types of soil samples, documenting the surroundings from which they were taken.	While collecting CO_2 data, examine the samples visually using both dissecting and regular (400x) microscopy.	After visually examining soil samples, determine the salinity, pH, and buffering capacity of the soil samples.

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 – Obtain samples (day before lab)

Strive for consistency in the collecting technique for each soil sample collected. Strive to collect samples of obviously different types.

1. ☐ Collect a soil sample by doing the following:

  a. Clean the digging device.

  b. Clear away leaves and any other contaminating debris.

  c. With the digging device, loosen the soil as deep as 8 centimeters.

  d. Place at least 200 mL (about 3/4 cup) of soil into a plastic bag.

  e. Seal the bag to preserve moisture.

  f. Label the sample (for instance:, “Vacant lot” or “Hiking trail”).

2. ☐ Collect two more soil samples using the same technique.

3. ☐ Why must you maintain the same technique when collecting the three different soil samples?

Using the same collecting technique minimizes variables you want to control so better comparisons can be made between samples.

4. ☐ In the Data Analysis section, complete the steps for recording soil information for all 3 samples.

You will set up and start "Part 2 – Soil respiration assessment.″ While you are collecting data for that part, you will complete Parts 3, 4, 5, and 6.

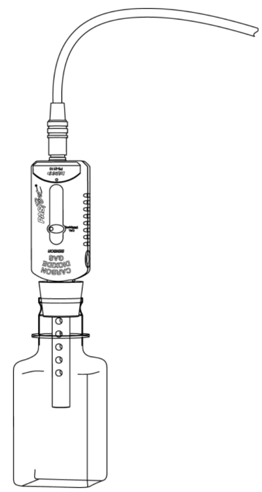
Part 2 – Soil respiration assessment

Set Up

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

6. ☐ Connect the CO_2 gas sensor to the data collection system using a sensor extension cable. �(2.1)

7. ☐ Display a graph of CO_2 gas versus Time in seconds (s). �(7.1.1)



Soil respiration of Soil Sample 1

8. ☐ Using the 50-mL beaker, add approximately 50 mL (4 tablespoons) of soil from Soil Sample 1 to the sampling bottle.

9. ☐ Lower the CO_2 gas sensor into the bottle and cork it tightly using the attached stopper.

10. ☐ Why are you tightly corking the bottle?

We are creating a closed system. All the CO_2 gas that the soil may generate will be captured and measured.

11. ☐ Predict which soil sample will have the highest rate of cellular respiration as indicated by the rate of increase in CO_2? Why?

Answers will vary. However, generally, the sample that contains the most living organisms will be the sample with the highest rate of cellular respiration, and thus the highest rate of CO_2 generation.

Collect Data

12. ☐ Start recording data. �(6.2)

13. ☐ Adjust the scale of the graph to show all data. �(7.1.2)

Note: While recording this data, proceed to "Part 3 – Examine the physical characteristics of the soil" and complete that investigation.

14. ☐ After 600 seconds (10 minutes), stop recording data �(6.2) and save your experiment. �(11.1)

15. ☐ Find the value for the CO_2 gas concentration at 600 seconds, �(9.1) and record it in Table 2 in the Data Analysis section.

16. ☐ Carefully remove the stopper.

17. ☐ Vigorously shake the bottle upside down to empty all soil and excess CO_2 gas.

Soil Samples 2 and 3

Note: During the 600-second data recording periods for the second and third soil samples, prepare the soil samples for Part 4, Part 5, and Part 6. You can use the same soil sample preparations to conduct all three of these analyses. Take the readings for Parts 4 through 6 at convenient times (such as after beginning the 600-second CO_2 data recording) during Part 2.

18. ☐ For Soil Sample 2 and then for Soil Sample 3, repeat the steps of the "Soil respiration of Soil Sample 1" subsection.

Choose the Sample to Microwave

19. ☐ Identify the soil sample with the highest increase in CO_2 concentration. Place a 50-mL aliquot of this soil sample in a paper or plastic container and put it into a microwave oven.

20. ☐ Expose the sample to a high level of microwaves for 120 seconds.

21. ☐ What happens to the living organisms in the soil sample when you microwave it?

All living organisms in the soil sample will be killed by the microwaves.

22. ☐ For the microwaved sample, repeat the steps applied to the first sample ("Soil respiration of Soil Sample 1")

23. ☐ What important scientific process is being conducted in this step?

A negative control is being created with this process. This step shows the effect on CO_2 gas generation of removing all living organisms from the soil. This step also verifies that the increase in the CO_2 gas levels in the untreated soil were due to the presence of living microorganisms. This step helps establish the connection between the increase in CO_2 gas levels and cellular respiration.

Part 3 – Examine the physical characteristics of the soil

24. ☐ Place a small sample of soil (no larger than a penny) from each soil sample on a sheet of white paper (you can use the back of the previous page).

25. ☐ Spread the small amount of each of the soil samples into its own thin layer.

26. ☐ Compare the soil color, texture, structure, and apparent moisture level of each sample, and enter your observations in Table 1 in the Data Analysis section.

Note: You may need to update some of the information you entered when you initially collected the samples.

27. ☐ Sprinkle a small amount of each soil sample on a microscope slide and label the slides using a marker. Look at each slide under a dissecting microscope.

28. ☐ Enter new observations about soil composition in Table 1 in the Data Analysis section, considering the following:

a. Particle size and characteristics like sand, silt, or clay

b. Plant material such as root or leaf parts

c. Animal parts such as an insect leg or wing

29. ☐ Use the pipet to add a drop of water to the soil on each slide and cover each one with a cover slip.

30. ☐ Look at each slide using a microscope that magnifies the sample 400 times.

31. ☐ Enter new observations to Table 1 about the type of live organisms you observe.

32. ☐ In which sample did you find the most living organisms?

Answers will vary. However, the soil sample that is darkest and richest looking will probably contain the most living organisms.

Part 4 – Determine the soil salinity

Set Up

Preparing the soil

33. ☐ Remove any rocks and sticks. Crush Soil Sample 1 into a fine dust with the end of the handle of your digging tool or other suitable instrument.

34. ☐ Why do you need to pulverize the soil?

The soil needs to be pulverized to increase the surface area that is available, so a representative sample of the minerals in the soil dissolves when water is added.

35. ☐ Place 50 mL of Soil Sample 1 into a 100-mL beaker. Label the beaker "#1".

36. ☐ Add an equal volume of distilled water.

37. ☐ Mix the soil and water thoroughly with a stirring rod.

38. ☐ Allow the mixture to sit for at least 5 minutes.

39. ☐ Why are you adding water to the sample?

Conductivity measurements cannot be made with solids. Generally, water must be added to liberate the ions for measurement.

40. ☐ Repeat the steps for preparing the soil for the other two samples, rinsing the stirring rod after mixing each sample.

Measure the salinity

41. ☐ Connect the conductivity sensor to the data collection system �(2.1) and monitor live data without recording �(6.1) If necessary, open a digits display of conductivity. �(7.3.1)

42. ☐ Rinse the conductivity probe with distilled or deionized water.

Collect Data

43. ☐ Lower the conductivity probe into the soil-water mixture. Gently stir the solution with the probe during data collection.

44. ☐ Wait for the measurement to stabilize (as long as 30 seconds).

45. ☐ If necessary, adjust the sensitivity of the conductivity sensor. �(4.2)

46. ☐ Wait for the measurement to stabilize.

47. ☐ Enter the soil salinity value in Table 2 in the Data Analysis section.

48. ☐ Repeat the steps for measuring the salinity for the other two samples.

Part 5 – Determining the pH of the soil

Use the soil-water mixtures you prepared in Part 4 of the lab.

Set Up

49. ☐ Calibrate the pH sensor �(3.6)

50. ☐ Why are you calibrating the pH sensor?

A pH sensor needs to be calibrated when pH data is going to be compared with a standard or norm, or when pH data will be compared with pH data taken with another pH sensor. Small differences in electronics and sensors can be corrected with calibrated adjustments. Calibration is especially important with the pH sensor because plants have a narrow range of pH tolerance.

Collect Data

51. ☐ Rinse the pH probe with distilled or deionized water. Monitor live data without recording �(6.1) If necessary, open a digits display of pH. �(7.3.1)

52. ☐ Lower the pH probe into the soil-water mixture, and gently stir the solution with the probe during data collection.

53. ☐ Wait for the measurement to stabilize (as long as 30 seconds).

54. ☐ Enter the pH value in the "Initial Soil pH" column of Table 2 in the Data Analysis section.

55. ☐ Repeat the steps for collecting data for the other two samples.

Part 6 - Explore the buffering capacity of the soil

Set Up

In this buffering part of the lab, use the soil-water mixtures you prepared in the soil salinity and soil pH sections of the lab.

56. ☐ Prepare 40 mL of a 10% vinegar solution.

- **a.** Pour 4 mL of vinegar into a graduated cylinder.
- **b.** Fill the cylinder to 40 mL with distilled water to make a 10% vinegar solution.
- **c.** Pour the solution into a 100 mL beaker.

57. ☐ Rinse the pH probe with distilled or deionized water.

Collect Data

58. ☐ Lower the pH probe into the vinegar solution and gently stir the solution with the sensor during data collection.

59. ☐ Determine the pH of the vinegar solution and record it here: ________________.

60. ☐ What does the pH of the 10% vinegar solution indicate?

Even though the vinegar is diluted, it is still acidic and has a notably lower pH than any of the soil-water mixtures.

61. ☐ If a soil sample has a high buffering capacity, what will happen to the pH when you add the acid?

The pH will not decrease as much as for samples with less buffering capacity.

Determine the buffering capacity

62. ☐ Add 10 mL of the 10% white vinegar solution to soil-water mixture number 1 and mix thoroughly.

63. ☐ Rinse the pH probe with distilled water.

64. ☐ Lower the pH probe into the soil-water mixture and gently stir the solution with the probe during data collection.

65. ☐ Wait for the measurement to stabilize (as long as 30 seconds).

66. ☐ Enter the pH value in Table 2 in the Data Analysis section.

67. ☐ Repeat the steps of the subsection "Determine the buffering capacity" for the other two soil-water mixtures.

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

Data Analysis

Record soil information

1. ☐ Record detailed observations for each soil sample and its environment in Tables 1a, 1b, and 1c, identified by the label on the sample. These should include, where applicable:

a. The appearance of the soil and soil composition, including conditions such as arid or humid; clay, sandy, loamy, or rocky

b. The appearance and types of plants and other organisms in the area from which the soil was collected, for example shrubs, conifers, fungus

c. What you hear, smell, touch, or taste, as well as what you see

d. Animal tracks and the appearance of animals

e. The terrain, holes in the ground, and the geological features of rocks

f. The type of habitat, such as grassland or urban, including any nearby buildings and whether nearby roads are asphalt, cement, gravel, or dirt

g. Anything unusual about the area, especially if it might be relevant to soil health, such as being next to an irrigated area, or a field with runoff from a roadway

Note: If the data is being collected during fall or winter months, it may not be possible to gather information such as yellowing of leaves or deformities on young leaves.

2. ☐ Use the back side of the paper to sketch any site details that might be helpful with your soil analysis. Sketch at least 10 square meters.

3. ☐ Record the site with a digital camera, if possible.

Note: A digital camera is a great source of objective data. Still, include a sketch as part of the recorded observations.

Table 1a: Detailed observations of Soil Sample 1

Location Description	Beside the road
Date and Time Collected	8/30/08, 11:00 a.m.
Air Temperature and Weather Conditions	30 °C, Fair, light breeze
Soil Color	Light brown
Soil Texture and Structure	Fine texture, clayey, hard, like hard pan
Soil Moisture	Very dry
Organisms Present	Some ants on the surface of the dirt, otherwise, none seen. We did not see more insects with the dissecting microscope, but we think we saw a few microorganisms with the 400x power microscope.
Detailed Observations	There were no plants growing in this soil. It was located next to a road and appeared to have been compacted by walkers.

Table 1b: Detailed observations of Soil Sample 2

Location Description	Field
Date and Time Collected	8/30/08, 11:15 a.m.
Air Temperature and Weather Conditions	30 °C, Fair, light breeze
Soil Color	Medium brown
Soil Texture and Structure	Mixture of fine texture and larger clumps of sand and humus
Soil Moisture	Slightly moist
Organisms Present	Some ants on the surface of the dirt, Some grubs, other small insects, and two earthworms in the dirt. Two butterflies flew by. We saw tiny insects with the dissecting microscope and lots of microorganisms in the 400x microscope.
Other Observations	The area was partly shaded by trees and shrubs.

Table 1c: Detailed observations of Soil Sample 3

Location Description	Compost pile
Date and Time Collected	8/30/08, 11:45 a.m.
Air Temperature and Weather Conditions	31 °C, Fair, light breeze
Soil Color	Dark brown/black
Soil Texture and Structure	Larger clumps of organic debris, very loose
Soil Moisture	Very moist
Organisms Present	Some small insects were in the compost. We saw other tiny insects with the dissecting microscope and lots of microorganisms with the 400x power.
Other Observations	We dug the compost out of the middle of the compost pile. On the top of the compost pile there were leaves and twigs.

Record measured results

4. ☐ Display the graphs for each of your data runs. �(7.1.3) Adjust the scale of the graph to show all data. �(7.1.2)

5. ☐ Make a sketch of each run of data for CO_2 concentration in parts per million versus Time. Label the overall graph, the scale of the y-axis, and the individual data runs.

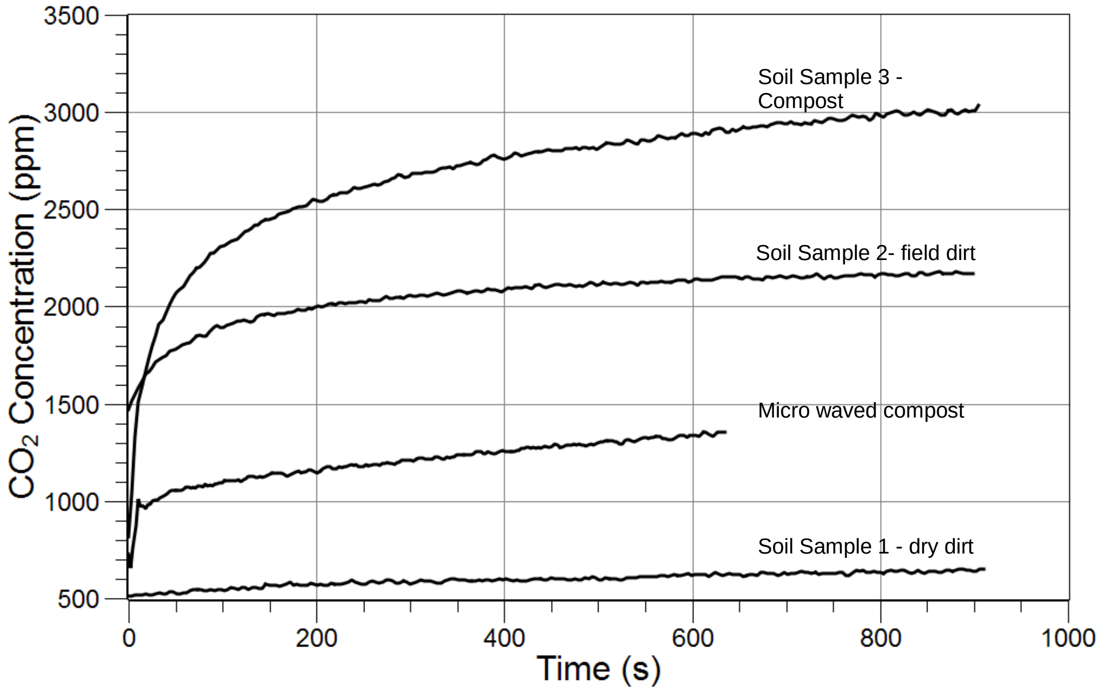


Table 2: Analysis of 3 soil samples

Soil Sample	Data Run	CO_2 Gas Generation (ppm)	Soil Salinity (conductivity) (µS/cm)	Initial Soil pH	Soil pH After Adding 10% Vinegar	Change in pH
1	1	610	65	5.9	5.3	-0.6
2	2	2180	121	6.1	5.9	-0.2
3	3	2900	44	6.6	6.4	-0.2
3	4	1200	45	6.6	6.3	-0.3

Analysis Questions

1. The rate of change of CO_2 gas concentration is indicative of the rate of change in cellular respiration. What kind of soil would you expect to produce CO_2 gas at a faster rate—dark, moist soil or dry, clayey soil? Why?

Moist, dark soil would be expected to produce CO_2 gas at a faster rate because it would be expected to contain more soil organisms. The soil would be high in humus and would contain three components essential to aerobic respiration by living organisms: water, food, and oxygen.

2. What were the effects of microwaving the soil? What happened to the rate of CO_2 gas increase after you microwaved the soil sample? Explain.

Microwaving the soil killed all the organisms in it. Therefore, the rate of respiration dropped to zero, as seen by the lack of increase in CO_2 gas concentration.

3. In which sample did you find the most soil organisms? Is this also the sample that had the highest rate of increase in CO_2 concentration? Discuss the relationship between respiration rate of soil organisms and changes in CO_2 gas concentration within the sample bottle.

Answers will vary depending on experimental results. However, the soil that apparently contained the most organisms should be the one for which the CO_2 gas concentration increased fastest.

4. Which of the three soil solutions had the highest conductivity? Explain why it might be higher than the other two samples. Recall the location of the sample.

Answers will vary. However, the student should include evidence from the collection site to explain why that soil had the highest conductivity. Answers should include mention of factors that might raise the salinity of the soil.

5. Which soil sample had the greatest buffering capacity? Did you see a relationship between buffering capacity and conductivity measurements? If so, explain why this relationship might exist.

Answers will vary. However, the student should include evidence from the change in pH after the acid was added to the soil-water mixture. Soil samples with higher buffering capacities should have higher conductivity readings, since calcium and magnesium salts are important contributors to the buffering capacity of soil.

In this example, soil samples 2 and 3 had the same buffering capacity. Sample 2, taken from a field, had the highest conductivity, indicating a high salt content that could contribute to buffering. Soil Sample 3 was taken from a compost pile. The organic material in compost increases the buffering capacity of soil.

6. Which of the soil samples would you predict would have the greatest capacity to support plant growth? Explain.

Answers will vary. However, students should support their answers in terms of a soil's texture, ability to retain moisture, pH, buffering capacity, salinity, humus content, and presence of decomposers.

In this example, Soil Samples 2 and 3 have most of the characteristics of soils that support plant growth: porous, retain moisture, contain humus, resist changes in pH, and have a thriving population of decomposers. Soil Sample 2 has a high salt content, which may limit its ability to support plant growth.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Based on your results, discuss the roles that soil plays in the carbon cycle.

The decomposers—macroscopic and microscopic organisms in the soil—break down the complex carbon-containing molecules in the soil, which they use as food. The decomposers digest this food in the process of cellular respiration to obtain chemical energy in the form of molecules like ATP, which they use to power their life processes. When cellular respiration occurs in the presence of oxygen gas, carbon dioxide gas is released as a byproduct. Thus, through aerobic cellular respiration by the decomposers, carbon is released from a solid form into a gas form, which can then be used by plants in the process of photosynthesis.

2. What effects do soils of high salinity have on plant growth? Why?

The high salt concentration results in a movement of water out of the root cells into the saline soil in an attempt to establish an osmotic equilibrium. The plant becomes stressed, wilts, and eventually dies.

3. Each plant type possesses an inherent tolerance level to salinity. In general, a crop should tolerate salinity levels up to 700 microsiemens per centimeter (µS/cm), without a decrease in yield; however, some plants tolerate even higher levels of salinity. If a soil contains more than this level of salt, what types of crops might be successfully grown in it?

Plants that grow in high salinity conditions include date palms, beets, kale, spinach, and asparagus.

4. It is best to avoid cultivation of highly saline and sodic (sodium-containing) soils because of the expense of reclaiming the soil. However, if it became imperative to salvage the land, how might you treat saline soil in order to harvest a crop with a high yield?

Cultural practices include growing salt-tolerant plants, planting trees to lower the water table, mulching to reduce evaporation, applying barnyard manure, applying chemical treatments (required prior to leaching saline-sodic or sodic soil to reduce the exchangeable sodium content with soluble calcium or gypsum), leaching with low-salt water, and by improving drainage by tilling through hardpan soil.

Leaching a highly saline acre of soil may require 48 acre-inches of water. This would mean about 27,152 gallons of relatively sodium-free water would be needed, since an acre-inch is defined as the volume of water required to cover 1 square acre of soil to a depth of 1 inch. To be successful, it may take multiple times leaching the soil to reduce accumulated salts.

5. What effects do very acidic or very alkaline soils have on plant growth? Why?

Symptoms of acidic soil include stunting of plants, young leaves with deformities, yellowing of leaves, roots that are weak and stubby instead of long (becoming more susceptible to drought), and poor crop yields. In legumes, highly acidic soils result in stem and petiole reddening, yellowing of older leaves, and a critical failure to produce root nodules (due to a decline of nitrogen-fixing bacteria). Highly acidic soils may mobilize high levels of aluminum, manganese, nickel, and iron, rendering the soil contaminated. In addition, these toxic elements interfere with the uptake of some essential nutrients, such as phosphorus, calcium, magnesium, and molybdenum.

Alkaline soils are usually soils with high salinity. Some alkaline soils cause movement of water from the root cells into the saline soil in an attempt to establish an osmotic equilibrium. The plant becomes stressed, wilts, and eventually dies. Some critical nutrients, such as iron, can become unavailable to plants in alkaline soils.

6. Each plant type grows best within a certain range of pH values. What are some plants that will grow well in relatively acidic soils (pH 5.0 to 5.5)? What are some plants that will grow well in relatively alkaline soils (pH 7.5 to pH 8)?

Some plants that grow well in relatively acid soils include blueberries, rhododendrons, strawberries, and potatoes.

Some plants that grow well in relatively alkaline soils include beans, barley, and alfalfa.

7. Describe methods that may be used to adjust the pH of soil.

The best way to raise the pH of soil (neutralize soil acidity) is to add lime to the soil. Lime products include dolomite, hydrated lime, ground limestone, and mixed lime.

To reduce the pH of soils (increase soil acidity) organic material such as peat moss, compost, manure, and sawdust can be added, increasing the soil microorganisms. Additionally, ground rock (elemental) sulfur can be carefully applied to lower soil pH.

8. Which of the three soil types would be more efficient at neutralizing acid rain? Explain.

Answers will vary, but students should choose the soil type that had the highest buffering capacity, since these buffering chemicals can neutralize acid.

9. List some possible remedies for the soil samples that seem to be less capable of supporting plant growth.

Answers will vary. However, they should include appropriate information from the answers above that apply to the particular characteristics of their soil samples.

Multiple Choice Questions

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

1. In which of the following do soil bacteria play an important role?

- **A.** The water cycle
- **B.** The carbon cycle
- **C.** The nitrogen cycle
- **D.** The phosphorous cycle
- **E. All of the above**

2. To which of the following characteristics of soil does humus *not* contribute?

- **A.** High water-holding capacity
- **B.** High nutrient-holding capacity
- **C. Mineralization**
- **D.** Aeration
- **E.** Water infiltration

3. Soils high in salinity cause plant damage because of which of the following?

- **A.** They are highly toxic to plants.
- **B.** They inhibit plant growth by preventing plant roots from taking in nutrients.
- **C.** They cause plants to wilt by creating osmotic pressure from roots to the soil.
- **D. Only B and C are true.**
- **E.** A, B, and C are true.

4. What can be altered as the result of change in soil pH?

- **A.** Growth of soil microorganisms
- **B.** Solubility of toxic substances in the soil
- **C.** Availability of mineral nutrients
- **D. All of the above**

5. Increase in soil acidity can cause which of the following?

- **A. Release of toxic metals such as Al, Fe, Mn, and Ni**
- **B.** Increase in alkalinity
- **C.** Release of calcium carbonate
- **D.** Increase in salts

6. Which of the following can make soil too acidic?

- **A.** Release of CO2 during soil respiration
- **B.** Release of calcium carbonate by parent rock
- **C.** Release of sulfur from burning of fossil fuels returning to the ground as acid rain
- **D. Answers A and C**

7. The addition of which of the following can raise the pH of acidic soils?

- **A.** Sulfur
- **B.** Salts
- **C.** Lime
- **D.** Compost or mulch
- **E. Either C or D**

Extended Inquiry Suggestions

Challenge students to try to remedy soil deficiencies as discussed in this activity, and then to re-test their soil samples to see if improvements were made.

2. Insolation and the Seasons

Objectives

Students determine how the earth's tilt and rotation around the sun is related to climate and the seasons. To do this they:

- Demonstrate the affect of changes in the angle of solar insolation on solar energy delivered to a given area.
- Connect changes tilt to seasonal temperature variations.

Procedural Overview

Students gain experience conducting the following procedures:

- Constructing a solar energy collection panel and aligning it relative to the sun
- Measuring the relative amount of solar energy captured by monitoring temperatures of the solar panel when positioned at different angles relative to the sun

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	75 minutes

Materials and Equipment

For each student or group:

- Mobile data collection system
- Stainless steel temperature sensor
- Small tripod base and rod
- Three-fingered clamp
- Protractor
- Scissors
- Cardboard, 15 x 15 cm
- Black construction paper, 15 x 15 cm
- Drinking straw
- Tape, roll
- Glue, bottle

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- How sunlight varies during the year due to the earth's tilt as it orbits around the sun.

- The difference in sunlight intensity and the resulting differences in the warming of the earth's surface produce seasonal variations in temperature.

Related Labs in This Guide

Prerequisites:

- Sunlight Intensity and Reflectivity

Labs conceptually related to this one include:

- Investigating Specific Heat

Using Your Data Collection System

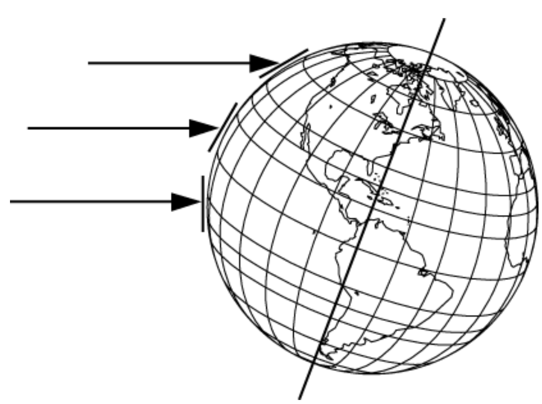
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions 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)
- Starting and stopping data recording �(6.2)
- Displaying data �(7)
- Saving your experiment �(11.1)

Background

Energy from the sun is by far the most important factor in our weather and climate. Solar radiation comprises more than 99.9% of the energy that warms the earth, drives the winds, and stirs the ocean currents. The solar energy that the earth receives is called insolation.

When the surface of the earth directly faces the sun at a 90-degree angle, insolation is highest. As the angle increases between the surface and the rays of sunlight, the same amount of energy is spread over a larger region and the insolation is reduced. This is known as the projection effect and is the reason why polar regions are much colder than equatorial regions. Therefore, the amount of insolation that a part of the earth receives during the day depends on the latitude at that part of the earth.



Earth spins daily around its axis (axis of rotation), which is tilted to approximately 23.5 degrees relative to its orbit around the sun. Thus, no matter the time of year, one part of the planet is always exposed to more direct insolation than another. As the earth orbits the sun, the amount of insolation will change at any particular location, causing the seasons to change. With its elliptical orbit, the distance from the earth to the sun varies by only 5 million miles, or about 3% of the average distance from the sun (the average distance from the sun is about 150 million miles) over the course of one year. The earth is closest to the sun (perihelion) around January 4th each year and furthest from the sun (aphelion) in early July.

At any point during the day, the amount of energy that a particular part of the earth receives changes due to the earth's 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 many other factors.

Pre-Lab Discussion and Activity

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.

Use a globe and a basketball (for the sun) to model and demonstrate the orbit of the earth around the sun.

A) 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 South Pole is pointed towards the sun.

Ask students the following questions:

1. 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?

The tilt of the earth on its axis relative to the sun is primarily responsible for warm temperatures in the summertime.

2. What time of the year is it (when the earth is closest to the sun and when the North Pole is pointed away from the sun)?

The time of the year is the December solstice, December 20 or 21, the shortest day of the year (winter solstice) in the northern hemisphere and the longest day of the year (summer solstice) in the southern hemisphere; the beginning of winter in the northern hemisphere, the beginning of summer in the southern hemisphere.

B) Model the orbit of the earth around the sun. Move the globe in a 90° clockwise arc around the basketball. Make sure the tilt and direction of the axis stay constant. Point out that now the North and South Poles are the same distance from the sun.

3. What time of the year is it?

The time of the year is the 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.

C) 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.

4. What time of the year is it?

The time of the year is the 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.

D) 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.

5. What time of the year is it?

The time of the year is the 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; this is the beginning of fall in the northern hemisphere, the beginning of spring in the southern hemisphere.

6. How does the angle of the sunlight reaching the earth's surface affect the temperature of that part of the earth.

Students should predict that the closer the angle of insolation is to 90°, the higher the concentration of energy that reaches the surface in a given amount of time. All other factors being equal, the higher the concentration of sunlight energy, the higher the temperature of the surface.

7. When do the warmest temperatures in summer and the coldest temperatures in winter usually occur?

The warmest temperatures in the summer and the coldest temperatures in the winter occur during the months after the solstices.

8. Why do the warmest temperatures in summer and the coldest temperatures in 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 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 results 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 troposphere, it stays warmer. The coldest surface temperatures occur during the next two or three months as the radiated heat dissipates.

Lab Preparation

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

1. Acquire a globe and a basketball for the pre-lab discussion and activity.

Teacher Tip: Although this lab is best done using the sun as the light source, a strong incandescent light source, such as a 150 W bulb, can also be used.

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
Align the straw with the sun's rays, and repeat the data collection step. Repeat the cooling step. Move the straw 30° more so the angle of insolation is 30°.	Go outside. Set up the solar panel so it is perpendicular (90°) to the sun. Measure the temperature while exposing the apparatus to the light for 5 minutes.	Construct a solar panel that will absorb light energy and that will allow you to quantitatively change its angle in relationship to the light source and measure the temperature of its surface.	Move the solar panel to a shady location. Move the straw 30° so the angle of insolation is 60°. Fan the solar panel until the temperature cools to its initial temperature.	Repeat the data collection step. Compare the temperature changes of the 3 experimental situations.

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.

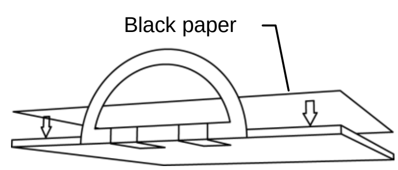
Part 1 – Make the solar panel and test it at 90° insolation

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 temperature sensor to the cardboard with its end near the center of the cardboard.

4. ☐ Take your solar panel, temperature sensor, data collection system, and rod stand outside. Find a sunny location sheltered from the wind.

5. ☐ Secure the solar panel using the tripod stand and 3-fingered clamp.

CAUTION: Do not look directly at the sun when performing the next step.

6. ☐ Arrange the angle of the surface of the cardboard so it is perpendicular (90°) to the sun and the straw is pointing at the sun.

Hint: When the surface of the cardboard is perpendicular to the sun, the light coming through the straw will be focused into a tight spot on the solar panel, and the shadow of the cardboard will be at its smallest size.

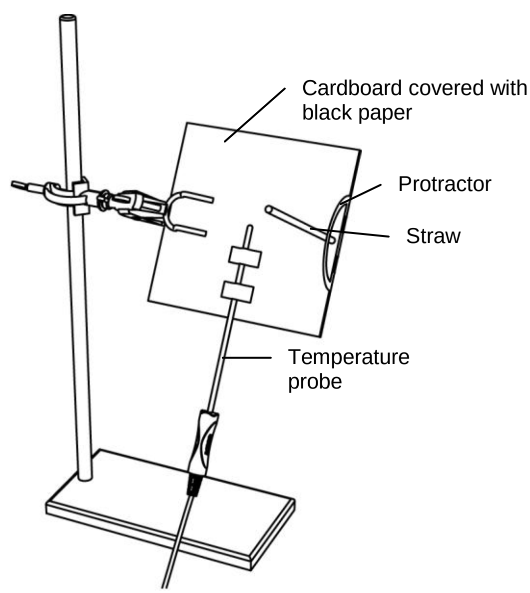
7. ☐ Start a new experiment on the data collection system. �(1.2)

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

9. ☐ Set up an appropriate display to view the data while it is being collected. �(7)

10. ☐ 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.



11. ☐ You will be testing three experimental situations with the cardboard positioned at:

- ♦ 90° relative to the light source
- ♦ 60° relative to the light source
- ♦ 30° relative to the light source

Will the position of the cardboard influence its temperature after 5 minutes at that position? Why?

The position of the cardboard influences how much the temperature will increase after 5 minutes because the sun’s rays are most concentrated at the largest angle of insolation. The temperature will be highest when the angle of insolation is 90°.

Collect Data

12. ☐ Start data recording. �(6.2)

13. ☐ Record data for 5 minutes.

14. ☐ Write your data run number here ____________.

15. ☐ Stop data recording. �(6.2)

Part 2 – Test the solar panel at 60° insolation

Setup

16. ☐ Remove the solar panel and take it to a shaded location.

17. ☐ Remove the straw and tape it 30° from perpendicular on the protractor such that when the straw is perpendicular to the sun, the solar panel will be angled towards the horizon 30°, resulting in an angle of insolation of 60°.

18. ☐ Fan the solar panel to increase the rate of cooling. When it returns to approximately its original temperature, secure it to the tripod stand.

19. ☐ Align the solar panel as you did before. This will angle the solar panel towards the horizon 30° from the last setup, and it will thus receive insolation at 60°.

CAUTION: Do not look directly at the sun.

Collect Data

20. ☐ Start data recording. �(6.2)

21. ☐ Record data for 5 minutes.

22. ☐ Write your run number here ____________.

23. ☐ Stop data recording. �(6.2)

24. ☐ Remove the solar panel and take it to a shaded location.

Part 3 – Test the solar panel at 30° insolation

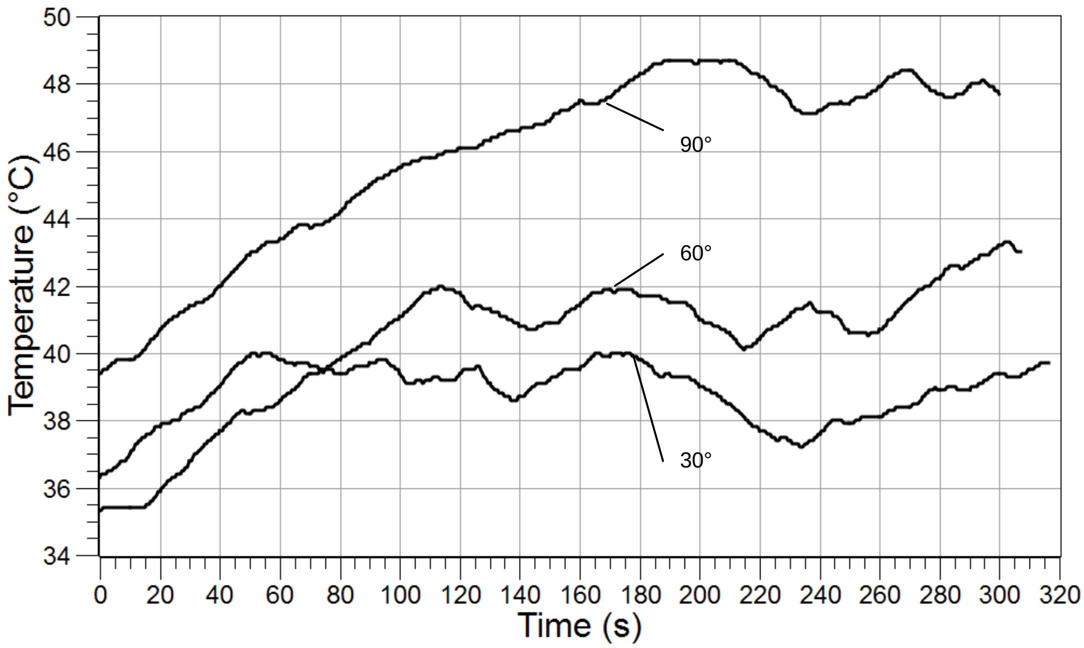
25. ☐ Repeat the procedure in Part 2 using a 60° tilt of the solar panel towards the horizon, and thus an angle of insolation of 30°.

26. ☐ Write your run number here_____________.

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

Sample Data

Temperature of the solar panel at three angles of insolation.



Data Analysis

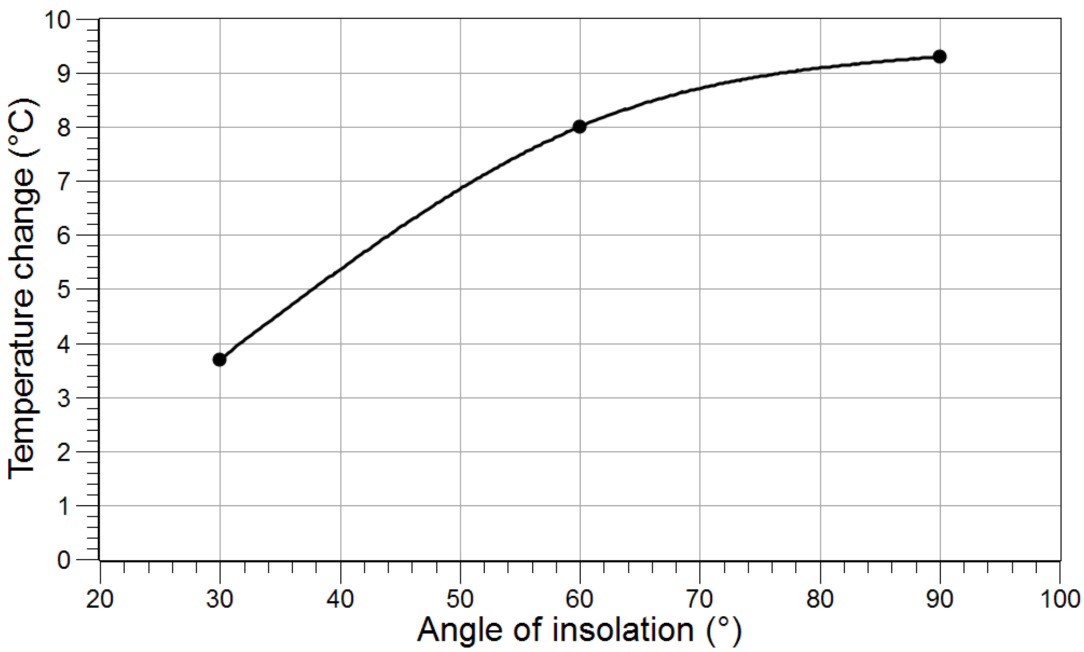
1. ☐ Find the minimum and maximum temperatures for the three data runs and calculate the change in temperature.

2. ☐ Enter these values in Table 1.

Table 1: Temperature comparison at different angles of insolation

Angle of Insolation	Minimum Temperature	Maximum Temperature	Δ Temperature
90°	39.4	48.7	9.3
60°	35.3	43.3	8.0
30°	36.3	40.0	3.7

3. ☐ Plot a graph of angle of insolation on the y-axis with change in temperature on the x-axis. Label the overall graph, the x-axis, the y-axis, and include units and scales on the axes.



Analysis Questions

1. Compare your results with your predictions.

Students should mention the specifics of their predictions and results.

2. What is the independent variable (the parameter you controlled) in this experiment?

The independent variable was the angle of insolation.

3. What is the dependent variable (the parameter that changed) in this experiment?

The dependent variable was the temperature of the solar panel.

4. What parameters did you try to hold constant in this experiment (controlled variables)?

The parameters held as constant as possible were time of exposure to the sun, initial temperature, type of solar energy collection device, time of day, location of data collection, air currents (wind) around the solar panel, and ambient air temperature.

5. Is the relationship between change in temperature and angle of insolation a linear one? Explain.

The relationship between the angle of insolation and temperature was not linear. The rate of change in temperature was slower when the angle of insolation changed from 90° to 60° than when it changed from 60° to 30°.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Using the results of this activity and what you know about the motion of the earth around the sun as well as the tilt of the earth's rotational axis relative to its orbital plane, explain why seasons occur.

Seasons occur because of the tilt of the earth's axis of rotation. Although the earth has an elliptical orbit around the sun, such that the earth is closer to the sun by about 3% of the average diameter of its orbit at the perihelion (January 4), this variation in distance from the sun obviously does not cause the seasons. If it did, you would expect it to be summertime in both the northern hemisphere and the southern hemisphere in January.

The tilt of the earth's axis of rotation causes the North Pole to be pointed away from the sun in January and towards the sun in July. This relationship causes the angle of insolation to be greatest in the northern hemisphere about June 21, resulting in the greatest amount of energy being delivered to the northern hemisphere by the sun at that time. The opposite happens about Dec 21, when the North Pole is pointed away from 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. Additionally, our data showed that the rate of decrease in insolation accelerates as the angle of insolation decreases.

Multiple Choice Questions

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

1. During wintertime in the northern hemisphere, 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

2. During summertime in the southern hemisphere, 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

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**

4. The warm temperatures of summer in the northern hemisphere north of the tropics occur primarily because:

- **A.** The earth is closer to the sun
- **B.** The days are longer
- **C. The northern hemisphere is tilted towards the sun**
- **D.** Wind patterns change to bring warmer temperatures

5. The Tropic of Cancer and Tropic of Capricorn, respectively, are circles of latitude on the earth that mark the northernmost and southernmost latitudes at which the sun may be seen directly overhead (at the June solstice and December solstice, respectively). These circles of latitude are located at approximately

- **A.** 0° latitude
- **B. 23.5° latitude**
- **C.** 30.0° latitude
- **D.** 60.0° latitude
- **E.** 90.0° latitude

Extended Inquiry Suggestions

Challenge students to use available resources to conduct a comparison of latitude and change in minimum and maximum temperatures of various cities worldwide

3. Investigating Specific Heat

Objectives

The high specific heat of water accounts for many characteristics of global weather and climate. In this activity, students determine and compare the specific heat of water to that of sand, as a model of land. Students:

- Determine the relative heating and cooling rates of water versus sand.
- Determine the specific heat of sand and compare it to the specific heat of water.
- Consider the effects on global weather and climate of the different specific heats of water and land.

Procedural Overview

Students gain experience conducting the following procedures:

- Using two temperature probes, simultaneously measure the heating and cooling rates of water and sand, and then compare these rates.
- Using two temperature sensors, measure the initial temperatures of water and heated sand, the final temperature of the water-sand mixture, and then calculate the specific heat of the sand using the law of energy conservation.

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	75 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Stainless steel temperature sensors (2)
- Fast-response temperature probes (2)
- Beaker, glass, 500-mL
- Test tube, glass, 18 x 150-mm (large)
- Beakers (2), glass, 250-mL
- Sand, 200 g
- Heat lamp or 150 W incandescent lamp
- Small tripod base, and rod
- Buret clamp (2)
- Disposable insulated cup (2) and lid
- Water, 650 mL
- Tongs
- Stirring rod
- Hot plate
- Mass balance or scale (1 per class)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ No matter what happens in a closed system, the total amount of matter and energy remain the same.
- ♦ Thermal energy is transferred through a material by the collisions of atoms within the material. Over time, the thermal energy tends to spread out through a material and from one material to another if they are in contact. Thermal energy can also transfer by means of currents in air, water, or other fluids.
- ♦ The temperature of substances is directly related to the motion of the molecules of that substance. The more motion, the higher the temperature.
- ♦ How to use ratios and projections, including constant rates, in appropriate problems

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Sunlight Intensity and Reflectivity
- ♦ Insolation and the Seasons
- ♦ Monitoring Microclimates

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 your data collection system � (2.2)
- ♦ Monitoring live data without recording � (6.1)
- ♦ Starting and stopping data recording � (6.2)
- ♦ Displaying data in a graph � (.1.1)
- ♦ Adjusting the scale of a graph � (7.1.2)
- ♦ Displaying two data runs in a graph � (1.3)
- ♦ Naming a data run � (8.2)
- ♦ Finding the values of a point in a graph � (9.1)
- ♦ Saving your experiment � (11.1)

Background

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. Specific heat is an intrinsic property of a substance and is dependent on its molecular structure and phase. The stronger the bonds (or intermolecular attractions) are, the higher the specific heat. 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.

Liquid water has a type of intermolecular attraction (hydrogen bonding) that causes it to have a high specific heat. The relatively strong bond between the water molecules means more energy is needed to heat water up, and water is more efficient at retaining this captured heat.

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.

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), and the opposite, 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 students 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. Ask students to compare their perceptions of the temperature of the water versus the temperature of the sand or ground they walked on or the air temperature above the land. 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.

Ask students the following questions.

1. How do these temperature differences occur, given the fact that the sun's energy is equally distributed on both areas throughout the day and equally absent at night?"

Record all ideas for student viewing. Tell students they will explore an intrinsic property of matter: specific heat, which results in these phenomena.

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

Closed Systems

The learning goals of this activity require that students understand the concept of conservation of energy in a closed system as well as the concept of transfer of thermal energy towards equilibrium. Test prior student knowledge to ensure that they understand these concepts.

2. 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 energy comes from the heat source used to boil the water.

3. What happens to the energy in boiling water if we pour it into ice water?

The energy in the boiling water will melt the ice.

4. How can we measure this transfer of energy?

The energy transfer can be measured by measuring the final temperature of the water (the temperature of ice water and boiling water can be measured prior to pouring the boiling water into the ice water.

5. 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.

Note: If you think your students experience difficulty grasping these concepts, consider doing a demonstration. Ask students to predict the resulting temperature in the two instances before performing the demonstration.

Determining the Rate of Heating and Cooling

Students should be able to determine the rate of heating and cooling of water versus sand. If necessary, review the 2-point method of finding a rate, or review the procedure for finding the best-fit line and its slope using the data collection system.

If necessary, work through an example of the 2-point method for finding the rate, for example, finding the rate of temperature increase if the temperature rose from 20 °C to 30 °C over a period of 20 minutes. For example, [(30 °C – 20 °C)/ 20 min = 0.5 °C/min].

Students should know how to construct a ratio in order to compare the specific heat of water to that of land. If necessary, review ratios with your students. Ask students to find the ratio of boys to girls in the classroom as a simple test for prior knowledge. They can then calculate the fraction that represents the ratio of boys to girls.

Lab Preparation

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

1. You will need some clean, dry sand for this activity. This is readily available in bags in garden supply stores, aquarium supply stores, and construction supply stores.

Teacher Tip: To obtain more clear-cut data, the heating (lamp on) and cooling (lamp off) operations for sand and water in Part 1 can be extended from 5 minutes for each condition, as described in the procedure, to 15 minutes for each condition.

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.

Part 1 – Rates of heating and cooling of water versus sand

1	2	5	4	3
Weigh 200 g of sand and 200 g of water in separate beakers.	Set up a graph display to show two runs simultaneously. Set it up to show Temperature versus Time.	Determine the change in heating and cooling (Δ°C) for the water and sand. Determine the rate of heating and cooling.	Enter the initial, maximum, and minimum temperatures on the data table.	Heat the beakers for 15 minutes using a bright light, and then cool the beakers for 15 minutes, recording data continuously.

Part 2 – Determining the specific heat of sand

5	4	2	1	3
Calculate the specific heat of the sand; compare it to the specific heat of water.	Combine the sand and water and record the temperature until the temperature of the mixture stabilizes. Note that temperature.	Make a calori-meter out of 2 nested insulated cups. Add water. Fill a test tube 1/2 full of sand; measure the sand's mass.	Arrange equipment so you can record the temperature of sand in a test tube as it heats in a beaker of boiling water.	Heat the sand in boiling water. Record the temperatures of the heating sand and the water in the calorimeter for 5 minutes.

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 – Rates of heating and cooling of water versus sand

Set Up

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

2. ☐ Connect two fast-response temperature probes to your data collection system. �(2.2)

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

4. ☐ Set up the graph display to show two data runs simultaneously. �(7.1.3)

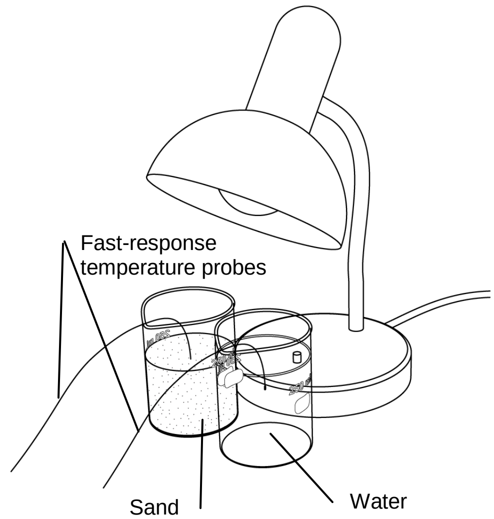
5. ☐ Put 200 g of sand into a 250-mL beaker.

6. ☐ Put 200 g of water into another 250-mL beaker.

7. ☐ Place a fast-response temperature probe in each beaker as shown in the illustration.

Note: Each of the temperature sensors should be approximately one inch below the surface.

8. ☐ Place the heat lamp directly above the beakers so that both beakers receive the same amount of energy from the lamp.



9. ☐ 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.

Collect Data

10. ☐ Start data recording. �(6.2)

11. ☐ Adjust the scale of the graph to show all data. �(7.1.2)

12. ☐ Record data for 30 seconds.

13. ☐ Turn on the light and record data for an additional 5 minutes (300 seconds). *Do not stop recording data!*

14. ☐ How much faster do you think the temperature of the sand will increase than that of the water? How much faster will it decrease when the light is turned off? Give a specific rate comparison (such as twice as fast or twice as slow).

Students should specify a rate comparison, such as: "I think the temperature of the sand will increase two times as fast as that of the water, and it will decrease two times as fast as that of the water."

Note: While the data is recording for 5 minutes, you can begin setting up Part 2 of the procedure.

15. ☐ Turn the light off.

16. ☐ Continue recording data for 5 minutes.

17. ☐ Stop recording data. �(6.2)

18. ☐ Name the data runs "Sand" and "Water". �(8.2)

19. ☐ Save your experiment. �(11.1)

20. ☐ Complete the steps in the Data Analysis section for Part 1.

Part 2 – Determine the specific heat of sand

Set Up

21. ☐ How do you think the specific heat of sand will compare with the specific heat of water? Give a rate comparison (such as twice as fast or twice as slow).

Students should include a quantity in their predictions. For example, the specific heat of water will be 7 times higher than that of sand.

22. ☐ Fill the 500-mL beaker about 3/4 full with water.

23. ☐ Place the beaker on the hot plate, and turn it on to the highest setting.

24. ☐ Bring the water to a boil.

25. ☐ Set up the tripod base and rod while you wait for the water to boil. Fasten a buret clamp just above the beaker.

26. ☐ Measure the mass of the test tube: 20.9 g .

27. ☐ Fill the test tube half full with sand.

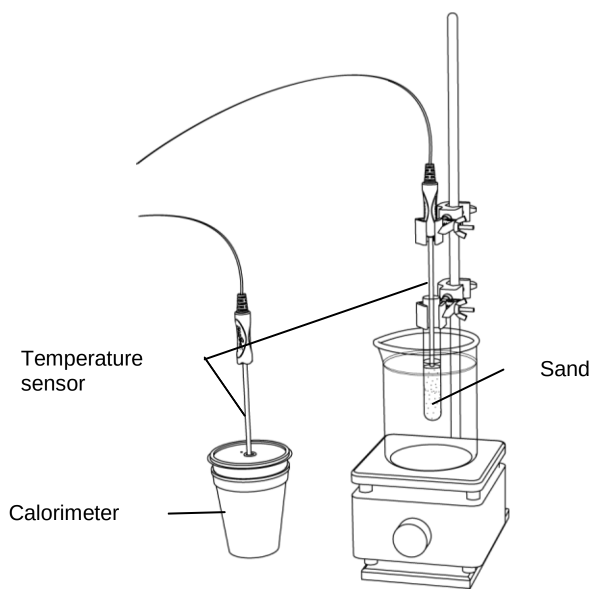
28. ☐ Measure the mass of the sand and the test tube: 40.7 g .

29. ☐ Calculate the mass of the sand alone and write the mass in Table 2 in the Data Analysis section.

30. ☐ Use the buret clamp to secure the test tube in the 500-mL beaker of boiling water. Make sure the sand in the test tube is below the water level.

31. ☐ Connect the two stainless steel temperature sensors to the data collection system. �(2.2)

32. ☐ Place one of the stainless steel temperature sensors into the middle of the test tube. Do not allow the sensor to touch the bottom or sides of the test tube.



33. ☐ Support the sensor with the second buret clamp.

34. ☐ Before making the calorimeter (by nesting two disposable insulated cups), make sure the lid has a hole in it that you can slide the stainless steel temperature sensor and stirring rod through.

35. ☐ Measure 70.0 g of room-temperature water.

36. ☐ Place the two disposable insulated cups together, and add the water into the top cup.

37. ☐ Use the other stainless steel temperature sensor to measure the temperature of the water in the insulated cup. �(6.1)

38. ☐ If necessary, open a graph display that shows Temperature on the y-axis and Time on the x-axis, �(7.1.1) and set up the graph display to show two data runs simultaneously. �(7.1.3)

Collect Data

39. ☐ Start recording data, �(6.2) and adjust the scale of the graph to show all data. �(7.1.2)

40. ☐ Record data for 600 seconds, then stop recording data.�(6.2)

41. ☐ Name the data run "Sand2". �(8.2)

42. ☐ Record the temperature of the sand in Table 2 in the Data Analysis section (T_{initial}).

43. ☐ Turn the hot plate off.

44. ☐ Use the same temperature sensor you used to measure the temperature of the water. Insert the temperature sensor through the hole in the lid (the lid is not on the disposable insulated cup yet).

45. ☐ Insert the stirring rod through the same hole and put the lid on the cup, making sure the thermometer is in contact with the water.

46. ☐ Start recording data, �(6.2) and adjust the scale of the graph to show all data. �(7.1.2)

47. ☐ Use tongs to remove the test tube and quickly pour the contents of the tube into the water in the calorimeter.

48. ☐ Immediately cover the disposable insulated cup with the lid, making sure the temperature sensor doesn't touch the side or bottom of the cup. Stir the water and sand mixture.

49. ☐ Why did you pour the sand into the water?

Hint: The specific heat of water is a known constant: 4.186 J/g °C.

Because the specific heat of water is a known constant, it is possible to calculate the total amount of energy added to the water from the change in the water temperature. Because the amount of heat lost by the sand equals the amount of heat absorbed by the water, you can find the unknown quantity: the specific heat of sand.

Although students may not know this answer yet, they should know it by the end of the lab and should be expected to complete the answer at that point. Tell students that if they do not know the answer to this question, return to it later when they do.

50. ☐ Continue stirring the water and sand mixture.

51. ☐ Record data until the temperature starts to level off, and then stop recording data. �(6.2) (This will take about 1 minute.)

52. ☐ Name the data run "Calorimeter". �(8.2)

53. ☐ Save your experiment. �(11.1)

54. ☐ How did the initial temperature of the water and sand added to the insulated cup compare to the final temperature of the water-sand mixture? Where did the heat energy of the sand go when you put it into the water?

The initial temperature of the sand was higher than the initial temperature of the water, but when the two were combined, their temperatures became equal (the sand lost heat energy and the water gained heat energy).

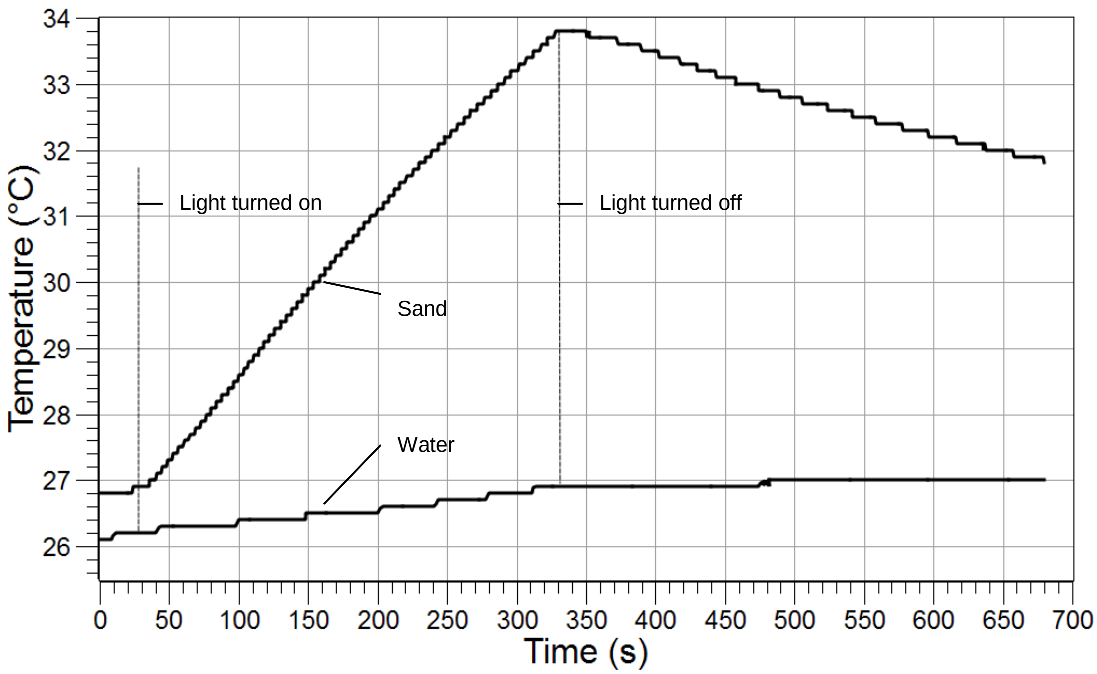
55. ☐ What was the purpose of using an insulated cup and lid rather than simply using a beaker?

The insulated cup reduces the amount of heat lost to the surrounding environment, helping to create a closed system.

Data Analysis

Part 1 – Heating and cooling of water versus sand

1. ☐ Sketch your two data runs, "sand" and "water," on the graph. Label both data runs, label the axes with units and a scale, and indicate when the light was turned on and turned off.



2. ☐ Use the graph tools to determine the temperature data points specified in the Table 1. �(9.1)

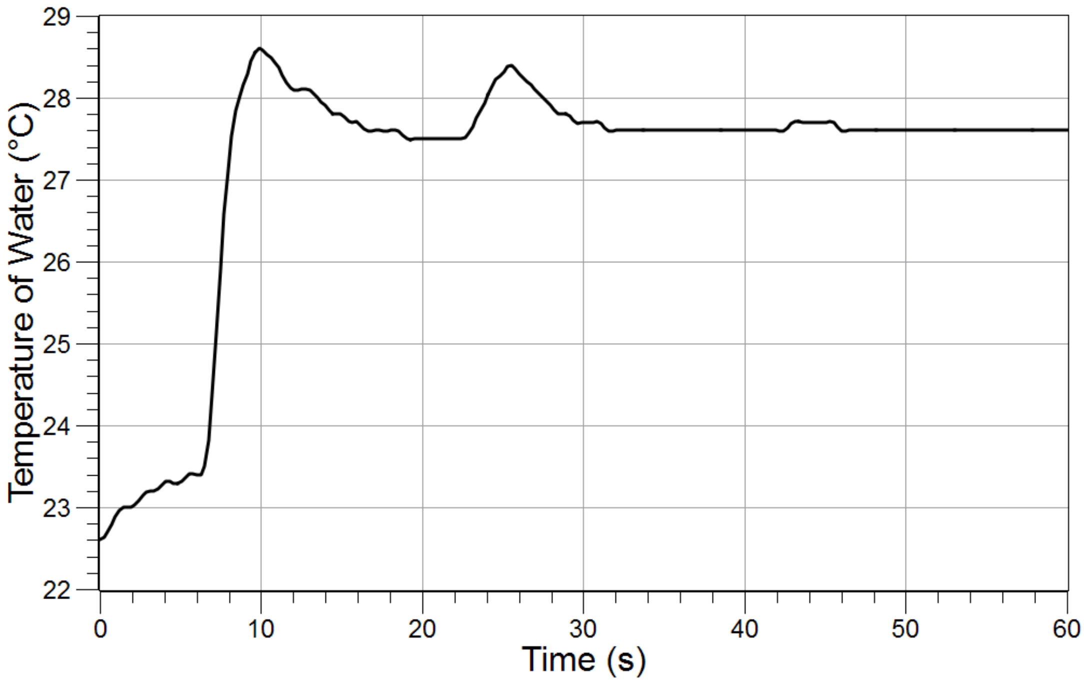
3. ☐ Complete the calculations for Table 1.

Table 1: Rates of heating and cooling of water and sand

	T_{initial} (°C)	$T_{\text{max,light on}}$ (°C)	$\Delta T_{\text{heating}}$ (°C)	$Rate_{\text{heating}}$ (°C/s)	T_{final} (°C)	$\Delta T_{\text{cooling}}$ (°C)	$Rate_{\text{cooling}}$ (°C/s)
Water	26.1	26.9	0.9	0.003	27.0	0.1	0.0003
Sand	26.8	33.8	16.10	0.018	31.9	1.9	0.0060

Part 2 – Determine the Specific Heat of Sand

4. ☐ Sketch the graph of the third data run of Temperature versus Time for the water-sand mixture. Be sure to label the x-axis and y-axis regarding parameter and units of measurement as well as the data runs.



5. ☐ Find the initial and final temperatures of the data run and enter them in Table 2. �(9.1) (The initial temperature of the sand should have been entered earlier).

6. ☐ Complete the calculations for Table 2.

Hint: Determine the amount of heat gained by the water (Q) using the mass of the water (m), the specific heat of the water (c), and the change in temperature of the water (ΔT.) This relationship is described by the equation: $Q = mc\Delta T$.

Table 2: Determining the specific heat of sand

Material	Mass m (g)	T_{initial} (°C)	T_{final} (°C)	ΔT (°C)	Q (J)	Specific Heat c (J/g °C)
Water	70.0	22.6	27.6	4.0	1172	4.186
Sand	19.8	78.4	27.6	50.8	1172	1.2

Analysis Questions

1. Calculate the ratio of the sand's rate of temperature increase to the rate of the water's temperature increase during the heating condition.

Answers will vary slightly from those in the example where the ratio of the rate of increase in temperature of sand to water is 0.018:0.003 or 6:1.

2. Calculate the ratio of the sand's rate of decrease to the rate of the water's temperature increase during the cooling condition.

Answers will vary slightly from those in the example where the ratio of the rate of decrease in temperature of sand to water is 0.006:0.0003 or 20:1.

3. How much faster did sand heat up and cool down compared to water? How does your prediction regarding the relative rates of heating and cooling compare with the results? Give a quantitative comparison.

Answers will vary. Students should compare their predictions to their answers. Using this example, students should state that they found that sand heated up 6 times faster and cooled down 20 times faster than water. Then they should compare those rates to the ones they predicted.

4. In Part 1 of this exploration, what was the independent variable and the dependent variable, and what factors did you hold constant?

The independent variable was the type of substance: sand or water. The dependent variable was the temperature of the substance. The factors held constant included the amount of energy added to the system, the mass of the substance being tested, the type of container holding the substance, the time of measurement, and the measurement technique.

5. Compare your results for Part 2 with your prediction, using specific quantities.

Answers will vary, but students should make a quantitative comparison. For example, students could say that they predicted that water has a specific heat that was 7 times that of sand, based on the comparative rates of heating and cooling of sand and water. In the example data for Part 2, students found that the specific heat of water was about 3.5 times greater than that of the sand.

6. What is the relationship between the specific heat of a substance and the rate of temperature change when the energy content of the environment around it changes?

The higher a substance's specific heat, the slower it changes in temperature when the energy content of its environment changes.

7. What characteristics of water account for its high specific heat?

Water's strong intermolecular bonds, especially the hydrogen bonds, account for its high specific heat.

8. In this activity, what does Q represent? Why was Q the same for the water and the sand?

Q represents the amount of energy transferred from the sand to the water when the two were combined. In this activity, Q was calculated from the change in temperature of the water, water's specific heat, and the mass of the water. To find the specific heat of sand, we assumed that all of the energy given up by the sand was transferred to the water. Therefore, by experimental design (using the calorimeter), Q was the same for the water and the sand.

9. List some important sources of experimental error that might occur in this activity.

In Part 1, the amount of energy added to each system might not be exactly the same. In Parts 1 and 2, an unknown amount of energy was lost to the environment, because we did not truly have closed systems. Also, there may have been calibration differences between the temperature sensors.

Synthesis Questions

Use available resources to help you answer the following questions.

In the following questions, assume that the data you obtained for sand represents data for land in general.

1. How could you modify the experiment to be more confident in this assumption?

Additional substances found on land, such as dry soils of different types, gravel, and vegetation, could be analyzed to determine their specific heat. A mean of these values could be compared with the specific heat of water.

2. Explain how the proximity to a large body of water influences weather. Provide an example.

Because of the high specific heat of water, proximity to a large body of water moderates the weather. The range of daily temperatures near the water is less than the range that occurs inland. Additionally, weather conditions near the coast can be foggy, whereas inland there will be no fog. For example, the weather can be foggy and cool in San Francisco, California, while simultaneously 100 miles inland, the weather can be sunny and hot.

Conversely, in the winter, the temperature in San Francisco can be cool, whereas the temperature 100 miles inland can be below freezing. On a day in July, the maximum temperature in San Francisco was 18 °C (65 °F), while the maximum temperature in Sacramento, in interior California at about the same latitude and elevation, was 38 °C (101 °F)

3. Explain how the proximity to a large body of water influences climate. Provide an example.

Because of the high specific heat of water, proximity to a large body of water moderates the climate. Compared to areas inland, 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 (77 °F) and 14 °C (58 °F). Those for Alice Springs, in the interior of Australia at the approximately the same latitude and elevation are 34 °C (93 °F) and 12 °C (53 °F), respectively.

In another example, farmers along the coast of California do not have to be concerned about crop damage due to frost, whereas in the central valley of California, frost is common during the winter.

4. Explain how a large land mass influences weather. Provide and example.

Because of the low specific capacity of land, a large land mass causes daily highs in temperature in the summer to be higher inland relative to that on the coast or over the ocean. For example, on a day in July, the maximum temperature in Vancouver, Canada (on the Pacific coast) was 23 °C (73 °F), whereas for Winnipeg, Canada, which is about the same latitude and elevation in interior Canada, the maximum temperature was 28 °C (82 °F).

5. Explain how a large land mass influences climate. Provide and example.

Because of the low specific capacity of land, a large land mass causes the average summer daytime temperature to be higher and the average winter daytime temperature to be lower than for smaller land masses at the same latitude. For example, the average temperatures in February and July for Manchester, England are

3 °C (37 °F) and 16 °C (60 °F), respectively. In contrast, those for Novosibirsk in the interior part of the Russian Federation at approximately the same latitude and elevation are –20 °C (–4 °F) and 19 °C (67 °F), respectively.

Multiple Choice Questions

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

1. In Part 2 of this activity, to complete your calculations you relied on the assumption that all of the heat energy in the heated sand was transferred to the water in the insulated cup until the temperatures of the sand and water were equal. Thus, you were counting on

- **A.** The laws of motion.
- **B. The first law of thermodynamics (energy conservation).**
- **C.** The second law of thermodynamics (entropy).
- **D.** The third law of thermodynamics (entropy reduces as temperature lowers but is always present).
- **E.** The law of gravity.

2. All of the following influence global air circulation EXCEPT

- **A.** Uneven heating of the earth’s surface.
- **B.** Rotation of the earth on its axis.
- **C.** The difference in specific heat of water compared to that of land.
- **D.** Seasonal changes in temperature and precipitation.
- **E. The position of Earth's moon relative to Earth.**

3. Compared to a substance with a low specific heat, a substance that has a high specific heat

- A. **Requires more heat per gram to be added to it to cause an increase in temperature.**
- **B.** Requires less heat per gram to be added to it to cause an increase in temperature.
- **C.** Requires the same amount of heat per gram to be added to it to cause an increase in temperature.
- **D.** Has a larger mass.
- **E.** None of these is true.

4. Water has a high specific heat because

- **A.** It changes from a solid to a liquid phase at a relatively high temperature.
- **B. It has intermolecular hydrogen bonds.**
- **C.** It boils at 100 °C.
- **D.** It freezes at 0 °C.

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.**

Extended Inquiry Suggestions

Ask students to conduct an Internet search to find the specific heat of various substances. Find the specific heat of common building materials. Challenge students to relate these specific heats to the phenomenon of the urban heat island effect found in cities. What would be the affect on city temperature of including a lot of foliage in a city (Remember that plants contain a lot of water and also transpire).

The specific heat of room-temperature air (about 23 °C, 40% relative humidity, 200 meters above sea level) is about 1 J/g °C. Challenge students to design an experiment to test the affect of humidity on the heat capacity of air. Ask them to state their hypothesis and then test the hypothesis.

4. Monitoring Microclimates

Objectives

This activity leads students to 1) understand the distinction between microclimate and climate when collecting weather and climate information and 2) to identify factors that affect measurements for reporting weather and climate information. To do this, students:

- Determine the requirements of a weather station
- Determine the requirements of the sites where weather stations are located

Procedural Overview

Students gain experience conducting the following procedures:

- Making weather stations and determining sites for measurement.
- Collecting and analyzing data collected with a weather sensor.
- Analyzing data sets to understand factors that contribute to variations in data

Time Requirement

♦ Pre-lab discussion and activity	50 minutes
♦ Preparation time	10 minutes
♦ Lab activity	45 minutes, plus time to stop collecting data, if data collection extends to several hours.

Materials and Equipment

For each student or group:

- Mobile data collection system
- Weather/anemometer sensor[1]
- Cardboard box, 20 cm^3 or larger
- Scissors
- Marking pen

[1]Alternatively, use separate temperature, humidity-dew point, and barometric pressure sensors.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Because the earth turns daily on an axis that is tilted relative to the plane of the earth's yearly orbit around the sun, sunlight falls more intensely on different parts of the earth during the year.

- The difference in intensity of sunlight and the resulting warming of the earth's surface produces the seasonal variations in temperature.

Related Labs in This Guide

Labs conceptually related to this one include:

- Investigating Specific Heat
- Sunlight Intensity and Reflectivity

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 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)
- Showing and hiding data runs in a graph �(7.1.7)
- Displaying data in a table �(7.2.1)
- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

Where does the data used by climatologists and weather forecasters originate? Until the arrival of satellite measurement capabilities, all data came from thousands of weather stations located across countrysides worldwide and on buoys scattered across the oceans. Today, data originating from both satellite observations and ground measurements are merged through complex computerized algorithms. These produce comprehensive results, for example, the low and high temperatures for a day for a particular area, the average temperature for a year in a given area, or the average global temperature for a year.

The features of a site for a weather station must be standardized across weather stations to minimize error introduced by particular aspects of the surrounding area. Inconsistencies can be caused by shade trees, heat reflected from buildings or parking lots, heat added from heating or air conditioning vents, proximity to a large body of water, the type of housing surrounding the weather sensors, and so on. The error introduced by these differences in microclimates can be considerable.

Pre-Lab Discussion and Activity

Engage students with an explanation of weather stations, including Stevenson screens. Consider noting that Stevenson screens were invented by Thomas Stevenson (1817-1887), the father of author Robert Louis Stevenson.

Explain that Stevenson screens shield instruments against precipitation and direct heat radiation from outside sources, while still allowing air to circulate freely. The use of a standard screen allows temperatures to be compared accurately with those measured in earlier years and at different places.

Explain that the National Climatic Data Center (NDCD) currently collects data from more than 1000 weather stations throughout the United States as a basis for calculating climate data.

Arrange for a local meteorologist to speak to the class in person or by telephone conference.

1. Use the Internet to find and share photographs of weather stations and Stevenson screens. What do they look like? What are the characteristics of the sites and the surroundings?

Student could submit pictures or written descriptions, or both.

2. What questions will you ask the meteorologist when he speaks with the class?

Three possible questions: Where does the data come from for their weather forecasts? How is the data for weather forecasts collected? Where are the local weather stations located?

3. How does the daily weather differ from the climate?

Climate is an average of the weather over the course of the year. Any particular day can be outside of the normal for a particular climate.

Lab Preparation

These are the appropriate preparations prior to the lab.

Decide on a time period that students will collect data. The sample data shown with this lab is for data collected over a time period of 3 hours. This yielded a data set with multiple opportunities for discussion and comparison. However, data suitable for class comparisons could be collected over a period of as little as 10 minutes.

Note: The main focus of this lab is to compare data from multiple weather stations placed in different sites. For analyzing data from an individual station, it is more meaningful when data is collected for at least a few hours.

Teacher Tip: If you have your students collect data for only 10 to 20 minutes, you will not need to adjust the sampling rate of the sensor.

Consider ahead of time what will be safe and acceptable locations for students to place their weather stations and how much time they might be left unattended. When the collection period lasts for several hours, you may need to determine how to stop data recording and how to gather the equipment. (For instance, students can be asked to return later, or a class later in the day may assist with this part of the activity.)

Ensure that the mobile data collection systems have fully charged batteries.

Provide students with a way to record the summary data from their weather station onto Table 2 so it is visible to the entire class. This will facilitate the sharing of class data and the calculation of class summary data.

Safety

Follow your normal outdoor class 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	5
Position the sensor and the protective housing and start collecting data.	Stop collecting data. Analyze it for maximum, minimum, and average values.	Set up your data collection system to collect data once per minute (if you will be recording for hours).	Find a suitable location for your weather station and record the characteristics of the site.	Compare your results with those of other microclimates.

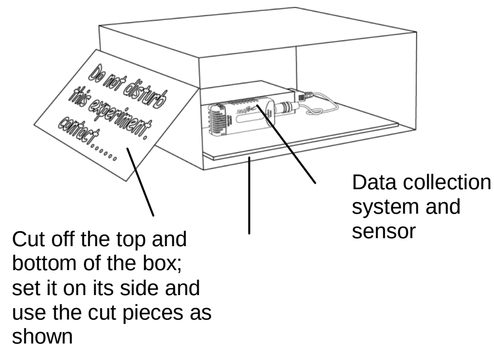
Procedure with Inquiry

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. ☐ Using a cardboard box 20 cm by 20 cm by 20 cm or larger, cut the box so that it has no top or bottom, only the four connected sides.



2. ☐ Using the top or bottom cut from the cardboard box, make a sign that says, "Do not disturb this experiment. Contact [your teacher's name]."

Note: This step is necessary only if you are going to leave the weather station unattended.

3. ☐ Use the top or bottom cut from the cardboard box as a mat that you will set inside this "housing" for the weather station.

4. ☐ Find a location outside with unusual characteristics, especially one that is unlike what anyone else has chosen. Here are some examples:

- ♦ Well shaded by trees
- ♦ Close to a big parking lot
- ♦ Close to a pond or lake
- ♦ In the middle of a field
- ♦ Next to the vent of an air conditioner
- ♦ In a sheltered, sunny area on the south side of a building
- ♦ In a sheltered, shaded area on the north side of a building

5. ☐ Check with your teacher to be sure it is safe and otherwise acceptable to set up a weather station in the location you chose.

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

7. ☐ Connect a sensor to your data collection system �(2.1)

Note: If you are going to collect data for longer than 20 minutes, set the sensor sampling rate to once per minute. �(5.1)

8. ☐ Display temperature data in a table on the data collection system. �(7.2.1)

9. ☐ Place the cardboard housing in the accepted location so that air can circulate through the two open ends and direct sunlight is least likely to shine on the equipment. (See the illustration above.)

10. ☐ Place the cardboard mat on the floor of the cardboard housing.

11. ☐ Place the data collection system and sensor on the mat.

12. ☐ Why are you protecting your weather sensor and other electronics from direct sunlight?

Shielding the weather sensor and other electronics from direct sunlight prevents damage to the equipment from the sun and eliminates the absorption of radiant energy from direct sunlight.

Collect Data

13. ☐ Collect data for the amount of time your teacher specifies.

Note: For the database of all data collected by the class, data collection for all weather stations should be for the same time period.

14. ☐ Start data recording. �(6.2)

15. ☐ Adjust the scale of the graph to show all data. �(7.1.2)

16. ☐ Record the following in Table 1 in the Data Analysis section:

- Starting time
- Primary physical characteristics of the site, especially anything that might affect temperature
- Prevailing weather conditions (such as cloudy, sunny, windy, or calm)

17. ☐ Will the maximum, minimum, and average temperatures of your site be higher or lower than the average temperature of all the sites? Why?

Answers will vary. For instance, temperature at a site near pavement might be higher than the average. Temperature on the north side of a building may be lower than average. The pavement holds and radiates more heat than other sites while the heat from the direct sun may be blocked on the north side of a building.

18. ☐ Stop data recording �(6.2) when instructed by your teacher to do so.

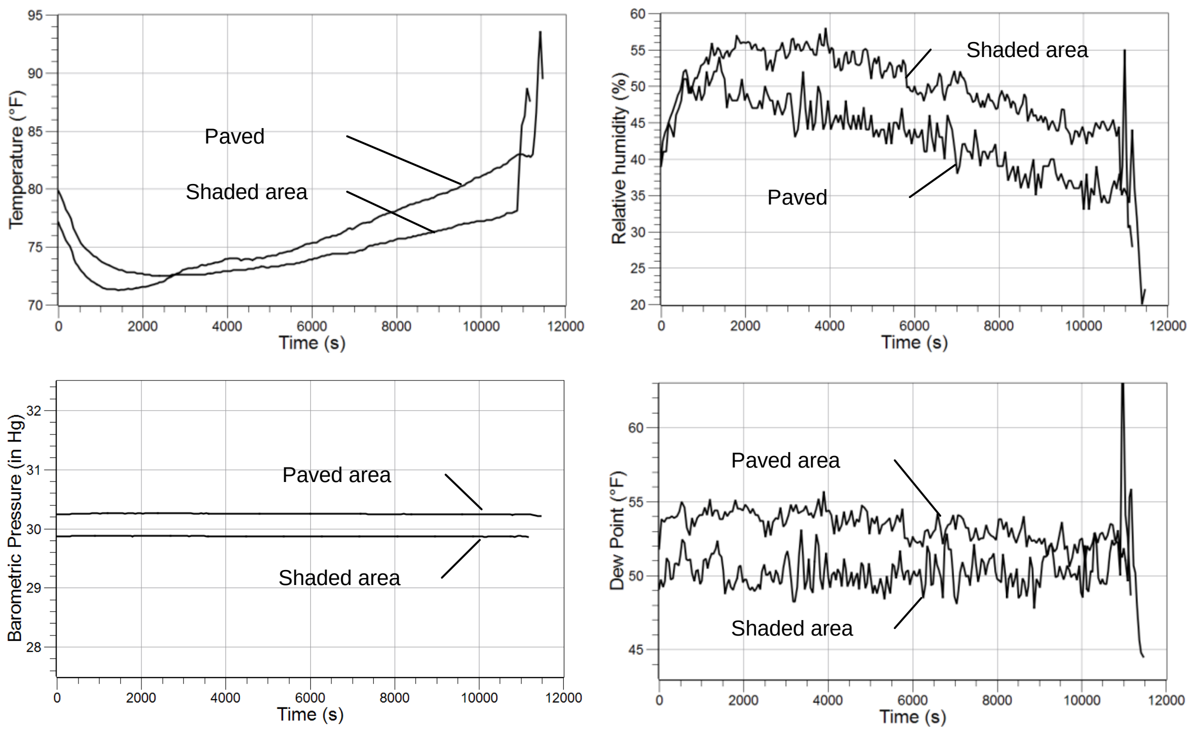
Note: For data collection lasting hours, make appropriate arrangements with other class teachers so you can stop the data recording at the specified time.

19. ☐ Record the time you stopped recording data in Table 1 of the Data Analysis section.

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

Sample Data

These graphs show a comparison of 4 weather parameters at 2 weather station locations: 1) a shaded area under trees and 2) a paved area near buildings.



Data Analysis

1. ☐ Open a graph display �(7.1.1) and display the temperature data on a graph of temperature (°C) versus time (s). �(7.1.7)

2. ☐ Adjust the scale of the graph to show all data. �(7.1.2)

3. ☐ Find the minimum, maximum, and mean values and record these values in Table 2. �(9.4)

4. ☐ Repeat this procedure for the barometric pressure, relative humidity, and dew point measurements. �(7.1.7)

5. ☐ Record your data for the individual weather station (from Table 2) on a table of class data your teacher has provided.

6. ☐ After every group has recorded its data on the class data table, complete Table 2.

Table 1: Weather station and data collection information

Date and time collection started	July 31, 2008 at 8:30 a.m.
Date and time collection ended	July 31, 2008 at 11:30 a.m.
Description of physical characteristics of the site, especially anything that might affect temperature	The weather station was placed on pavement in the parking lot on the south side of the building about 3 meters from the side of the building.
Prevailing weather conditions (such as cloudy, sunny, windy, or calm)	The prevailing conditions were sunny, clear sky, and calm wind.

Table 2: Individual and class weather station data

	Individual Weather Station			Average for All Class Stations		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Temperature (°F)	71.38	83.4	76.2	71.2	78.1	75.6
Barometric Pressure (in Hg)	29.86	30.21	30.20	30.04	30.07	30.06
Relative Humidity (%)	33	54	43	37.5	56	46.5
Dew Point (°F)	44.49	53.17	50.20	47.55	54.44	51.80

Analysis Questions

1. How did your data compare with the class data?

Answers will vary. For this example, the minimum, maximum, and mean temperatures at the individual station were higher than those for the class. The average barometric pressure at this station was higher, which doesn't make sense, because the stations were located in close proximity. Perhaps this difference is due to a calibration issue with the different sensors. The humidity and the dew point at the individual station were lower than the class average.

2. Compare your actual statistics with your predictions.

Answers will vary, but students should be specific.

Synthesis Questions

Use available resources, and the following ideal characteristics for a climate monitoring station (according to the United States Climate Reference Network of the National Oceanic and Atmospheric Administration (NOAA)), to help you answer the following questions.

- Flat and horizontal ground
- Surrounded by a clear surface with a slope less than 1/3 (less than 19 degrees)
- Grass or other low vegetation ground cover, less than 10 centimeters high
- Sensors located at least 100 meters from artificial heating or reflecting surfaces, such as buildings, concrete surfaces, and parking lots
- Far from large bodies of water, except if it is representative of the area, and then located at least 100 meters away
- No shading when the sun elevation is greater than three degrees

1. How does the site you chose compare with the characteristics from the NOAA?

Answers will vary. For this example, the site did not match these specifications in any way.

2. Do your statistics or the average statistics from the class best describe the weather conditions in your area? Why?

Answers will vary. For this example, the class average is more representative because it includes data from multiple microclimates that represent the area. The individual station data was skewed higher for temperature and lower for humidity because the pavement absorbs and radiates more heat than other surface materials.

3. Which sites used in class would best contribute to the national climatology database? Why?

Answers will vary. A weather station situated in a manner that is closest to the NOAA specifications might be recommended.

4. Besides making sure sensors are calibrated and functioning properly, what site conditions should be monitored regularly to ensure collections of valid data?

Make sure the site is maintained properly. Check that the weather station is still level, that no trees or other shading have been introduced, that no buildings have been erected or paving has been added nearby. Check that the housing for the weather station is in good repair.

Multiple Choice Questions

1. Respectively, what are the short-term and long-term atmospheric conditions in a local area known as?

- **A.** Weather, patterns
- **B.** Climate, weather
- **C.** Weather, current
- **D.** Patterns, weather
- **E.** **Weather, climate**

2. What main environmental factors form the climate of an area?

- **A.** Average temperature
- **B.** Average precipitation
- **C.** Average humidity
- **D.** **A and B only**
- **E.** All of the above

3. Why do weather stations need to be level?

- **A.** The sensors do not work well if they are not level.
- **B.** They are more likely to fall over if they are not level.
- **C.** **Accurate precipitation data require collection chambers that are level.**

4. In order for a weather station site to provide useful and reliable data that represents the local climate and not a microclimate, what site characteristics must be satisfied?

- **A.** It is not near a pond or small lake.
- **B.** It does not have high vegetation growing in the surrounding area.
- **C.** I is not shaded.
- **D.** It is not close to buildings, paving, or artificial or reflected heat sources.
- **E.** **All of the above**

5. Which of the following apply to the calibration and regular maintenance of modern weather sensor equipment?

- **A.** It does not have to be done as often as in earlier times because of advances in technology
- **B.** **It has to be done more often than in previous times because of the tendency of electronic equipment to drift off calibrated settings over time.**
- **C.** It needs to be done as often today as in the 1800s when data was first being collected for climate studies.

Extended Inquiry Suggestions

Find out if there are official weather stations in your area. If so, visit and evaluate them according to NOAA's criteria for the placement of weather stations.

Have students do research on the locations of weather stations around the globe that provide data for global climate determinations. Have them report to the class on their findings.

Compare the daily weather to that of the local climate and explain the similarities/differences.

Consider adding GPS location to your data collection and importing into Google Earth or ArcGIS. Once the data has been exported, investigate the features that led to regional geographic variation. Additionally, consider collecting data at different times of the year with different classes and compare the averages from one time of the year to the next.

5. Sunlight Intensity and Reflectivity

Objectives

Students explore the concept that air temperatures near the earth's surface result largely from the interplay of the sun's incoming energy and the absorption, reflection, and radiation of that energy by materials on the earth's surface. In the process, students:

- Analyze the laboratory evidence showing the differences in reflectivity of various earth materials
- Explain the effect of the earth's reflectivity on surface temperatures

Procedural Overview

Students gain experience conducting the following procedures:

- Using light and temperature sensors to measure the reflectivity (albedo) of various earth materials
- Using light and temperature sensors to measure air temperature and sunlight intensity throughout the day

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	90 minutes (or two 45-minute sessions)[1]

[1]If you (rather than your students) collect the data for part 2, the lab will require one 45-minute session.

Materials and Equipment

For each student or group:

- Mobile data collection system
- PASPORT Sensor Extension Cable
- Light sensor
- Fast-response temperature probe
- Stainless steel temperature sensor
- Mass balance (1 per class)
- High intensity incandescent lamp
- Large disposable plate
- Tripod base and support rod
- Three-finger clamp
- Rod and clamp
- White sand[1], 500 g
- Dark sand[1], 500 g
- White rock[1], 500 g
- Dark rock[1], 500 g
- Small cardboard box, $(20\text{ cm})^3$ or larger
- Tape
- Paper and marking pen
- Scissors

[1]Such as that found at an aquarium supply store

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Energy transformation
- ♦ Light and other electromagnetic waves can warm objects
- ♦ Thermal energy transfer

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Insolation and the Seasons
- ♦ Investigating Specific 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.

- ♦ Stating a new experiment on the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data collection system �(2.2)
- ♦ Selecting a measurement range on a light sensor �(4.3)
- ♦ Changing the sample rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data �(7)
- ♦ 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 of a graph �(7.1.10)
- ♦ Displaying multiple graphs simultaneously �(7.1.11)
- ♦ Naming a data run �(8.2)
- ♦ Finding the values of points in a graph �(9.1)

- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

The air temperature near the earth's surface depends primarily on two things: the amount of energy provided by the sun and the amount of energy the earth is radiating. When these two factors are added together, the total energy is greatest shortly after the time of greatest sunlight intensity. On a sunny day, the greatest intensity of sunlight occurs around mid-day. However, the hottest part of the day typically occurs from one to several hours later.

The amount of heat the earth's surface can absorb and subsequently radiate depends on the composition of the materials comprising the surface. Dark, rough materials absorb greater amounts of incoming solar radiation and therefore radiate more energy. Conversely, light colored, smooth materials reflect greater amounts of solar radiation and as a result have less energy to radiate. The reflectivity of a surface is its *albedo*. The higher the albedo, the more light is reflected and the less energy is absorbed.

Pre-Lab Discussion and Activity

Show students maps of global temperatures.

Teacher Tip: Use the following keywords in an Internet search engine to find suitable Web sites: IRI Global Climatological Temperature.

Then show students illustrations from a textbook of angles of incoming solar radiation (insolation) relative to the earth's surface. Discuss with students the reasons why the highest global temperatures correspond to the greatest angle of insolation.

Ask students to sketch a graph of their prediction of the light intensity from the sun starting at sunrise and ending at sunset.

On the same graph, have them sketch their prediction of the graph of air temperatures versus time of day.

Ask students:

1. What time of day do you expect the intensity of insolation to be the greatest?

Correct answers will include mention of the time of day when the sun has reached the greatest angle of insolation, about noon. You may choose to leave this question unresolved until after the lab activity.

2. What time of day do you expect the air temperature to be the highest?

Students may say that the highest air temperature will occur at the same time that the insolation angle is the greatest, that is, about noon. However, due to the additive effect of earth's reflectivity, the highest air temperature will generally occur later in the day (particularly on a sunny day with light winds), usually about 3 or 4 p.m. You may choose to leave this question unresolved until after completing the lab activity.

3. Make a list of the materials you will be using in the order you predict will be the least reflective material to the most reflective.

Students should rank the materials they have to work with in the lab from least to most reflective. For this activity: dark rock, dark sand, white rock, white sand.

Lab Preparation

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

1. Purchase the rock and sand. These can be purchased from any store that sells aquarium supplies.

2. Arrange to have students collect their equipment stations and stop data recording in the late afternoon or evening. Alternatively, you can place the equipment stations and collect the data for this part.

Teacher Tip: The activity in Part 2 is best performed on a sunny day with little or no wind.

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.

Part 1 – Measuring reflection and radiation of sand and rock

- (2) Mount a light sensor on a stand. Set it next to the plate on the side opposite the light. Aim it towards the plate of sand at the angle of reflection.
- (3) Using the stand, position the end of a quick-response temperature probe about 1 cm above the sand.
- (1) Cover the bottom of a plate with 500 g of white sand. Set up a high-intensity light on one side of the plate and aim it towards the sand.
- (4) Shine the light on the sand. Record light intensity and temperature data for 1 minute. Turn the light off and continue recording data for 3 minutes.
- (5) Repeat this process for dark sand, white gravel, and dark gravel. Compare rates of heating and cooling of the solid material and the air above it.

Part 2 – Measuring sunlight intensity and the earth's reflectivity

4	1	3	5	2
Set the equipment station in a sunny location that will not receive shade during the day and that also is not on pavement or near a building.	Make sure your mobile data collection system is fully charged.	Connect the sensors to the data collection system and change the sampling rate to 1 sample per minute. Set up a graph display for the 2 parameters.	Make a DO NOT DISTURB sign. Record data until sunset. Stop recording data and save the file.	Make an outdoor equipment station that shields the data collection system from the sun but still exposes the sensors to the sunlight and 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.

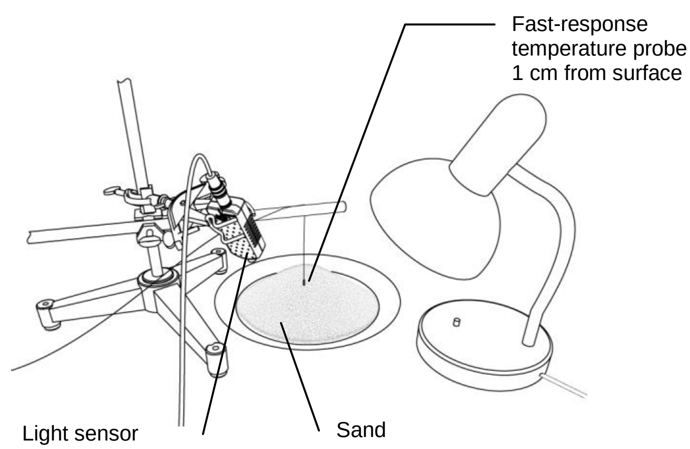
Part 1 – Measuring reflection and radiation of sand and rock

Set Up

1. ☐ Put 500 g of white sand in a large plate.

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

3. ☐ Connect light level sensor to PASPORT sensor extension cable. Then connect the light sensor and a fast-response temperature probe to the data collection system. �(2.2)



4. ☐ Set up appropriate displays to view the data as it is being collected. �(7)

5. ☐ Place the lamp on one side of the plate so it will shine down into it at about a 60° angle.

6. ☐ Mount the light sensor on the tripod base and rod stand, using the three-finger clamp. Position it on the other side of the plate, directly opposite the light and angled at approximately the same angle as the light source towards the plate.

7. ☐ Set up the fast-response temperature probe so it hangs about 1 cm above the surface of the sand.

8. ☐ Which material do you predict will have the greatest albedo? Which the least?

Predictions will vary, and all predictions should be accepted. The lightest-colored materials generally have the greatest albedo, while the darkest-colored ones have the least.

9. ☐ Which material do you predict will absorb the most heat from the light energy?

Predictions will vary, and all predictions should be accepted. The darkest-colored materials absorb the most heat from the light energy.

10. ☐ Which material do you predict will radiate the most heat after the light is turned off?

Predictions will vary, and all predictions should be accepted. The darkest-colored materials will radiate the most heat after the light is turned off.

11. ☐ Are you measuring direct light or reflected light?

Reflected light is being measured in this activity.

Collect Data

12. ☐ Turn on the light.

13. ☐ After 30 seconds, start data recording. �(6.2)

14. ☐ After 60 seconds, turn the light off. *Do not stop recording data.*

15. ☐ Record data for an additional 180 seconds.

16. ☐ Stop data recording. �(6.2)

17. ☐ Put the sand back into the container.

18. ☐ Name your data run. �(8.2)

19. ☐ Save your experiment with an appropriate file name. �(11.1)

20. ☐ Repeat this procedure for the remaining materials: dark sand, white rock, and dark rock.

Note: Exercise care to keep the positions of the light, plate, temperature sensor, and light sensor constant throughout the testing of the four materials.

Part 2 – Measuring sunlight intensity and the earth's reflectivity

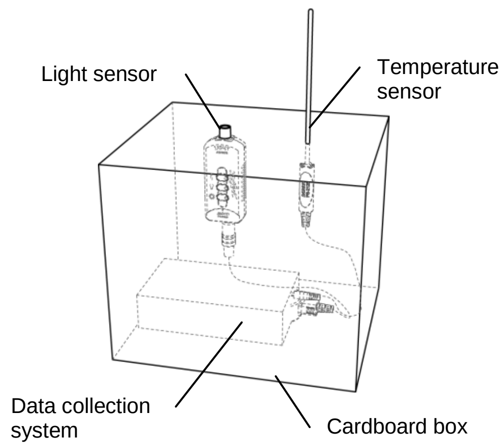
Set Up

21. ☐ Make an outdoor equipment station: Cut two holes in the bottom of a small cardboard box such that a light sensor will be held snuggly in one and a stainless steel temperature sensor will be held snuggly in the other.

22. ☐ Make sure your data collection system is fully charged.

23. ☐ Connect the sensors and change the sample rate to 1 sample per minute. �(5.1)

24. ☐ Set up appropriate displays to visualize the data. �(7)



25. ☐ Select the widest range on the light sensor. �(4.3)

26. ☐ Make a portable experiment station

a. Turn the box upside down

b. Thread the light and temperature sensors through the holes until they fit securely, and point straight up in the air. Use tape if necessary to help secure them.

27. ☐ Make a sign that says: DO NOT DISTURB! EXPERIMENT IN PROGRESS. CONTACT: [YOUR NAME]. THIS EXPERIMENT IS BEING CONDUCTED FROM [DATE] [TIME] TO [DATE] [TIME].

28. ☐ Carry the portable experiment station, sign, and tape outside. Find a location with the following characteristics:

- ♦ It is a safe place to leave the experiment station;
- ♦ It will receive full sun all day with no shading;
- ♦ It is not near (within 5 meters) a building or on pavement;
- ♦ The box will not get wet from sprinklers.

29. ☐ What time of day do you predict the intensity of insolation will be the greatest?

Predictions will vary, and all predictions should be accepted. On a sunny day, the greatest intensity of insolation is around noon. If the day is partly cloudy, the pattern is less predictable.

30. ☐ What time of day do you predict the air temperature will be the greatest?

Predictions will vary, and all predictions should be accepted. On a sunny day, the highest temperature generally occurs between 3 and 4 p.m. If the day is partly cloudy, the pattern is less predictable.

Collect Data

31. ☐ Start data recording. �(6.2) Record your starting time in Table 2.

32. ☐ Carefully enclose the data collection system inside the box using tape to hold the flaps closed.

33. ☐ Place the box in the test location. Make sure the sensors are still pointing straight up.

34. ☐ Record data until late afternoon or evening. Then, stop data recording �(6.2), save your experiment �(11.1), and clean up according to your teacher's instructions.

Data Analysis

Part 1 – Measuring reflection and radiation of sand and rock

1. ☐ Display two graphs simultaneously. On one graph, display Light intensity on the y-axis with Time on the x-axis. On the second graph, display Temperature (°C) on the y-axis with Time on the x-axis. �(7.1.11)

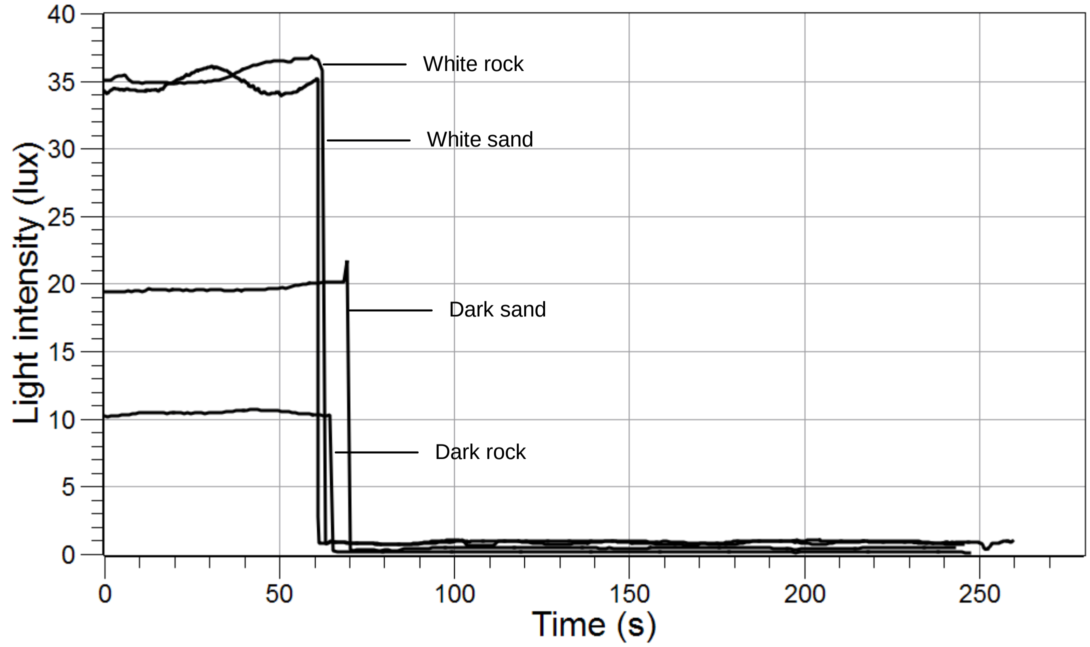
2. ☐ Adjust the scale of the graphs to show all data. �(7.1.2)

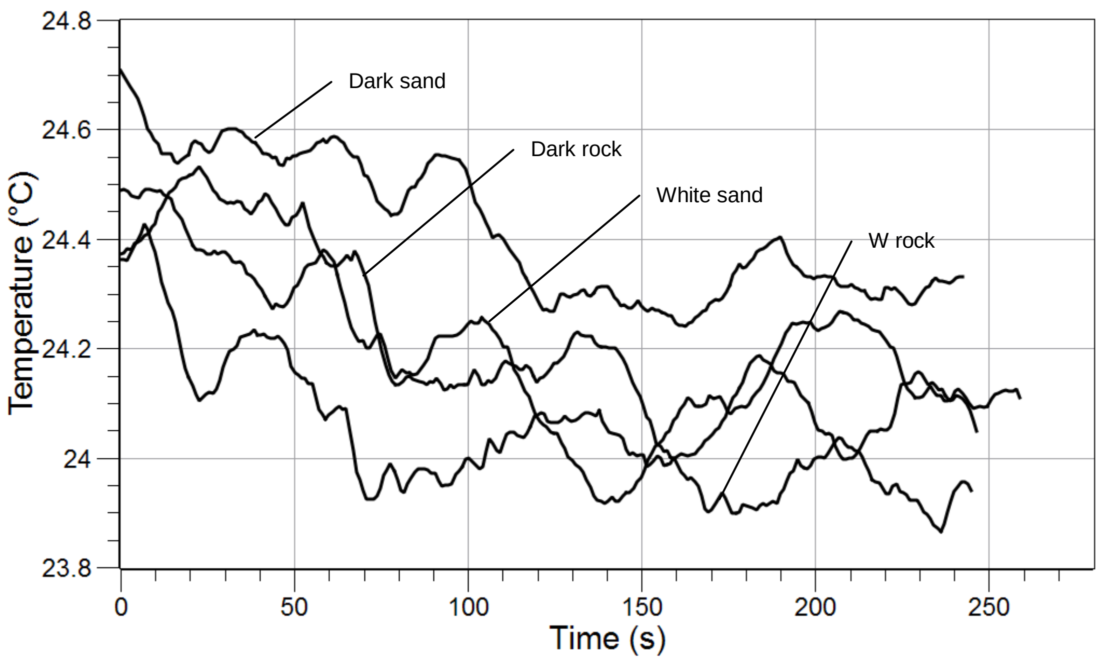
3. ☐ View the statistics for each graph, �(9.4) select the appropriate data points on each data run, �(7.1.4) and record the mean values that are called for in Table 1.

Table 1: Reflection and radiation of sand and rock

Material	Mean Reflected Light Intensity (lux)	Mean Air Temperature (Light Off) (°C)
White Sand	36.06	24.2
Dark Sand	5.95	24.4
White Rock	9.68	24.0
Dark Rock	2.87	24.2

4. ☐ Sketch parameter (light intensity, temperature) versus time graphs of your data for the four experimental conditions. Label your four runs, the overall graphs, the x-axes, and the y-axes. Including units and scales on the axes.





Part 2 – Measuring sunlight intensity and the earth's reflectivity

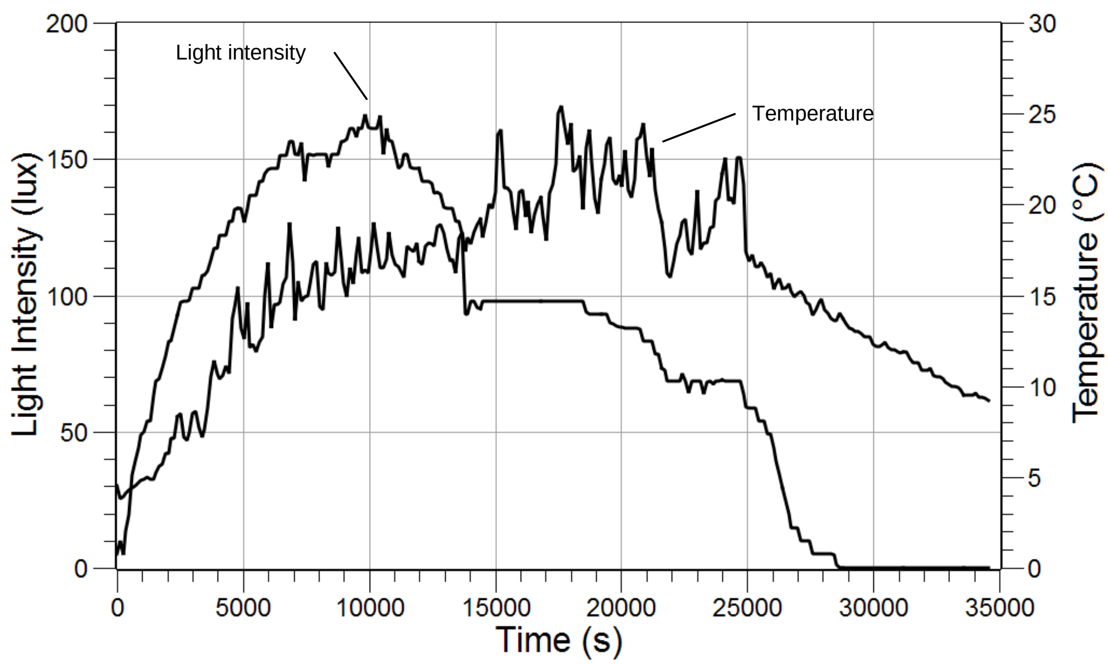
5. ☐ Display both Light intensity and Temperature (°C) on the y-axis of a graph with Time on the x-axis. �(7.1.10)

6. ☐ Find the coordinate values for the maximum temperature and light intensity on the graph, �(9.1) and complete Table 2.

Table 2: Reflection and radiation of sand and rock

	Start Time	Greatest Value	Seconds from Start When Maximum Occurred	Time of Day
Light Intensity (lux)	10:00 a.m.	166	10,000	12:45 p.m.
Temperature (°C)	10:00 a.m.	25.4	17,804	2:55 p.m.

7. ☐ Sketch a parameter versus time graph of your data for the two experimental variables. Use a key to differentiate your two variables. Label the overall graph, the x-axis, the y-axis, and include units on your axes.



Analysis Questions

Part 1 – Measuring reflection and radiation of sand and rock

1. **Compare your predictions with your results.**

Students should be specific regarding their predictions and comparisons with results.

2. What were the dependent variables in this experiment? The independent variable?

The dependent variables were the temperature of the air just above the material and the light intensity. The one independent variable was light energy.

3. Why were you careful to leave the same amount of space between each material and the light sensor, temperature sensor, and light source for each data collection?

It was important to control these variables to ensure that the same amount of light energy was applied to each trial, the same angle of incidence of light was used, and the same conditions for recording temperature were preserved.

4. Which characteristics of the materials make them good reflectors?

The materials that were good reflectors were light in color and smoother in texture.

5. What is the relationship between the magnitude of the albedo of the material and the final air temperature?

The higher the albedo, the lower the final air temperature is.

6. What happens to the light that is not reflected? What happens to this energy? How might this occurrence affect daily temperatures on the earth's surface?

The light that is not being reflected is absorbed by the earth materials. Some of this energy is then radiated back into the air as heat energy. For the earth, this means that earth materials absorb sunlight and then radiate some of this energy as heat into the air later in the day, so the ground temperatures stay warm longer after the sun goes down. Deserts and beaches with light colored sand would have higher temperature fluctuations over a 24-hour period than those with dark-colored sand.

Part 2 – Measuring sunlight intensity and the earth's reflectivity

7. Does your data support your predictions? Explain

Students should give specific details regarding what they predicted and how that relates to what they measured.

8. Explain how the warmest temperature of the day could be in the late afternoon when the sun's greatest intensity is earlier in the day.

During the time of day when the sun's light is most intense, the earth's surface materials are absorbing some of this energy, depending upon their albedo. As this absorbed energy is radiated from the surface of the earth, it warms the air molecules at the surface. This heat is added to the air near the surface, raising the air temperature after the sun's intensity begins to reduce.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Discuss what happens to the energy in sunlight when it strikes surfaces that have a high albedo.

When sunlight strikes surfaces with a high albedo, most of it reflects back into the atmosphere. The material it strikes absorbs little energy, so there is less energy to be converted to heat. Thus, less heat subsequently radiates to the air molecules.

2. Discuss what happens to the energy in sunlight when it strikes surfaces that have a low albedo.

When sunlight strikes surfaces with a low albedo, most of it is absorbed by the material, and much of this energy is converted into heat. Some of this heat energy is radiated to the air molecules near the surface.

3. Explain how the warmest temperature of the year could be after the date when the sun's greatest intensity occurs.

The warmest day of the year is often after the date of the sun's greatest intensity because the earth absorbs the sun's energy and continues to radiate it to air molecules. This heat accumulates in the atmosphere, and over time, weather conditions can move this heat to a surface location where temperatures rise to their maximum summer temperatures.

4. What type of material would you use to make a solar heater for a swimming pool? Why?

You would want to use black material because it absorbs the most sunlight energy, which can be transferred to the water.

5. What type of material would you use to make summer curtains for your home windows? Why?

You would want light-colored material with a smooth texture, because these characteristics of materials cause them to have a high albedo. The curtains would reflect much of the sunlight to the outside.

6. You want to build a new home using energy efficient passive solar technology. Since you live in Columbus, Ohio, you want your house to be cool in the summer and warm in the winter. Answer the following questions:

a. At latitudes above the Tropic of Cancer and below the Tropic of Capricorn, how does the angle of the sun change with the seasons? How would you use the difference to help you with the design of your new home?

At mid-day in the summer, the sun is more directly overhead. As fall and winter approach, it sinks lower towards the horizon. You would orient your home so windows face the south to catch the winter sun, and you would design the roof to overhang all the windows of the house to shade them from the summer sun.

b. What are two ways to enhance solar absorption in the winter?

Ways to enhance solar absorption in the winter are to have large windows on the south side of the house and dark-colored flooring next to these windows. Shade trees should be deciduous.

c. What are two ways to reduce solar absorption in the summer?

Two ways to reduce solar absorption in the summer are to have a light-colored roof with ample overhangs and to plant shade trees on the east, south, and west sides of the house.

Multiple Choice Questions

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

1. Which factor relates to the reflective nature of a surface?

- **A.** Light intensity
- **B.** **Albedo**
- **C.** Absorption
- **D.** Angle of incident
- **E.** Temperature

2. Compared with a material with a high albedo, a material with a low albedo:

- **A.** Radiates more heat
- **B.** Radiates less heat
- **C.** Reflects more light
- **D.** Reflects less light
- **E.** **Both A and D**
- **F.** Both B and C

Extended Inquiry Suggestions

Challenge students to predict the reflectivity and measure additional earth materials, and compare the results with those from this lab activity.

Challenge students to measure sunlight intensity and air temperature for several days exhibiting different weather characteristics, such as seasonal differences, cloudiness, and windiness. Have them compare the results with this lab activit

6. Tracking Weather

Objectives

Analyze atmospheric data to determine how variations in temperature, humidity, barometric pressure, dew point, wind speed, and sky conditions relate to each other and produce specific weather conditions. Through this investigation, students:

- Describe how a change in barometric pressure affects sky conditions
- Determine the relationship between temperature and relative humidity
- Recognize and identify different types of clouds

Procedural Overview

Students gain experience conducting the following procedures:

- Sampling atmospheric variables including temperature, humidity, barometric pressure, dew point, wind speed, and sky conditions (including types of clouds present) over a period of at least 6 hours
- Analyzing the weather data collected to determine relationships between temperature, humidity, barometric pressure, dew point, wind speed, and sky conditions.
- Comparing weather data that was collected on days with different weather conditions such as a nice clear calm day, an overcast day, a rainy or snowy day, or a windy day

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	15 minutes of set up, 6 hours of data collection, and 50 minutes to analyze weather data

Materials and Equipment

For each student or group:

- Mobile data collection system
- Weather/anemometer sensor
- Brick or board (2)
- Weather shield[1]
- Weather data for comparisons[2]

[1]Refer to the teacher preparation on how to create a weather shield using a plastic or cardboard box.

[2]Refer to the teacher preparation on how to create the weather data students will use to compare with their data

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Air pressure
- Humidity
- Temperature and kinetic molecular motion
- Definition and causes of wind

Related Labs in This Guide

Labs conceptually related to this one include:

- Insolation and the Seasons
- Radiation Energy Transfer

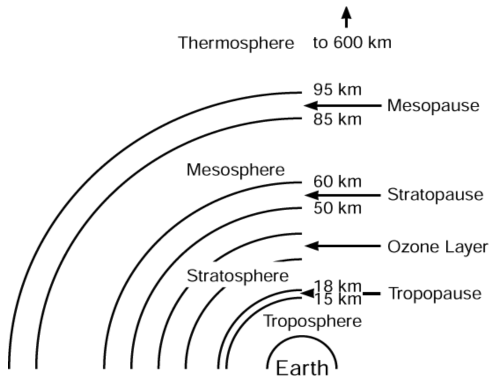
Using Your Data Collection System

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 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 data in a table �(7.2.1)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

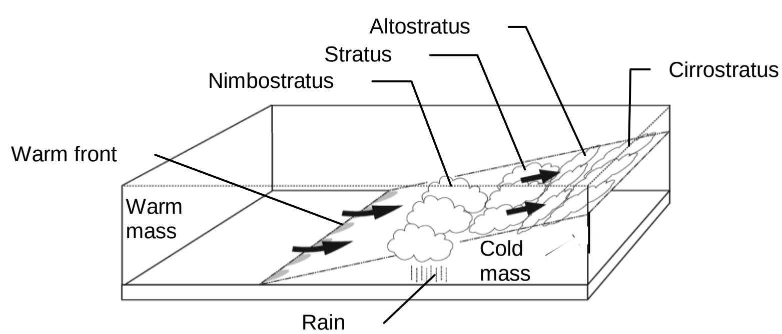
Weather is a daily "snapshot" of the atmosphere at a specific place and time. Weather occurs in the troposphere, the atmospheric layer closest to the earth and is about 9 to 16 kilometers thick. This distance, in comparison to the rest of the planet, is as thin as the skin of an apple.



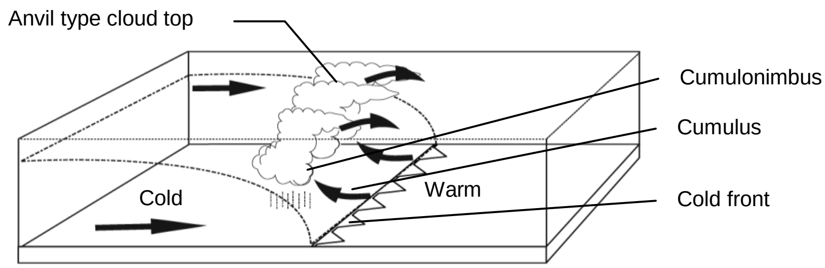
Four main constituents of weather include temperature, wind, moisture, and air pressure. In the troposphere, incoming solar radiant energy warms the air and also warms the earth which then radiates heat back into the troposphere, increasing the molecular energy of the atmospheric gases. Warmer air is less dense and consequently rises, being replaced by colder air molecules. This process of convection creates winds and transports evaporated water to form clouds which bring precipitation.

Air temperature is a measure of the average kinetic energy of molecules in the atmosphere. The uneven heating of Earth's surfaces is responsible for the creation of large air masses of warm or cold air. As air warms, its kinetic energy increases and its density decreases. As air cools, its kinetic energy decreases and the air becomes more dense. When a warm air mass meets a cold air mass, the cold air mass will end up under the warm air mass; how that happens and the winds, precipitation and clouds that occur as a result depend on which air mass is advancing and which is stationary.

Air masses and fronts



In the above diagram, a warm air mass is advancing on a stationary cold air mass. The warm air mass rises up the frontal wedge of cold dense air. The suite of clouds that form are characteristic of this warm front. Far in advance of the front, cirrus and cirrostratus clouds form high in the atmosphere. Following them are the altostratus and stratus clouds, followed by nimbostratus clouds and rain immediately preceding the warm front. The rain is a steady widespread rain in general, and winds can be moderate. A long, gray, rainy day is the result.



In this cold front diagram, a cold air mass is advancing on a stationary warm air mass. Since the cold air is more dense than the warm air, the meeting of the two fronts is not as "polite" as in the previous case. Here, the cold air mass plows into the warm air mass, lifting it quickly and violently. Cumulonimbus clouds form, accompanied by thunder and lightning, rain and hail.

Air pressure and wind

Air pressure is a measurement of the amount of air molecules stacked up in a given surface area. As air masses move around in the troposphere, the air pressure changes. In places where air is lifting, the air pressure can drop markedly and clouds will form. If the temperature also drops to the dew point, precipitation will form. Therefore falling pressure is associated with stormy weather. Where air masses pile up, high pressure occurs. Rising pressure is associated with clear weather because high pressure prevents the formation of clouds.

Atmospheric pressure is measured using a barometer, and is often referred to as barometric pressure. The media and aviation industries report pressure in inches of mercury (Hg), while meteorologists prefer units in millibars (mb), or kilopascals (kPa).

Air pressure depends upon the temperature of the air and the altitude above sea level. There are fewer air molecules at higher altitude, and air pressure is less. For example, atmospheric pressure exerts a force of 14.7 pounds per square inch (PSI) (101.325 kPa) at sea level, but at an elevation of 6200 feet, the pressure drops to 12 PSI (82.7 kPa).

Wind is the air in horizontal motion across the earth. Air will always flow from areas of high pressure to the areas of low pressure. Greater differences in pressure result in faster winds. In some areas winds blow from the same direction fairly consistently because of geographical features. We measure wind speed with a wind anemometer, and the units can be knots, kilometers per hour or miles per hour.

Humidity and Clouds

Humidity is a measure of the amount of water vapor in the air, measured by a hygrometer. Meteorologists describe humidity using several terms such as absolute humidity, relative humidity, or specific humidity. Clouds form when moist air cools and water vapor condenses onto microscopic particles of dust, smoke, or salt in the troposphere. These tiny droplets of water vapor are extremely small; indeed, it takes a million of them to form a single raindrop.

Clouds are named according to their height and appearance. High-forming clouds are assigned the prefix ‘cirro’, whereas clouds formed at a middle altitude receive the prefix ‘alto’ (low-forming clouds do not receive a prefix). Rain-producing clouds usually receive the suffix ‘nimbus’. Two main cloud types are cumulus or clumped clouds and stratus or layered clouds. Depending on their location, they may have the alto- or cirro- prefixes.

Cumulus clouds typically signal fair weather, but if they expand into the upper part of the atmosphere, they become cumulonimbus or rain clouds. These clouds are tall (can surpass 15 km) and dark. They are an indication of rapidly changing air masses capable of producing lightning, heavy rain, hail, high winds, and tornadoes.

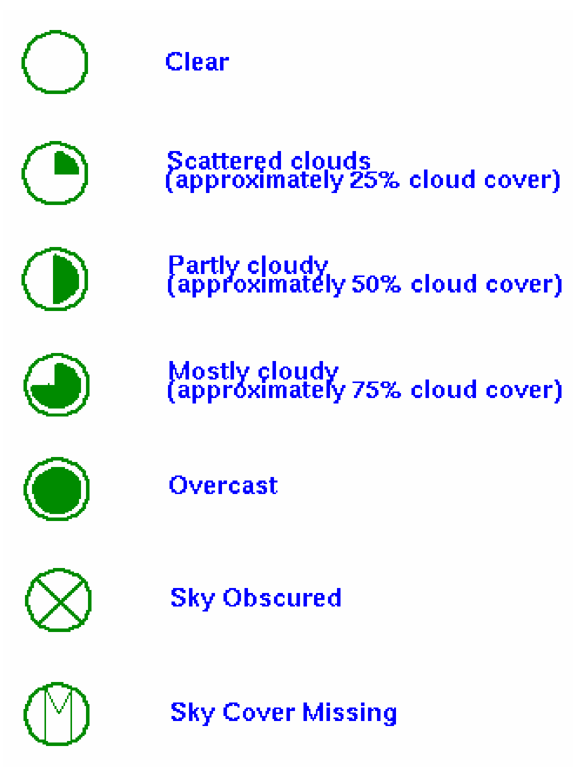
Stratus clouds are layered and not as tall as cumulus types. Precipitation can occur as rain, freezing rain, sleet, hail, and snow with varying intensity. Water droplets with a diameter greater than 0.5 mm are classified as rain, but when smaller than this, as drizzle.

Symbols

Meteorologists monitor the weather daily, using a variety of instruments. Temperature, humidity, wind (direction and speed), cloud coverage, and barometric pressure statistics are compiled for mathematical analysis. All this information is collected from weather balloons, satellites, airplanes, ships, and Doppler radar. Weather maps are used to portray high and low pressure systems, the fronts between them, and their movement across the country.

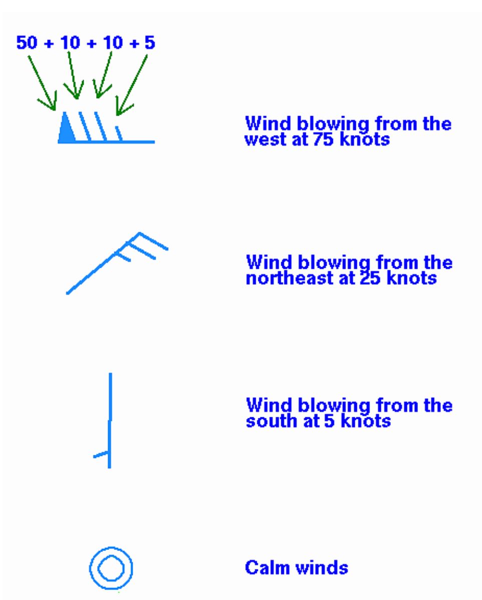
Meteorologists use weather symbols to visually communicate the current weather conditions, which are then printed in daily newspapers and reported on weather Internet websites. Weather symbols are given below for sky cover, wind, precipitation, and air pressure.

Sky Cover: The amount of the circle that is filled represents the amount of sky that is covered by clouds

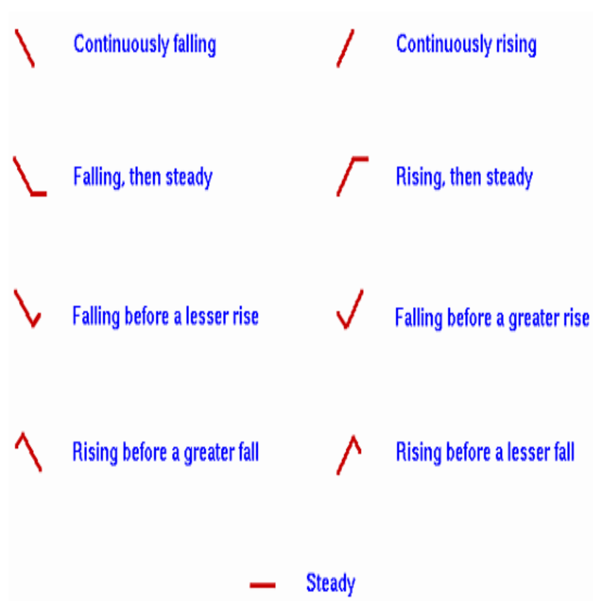


Weather: Precipitation in the form of drizzle, rain, fog or snow is represented.

Wind Barb: shows the direction the wind is blowing from and the strength in knots.



Air pressure: Both a number and a symbol show the change in air pressure over the last three hours. The number is in tenths of millibars and omits the first two digits. (1013.7 mB = 137)



Note: Print these symbols for your students, or display them as a reference in the classroom.

Monitoring the weather

Meteorologists monitor the weather daily, using a variety of instruments. Temperature, humidity, wind (direction and speed), cloud coverage, and barometric pressure statistics are compiled for mathematical analysis. All this information is collected from weather balloons, satellites, airplanes, ships, and Doppler radar. Weather maps are used to portray high and low pressure systems, the fronts between them, and their movement across the country.

In contrast to weather, climate describes distinctive weather conditions at a specific locale and is measured over a period of at least 30 years. Climate is influenced by many environmental components, including temperature, latitude, elevation, precipitation, winds, ocean currents, topography, and soil types.

Pre-Lab Discussion and Activity

Low Pressure Regions

Ask students to clip out a weather map from your local or national paper to bring to class. Have the students find areas on the map marked as low pressure. Guide the students through a discussion about weather surrounding the low pressure regions.

1. How do temperatures around low pressure zones on your map compare to surrounding areas?

This will depend on two situations: if air is being drawn in to the low pressure system from southerly warmer areas, or if the air is coming from a colder area to the north. If southerly winds are blowing in, the area will show warmer temperatures. But generally, the air temperatures are cooler than the surrounding air because the air in a low pressure system is lifting and cooling, and because the winds are cooling the area.

2. What is the general weather surrounding these low pressure areas like?

Low pressure systems are cloudy, and rain accompanies these systems. Low pressure systems are also called cyclones, and tornadoes are associated with them on the southwestern edge of the systems.

High Pressure Regions

Find areas marked as high pressure on your weather map.

3. How are temperatures around the high compared to those further away from it?

High pressure systems could have cold weather associated with them if the air mass is from the north. Winter highs are usually cold and clear. But southerly highs could have clear skies and hot air temperatures.

4. Describe the general weather around these high pressure areas.

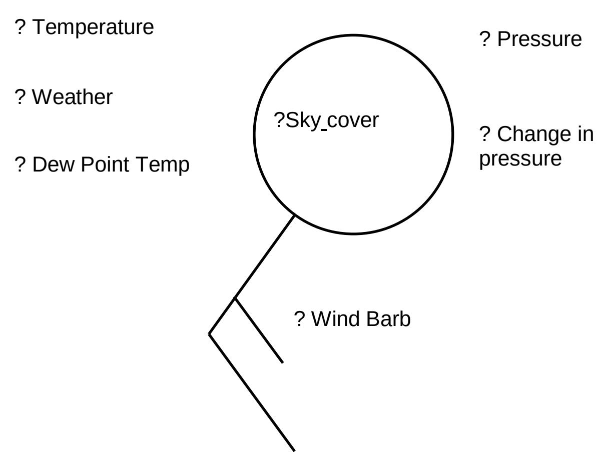
There are no rain patterns around high pressure systems. The skies are clear and sunny.

5. If the weather stayed like it is right now for the rest of the day, predict how the barometric pressure, temperature, relative humidity, dew point, and wind speed might change throughout the day?

Answers will vary depending on your current weather. As an example, students might say that air pressure will stay the same, relative humidity will decrease as temperatures increase, and winds will increase as the air warms and rises. The only change will be that there is an increase in solar radiant heat as the day progresses.

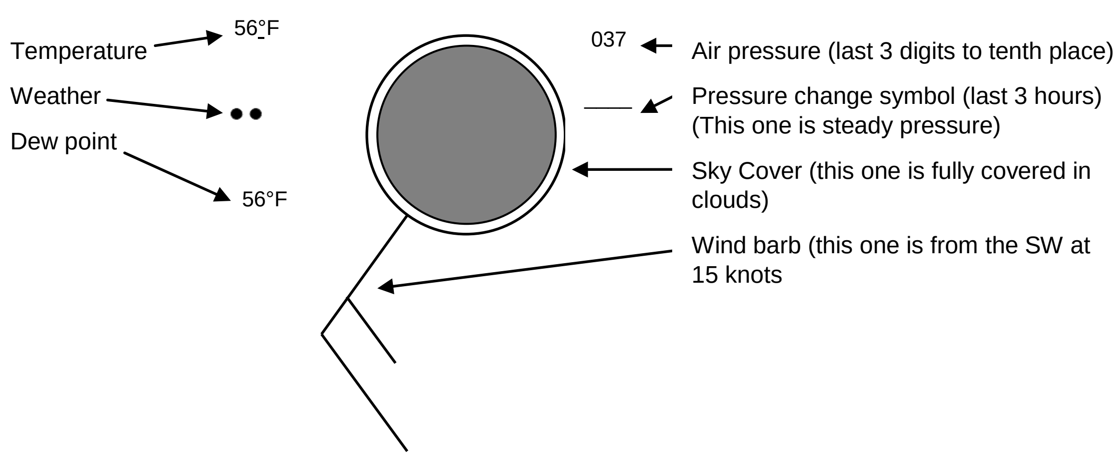
Weather Symbols

6. Find the weather symbol on the map for a given location. It should look something like this:



7. Practice recording weather symbols for various weather conditions such as the following:

56°F, light rain, 56°F dew point, pressure of 1003.7 mB (037) and not changing, and winds out of the Southwest at 15 knots, and the sky is covered in stratus clouds



Lab Preparation

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

1. Construct a weather shield:

- ♦ A weather shield can be made from a cardboard box by cutting off the top and two sides that are opposite of each other. The weather shield is placed over the data collection system to protect it from the weather and the open sides will allow good air flow.
- ♦ Instead of keeping the data collection outside, a sensor extension cable can be used with the data collection system. The sensor extension cable will allow you to place the sensor outside of a window and keep the data collection system inside.

2. Collecting data for weather comparisons:

- ♦ If you have multiple classes have each class collect data on different days with different weather conditions. One class may summarize a clear warm set of days, another may capture a windy cloudy day, while another will catch a stormy rainy day. Copy data from each of the classes to share with the other classes.
- ♦ Collect data on your own during different weather conditions. Provide students with a set of graphs from each different type of weather.
- ♦ Have your students collect data for 5 days (with different weather conditions) and then have them use all their own data to complete the lab.

Teacher note: Make sure your data collection systems are fully charged.

Safety

Add this important safety precaution to your normal laboratory procedures:

- ♦ If students go outdoors to set up their data collection, be aware of hazards both from weather and traffic for students and also for the data collection systems.

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
Collect temperature, humidity, barometric pressure, wind speed and dew point data for at least 6 hours.	Connect your weather sensor to the data collection system.	Compare your data to data collected in other weather conditions.	Set your sample rate to collect data once every ten minutes.	Analyze the data you collected to determine the relationship between different weather variables and sky conditions.

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

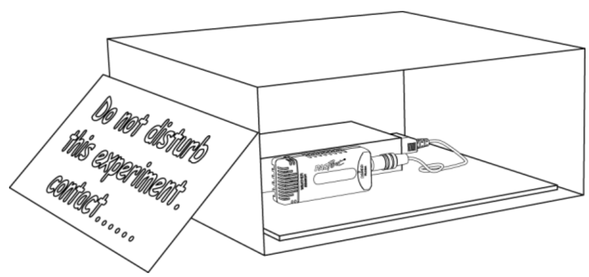
1. ☐ Select a location for your experiment according to your teacher's instructions.

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

3. ☐ Attach the weather/anemometer sensor to the data collection system. �(2.1)

4. ☐ Display barometric pressure, temperature, relative humidity, wind speed, and dew point in a table. �(7.2.1)

5. ☐ Change the sample rate to once every 10 minutes. �(5.1)



6. ☐ Place the data collection system on a brick or on a couple of boards to keep it off the ground.

7. ☐ Keep the direct sun from shining on your system by placing a weather shield over it.

Collect Data

8. ☐ Start data recording. �(6.2)

9. ☐ Describe the location of the data collection system.

The data collection system was placed in an open field.

10. ☐ Make a careful description of the current sky conditions each hour as the data is being collected.

Table 1: Sky conditions and cloud cover

Time	Sky conditions	Type of clouds present
8:00 a.m.	(answers will vary)	
9:00 a.m.		
10:00 a.m.		
11:00 a.m.	Sunny, clear	None
12:00 p.m.		
1:00 p.m.		
2:00 p.m.		
3:00 p.m.		
4:00 p.m.		

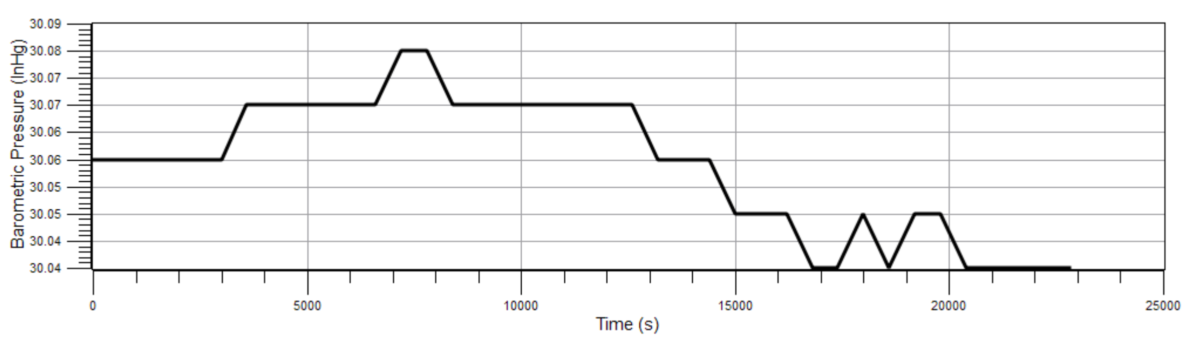
11. ☐ After the data has been collected for at least 6 hours, stop recording data. �(6.2)

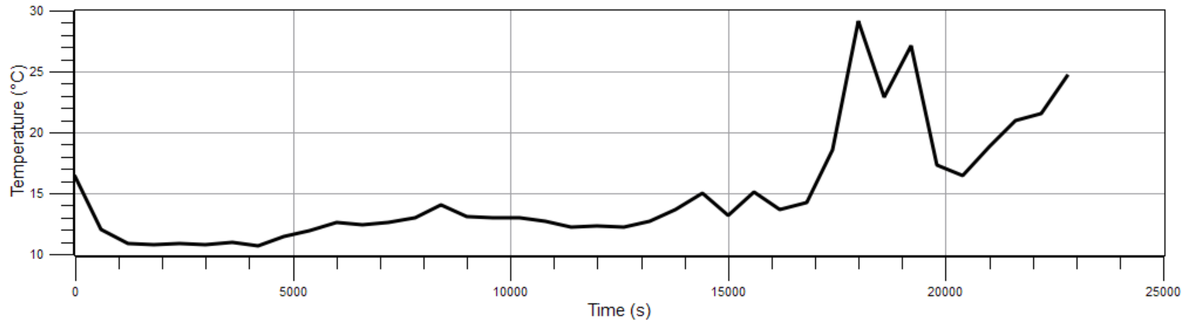
12 ☐ Save your experiment. �(11.1)

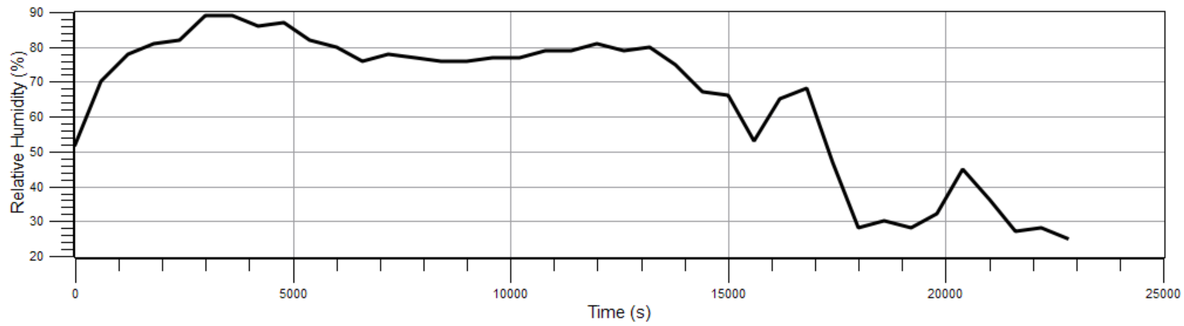
13 ☐ Return the equipment and the data collection system to the classroom.

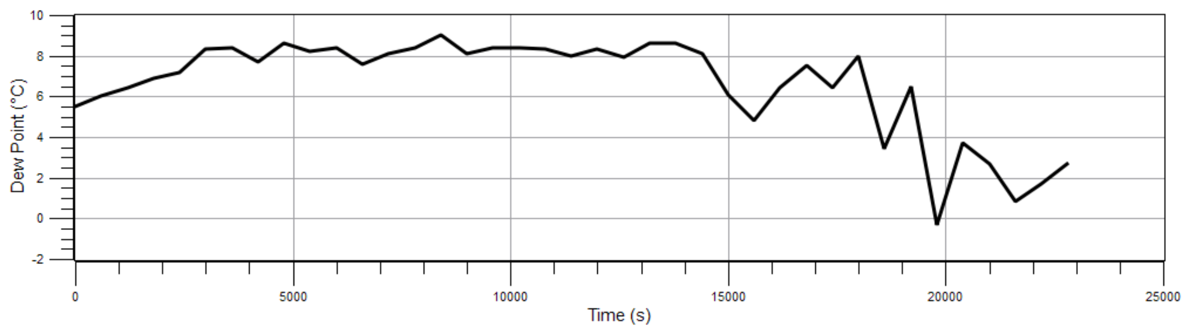
Data Analysis

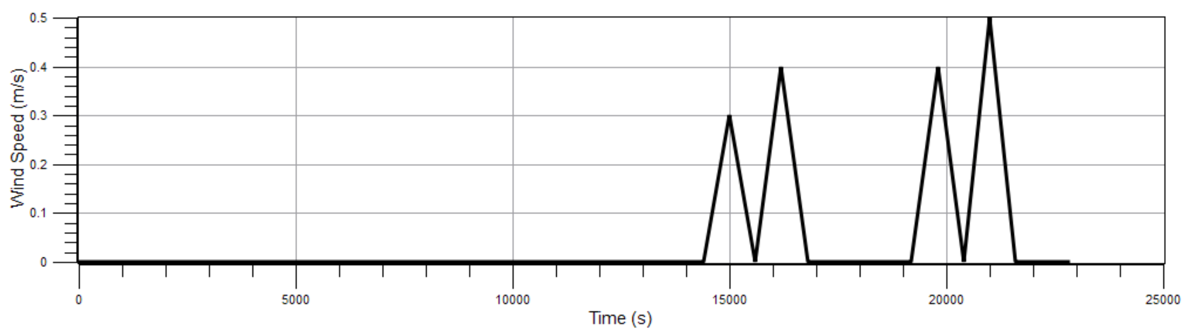
1. ☐ Using your collected data, create graphs for each of the following variables versus time: barometric pressure, temperature, relative humidity, wind speed, and dew point. �(7.1.1) Sketch or print each graph. Label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)











2. ☐ Describe the weather conditions in general over the test period. If clouds were present, what type were they?

The data was collected on a clear, sunny, and calm fall day. There were no clouds present.

3. ☐ How did the barometric pressure change during the data collection period? What weather conditions were related to this change in pressure?

The barometric pressure was fairly constant in this sample, changing only in the hundredths of inHg.

4. ☐ How does the temperature vary as the relative humidity changes?

The temperature increased as the relative humidity decreased.

5. ☐ How did the wind speed vary over the time you collected data? What conditions could explain this observation?

There was very little wind observed. This is most likely due to a steady air pressure throughout the area. There were small breezes in the afternoon and the temperature spiked. These may be related to convection of warm air.

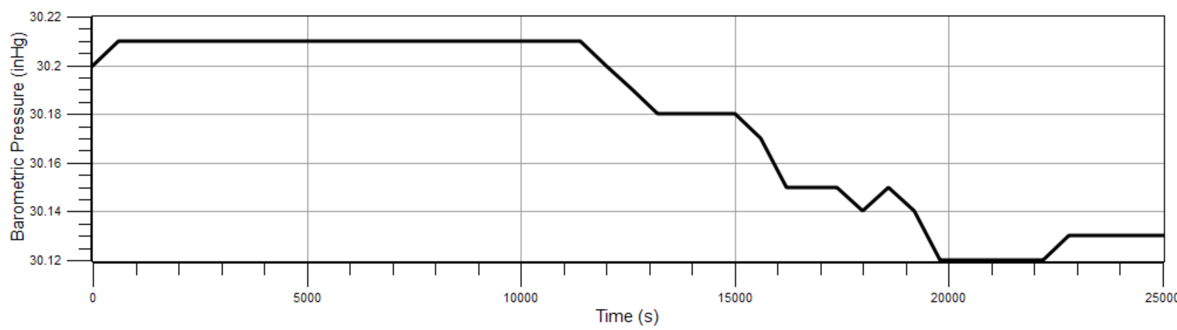
6. ☐ How would you classify the weather conditions during your data collection? Summarize the data you found for this type of weather.

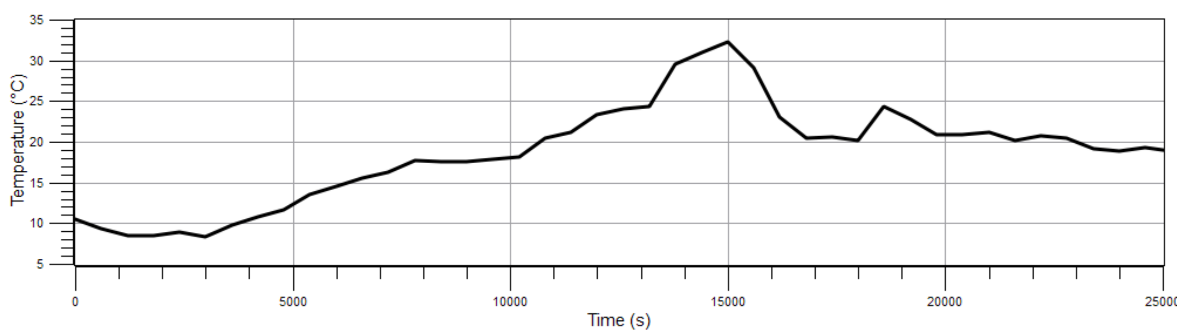
During my data collection the weather was sunny, clear, and calm. The temperature steadily increased throughout the day, the relative humidity slowly decreased, the barometric pressure decreased very slightly, the dew point was very low compared to atmospheric temperature, and the wind was relatively calm with a few light breezes.

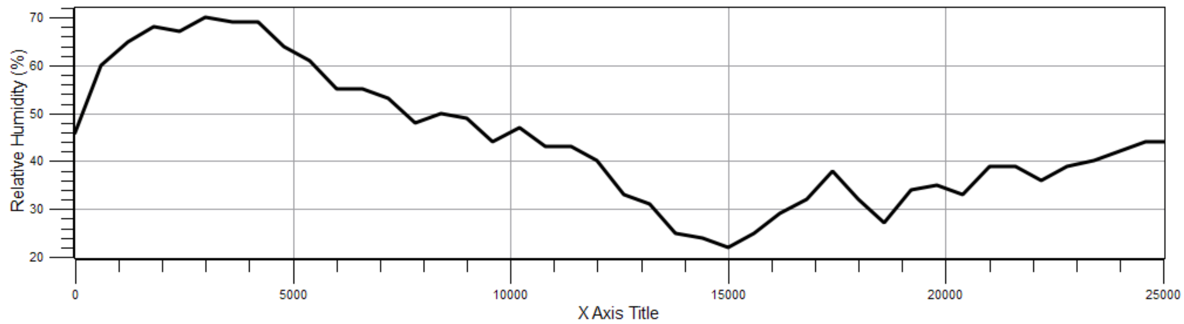
Analysis Questions

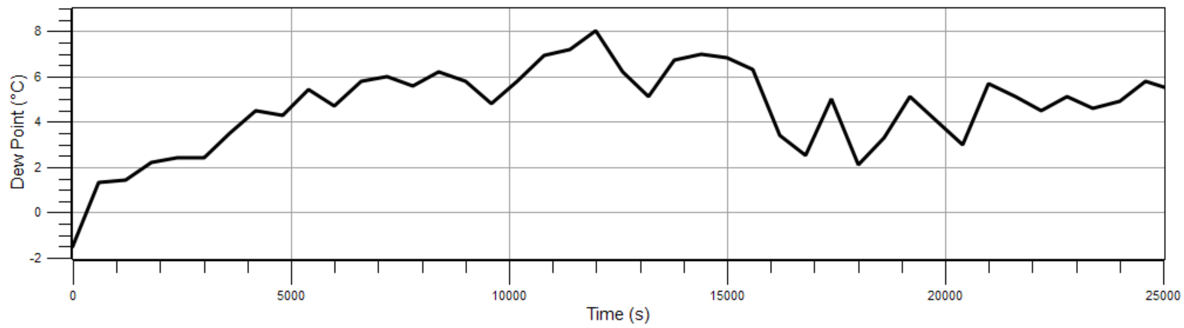
Sample Day 2 Weather Data

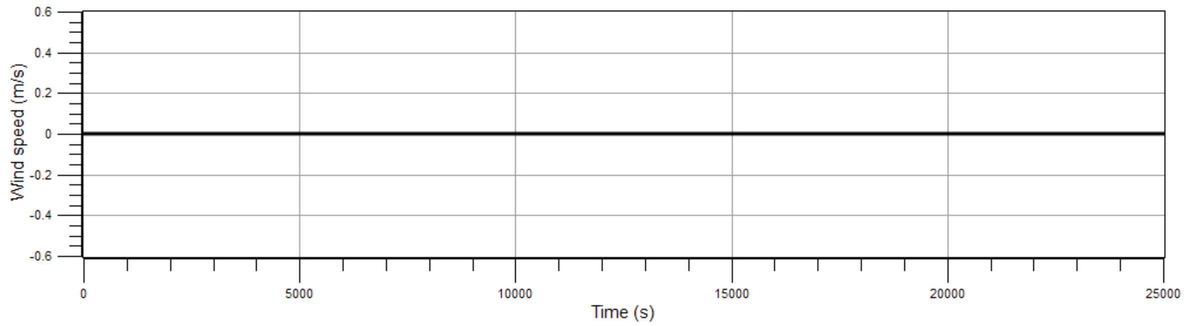
Note: This data is provided for your convenience if you cannot obtain other data sets for comparison.






Relative Humidity (%)
X Axis Title


Dew Point (°C)
Time (s)


Wind speed (m/s)
Time (s)

1. Compare weather data that was collected on days with different weather conditions. Fill in the first row of Table 2 with the data you collected and get weather data for four other weather conditions from your teacher. Summarize the general trends in the data from your teacher in the remaining four rows in Table 2.

Table 2: Comparisons for weather data

Weather Conditions	Barometric Pressure	Temperature	Relative Humidity	Dew Point	Wind Speed
My Data: Clear, sunny day	Steady, slightly falling	Rising, with a spike in mid afternoon	Falling	Very low compared to air temperature	Steady with a few breezes
Data Set 2:	Falling	Steady where the pressure is falling	Rising where pressure is falling	Rising	Steady

2. Weather data recorded over several weeks may show trends. Would you be able to predict those trends based on the data you gathered?

Students may want to predict trends. If the pressure was falling, they may predict a storm. If temperatures were rising, they may predict clear weather. But weather data gathered for a short period of time in one location is unreliable for predicting long range trends.

3. In general, what is the relationship between temperature and relative humidity?

When temperature goes up, relative humidity goes down. Relative humidity tells you how near the air is to saturation, and since warm air can hold more water than cold air, the relative humidity decreases as the temperature increases.

4. What correlations can you make between the barometric pressure and sky conditions?

In general a quick drop in pressure indicates that a storm is coming and a large rise in pressure indicates that good weather is on the way.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What type of weather would you expect if the atmospheric barometric pressure were dropping quickly and humidity was on the rise?

When pressure drops, it means that the air column is lifting overhead. Clouds will form, increasing the relative humidity and could lead to rainfall if the temperature drops and the dew point is reached.

2. How can clouds form if the humidity is less than 100% at your measuring site?

Clouds form at the place in the air column where saturation is occurring. It could be less than 100% at ground level, where the air is warmer and can hold more water vapor, but be 100% at higher elevations where the air is colder and holds less water vapor.

3. What atmospheric condition would have to change the most for it to remain windy throughout the day?

A front needs to be moving through the area, or approaching. Differences in air pressure cause winds.

Multiple Choice Questions

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

1. _______________ is the amount of water vapor in the air.

- **A.** Barometer
- **B.** Dew point
- **C.** Troposphere
- **D.** **Humidity**
- **E.** Temperature

2. If the temperature of an area is increasing what would you expect to happen to the humidity?

- **A.** The humidity is probably increasing.
- **B.** **The humidity is probably decreasing.**
- **C.** The humidity will probably stay the same.
- **D.** The temperature will keep increasing until it is the same as the humidity.
- **E.** Both C and D are correct.

3. Which of the following conditions will create the strongest winds?

- **A. An area of high pressure next to an area of low pressure.**
- **B.** A vertical movement of air.
- **C.** An area in which the pressure is constant.
- **D.** Water vapor condensing in clouds.
- **E.** All of the above will create wind.

4. Weather is best described as ____________________.

- **A.** Conditions at a specific location measured over a period of at least 30 years.
- **B.** Temperature changes over a period of 24 hours.
- **C. A daily "snap shot" of the atmosphere at a specific place and time.**
- **D.** Changes in the atmospheric conditions as the seasons change.
- **E.** Both A and D together.

5. What type of cloud would most likely cause rain?

- **A.** Altostratus
- **B.** Cirrostratus
- **C.** Cirrus
- **D.** Cumulus
- **E. Cumulonimbus**

Key Term Challenge

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

1. Weather is generated at the **boundaries** of large warm and cold **air masses**. Air property differences occur because the sun heats the earth's surfaces **unevenly** which in turn influences the air masses above them. Warm air masses expand and generally exert less or **low pressure** on the earth's surface because they are less dense. Colder air is denser and can be detected as a **high pressure** air mass or system.

2. When these air masses collide, their leading edges that meet form **fronts**. When denser, colder air masses collide with stationary warm air masses, their **cold fronts** typically produce **cumulonimbus** or storm clouds with thunder and lightning. (In the winter these may be snow storms.) **Warm fronts** move more gradually over **stationary** air. A warm air mass is **less dense** and will typically overlay the leading **wedge-shaped** edge of the stationary colder air mass, gently pushing it out of the way. These warm fronts generally produce overcast **stratus** clouds and if they have enough moisture become **nimbostratus**.

3. Naming clouds is mostly based on two features: their **shape** and their **height**. Middle altitude clouds generally have the prefix **alto** in front of the clouds name. High altitude clouds are called **cirrus** or have the prefix **cirro**. Clouds bringing precipitation of any height will either begin with **nimbo**- or end in **nimbus**. Cloud shapes generally compose the root of the cloud name. Clouds that blanket the sky are called **stratus**. Light pockets of fluffy clouds are called **cumulus**. Thin wisps of clouds generally form at high altitudes helping the name **cirrus** to mean both their height and their shape. These terms and their combinations are the most common names used for cloud descriptions in weather **forecasts**. While there are more special names for clouds that form in special geographic regions or interesting conditions, the total combination of common cloud types are: stratus, altostratus, nimbostratus, cirrostratus, cumulostratus, cumulus, cumulonimbus, and cirrus.

Extended Inquiry Suggestions

Have the students create a weather logbook. Over the next several weeks have the students work in small teams to sample a wide variety of weather events.

Give students the chance to make a summary explanation for what happens to the weather variables shortly after any new weather events. Leave room for adding digital pictures that students take as well. Ideas for separate weather events could include but are not limited to:

Extreme weather such as hail storms, thunderstorms, blizzards, hurricanes, or heat waves are good hooks to excite students about local weather. Certain geographic regions face specialty conditions such as Santa Anna winds, Chinooks, or valley winds. Any of these phenomena would be good for students to summarize how air's properties change during these events.

7. Earth's Magnetic Field

Objectives

Use models to visualize the magnetic field lines surrounding Earth. Through this activity, students:

- Describe the variations in magnetic field strength surrounding Earth
- Explain that the internal structure and composition of Earth's core creates Earth's magnetic field
- Discuss how Earth's magnetic field is used by navigators

Procedural Overview

Students gain experience conducting the following procedures:

- Building a model compass
- Visualizing the magnetic field generated by a bar magnet
- Using a bar magnet as a model to understand the Earth's magnetic field
- Measuring the magnetic field of a bar magnet using a magnetic field sensor

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Magnetic field sensor
- Bar magnet
- Small cork
- Sewing needle
- Pin
- Water, 500 mL
- Clear plastic cup
- Magnetic field demonstrator plate (4), 2D
- Degree wheel template[1]
- Map of Earth template[1]

[1]The templates are provided at the end of the lab.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Magnetism
- Location of the Earth's geographic north and south poles
- Declination and inclination

Related Labs in This Guide

Labs conceptually related to this one include:

- Seafloor Spreading and Plate Tectonics

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)
- Putting the data collection system into manual sampling mode with user 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)
- Adding a note to a graph �(7.1.5)
- Changing the variable on the x- or y-axis �(7.1.9)
- Finding the coordinates of a point in a graph �(9.1)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

All magnetic objects produce fields of magnetic force that exist between the poles of the object. These fields are often modeled with lines that extend out from each pole and connect the poles on the object. Although the Earth's magnetic field makes it appear that a powerful bar magnet exists near the Earth's center, such a bar magnet does not exist. The Earth's magnetic field is produced by a complex interaction between the convection currents in the molten outer core and the solid inner core, both of which contain large quantities of ferromagnetic metals, such as iron, nickel, and cobalt. Like a dynamo where a strong electric current is created in a coil of wire and a magnetic field is generated as a result, the same type of mechanism creates the Earth's magnetic field. Because the motion of the molten outer core around the solid inner core is a dynamic process, the magnetic field generated is also dynamic and not static.

Additionally, careful measurements of the north magnetic pole have revealed that its location wobbles throughout the day, so that its location is an average for its position. The cause of this daily vacillation is related to the sun, which emits charged particles that interact with Earth's upper atmosphere and influence the magnetic field.

Comparing Geographic North with Magnetic North

What is the difference between the north magnetic pole and geographic north? The north magnetic pole is the point at which the geomagnetic field in the north points vertically, that is, the magnetic dip is 90°. Compass needles generally point towards the north and south magnetic poles of the Earth. The geographic North Pole is the point at which the longitudinal meridians intersect in the north. It is also on the axis of rotation of the Earth. Therefore, the magnetic poles are not in the same place as the geographic poles. In April of 2007 the north magnetic pole was at 83.9°N and 120.7°W while the geographic North Pole is by definition always located at 90°N and 0°W.

When a compass is used to find direction, the angular difference between the north geographic pole and the north magnetic pole is compensated for by magnetic declination. The movement of the location is simply a matter of the failure or weakening of the field for a brief time in its present location and then the recreation of a stronger field in a new location a short distance away. In the past 100 years, since we started measuring its location, the Earth's north magnetic pole has wandered approximately 600 miles to the north to its present location in the Canadian Arctic. Recent measurements have shown the north magnetic pole to be migrating as much as 15 km per year. Similarly, the magnetic south pole has also migrated. In 2005, it was found to be located at 64.5°S, 137.8°E, but its location changes constantly.

Magnetic Reversals

What are magnetic reversals? Considering that ships, planes and scouting groups navigate by it, the Earth's magnetic field is less reliable than you would think. Rocks in an ancient lava flow in Oregon suggest that for a brief time about 16 million years ago magnetic north shifted as much as 6 degrees per day. After little more than a week, a compass needle in the United States would have pointed toward Mexico City. According to this same data, the lava caught the Earth's magnetic field in the act of reversing itself, showing that the magnetic north headed south, and—over about 1,000 years—the magnetic field completely reversed. Geologic evidence, in the form of the "paleomagnetic" record, confirms such reversals have happened many dozens of times in Earth's history. Today, seafloor spreading can be measured by mapping the magnetic reversals in crustal rock in both directions from the diverging boundary in the Mid-Atlantic Ridge. Knowing the width of a band of rock with a similar polarity, and the amount of time it took to be created, the rate at which the plate moved can be determined.

Measuring the Magnetic Field

How is the Earth's magnetic field measured? Measurement of the Earth's magnetic field is made continuously at about 70 permanent magnetic observatories throughout the world. In the past, measurements at sea have been made using nonmagnetic ships constructed especially for this purpose. However, this is a slow, expensive method of surveying the 71 percent of the Earth's surface that is covered with water. During World War II, an airborne magnetometer was developed by the U.S. Navy. Using this instrument, continuous readings can be made automatically during long over-water flights.

A dip needle is a tool for finding magnetic North and also latitude. The dip needle shows declination when it is oriented in the horizontal direction; it points to the Earth's magnetic North. When the dip needle is rotated to the vertical plane, the angle between the Earth's surface and the magnetic field, the inclination, can be used to find latitude.

The unit of measure for the magnetic field of an object is the gauss, named for the German mathematician and physicist Carl Friedrich Gauss. One gauss is defined as one maxwell per square centimeter. (A maxwell relates to the strength of the magnetic field.)

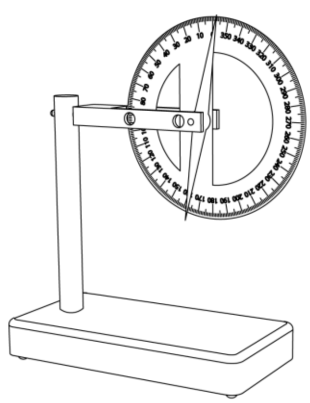
The Earth's magnetic field measures about 0.5 gauss, a small iron magnet has a field of about 100 gauss, a small neodymium-iron-boron (NIB) magnet has a field of about 2,000 gauss, a big electromagnet has a field of about 15,000 gauss, and the surface of a neutron star has a field of about 10^{12} gauss.

Pre-Lab Discussion and Activity

Materials and Equipment for Pre-lab Activities:

♦ Magnetic dip needle

Establish basic local area location information for students to draw from as they work through the concepts presented in the laboratory activity by using a magnetic dip needle to explore the declination (the angle formed between the direction of a magnetic needle and the geographical meridian) and inclination (the downward direction) of the Earth's magnetic field in your location.



Assemble the magnetic dip needle. Be sure to use this far away from any magnetic material. Rotate the dip needle so that the plastic scale is in the horizontal plane. In this orientation, the magnetic dip needle acts as a compass. The colored tip of the needle points toward magnetic north.

1. What is the difference between magnetic north and geographic north?

Magnetic north is the location on the surface of the Earth where magnetic field lines converge. Compasses point to this location. Geographic north is the northern axis point around which the Earth rotates and at which all longitude lines converge.

Use a declination calculator to find the direction of true north from your location. Direct your Internet search to the National Geophysical Data Center for the declination calculator.

Example: For the U.S. zip code of 95747, The latitude is 38.7688°N and longitude is 121.3363°W. The declination is 14°26’ changing by 0°6’W per year. This means that true North is 14°26’ to the east of geographic North.

2. Explain what declination is measuring.

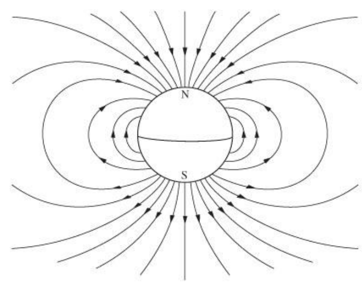
Declination is the difference in degrees between the geographic pole and the magnetic pole. The variation is measured horizontally. That is why the compass is oriented horizontally for this reading.

Rotate the base of the dip needle so that the needle is aligned with the body of the device. Thus, the needle should be pointing to 270°.

Rotate the shaft at its banana plug connection until the plastic scale is in the vertical plane. In this orientation, the needle is used to find inclination of the magnetic field.

Once the needle comes to rest, read the angle θ from the scale to which the upper needle is pointing, in degrees from zero. Subtract the angle θ from 90° to obtain the dip angle, which is the inclination of the Earth’s magnetic field.

Example: At this location, the dip needle reads 28°.
90° – 28° = 62°, which is the inclination of the magnetic field at this latitude. The dip needle will always point downward in the northern hemisphere and upward in the southern hemisphere. If you were standing on top of the north magnetic pole, the dip needle would be pointing to 90° and the dip angle would be 0°.



3. Explain what inclination is measuring.

Inclination is the dip of a magnetized needle toward the surface of the Earth. You can think of inclination as an indication of the direction of the field lines where you are located on the Earth’s surface. The closer you get to the actual poles, the steeper is the dip angle.

4. When would inclination be a problem in compasses?

Inclination causes the needle to dip downward inside the compass. If the compass does not compensate for this, the tip of the needle will drag on the face of the compass and cause the reading to be inaccurate. Also, inclination dips cause compasses to become inaccurate in airplane banking turns.

5. How are these problems circumvented?

In airplanes, the south-pointing needle is weighted to help lift the north-pointing needle up. Another way to set this up is to float the magnetized needle in oil so that it can show both inclination and declination at the same time.

6. Imagine that a plane is flying from northern Maine to southern California; discuss the compass adjustments required for the aircraft to stay on course.

When the plane is in Maine, magnetic north will be to the left of geographic north. As you fly southwest, there will come a point when the plane, magnetic north and geographic north will all be in alignment. Once you reach southern California, magnetic north lies just to the right of geographic north. This concept is easily demonstrated with three objects, or people. The curvature of the Earth adds to this perspective.

Discuss why we think the magnetic poles are constantly shifting. Refer to the Background for this discussion.

Lab Preparation

Although this lab 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 magnets 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.

2	5	1	3	4
Float the cork with the magnetized needle in the beaker and label N, S, E, W.	Collect data at several locations around the degree wheel.	Begin by magnetizing the needle. Rub the needle across the south end of the bar magnet 30 to 40 times.	Place the Magnetic Field Demonstrator on the template of Earth; place the magnet on top and sketch the field lines.	Leaving only the magnet in place, align the tip of the magnetic field sensor with the zero degree marking on the template.

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 – Constructing a simple compass

You will build a compass using a needle, a cork, and a magnet. Remember, the needle of a compass always points towards magnetic north.

1. ☐ Magnetize the needle:

- **a.** Hold the needle by the needle's eye.
- **b.** Hold the bar magnet at its north end with the magnet horizontal.
- **c.** Stroke the needle off the south end of the magnet, from the needle's eye to the needle's point and repeat this motion 40 to 50 times.

2. ☐ Test the magnetic ability of the needle by placing the magnetized needle next to a pin.

3. ☐ How do you know whether or not the needle has become magnetized?

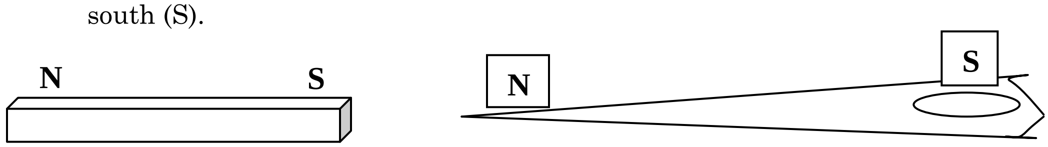
If the needle is magnetized it will attract the pin to it. If the needle is not magnetized it will not be able to attract the pin.

4. ☐ In general, explain how two magnetized objects respond to each other.

The north end of one magnet attracts the south end of a second magnet. The south end of a magnet repels the south end of another magnet and the north end of a magnet repels the north end of another magnet.

5. ☐ Determine which end of the needle is north and which end of the needle is south by placing the needle next to the bar magnet.

6. ☐ Draw a diagram of your needle next to the south end of the bar magnet you see pictured below. Label which end of the needle is north (N) and which side of the needle is south (S).



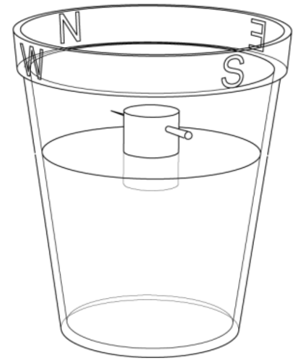
7. ☐ Cut off a small piece of cork and push the magnetized needle through it.

8. ☐ Label a clear plastic cup with the coordinates N, E, S, W.

9. ☐ Fill the cup with water.

10. ☐ Float the cork with the needle in the water.

11. ☐ Rotate the cup so the needle points to the N to complete your simple compass.



12. ☐ Which end of the needle compass is pointing toward the north magnetic pole?

The needle's pointed end, which we have labeled North, points toward the north magnetic pole.

13. ☐ What does this tell you about the polarity of Earth's north magnetic pole?

This means that Earth's north magnetic pole is actually a south pole. It is called north because it is near the geographic North Pole.

14. ☐ Who uses compasses and why are they used?

Navigators use compasses to monitor their location. They are used by pilots and by captains of ships in the ocean.

15. ☐ Is the north magnetic pole the same as the geographic North Pole?

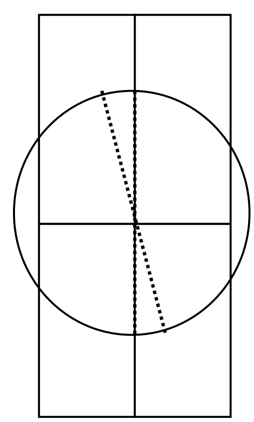
The geographic North Pole is not in the same location as the magnetic north pole. The geographic poles are located at 180° north or south latitude and are map locations. The magnetic poles are associated with the magnetic field strength of the planet and vary over time in intensity and in location.

16. ☐ How do navigators account for any difference?

The differences are accounted for by allowing for the declination change wherever you are located. It is a simple subtraction, once you know your declination. Pilots also have to allow for inclination changes.

Part 2 – Visualizing the Earth's magnetic field

17. ☐ Lay all four 2D magnetic field demonstrator plates on top of the Map of Earth template to make a large rectangle as shown.



18. ☐ Place the bar magnet on top of the magnetic field demonstrator plates, lining it up with the magnet diagram on the template.

19. ☐ Ensure that the south pole of the magnet is in the North as shown on the template.

20. ☐ Why is the south pole of the magnet near the North Pole?

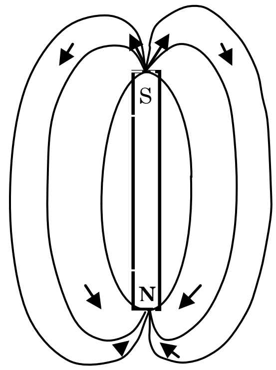
In Part 1, it was shown that the north end of a compass needle points to the north magnetic pole, which means that the north magnetic pole is actually like the south end of a magnet..

21. ☐ Allow the iron pieces within the magnetic field demonstrator plates to orient themselves with the magnetic field of the bar magnet.

22. ☐ Describe the pattern the iron pieces make around the Earth (on the template).

The field lines draw in at the poles and run parallel to the sides of the magnet.

23. ☐ Make a sketch showing the alignment of the iron pieces over the template. You might want to use short arrows to indicate how the iron filings pointed relative to the magnet.



Part 3 – Measuring the magnetic field of a bar magnet

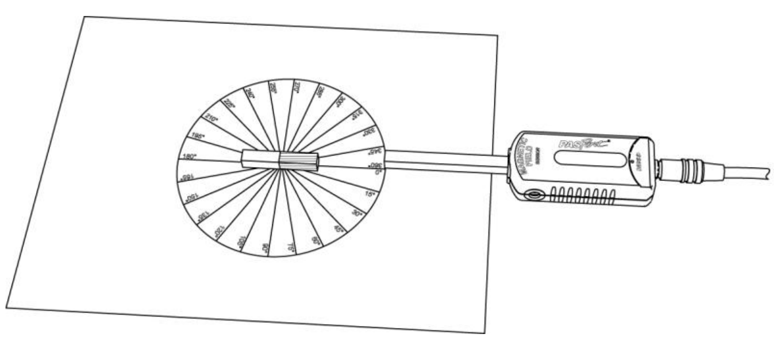
Set Up

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

25. ☐ Connect a magnetic field sensor to the data collection system. �[(2.1)]

26. ☐ Put the data collection system into manual sampling mode with manually entered data. Name the manually entered data for the table “Degrees” and add a column to display “Magnetic field strength.” �[(5.2.1)]

27. ☐ Place the bar magnet on the degree wheel template so that the north pole on the magnet points to the 0 degree line on the template.



28. ☐ Position the magnetic field sensor’s tip at the 0 degree line on the template as shown in the diagram. The closer you place it, the stronger the field will be; keep the sensor the same distance from the magnet and in line with the circle.

Collect Data

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

30. ☐ Record the magnetic field strength every 15 degrees starting at the 0 degree mark on the template.�(6.3.2)

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

Analyze Data

32. ☐ Display Magnetic field strength on the y-axis of a graph with Degrees on the x-axis. �(7.1.1)

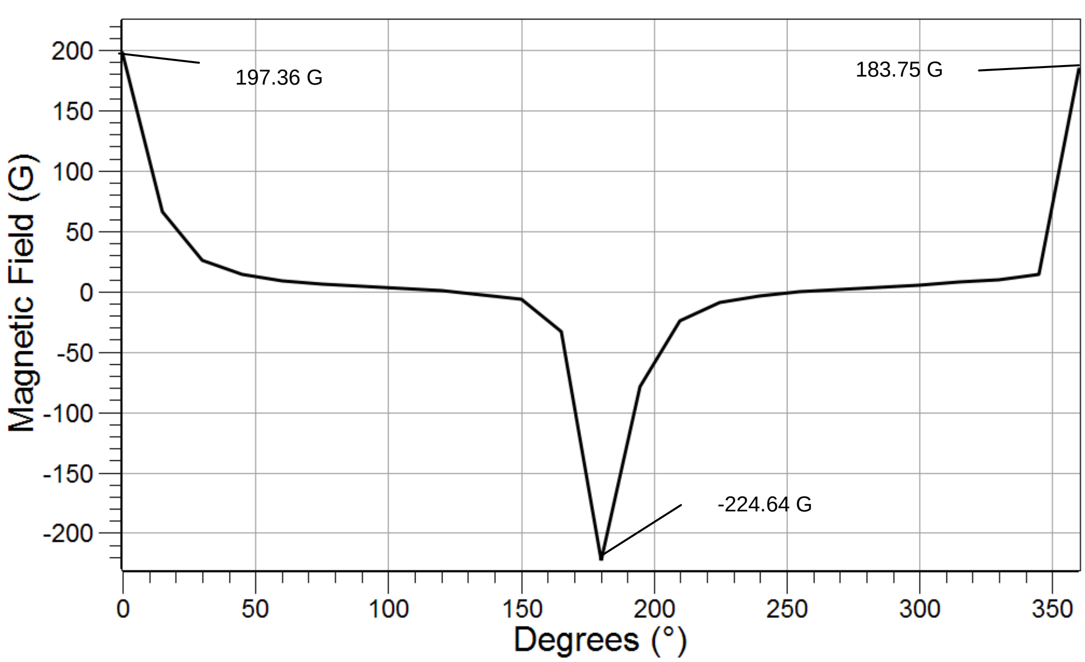
33. ☐ Find and label the coordinates of the data point with the highest magnetic strength value and the lowest magnetic strength value. �(9.1)(7.1.5)

34. ☐ What was the highest and lowest magnetic strength value recorded?

At 0° the field was 197.36 gauss. At 180° the field was –222.64 gauss. In between these values, the field reached 0 gauss.

35. ☐ Sketch or print a Magnetic Field versus Degrees graph. Label the overall graph, the x-axis, and the y-axis. Include units and scales on the axes. �(11.2)

Magnetic Field Strength Recorded Around a Bar Magnet



36. ☐ In the data, some of the values are positive and some are negative. What does that mean for the polarity?

This means that different polarities were recorded, one was positive and the other was negative. A change in polarity is recorded when the numbers change from positive to negative.

37. ☐ At which locations on the magnet was the field strength the greatest? At which locations was it the least?

Students will note that the greatest values were found at the ends of the magnet, and the least values were found on the sides of the magnet.

38. ☐ Save your file and clean up according to the teacher's instructions. �(11.1)

Data Analysis

1. ☐ If the north pole of the needle magnet pointed to the north magnetic pole, what is the polarity of the north magnetic pole? Explain your reasoning.

The polarity of the north magnetic pole would have a south polarity. The south end of the bar magnet attracted to the point of the needle, meaning that the pointed tip of the needle was a north pole. This tip was attracted to the north. Since opposites attract, the northerly magnetic pole on our planet must have a south polarity.

2. ☐ Describe how the magnetic field strength on Earth varies.

The magnetic field strength is stronger at the poles and weaker at the equator.

3. ☐ On the Map of Earth template, label the highest positive magnetic field strength readings and the lowest negative readings at their corresponding degree. What part of the bar magnet does each data point represent?

Answers will vary depending on the size of the bar magnets used in relation to the Earth model, the highest positive values will be around the 0 degree location, and the lowest negative reading will be at 180 degrees

Analysis Questions

1. Why did the needle on your compass point north? Explain.

The compass needle pointed to the north because the needle is aligning itself with the Earth's magnetic field. The tip of the needle is magnetized as a north magnetic pole. The tip points north because it is attracted to the Earth's south pole, which is the north magnetic pole currently.

2. Is the Earth's magnetic field a two or three dimensional magnetic field? Do you have any evidence for this?

The Earth's magnetic field is three dimensional. Using the 2D magnetic field demonstrator does not allow us to see this, but the magnetic field sensor can get gauss readings in every orientation around the magnet. The magnetic field dips in toward the poles, and at the poles it is 90°. So at the poles, the filings are almost perpendicular to the surface.

3. What would the graph look like after a magnetic reversal? Explain.

The central dip would be a central peak, with positive value, and the two positive values at 0° and 360° would be negative. The shape of the curve would be the same, just reversed.

4. Do you think the model of the Earth's magnetic field you recorded in the lab would be different if you used a much stronger or much weaker magnet? Explain your answer.

Yes the field strength does vary with the strength of the magnet and with proximity. This can be tested by bringing the sensor closer to and farther from a single magnet. Then try doubling the magnet and compare the field strength.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Is the Earth's magnetic field a static, rigidly set magnetic field like a bar magnet? Explain.

No, Earth's magnetic field varies over time and is constantly in flux. A magnetic field is created when an electric current wraps around magnetic material and varies with the changes in the electric current. In the same way, the Earth's core is in motion and electric currents associated with the core vary. This causes the magnetic field strength to vary.

2. Humans use compasses to navigate the world. What other animals use Earth's magnetic field? Explain.

Students will list bird and whale migratory patterns, as well as other particular animals they may discover that use field strength for migration.

3. How does the magnetic field of the Earth protect the planet in space?

The magnetic field of the planet acts like a shield helping to deflect charged particles streaming from the sun.

4. What would cause the magnetic field of Earth to disappear altogether? Explain.

The field is created by the electrical interaction of the molten outer core and the solid inner core. If the molten outer core cools enough to solidify, the dynamo would such down and the magnetic field of the planet would disappear. Earth would become a dead planet, because the shielding effect of the magnetic field would be gone and Earth would be exposed to more charged particles from the sun.

Multiple Choice Questions

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

1. The needle on a compass points north because the Earth's magnetic field resembles a

- **A.** Horseshoe magnet
- **B. Bar magnet**
- **C.** Refrigerator magnet
- **D.** Single pole magnet
- **E.** None of the above

2. Which statement best describes the pattern in which the magnetic field of a bar magnet varies with location from 0 or 360 degrees to 180 degrees?

- **A. Strong positive value at 0 or 360 degrees to strong negative at 180 degrees**
- **B.** Strong negative value at 0, 180 and 360 degrees, strong positive at 90 and 270 degrees
- **C.** Strong negative value at 0 or 360 degrees to strong positive at 180 degrees
- **D.** Strong positive value at 0, 180 and 360 degrees, strong negative at 90 and 270 degrees
- **E.** None of the above

3. Which statement best describes the orientation of magnetic field lines around a bar magnet?

- **A.** The magnetic field lines resemble a series of straight lines from the north to the south pole in two dimensions.
- **B.** The magnetic field lines resemble a series of straight lines from the north to the south pole in three dimensions.
- **C.** The magnetic field lines resemble a two dimensional series of loops from one pole to the other.
- **D. The magnetic field lines resemble a three dimensional series of loops from one pole to the other.**
- **E.** The magnetic field lines run perpendicular to the surface of the magnet.

4. Which statement best describes the Earth's magnetic field?

- **A.** The Earth's magnetic field is permanent.
- **B.** The Earth's magnetic field reverses every 1000 years.
- **C. The Earth's magnetic field has varied in strength and orientation over time.**
- **D.** The Earth's magnetic field is static.
- **E.** The Earth's magnetic field varies in strength and orientation with the lunar cycle.

5. Magnetic declination:

- **A. Varies according to location**
- **B.** Is stronger near the South Pole
- **C.** Is constant within a hemisphere
- **D.** Is stronger near the North Pole
- **E.** Is zero when you are standing at the Equator

Key Term Challenge

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

1. At first glance it appears that the Earth contains a giant **bar magnet**. However, we know that the temperatures in the Earth's core are too **high** for the materials to remain permanently magnetized. A widely accepted view of the mechanism responsible for generating the Earth's **magnetic field** suggests that the Earth's magnetic field is produced by a complex interaction between the convection currents in the molten **outer** core and the solid **inner** core, both of which contain large quantities of **ferromagnetic** metals, such as iron, nickel, and cobalt.

2. The magnetic field of the Earth is **three** dimensional: the **latitudinal** axis, the **longitudinal** axis, and the radial axis, up from the surface of the Earth. The **inclination** of the needle on a compass can be used to help pilots find their latitude. The **declination** of the needle on the compass can help determine variation from **geographic** north. Navigators, especially small plane pilots, use both the declination and the inclination from special magnets called **dip needles** to find their true position.

3. During the 1960s, geophysicists learned that the Earth's magnetic field reverses **polarity** periodically. That is, the magnetic north and south poles **switch** positions. The cause of the reversal seems to involve fluctuations in the **strength** of the magnetic field over time followed by a rapid recovery after the new orientation has been established. Evidence for these **reversals** can be found in a study of the **magnetism** of lava fields, and an examination of rock on the seafloor. The study of the magnetic field orientation in rock as it formed is called **paleomagnetism**.

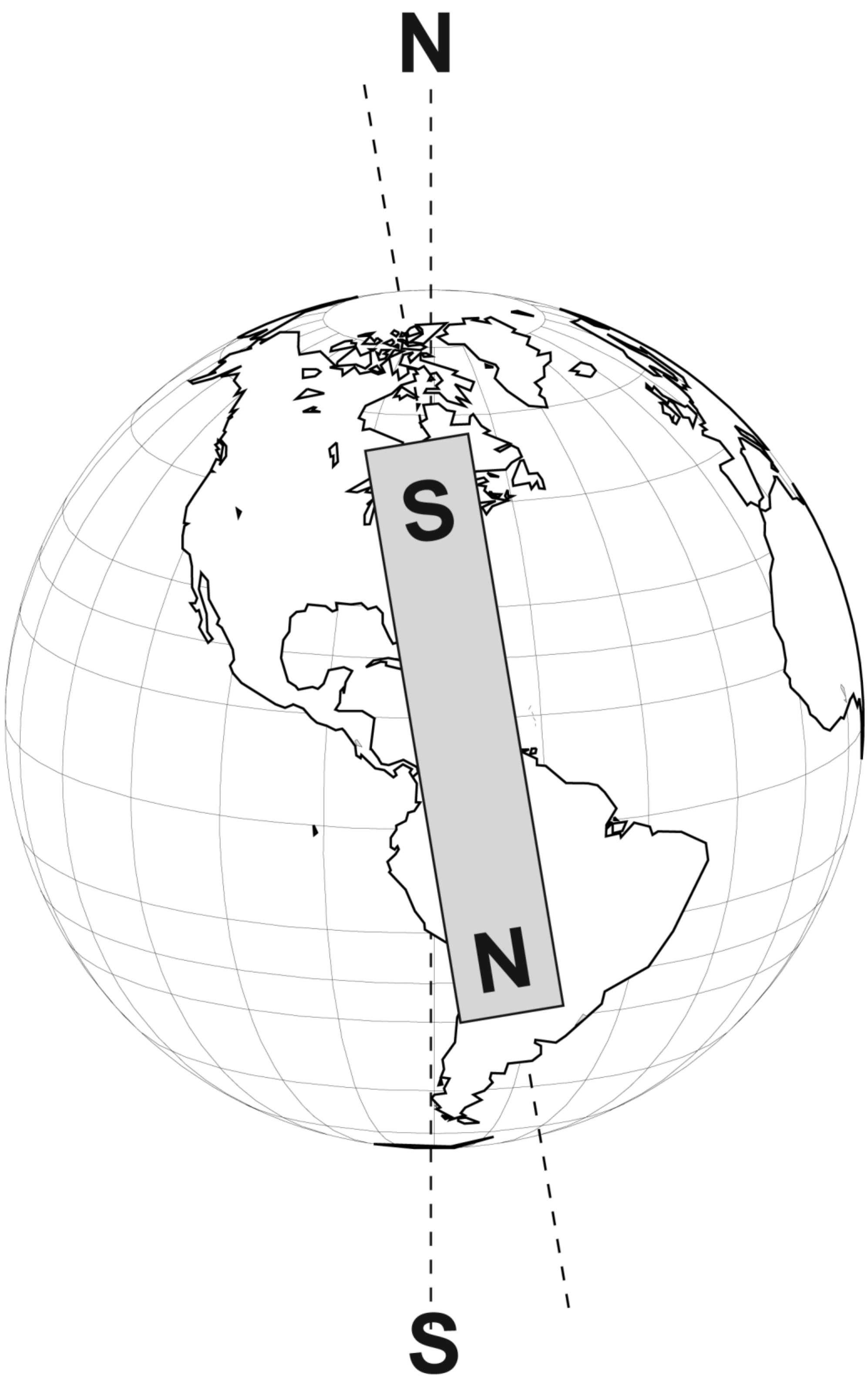
Extended Inquiry Suggestions

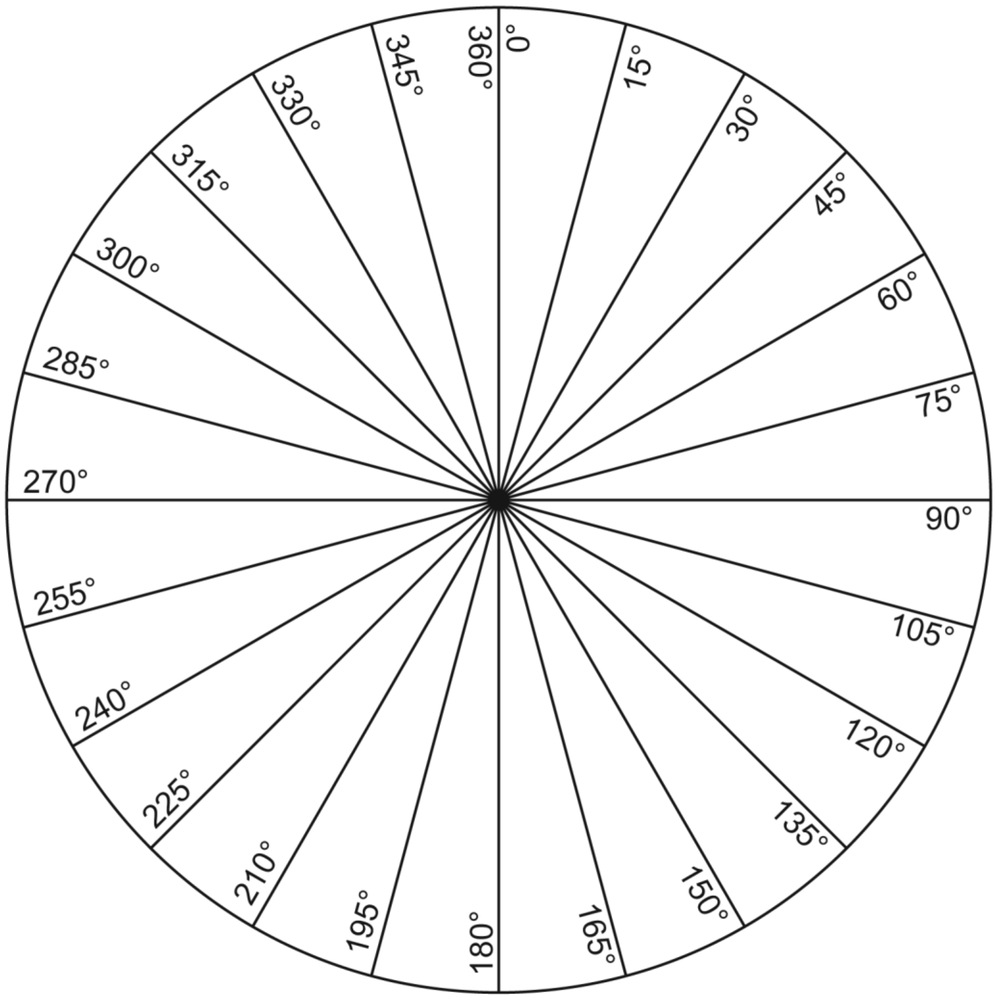
Use the magnetic field sensor to explore the Earth's magnetic field in your area. To do this, simply go outside and stand away from any power lines or other source of magnetic force. Begin recording data on a graph and turn slowly in a circle. Verify that the strongest positive readings are found when the magnetic field sensor is pointed towards the north.

Conduct an Internet search to find information on the shifting location of the north magnetic pole over time.

There is much discussion and little agreement about the time frame for magnetic reversals. Research articles on this subject and summarize the arguments.

Research how pilots use instruments that monitor the Earth's magnetic field for navigation.


N
S
N
S


0°
15°
30°
45°
60°
75°
90°
105°
120°
135°
150°
165°
180°
195°
210°
225°
240°
255°
270°
285°
300°
315°
330°
345°
360°

8. Radiation Energy Transfer

Objectives

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
- Greenhouse Gases
- 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.

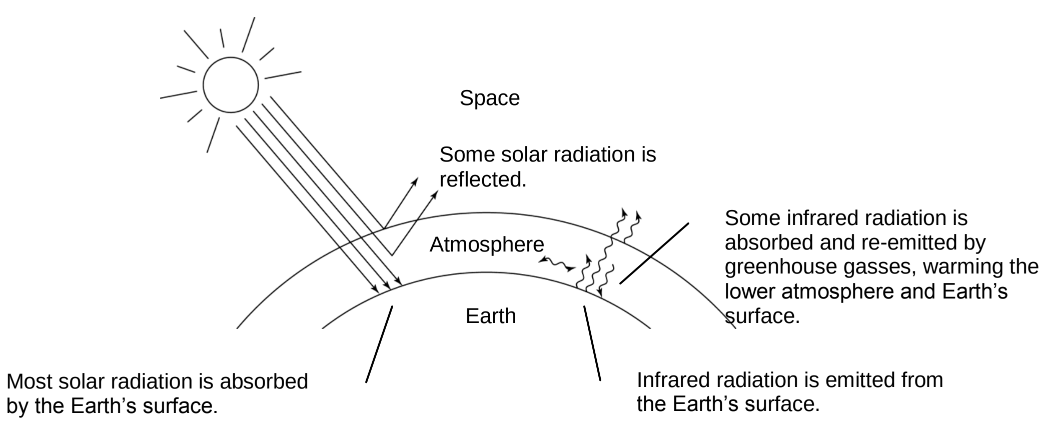
Electromagnetic Spectrum

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 (1852 lux) than black paper (1320 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

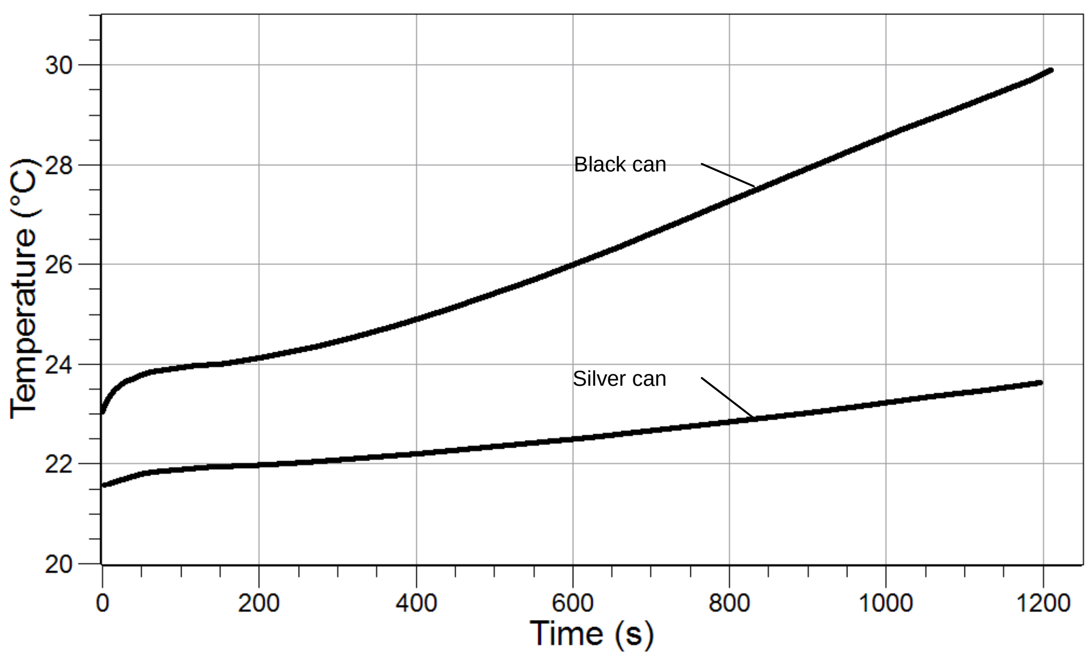
1. ☐ Use the graph of Temperature versus Time to determine the initial temperature, final temperature, and change in temperature for each radiation can and record the answers in Table 1. �(9.1) (9.2)

Table 1: Recorded and calculated temperatures

	Initial Temperature (°C)	Final Temperature (°C)	Change in Temperature (°C)
Silver Can	18.8	21.2	2.4
Black Can	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 their **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.

9. Seafloor Spreading and Plate Tectonics

Objectives

Use models to explore the movement of Earth's crustal plates and the evidence that is used to support the theory of plate tectonics. During this investigation, students:

- Explain that seafloor spreading causes Earth's plates to move
- Explain how paleomagnetism provides the evidence for seafloor spreading
- Explore the reason for magnetic reversals within rock

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the magnetic field of a bar magnet using a magnetic field sensor
- Measuring and comparing the magnetic fields of natural hand size specimens of magnetite and basalt
- Measuring the magnetic field on an ocean floor model and determining the location of the spreading center
- Identifying the pattern of magnetic reversals surrounding a spreading center

Time Requirement

♦ Preparation time	60 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	60 minutes

Materials and Equipment

For each station:

Station 1

- Strip of paper, 10 cm × 28 cm
- Colored pencils or markers, red and green
- Tape, roll
- Scissors
- Cardboard or card stock, 15 cm × 20 cm

Station 2

- Data collection system
- Magnetic field sensor
- Bar magnet

Station 3

- Data collection system
- Magnetic field sensor
- Basalt, hand size specimen
- Magnetite, hand size specimen

Station 4

- Data collection system
- Magnetic field sensor
- Seafloor spreading model[1]

[1]Refer to the Lab Preparation section for instructions on how to build a seafloor spreading model from magnets and a shoe box.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The location of the Earth's magnetic poles
- Convergent and divergent boundaries
- Layers of the Earth
- Subduction zones
- The composition of the oceanic crust (basalt)

Related Labs in This Guide

Labs conceptually related to this one include:

- Earth's Magnetic Field

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 �[(6.1)]
- Recording a run of data �[(6.2)]
- Displaying data in a graph �[(7.1.1)]
- Adjusting the scale of a graph �[(7.1.2)]
- Printing �[(11.2)]

Background

Plate tectonics is a relatively new scientific concept, introduced some 40 years ago, but it has revolutionized our understanding of the dynamic planet on which we live. The theory unified the study of the Earth by drawing together many branches of the Earth sciences, from paleontology (the study of fossils) to seismology (the study of earthquakes). It provides explanations to questions that scientists have speculated about for centuries, such as why earthquakes and volcanic eruptions occur in very specific areas around the world, and how and why mountain ranges like the Alps and Himalayas formed.

The theory of plate tectonics states that the Earth's lithosphere is fragmented into a dozen or more large and small plates that are moving relative to one another as they ride atop the hotter, more mobile asthenosphere. The theory was preceded by the idea of continental drift, advanced by Alfred Wegener in 1912 who proposed that the supercontinent Pangaea split apart around 200 million years ago. Continental Drift was first suggested as early as 1596 by the Dutch map maker Abraham Ortelius in his work *Thesaurus Geographicus*, who suggested that the Americas had been torn from Africa and Europe. But Ortelius did not have an explanation for his observations, nor evidence to support his idea.

Evidence for Continental Movement

Wegener was intrigued by the occurrences of unusual geologic structures and plant and animal fossils found on the matching coastlines of South America and Africa, which are now widely separated by the Atlantic Ocean. He reasoned that it was physically impossible for most of these organisms to have swum or been transported across the vast oceans.

In Wegener's mind, the drifting of continents after the break-up of Pangaea explained not only the matching fossil occurrences but also the evidence of dramatic climate changes on some continents. For example, the discovery of fossils of tropical plants (in the form of coal deposits) in Antarctica led to the conclusion that this frozen land previously must have been situated closer to the equator in a more temperate climate where lush, swampy vegetation could grow.

Wegener’s theory of continental drift was hotly debated on and off for decades following Wegener's death before it was largely dismissed. However, beginning in the 1950s, a wealth of new evidence emerged that revived the debate.

Seafloor Spreading

In 1960 an American Geologist named Harry Hess proposed an idea based on data from magnetometers that mapped the bands of magnetism in the oceanic crust. His theory, called seafloor spreading, explained how new oceanic crust is created when magma rises to the surface along mid-ocean ridges, cracking the overlying basalt and forcing its way to the surface. The new basaltic lava spreads out and cools, leaving the older oceanic crust further away from the ridge and newer cooling basaltic rock closest to the ridge. As this process is repeated over time, matching layers of progressively older rock can be found on either side of the spreading center. In this way, seafloor spreading becomes the mechanism for plate tectonics.

Magnetic Orientation

The basaltic lavas that make up the oceanic crust are rich in the magnetic mineral magnetite. As the basaltic lava cools, the magnetic orientation of iron within the magnetite aligns with the magnetic field of the Earth. The temperature of the molten rock contributes to the ability of the iron rich ore to magnetize. When the molten rock is very hot (above 768°C or 1414 °F for iron) the iron molecules are too fluid to hold their orientation. . But as the magma cools to that particular temperature, the molecules begin to align themselves with the Earth's magnetic field.This temperature is known as the Curie Point. As the magma cools below this point, the magnetic field of this ferromagnetic material becomes stronger and more defined until cooling no longer allows the reorientation of the crystals.

The Earth's magnetic field is weak (around 0.5 Gauss) but it is strong enough to align the crystals of ferromagnetic material in the basaltic lava on the seafloor as it cools. Because magnetic materials exhibit a polarity, the seafloor can be mapped for its magnetic properties. Recent mapping has revealed that the magnetic orientation of ferromagnetic materials in ocean floor basalt has reversed polarity with some regularity in the last several million years.

Since the polarity of the Earth at the time basaltic rock crystallizes is locked into its structure, the pattern of magnetic polarity reversals is readily determined from the basaltic oceanic crust and serves to map the matching layers on either side of the spreading center of the sea floor. In this way, magnetic reversals on the seafloor provide evidence for seafloor spreading, and thus for plate tectonics.

Pre-Lab Discussion and Activity

Materials and Equipment for Pre-lab Activities

Demonstrating Convection

- Beaker (2), 100-mL
- Hot plate
- Corn syrup
- Red food coloring
- Disposable pipet
- Water
- Tongs, to fit the 100-mL beaker
- Ruler, metric

Ferromagnetism Investigation

- Bunsen burner
- Strong neodymium or speaker magnet
- Paperclip
- Ring stand
- Ring clamp (2)
- Magnetite, that is weakly magnetic
- Basalt[1]

[1]Balsalt, or any dark mafic rock, will require longer heating than magnetite for this demonstration, but will become magnetized enough to hold a paperclip.

Demonstrating Convection

Demonstrate convection to students:

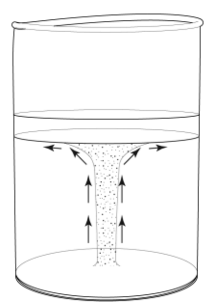
Pour corn syrup to a depth of about 1 cm in a 100-mL beaker and add several drops of red food coloring. Place this beaker on the hot plate and heat until it just begins to boil.

Pour cold corn syrup to a depth of about 4 cm in the second 100-mL beaker (this represents the Earth's mantle). Use a pipet to add approximately 1 cm of cold water on top of the corn syrup layer (this represents the Earth's crust).

Fill the plastic pipet with hot, red corn syrup. With the pipet held vertically, slowly lower the tip to the bottom in the center of the beaker holding the corn syrup and water. Squeeze the hot red corn syrup out of the pipet onto the bottom of the beaker and remove the pipet.

Have students observe the behavior of the corn syrup over the next 5 to 8 minutes and then ask the following questions:

1. Draw a diagram of what happened when the red, hot corn syrup was added to the cold corn syrup and water. Use arrows to show the direction the red hot corn syrup moved.



2. Describe the motion of the corn syrup using terms like: hot and cold, floated, rose upward, and sank downward.

The hot corn syrup moves upward in the cold corn syrup until it gets to the top of the cold layer. Then it spreads out across the surface of the corn syrup but under the layer of the cold water, which is less dense and continues to float. As the heat in the hot syrup neutralizes with the surrounding cold syrup and overlying cold water, it cools and starts to mix into the plain syrup. It may dilute in color. It may appear to sink again.

3. Describe how this model with corn syrup and water demonstrates convection within the Earth.

The different densities of corn syrup represent different layers within the mantle and asthenosphere, where superheated molten rock can rise through the overriding , comparatively cooler rock strata. The water layer represents the outer crust of the Earth. As the rising material cools, it spreads out and cools even more. Any material that is cooler than the surrounding material will proceed to sink, and the cycle starts over.

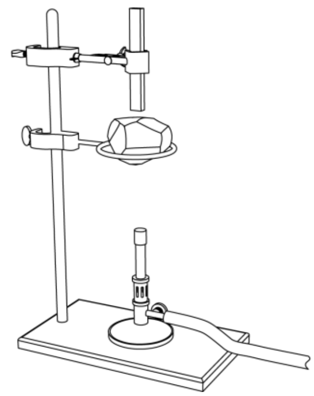
4. How is convection within the Earth related to plate tectonics?

Convection cycles hot magma from the mantle into the asthenosphere, and from the asthenosphere into fissures and weak places in the crust, particularly in divergent boundaries.

Ferromagnetism Investigation

Demonstrate how magnetism is "recorded" in rock:

Demonstrate the magnetism of the magnetite by placing the paperclip near it. If it is only weakly magnetic, the paperclip will not be attracted strongly enough to be held by the magnetite.



Place the magnetite specimen on the stand above the Bunsen burner and light the burner. Allow the magnetite to heat for several minutes. Extinguish the flame and immediately place the strong magnet in the clamp above the magnetite. Allow the magnetite to fully cool.

Have students observe that a paperclip is strongly attracted to the magnetite after it has cooled. Then ask the following questions:

5. How is this demonstration similar to the way rock is formed?

Igneous rocks are formed when magma cools. As the magma cools, the iron atoms in the rock aligns itself with the Earth's magnetic field. In this demonstration, we are heating the rock just enough to allow the iron atoms the freedom to move and realign themselves. In this example, the magnet (instead of the Earth's magnetic field) is being used to align the particles.

6. What is the Curie Point?

The Curie Point is the temperature below which magnetic properties in rock are exhibited. The iron atoms align themselves with a magnetic field and the rock demonstrates magnetic properties. Above the Curie Point, magnetism is not demonstrated. In the cooling of magma, any ferromagnetic material will have its own Curie Point, and its magnetic properties will develop at or below that temperature.

7. Do you think that any rock could be made to be magnetic in this way?

Students will state that any rock with iron in it could be magnetized in this way, but rocks with no iron in them would not be magnetized. If time permits, try to magnetize a piece of basalt in this way. Students should not think that the rock became strongly magnetized simply because it was magnetite.

8. What is a magnetic reversal? How could we simulate a magnetic reversal using this set up?

A magnetic reversal is when magnetic north and magnetic south switch positions. This happens infrequently, in the time span of tens of thousands of years. Yet there is evidence that this planet's magnetic polarity has reversed often. We could simulate this reversal by placing the magnet on the other side of the rock as it cools.

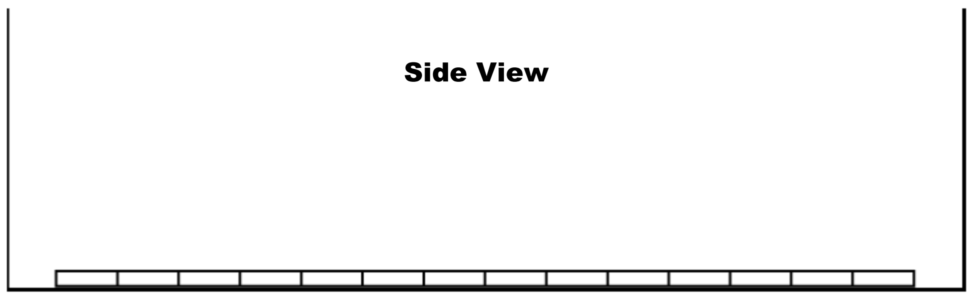
Lab Preparation

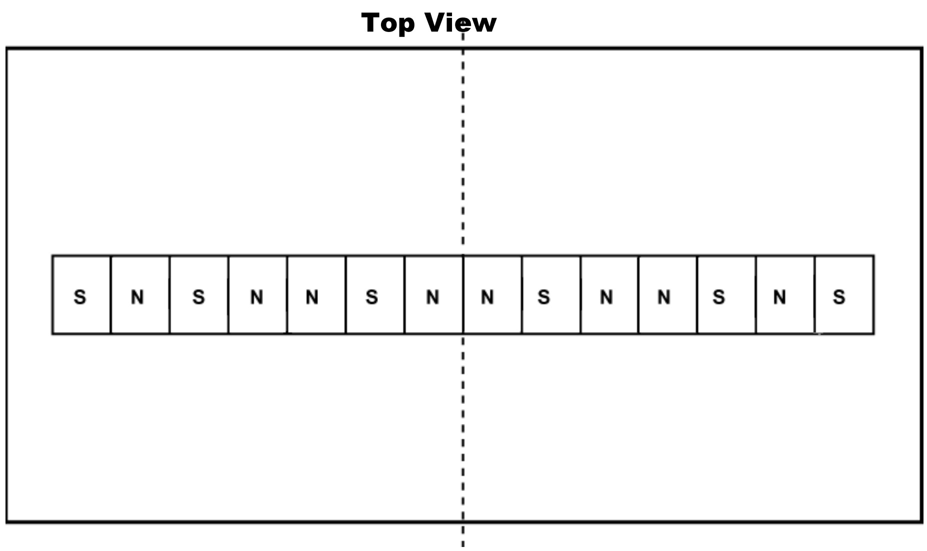
These are the materials and equipment to set up prior to the lab:

1. Create 1 to 3 of each lab station depending on the number of students you plan to have rotating through the groups. Each group of students may go to each station in any order.

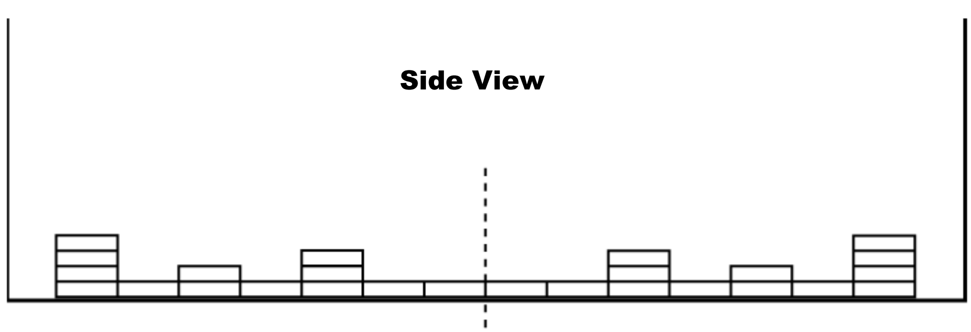
2. To create the spreading seafloor model:

a. Tape or use a hot glue gun to attach one row of magnets along the bottom of the shoe box. Orient the magnets so they are symmetrical about the center of the box. Be sure to orient the poles of the magnets as shown, or alternate them in some way. Note that their pattern matches in a mirror image from the center.





b. Symmetrically tape or glue additional magnets on the first row to add variations in strength.



c. Put the lid on the box and turn the box over. This way the students will run the magnetic field sensor right over the top of the magnets.

Safety

Add this important safety precaution to your normal laboratory procedures:

♦ Keep magnets 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.

1	2	5	4	3
Visit each of the stations your teacher has set up, in any given order.	Perform the measurements at each of the given stations, and record your data and answers carefully.	Relate evidence for seafloor spreading to larger processes of plate tectonics.	Relate the magnetic field reversals in the model to magnetic field reversals in the planet.	Compare the model of the seafloor to the actual sea floor, and identify the pattern.

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.

Station 1 – Constructing a paper spreading seafloor model

1. ☐ Color the long strip of paper (10 cm × 28 cm) so that there are several alternating red and green colored bands of differing thicknesses across the width of the paper.

2. ☐ What do the red and green bands represent?

The red and green bands represent alternating magnetism in the rock layers on the sea floor.

3. ☐ Fold the paper in half lengthwise so that the top length lies over the bottom length and the bands match up. Cut the paper down the fold.

4. ☐ Tape the strips together at one end.

5. ☐ What causes a switch in the polarity of magnetism in bands of rock on the sea floor (one color band to another color band on your model)?

Magnetic reversals cause the iron atoms in rocks to align in different directions as the magma is cooling. If new magma is forming at the same time as the polarity of the Earth is switching, the new layer will have a different polarity than the older layer beside it.

6. ☐ Cut three slits in the 15 cm × 20 cm piece of cardboard: one in the center and the other two about two centimeters from each edge.

7. ☐ Feed the un-taped ends through the center slit from the underside up and allow them to open and spread toward the slits on the sides exposing the colored bands. Do this slowly.

8. ☐ What do you notice about the pattern created by the strips moving away from each other?

Students should notice that the pattern is a mirror image of itself as the two strips move away from each other toward the far edges of the cardboard.

9. ☐ What type of boundary does the center slit in the cardboard represent on the ocean floor?

The center slit represents the spreading center of the mid-ocean ridge. This is a divergent boundary.

10. ☐ When the strips reach the side slits in the cardboard, pull them down through the side slits.

11. ☐ What type of boundary does pulling the strips down through the side slits on the cardboard represent on the ocean floor?

Pulling the strips down through the side slits represents a subduction zone on either side of a spreading center. These subduction zones are convergent boundaries.

12. ☐ Carefully remove the colored strip of paper from the cardboard.

13. ☐ Re-feed the un-taped ends through the center slit from the underside and number each pair of colored bands similarly (the first color band that comes out of the slit will be numbered “1” on both the right and the left sides of the paper strip, the second color band will be numbered “2” on both the right and the left sides, and this process is continued until all the band s are numbered).

14. ☐ When the strips are mostly pulled out, look at the numbering. Where are the first colored bands located? Where are the last colored bands located?

The first colored bands are located farthest from the center, and the last colored bands are located closest to the center.

15. ☐ What does this pattern tell you about the age of the bands of rock as they emerge from the spreading center on the sea floor?

The first band of rock to emerge represents the oldest rock. They end up the farthest from the center. The youngest rock is the closest to the center. New rock is formed at the center, then gets pushed farther out by the emergence of newer rock.

Station 2 – Measuring the magnetic field of a bar magnet

Set up

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

17. ☐ Connect a magnetic field sensor to the data collection system. �(2.1)

Collect Data

18. ☐ Monitor live magnetic field data in a digits display. �(6.1)

19. ☐ Position the magnetic field sensor's tip at the north pole of the bar magnet and record the value on the diagram below. (Positive Gauss values represent north magnetic polarity; negative Gauss values represent south magnetic polarity.

Note: the magnetic field sensor should be in the same plane as the bar magnet (the tip of the sensor should NOT be perpendicular to the magnet).

–481.26	S	–.80	N	+353.79

20. ☐ Move the magnetic field sensor's tip to the south pole of the bar magnet, allow the reading to stabilize, and record the value on the diagram.

21. ☐ Move the magnetic field sensor's tip to the point midway between the bar magnet's north and south poles, allow the reading to stabilize, and record the value on the diagram.

Analyze Data

22. ☐ Describe what happens to the strength of the magnetic field as you move the sensor up one side of the magnet and down the other.

Starting at the positive end, the reading drops off very quickly, going from 353.79 to 221.82 just in rounding the corner. Then it continues to drop off steadily until it comes very close to zero in the center. Then the reading increases rapidly until it gets to the maximum negative force at the negative end of the magnet. Moving down the other side of the magnet, the decrease and increase happens again.

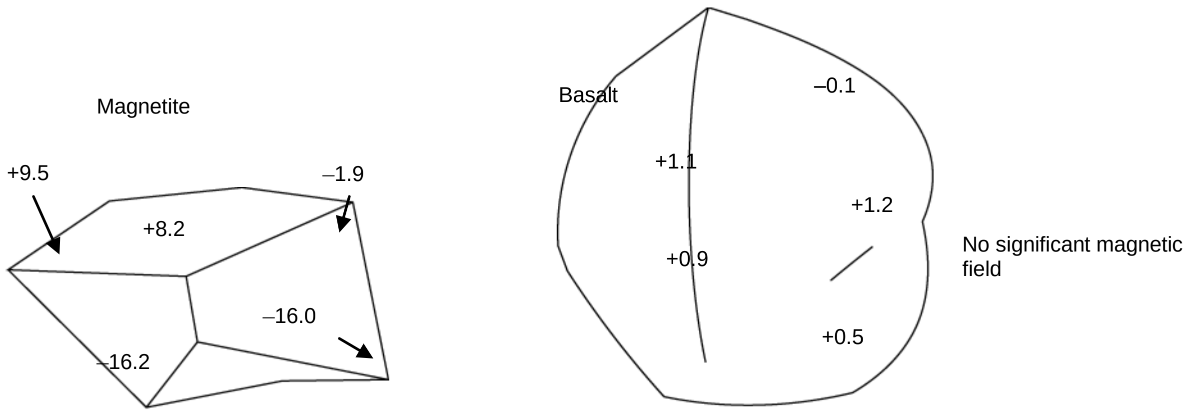
23. ☐ How does the field strength on the magnet relate to magnetic field lines on the Earth?

The field is strongest at the poles where the field lines are perpendicular to the surface, and weakest at the midpoint, where field lines are parallel to the surface. This is similar to the Earth's field lines.

Station 3 – Comparing the magnetism of magnetite and basalt

Set up

24. ☐ Draw an illustration of your sample of magnetite and your sample of basalt in the space provided. Label each illustration.



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

26. ☐ Connect a magnetic field sensor to the data collection system. �(2.1)

Collect Data

27. ☐ Monitor live magnetic field data in a digits display. �(6.1)

28. ☐ Use the magnetic field sensor to map out the magnetic field strength of each specimen:

- **a.** Determine the magnetic field strength in one location on a specimen.
- **b.** Allow the reading to stabilize and record the value (including the positive or negative sign) on the illustrations you drew above.
- **c.** Repeat this process until you have found at least 5 different magnetic field values on each specimen.

29. ☐ Do both hand specimens appear to be magnetic?

The magnetite appears to have magnetic fields but the basalt does not (or it is very low).

30. ☐ What type of rock is oceanic crust made up of? Is the collected data consistent with your knowledge of the oceanic crust?

Oceanic crust is made up of basalt and basalt contains magnetite (which contains iron). This means that basalt should have a magnetic field strength less than that of magnetite. The magnetic field strength of basalt is likely to be very low and may require a sensitive magnetometer to get an accurate reading.

31. ☐ Were there regions in the magnetite specimen that were either strongly positive or strongly negative? What does this suggest about the orientation of individual magnetite crystals at those locations?

There were some areas of stronger magnetic field properties in the magnetite. This indicates that as that sample was formed and cooled, the orientation of the crystals were oriented with the magnetic field of the Earth. Since samples cool and reheat more than once above and below the temperature at which the crystals can reorient, the sample shows a variety of magnetic field values.

Station 4 – Magnetism as Evidence for Seafloor Spreading

Set Up

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

33. ☐ Connect a magnetic field sensor to the data collection system. �(2.1)

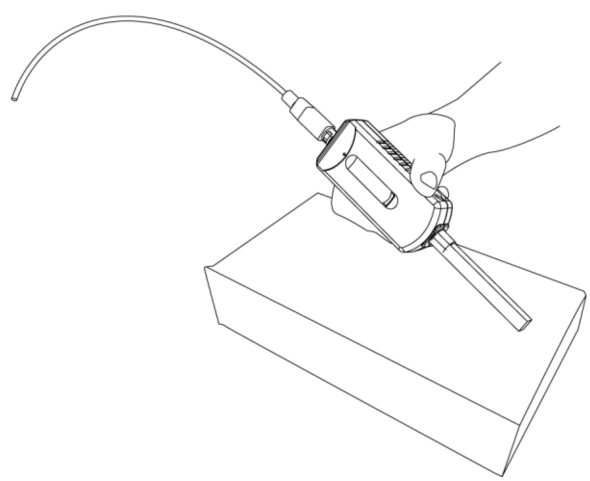
Collect Data

34. ☐ Create a graph with Magnetic Field on the y-axis and Time on the x-axis. �(7.1.1)

35. ☐ Hold the magnetic field sensor perpendicular to one end of the seafloor spreading model.

36. ☐ Start data collection. �(6.2)

37. ☐ Slowly move the tip of the sensor from one end of the model to the other. It should take about 15 to 30 seconds to move across the model.



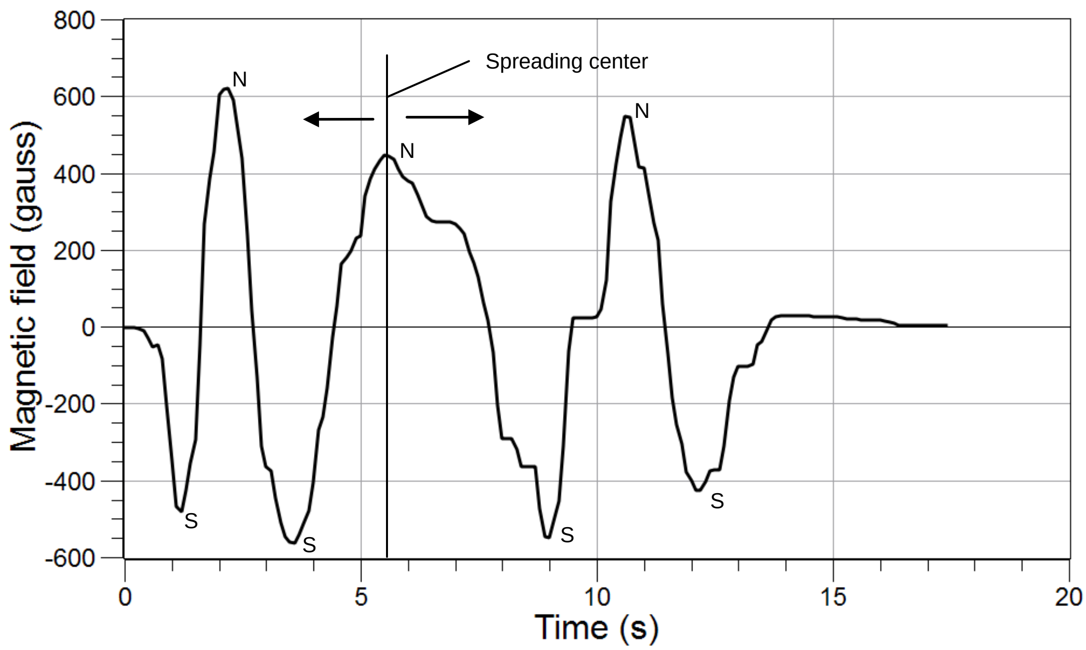
Note: Adjust the scale of the graph as necessary. �(7.1.2)

38. ☐ Stop data collection. �(6.2)

Analyze Data

39. ☐ Sketch or print a copy of the graph of Magnetic Field versus Time. Label the overall graph, the x-axis, the y-axis, and include numbers on the axes. �(11.2)

Magnetic Field Data for the Seafloor Spreading Model



40. ☐ Label the positive and negative peaks as either north or south. Then, label the spreading center (rift zone) and draw arrows showing the direction of plate motion.

41. ☐ Is the pattern of magnetism symmetrical about the spreading center?

Yes, it is symmetrical on either side of the spreading center.

42. ☐ Do you think the mechanism for moving the rock to either side of the spreading center is a pulling mechanism or a pushing mechanism? Explain your reasoning.

The mechanism is probably a pushing force. As new rock emerges form the spreading center, it has to go somewhere. Some of it piles up, so the spreading center is a mountain range. But eventually, the force of the new rock creation causes the older rock to be shoved aside.

Analysis Questions

1. How does seafloor spreading causes Earth's plates to move?

Seafloor spreading occurs when magma rises to and breaks through Earth's surface. This magma cools and forms new rock on the ocean floor. The old rock has been cracked and pushed aside by the new rock. In time, this new rock gets cracked by even more upwelling magma, and gets pushed aside. In this way, upwelling magma constantly creates new rock and spreads the older layers of rock aside. All of this causes Earth's plates to move a tiny bit at a time.

2 What are magnetic reversals and how do they affect paleomagnetism in rock?

Magnetic reversals are when the Earth's magnetic north pole and magnetic south pole switch sides. Magnetic pieces in cooling magma align themselves with Earth's magnetic field. Depending on the orientation of Earth's magnetic field when magma is cooling, the newly forming rock will align with the field. In time, the magnetic field reverses, about every 10,000 years to 20,000 years. New magma forming after the reversal will have the opposite polarity of rock formed before the reversal.

3. How does paleomagnetism provide evidence for seafloor spreading?

Newly formed rock has a magnetic polarity. As it is cracked and shoved aside from the spreading center, each half's polarity matches its sister half on the other side of the center. To study paleomagnetism means to study the magnetic polarity of bands of rock. When we find matching bands on either side of a mid-ocean ridge, we can assume that those bands formed together from the same magmatic event and have been split by seafloor spreading.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What is the relationship between the mid-Atlantic ridge and the puzzle-like fit of Africa and South America?

The Mid-Atlantic Ridge is a spreading center, called a divergent plate boundary. This active boundary has caused the continents of South America and Africa to rift apart and move to their present locations.

2. Describe the relationship between convergent boundaries and divergent boundaries on the Earth's crust. Use terms like subduction and spreading center in your description. How do these processes affect the size of the planet?

New rock is formed in the divergent boundaries, at the spreading centers. Old rock is drawn back in to the Earth and melted at the convergent boundaries in the subduction zones. In this way, the size of the planet does not change.

3. Describe how the crystals in magnetite are "frozen" into the magnetic field in the basaltic rocks that make up the oceanic crust.

While the magnetite is in a molten state, the molecules are free to move around. Since they are magnetic, they line up with the magnetic field within the Earth just like a compass needle lines up with the north magnetic pole. As the magnetite cools, the molecules form their solid matrix in the same orientation they were in while molten.

Multiple Choice Questions

1. According to the seafloor spreading theory, the oldest rock on the seafloor is located ______________________.

- **A. Near the continents**
- B. In the center of the ocean floor
- C. Halfway between the center of the ocean and the continents
- D. Near the North Pole
- E. Rock is the same age everywhere on the seafloor

2. Why do Earth's plates move?

A. They are blown by the wind.

B. They are pushed apart by the formation of new rock at spreading centers.

C. The less dense oceanic crust float on top of the more dense continental crust.

D. The continents float on the surface of the ocean.

E. All of the above are correct.

3. Magnetic patterns associated with mid-ocean ridges are configured as:

A. Concentric circles around a rising plume of hot, mantle rocks and magma

B. Reversed magnetizations along the rift valleys and normal magnetizations along the trench

C. Normal and reversed magnetized strips parallel to the ridge axis (spreading center)

D. Normal and reversed magnetized strips perpendicular to the ridge axis (spreading center)

E. Both A and D are correct

4. Which of the following provides evidence for seafloor spreading?

A. Volcanic eruptions

B. Lithosphere

C. Asthensophere

D. Paleomagnetism

E. Both B and C are correct

5. When do the magnetic particles in rock align themselves with the magnetic north pole?

A. During erosion

B. When the rock is formed

C. It takes about 100 years after the rock is formed for magnetic aligning to take place

D. Rocks do not contain magnetic particles

E. Both A and C are correct

Key Term Challenge

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

1. When seafloor spreading occurs, new basaltic **crustal** material is added to the seafloor. This material is **molten** when it is extruded at the spreading center. Since **basalt** contains iron, it is aligned with the Earth's magnetic field when it cools below the **Curie** point; thus, when the **iron** cools it is magnetized by the magnetic field of the Earth. So the magnetic field that forms at any time on the seafloor is **aligned** with the Earth's magnetic field at that time.

2. The Earth's magnetic field reverses at **irregular** intervals lasting tens of thousands of years. When a reversal does occur, basaltic material formed at the **spreading center** is orientated magnetically **opposite** the rocks that previously formed. This discovery led to the understanding that the Earth's **magnetic field** reverses—the magnetic north pole becomes south and the magnetic south pole becomes north. Magnetic **polarity** reversals provide further evidence of seafloor spreading. Scientists measure the magnetic polarity of the ocean floor using **magnetometers** that record the strength and direction of the magnetic field in the region.

Extended Inquiry Suggestions

Students may want to explore maps of the known magnetic field patterns on the seafloor.

Students can investigate the equipment and methods used to map the seafloor. A simple search for oceanographic exploration vessels will yield ample resources.

An advanced project would include an investigation of the relationship between the location of the rift zones and the relative distance to the center of the Earth at those areas. Why are divergent plate boundaries under the oceans?

The Living World

10. Modeling an Ecosystem

Objectives

To use terrariums as a closed system to design and sustain a stable ecosystem, students:

- Configure multiple, interconnected terrariums in which they design and conduct investigations of the interrelationships of biotic and abiotic structures in ecosystems
- Learn to use this closed system to change one variable at a time, control other variables, and monitor multiple variables simultaneously

Procedural Overview

Students design, execute, and analyze controlled investigations using sensor technology to monitor independent and dependent experimental variables.

Time Requirement

♦ Preparation time	60 minutes
♦ Pre-lab discussion and activity	60 minutes
♦ Lab activity	Several days to several weeks

Materials and Equipment

For each student or group:

- Data collection system (one or more per group, depending on the experimental design)
- Oxygen gas sensor [1]
- Carbon dioxide sensor[1]
- Temperature sensor[1]
- pH sensor [1]
- Conductivity sensor[1]
- Weather sensor[1]
- Water quality colorimeter[1] and sample vials (nitrate and ammonia recommended)
- USB hub (depending on data collection system)[2]
- Sensor extension cable
- EcoZone™ System
- Different types of living organisms [3]
- Strong incandescent or full-spectrum fluorescent light source
- Plant seeds or seedlings, or moss
- Water, dechlorinated (quantity depends on design)
- Pollution source[4]
- Compost or soil

[1]These are a sample of the sensors for this student-designed activity. Not all are needed for a successful experiment.

[2]To determine if a USB hub is required, refer to the data collection system Tech Tip file.

[3]See the Lab Preparation section for suggestions of live organisms students can use.

[4]See the Lab Preparation section for information on how to create pollution sources using fertilizer, HCl (or white vinegar), and detergent.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Most food energy originally comes from sunlight.
- ♦ During photosynthesis, carbon dioxide gas is consumed and oxygen gas is released. Photosynthesis requires light energy, generally from the sun.
- ♦ During cellular respiration, oxygen gas is consumed and carbon dioxide gas is released. Cellular respiration occurs continuously in living cells.
- ♦ Human beings are part of the earth's ecosystems. The activities of people can alter the equilibrium in ecosystems.
- ♦ To identify the independent variable, ask "What do I change?"
- ♦ To identify the dependent variable, ask "What do I observe?"
- ♦ To identify the controlled variables, ask "What do I keep the same?"

Related Labs in This Guide

Prerequisites:

- ♦ Weather in a Terrarium
- ♦ Photosynthesis and Cell Respiration in a Terrarium

Labs conceptually related to this one include:

- ♦ Monitoring Water Quality
- ♦ Photosynthesis and Primary Productivity
- ♦ 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 your data collection system�(2.1)
- ♦ Using an extension cable�(2.1)
- ♦ Connecting multiple sensors to your data collection system�(2.2)

- Calibrating a CO_2 gas sensor �(3.1)
- Calibrating a dissolved O_2 sensor �(3.3)
- Calibrating an O_2 gas sensor �(3.5)
- Calibrating a pH sensor �(3.6)
- Calibrating a turbidity sensor �(3.7)
- Setting up a conductivity sensor for a particular measurement range �(4.2)
- Changing the sample rate �(5.1)
- Starting data recording �(6.2)
- 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 �(7.1.3)
- Selecting data points in a graph �(7.1.4)
- Finding the values of a point in a graph �(9.1)
- Measuring the distance between two points in a graph �(9.2)
- Saving your experiment �(11.1)

Background

The term "ecosystem," coined by British botanist Roy Clapham in 1930, refers to any system of living, or biotic, organisms that functions with non-living, or abiotic, chemical or physical factors in the environment. The central idea behind the ecosystem is that all biotic organisms are continually engaged in a relationship with other biotic and abiotic components. The ecosystem develops as a product of each organism's relationship with every other organism. Ecosystems are highly sensitive to change, and introducing new elements can have dramatic effects on both the biotic and abiotic organisms present.

An environment does not have to be large or exotic to be considered an ecosystem. A system as small as a single plant and soil, or one as large as a rainforest, can be considered an ecosystem. Any ecosystem is governed by the sum of individual responses from all organisms in the ecosystem. Prominent ecosystems include the Amazon Rainforest, the Great Barrier Reef, and Yellowstone Park.

In this activity, students will be asked to design 3 individual chambers which will be interlinked. There are many types of environments they could attempt to emulate including aquatic, decomposition, and terrestrial ecosystems. They can add living organisms to their design, including plants, fish, and insects and they can use different soil types and organic material in the different chambers.

It is important to first brainstorm and then clearly identify what to put into each terrarium prior to setting up the activity. Things they should keep in mind include: 1) the type of water to add (for example, distilled, tap, or from a local water source), 2) the types of living organisms to add to the ecosystem and how they will be obtained, 3) soil sources and how the soil will be obtained, and 4) the parameters they want to monitor.

Pre-Lab Discussion and Activity

Engage students by explaining that they will be creating 3 interactive mini-ecosystems and monitoring several parameters in those ecosystems for several days. These ecosystems will not interact with the external environment. Make students aware that they will be responsible for designing the entire experiment.

Let the students know that you will provide the technology, a few resources, and a basic guideline for the activity, but you will not provide step-by-step instructions on how to complete it. Discuss the following questions before you pass out the Student Inquiry Worksheet for this activity.

1. What is required to create an ecosystem in a terrarium to maintain life?

The resources required for setting up an ecosystem to maintain life depend on the organisms living in that ecosystem. The typical terrestrial chamber may contain several plants and snails, worms, or insects. These plants will need sufficient CO_2 and light to perform photosynthesis, as well as sufficient water. Snails, worms, and insects will require sufficient food sources.

The typical aquatic chamber may contain aquatic plants, which will likewise require sufficient light to stay healthy. High levels of dissolved oxygen and a food source are necessary to maintain any aquatic life, such as fish or snails.

A decomposition chamber should only require decomposing material in order to sustain any decomposers.

2. Can the quality of life in one chamber affect the quality of life in adjoining areas?

Yes. If a pollutant is added to the terrestrial chamber, polluted water will wick from this chamber to the remaining chambers. This polluted water will affect the water quality of the aquatic chamber. In the same way, high levels of waste from aquatic organisms in the aquatic chamber (such as ammonia) can wick to the terrestrial chamber, damaging plants. Gases from the decomposition chamber, particularly CO_2, are necessary to maintain healthy plants in the terrestrial chamber, but high concentrations of these gases may affect the dissolved oxygen content of the aquatic chamber after time.

3. Brainstorm to obtain a broad list of materials students may need to put into the terrariums.

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity. Highlight the most important components of an ecosystem—sufficient energy for all factors, reasonable competition for resources, et cetera.

Student suggestions should include a variety of live organisms, soil, and plants.

Continue the discussion by asking students these questions:

4. How can we link individual ecosystems together and still keep them isolated from the classroom environment? Why is this important?

If we are trying to see how the biotic and abiotic components of the *students'* designed ecosystem are working together, we need to eliminate as many outside variables as possible.

The EcoZone™ chambers have coupling devices that allow the 3 separate chambers to become affixed to each other and be sealed from external conditions. If you are using another system (such as 2-liter bottles) you will need to devise a way to create a seal.

5. How can we measure conditions inside the chambers? What types of parameters would we *want* to monitor? How are these parameters dependent upon what is placed in each of the chambers?

Placing sensors into the special holes pre-drilled in the EcoZone chambers will allow us to monitor different measurements inside the chambers without exposing them to external conditions.

Ideas for useful parameters may include: oxygen gas, dissolved oxygen in water, carbon dioxide gas, ammonia and nitrate levels in water, temperature, humidity, pH, conductivity, and light intensity.

Some of these parameters may be more important to monitor than others, depending on your setup. For example, if you do not have terrestrial plants or animals, gaseous CO_2 or O_2 may not be as important to monitor as dissolved oxygen levels.

6. Based on the ideas we have generated, will we be monitoring an open or a closed system?

Based on the information discussed so far, students will be attempting to create a closed system. However, it is difficult to create a 100% perfectly closed system, especially when student intervention may be required to keep organisms alive. The experimental designs should attempt to keep external environmental influences to a minimum.

7. We will be adding a pollutant to the ecosystem to simulate some effects people have on ecosystems. What pollutants could we add? If we add it to one of the chambers, will it affect them all?

There are many different kinds of pollutants that can be used to simulate some effect people have on ecosystems. Examples are: fertilizers, petroleum, detergent or simulated acid rain. Adding pollutants to one of the chambers will affect all of the chambers over time either directly or indirectly and may have either positive or negative influences.

After all students have been able to participate in the brainstorming activity, inform them of the materials that you will be providing. Also, discuss the following ideas for creating different types of chambers.

a. Terrestrial chamber suggestions:

- ♦ To avoid opening the chamber to water any plants, soak a sponge or peat moss and place it in the chamber.
- ♦ Suggest that students use quick sprouting seeds or moss.
- ♦ Use regular dirt instead of potting soil to establish baseline nitrogen, ammonia and phosphate levels before adding the fertilizer or other pollutant.
- ♦ Provide a light source.
- ♦ Snails, worms and insects are appropriate organisms to add to the chamber.

b. Aquatic chamber suggestions:

- ♦ Add a dechlorinator to tap water during set up.

- ♦ Add a biotic conditioner to the water to begin with a healthy, balanced, bacterial population prior to adding animals such as fish and aquatic snails.
- ♦ Add aquatic plants to the water to help maintain healthy dissolved oxygen levels.

c. Decomposition chamber suggestions:

- ♦ Add some rich compost or soil to the bottom of the chamber.
- ♦ Worms, crickets, and other small invertebrates will do well in this chamber.

Allow students to break into groups and design their experiment. They can record their design on the student worksheet. Encourage students to draw labeled diagrams that show what substances will be in which container, and which sensors will be placed in each container. Encourage them to bring in additional items from home on the day they will set up the experiment.

Lab Preparation

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

Note: Students should be experienced using the EcoZone chambers and in developing hypotheses and designing experiments, using a chamber, to test their hypotheses. "Weather in a Terrarium" or "Photosynthesis and Cell Respiration in a Terrarium," or both, should be completed prior to carrying out this activity.

Suggestions for live organisms

1. Terrestrial chamber: snails, worms and insects
2. Aquatic chamber: aquatic plants, fish, aquatic snails
3. Decomposition chamber: worms, crickets, and other small invertebrates
4. Other types of chambers: students can create other biosystems

Prepare a "pollutant"

1. "Fertilizer pollutant": Dissolve 10 g of solid granulated fertilizer into 1 L of water.

Note: It is suggested that you add the fertilizer as pollutant if you are using the water quality colorimeter to monitor nitrate levels.

2. "Acid rain": Use 1.0 M HCl to represent acid rain.

   To prepare 100 mL of 1.0 M hydrochloric acid solution, adding 16.6 mL of concentrated HCl per 100.0 mL of solution. Pour the concentrated HCl into about 80 mL of water and bring the solution up to 100 mL with water. Do not pour water into the concentrated acid.

Note: For "acid rain," you can substitute household white vinegar if you do not have 1 M HCL.

3. Industrial or home runoff: Detergent

   To prepare the detergent, mix 10 mL of liquid soap in 100 mL of water.

Teacher Tip: You may want to have students adjust the sample rate of the sensors to record data points once every ten minutes or once every hour, to reduce the number of data points being collected and to prevent the data collection systems memory from becoming filled.

Teacher Tip: In most cases, the ecosystems students design will fail. Lack of sufficient light is one of the most common reasons that plants within the ecosystem die. Position the EcoZone System as close to a natural light source as possible, or have ample artificial light. Consider allowing your students to modify the ecosystem after it is set up to increase the time the ecosystem will sustain itself.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Consult the manufacturer's material safety data sheets (MSDS) for instructions on handling, storage, and disposing of hydrochloric acid. (You can find these on the Internet.) Keep these instructions available in case of accidents.
- ♦ Do not touch the hydrochloric acid (HCl). Handle the pipet with HCl with extreme care.
- ♦ After completing the lab, wash your hands.
- ♦ Wear safety glasses and lab coats or aprons.

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	1	3	5
Design your experiment: determine your question and the ecosystems and parameters to measure in order to answer the question.	Set up the data collection system to record data.	Brainstorm ways to set up the EcoZone chambers.	Gather your materials and set up the chambers, including all materials and sensors.	Repeat the procedure, changing the independent variable.

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.

There are three chambers to the EcoZone System. Each of these chambers can be filled with any abiotic material or living organism you can bring in from home or that your teacher can provide for you.

Discuss with your team the important factors in building an ecosystem. Remember that adding live organisms to these zones means you are responsible for providing them with all of the necessities of life.

Part 1 – Design your experiment

1. ☐ Write a brief outline of the procedure you will use to set up the EcoZone chambers and collect data. Include the following information:

a. What are your principle design considerations (what is the goal of your experiment)?

The purpose of this lab is for students to design and sustain a stable ecosystem. In this example the students

1. Monitor the interaction of the abiotic and biotic components of each chamber and the relationship between the 3 chambers. (How does a closed, controlled environment behave?)

2. Monitor the affects of pollutants, such as fertilizers, on water quality— how do fertilizers affect pH, dissolved oxygen, ammonia, phosphate, and nitrate levels?

3. Monitor the affects of fertilizer on plant health, including subsequent oxygen and CO_2 cycling.

b. What are the independent variables? What are the dependent variables? What are you keeping the same? What parameters will you measure?

The independent variable is the fertilizer. The dependent variables are the nitrate, ammonia, and phosphate levels of the water in the aquatic chamber, and the plant health in the terrestrial chamber.

The parameters being measured specifically for the purpose of monitoring the water quality of the aquatic chamber are:

♦ Nitrate levels, phosphate levels, ammonia levels, dissolved oxygen, pH

The parameters being measured specifically for the purpose of monitoring plant health in the terrestrial chamber, in conjunction with visual data, are:

♦ Oxygen gas levels, carbon dioxide gas levels

c. What are the biotic and abiotic components you are adding to each chamber?

Terrestrial Chamber

♦ Biotic components include the small fern and crickets.

♦ Abiotic components include the soil, outside light sources (lamp and building lights), and a portion of the cotton wick from the aquatic chamber.

Aquatic Chamber

♦ Biotic components include the Elodea and orange platyfish.

♦ Abiotic components include the aquarium rocks, deionized water, and a portion of the cotton wick from the terrestrial chamber.

Decomposition Chamber

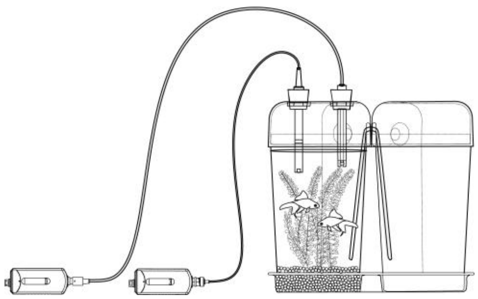
♦ Biotic components include moss and lichens.

♦ Abiotic components include dead sticks and leaves with signs of moss and lichens.

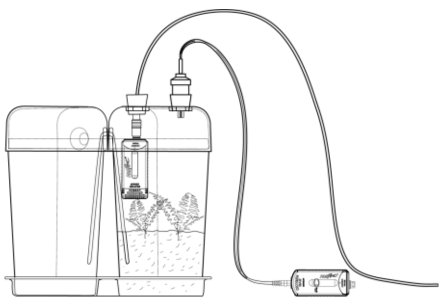
Note: Part of your experiment should determine the effect of the addition of a pollutant.

2. ☐ Draw a diagram of the experimental setup you will use. Be sure to label the biotic and abiotic materials in each chamber and the sensor or sensors that will be in each chamber.

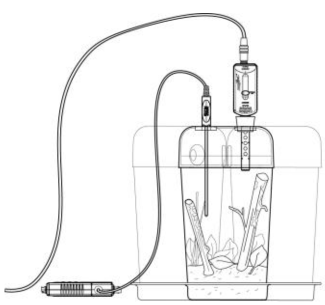
Aquatic chamber



Terrestrial chamber



Decomposition chamber



3. ☐ What roles will you and your research team play in creating, monitoring, and analyzing the EcoZone system?

Students can divide the responsibilities for the different aspects of this experiment among the group members.

4. ☐ Will the system remain closed? Will you open the system periodically to water plants or feed organisms? How will you account for your influence on the system if it is opened?

Students should plan to leave the system closed for as long as possible to limit any external environmental changes to the ecosystem but should keep in mind that it is their responsibility to provide everything needed for life to thrive in their ecosystem. If students choose to open the system periodically, they should do it as consistently as possible and document each opening. This will allow students to properly analyze their data later.

Part 2 – Set up your experiment and collect data

5. ☐ Calibrate sensors that require calibration, according to the instructions provided with the sensor.

Note: Keep the file open that contains this calibration information. The sensor calibration remains with the file that was open when you performed the calibration.

6. ☐ Why is it necessary to calibrate sensors?

You need to calibrate the sensors with an external standard so measurements can be reliably compared between groups and when collected at different times or using different sets of equipment. Otherwise, any changes that take place in the EcoZone system are only relative.

7. ☐ Add the materials to each chamber.

8. ☐ Seal the chambers so they are airtight.

Hint: One way to be sure that the terrarium is airtight is to exhale several times into the empty chamber to raise the CO_2 level of the air in the terrarium relative to the room air. Then seal the terrarium and monitor the CO_2 level for several minutes with a carbon dioxide gas sensor. After the reading stabilizes, the level should not drop. If it does, you probably have a leak. Once you have learned how to make the terrarium airtight, use this procedure in your investigations.

9. ☐ Insert the sensors and begin collecting data. Collect data for at least 24 hours. Your teacher may want you to monitor data for an extended period of time.

Note: For longer investigations, you may need to decrease the sampling rate of the sensors. Choose a time interval that will provide adequate information while limiting the number of data points collected to a practical quantity. �(5.1) For example, if you choose to monitor the terrarium for 24 hours, you might set the sampling rate to 1 sample every 10 minutes. Or if you choose to monitor for a week, you might set the sampling rate to 1 sample every 30 minutes.

Note: Take detailed notes about the status of your chambers, including the live organisms, daily. Do not wait for an organism to begin dying to intervene – you can manipulate the chambers as you see fit during the experiment as long as it is properly documented.

Part 3 – Add a pollutant and monitor data

10. ☐ After a minimum of 24 hours of data collection, add the pollutant provided by your teacher to at least one of the chambers.

11. ☐ Why do you need to wait 24 hours before adding a variable?

Waiting for 24 hours before adding or changing any variables ensures that there is a control to compare changes to after the addition of that variable. For example, if you add fertilizer to the terrestrial chamber, the control data will provide a baseline for nitrate readings and plant health so you can detect changes as the fertilizer begins to affect the chambers.

12. ☐ What type of pollutant did you add to your system? What chamber did you add the pollutant to?

Many students will likely choose to use fertilizer, as runoff from yards and parks is common and familiar. Fertilizer should be added to the terrestrial chamber. Simulated acid rain will likely be added to the aquatic chamber and detergent may be added to the terrestrial chamber. In general, no pollutants will be added to the decomposition chamber.

13. ☐ What effect do you think the pollution will have on the measurements being recorded in each chamber?

Adding fertilizer to the terrestrial chamber will cause any plants in that chamber to grow more rapidly but may potentially kill any organisms with wide exposure to the ground water. The plant itself may die if the nitrogen concentration rises too high. In turn, the polluted water will wick to the aquatic chamber and cause a decrease in water quality.

14. ☐ Why is the substance you added to the chamber considered a pollutant?

Fertilizers and detergent are considered pollutants in water systems because if too much phosphorus and nitrate (found in fertilizer) enter a body of water, the result can be an overabundance of plant growth, commonly seen as an “algal bloom.” Later these abundant plants die off and cause rapid eutrophication.

Acid rain causes acidification of lakes and streams. It also reduces crop productivity and forest growth rates and can accelerate 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.

Data Analysis

1. ☐ Record any changes made to your experimental design, or any time the system was opened to the external environment

In this example there was no change to the experimental design and the chamber was opened only after the pollutant was introduced.

2. ☐ Create a table below that displays data you feel is relevant for others to know about the experiment *before* the pollutant was added. Below the table, add comments regarding the conditions in the chambers throughout the course of the experiment.

Measurements before adding pollution

Parameters Measured	Initial Measurement	Measurements After 24 Hours
Nitrate	0.00 mg/L	0.19 mg/L
Ammonia	0.00 mg/L	0.10 mg/L
Phosphate	0.09 mg/L	5.89 mg/L
CO_2	3277 ppm	11738 ppm
pH	7.37	7.23
Relative Humidity	66%	87%

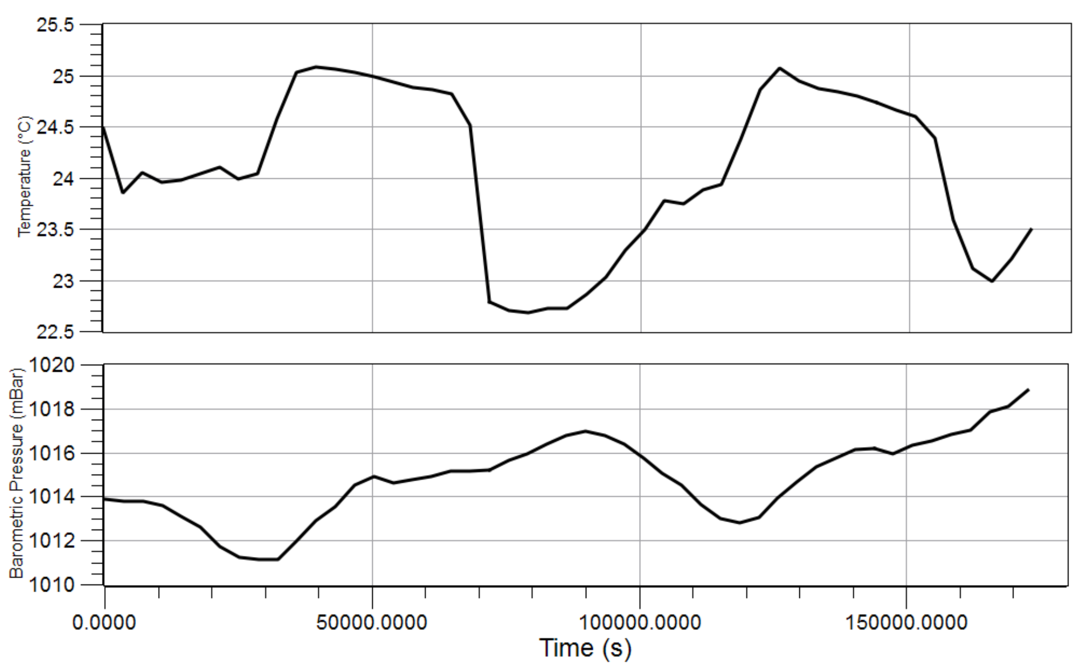
It was noted that the percent oxygen concentration remained fairly stable throughout the experiment. Also, temperature and barometric pressure appear to be cyclic, and will be shown in a graph. The system was not opened at all for the 24 hour time period that was recorded. At the end of the time period, there was a large amount of water that had wicked from the aquatic chamber and pooled in the terrestrial chamber, which is probably related to the increased humidity. Also, there was a large spike in phosphates, which is probably related to dissolved minerals from the gravel.

3. ☐ Create a table below that displays data you feel is relevant for others to know about the experiment *after* the pollutant was added.

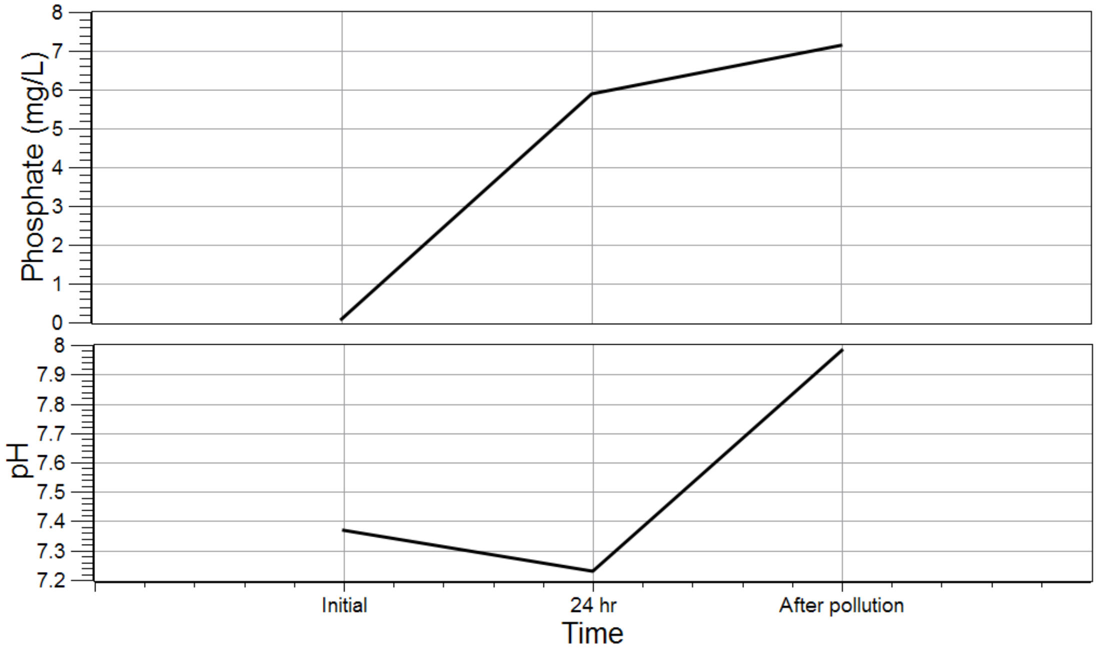
Measurements after adding pollution

Parameters Measured	Initial Values	Measurements After 24 Hours	Measurements After Fertilizer Addition
Nitrate	0.00 mg/L	0.19 mg/L	0.22 mg/L
Ammonia	0.00 mg/L	0.10 mg/L	0.00 mg/L
Phosphate	0.09 mg/L	5.89 mg/L	7.15 mg/L
CO_2	3277 ppm	11738 ppm	11756 ppm
pH	7.37	7.23	7.98
Relative Humidity	66%	87%	89%

4. ☐ Graph the set of data that changed the most over the period of data collection prior to adding the pollutant.



5. ☐ Graph the set of data that changed the most after the pollutant was added.



Analysis Questions

1. Describe any significant changes you observed in the chambers during the course of the experiment

Answers will vary depending upon the setup and the pollutants added to the system. Assuming students choose the typical decomposition: terrestrial, and aquatic arrangements for the three chambers, and add fertilizer to the system, changes in the nitrate concentration of the water in the aquatic chamber should be observed – particularly watching for an increase in nitrate concentration and possible organism death. Plant health in the terrestrial chamber should increase until the fertilizer concentration is too high.

2. What parameter changed the most prior to adding the pollutant? Explain why you think that factor changed the most.

Answers will vary depending upon the set up. In general, the only significant changes should be in humidity as the water evaporating from the aquatic chamber or wicking into the terrestrial chamber no longer has an open-air source.

3. What parameter changed the most after the pollutant was added? What is the significance of this?

Answers will vary depending upon the pollutant added. In general, pollutants of any type will affect the water and soil quality of the aquatic and terrestrial chambers. In many cases, the decomposition chamber will not be drastically affected until the organisms facilitating plant decay are killed.

4. The pollutant may, or may not, have affected your chambers.

a. If there was a significant change, what further tests would you want to conduct to determine if the pollutant was the sole cause of the change?

Students may suggest setting up an environment WITHOUT living organisms in it to verify that the pollution was the source of any changes.

b. If there was no significant change, what further tests would you want to conduct to determine if the concentration of the pollutant is important?

Students may suggest increasing the amount, or type of pollutant added to the system, or adding it to a different chamber.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Design an additional study to determine how a different pollutant could affect the ecosystem. What pollutant would you use? What changes would you expect to see? How would you measure those changes?

Answers will vary depending upon the original pollutant added to the ecosystem. If HCl is added to simulate acid rain, the ezSample testing kit for chlorine can be used in conjunction with monitoring the pH. If detergent is being added as a pollutant, the phosphate ezSample testing kit can be used.

2. Consider the type of pollutant you added to your system. Where could you find a similar pollution source in a natural environment?

Fertilizers would be found in creeks or lakes close to houses or agricultural areas. For example, houses adjacent to creeks will cause considerable runoff to enter the creek from fertilizers used in the backyard.

Detergents may also enter creeks and lakes from residential areas but are more likely to enter from industrial areas. Acid rain will also pollute creeks, lakes, and ground water and may be caused by a variety of environmental and man-made factors. The major source of nitrogen oxide gas, a cause of acid rain, is nitrogen-bearing fuels such as certain coals and oil. Natural sources of nitrogen oxide gas include volcanoes and biological decay.

3. Agricultural farming typically requires fertilizer to be added to the soil to ensure high quality crops. Rain and runoff wash excess fertilizers into local waterways. Based on your experience, what type of positive and negative consequences could result from this runoff?

Fertilizers applied sparingly and appropriately produce crops that have high yields which means they can feed more people per square acre than low yield crops. Run off into rivers and streams can also supply nutrients to plants in naturally occurring areas, which can provide denser habitat and food sources for native species.

High levels of nitrates and phosphate in water often lead to large, rapid development of aquatic plants, and algal blooms. Eventually the limiting nutrients are consumed by the new growth, and if the fertilizer runoff stops, the algae and plants can die, leading to rapid deoxygenation of the water and eutrophication of the waterway. Fertilizers that run off into natural waterways often end up concentrating nitrate and phosphates to levels that can be toxic to living organisms.

Multiple Choice Questions

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

1. **Which of the following are considered consumers?**

- **A.** Green plants
- **B.** Photosynthetic protists
- **C.** **Parasites associated with plants and animals**
- **D.** Chemosynthetic bacteria

2. **Bacteria found in the soil are important in which of the following cycles?**

- **A.** The water cycle
- **B.** The carbon cycle
- **C.** **The nitrogen cycle**
- **D.** The phosphorus cycle
- **E.** All of the above

3. **The transitional zone found between two adjacent ecosystems is called the:**

- **A.** Community
- **B.** Biome
- **C.** **Ecotone**
- **D.** Optimum
- **E.** Zone of tolerance

4. **What types of organisms are found in the first trophic level in an ecosystem ?**

- **A.** All heterotrophs
- **B.** Carnivores
- **C.** Herbivores
- **D.** **All autotrophs**
- **E.** A and B

5. **Which of the following is not a natural process that occurs in ecosystems?**

- **A.** **Production of pollutants**
- **B.** Erosion control and topsoil building
- **C.** The control of the earth's climate
- **D.** Maintaining of biogeochemical cycles
- **E.** Regulation of global carbon dioxide

6. Ecosystems are comprised of which of the following components:

- **A.** Living organisms only
- **B.** Non-living structures in the environment only
- **C. Both biotic and abiotic factors**
- **D.** Flora and fauna
- **E.** Fauna only

Extended Inquiry Suggestions

Revise the system. In many cases, the organisms within the ecosystems will die over the course of a two-week experiment. Ask students to compare the various ecosystems that were built and revise their own ecosystem to better support life.

Set up a single chamber to observe and measure the life cycle of an organism. For example leave the chamber open with cut pieces of fruit. Once you see fruit files on the fruit, close and seal the chamber. Include any sensors you see as appropriate (for example, temperature, humidity, oxygen and carbon dioxide gas). Observe the files over a two week period. The females in your trap will lay eggs, and in a few days the eggs will hatch. Watch for the different stages – eggs, larvae, pupae, fruit fly. The entire life cycle is only about 2 weeks. After two weeks consider using your fruit fly colony to feed a predator species like a spider.

Model existing Biomes: Create the conditions that model specific biomes within a single ecochamber. For example, create a desert biome which includes the plants, animals, and environment of a desert. Monitor the conditions that are present in a specific desert (a tropical desert versus a temperate desert).

Model the same ecosystem with different conditions. Build the same ecosystem in two different chambers and put them in separate environments. For example, build two decomposition ecosystems and put one in warm dark conditions, and the other in cold light conditions.

Have students research large-scale ecosystem modeling projects like the Biosphere Project. Have them discuss why it is so difficult to build, measure and maintain a balanced ecosystem.

11. Photosynthesis and Primary Productivity

Objectives

Students determine the primary productivity of an aquatic plant.

Procedural Overview

Students will gain experience conducting the following procedures:

- Use a dissolved oxygen sensor to measure the rate of change in dissolved oxygen concentrations in a closed chamber while exposing an *Elodea* plant to bright light and in darkness.
- Calculate the net primary productivity (NPP) rate, cellular respiration (R) rate, and gross primary productivity (GPP) rate.
- Estimate the total GPP, R, and NPP of the *Elodea* plant if maintained in the experimental condition for 24 hours.

Time Requirement

♦ Preparation time	1 to 3 hours (depending on the availability of *Elodea sp.* plants)
♦ Pre-lab discussion and activity	50 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dissolved oxygen or water quality sensor
- Photosynthesis tank
- Rubber stopper, #3 (included with photosynthesis tank)
- *Elodea sp.* plant (several sprigs)
- Magnetic stirrer and stir bar
- Black cloth, opaque, 50 cm x 50 cm
- Lamp, 100 W or high-intensity
- Dechlorinated tap water, 1 L[1]
- Ice (optional)

Alternative to the photosynthesis tank:

- Shallow pan or dish, large
- Large base and support rod
- Mineral oil
- Erlenmeyer flask, 250-mL
- 3-finger clamp

[1]Methods for dechlorinating tap water are detailed in the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Most food energy comes originally from sunlight.
- Plants use light energy to make sugars from carbon dioxide and water, releasing oxygen gas as a byproduct.
- Plants can make their own food and use it immediately or store it to use later.
- The cells of green plants, but not animals, contain chloroplasts, which are organelles in which photosynthesis takes place.
- Chlorophyll, a molecule found in chloroplasts, is required for the process of photosynthesis; chlorophyll is responsible for the green color of plants and algae.
- During photosynthesis, carbon dioxide gas is consumed and oxygen gas is released.
- During cellular respiration, oxygen gas is consumed and carbon dioxide gas is released.
- To identify the independent variable, ask "What do I change?"
- To identify the dependent variable, ask "What do I observe?"
- To identify the controlled variables, ask "What do I keep the same?"

Related Labs in This Guide

Prerequisite:

- Cellular Respiration and the Carbon Cycle

Labs conceptually related to this one include:

- Photosynthesis and Cell Respiration in a Terrarium

Using Your Data Collection Systems

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)
- 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]

- Finding the values of a point in a graph �[9.1]

- Finding the slope and intercept of a best-fit line �[9.6]

- Saving your experiment �[11.1]

Note: Provide for reference to your students the user manual for the dissolved oxygen sensor or water quality sensor.

Background

Primary productivity is principally the production of carbohydrates from carbon dioxide gas, electromagnetic radiation from the sun, and water, through the process of photosynthesis. All life on Earth is directly or indirectly reliant on primary production. The organisms responsible for primary production are known as primary producers, or autotrophs, organisms that can make their own food, usually through the process of photosynthesis. These primary producers form the base of the food chain, functioning at the first trophic level.

In terrestrial ecosystems, autotrophs are primarily vascular plants. In aquatic ecosystems, primary producers include photosynthetic bacteria, phytoplankton (single-celled photosynthetic aquatic organisms), multicellular algae, and vascular plants, such as *Elodea sp*. Most photosynthetic autotrophs contain chloroplasts, organelles that contain chlorophyll and in which photosynthesis takes place.

It has been estimated that aquatic autotrophs carry out about 50% to 70% of the primary production on Earth. Although most of the autotrophs are consumed by zooplankton or aquatic animals, some of the organic material in dead autotrophs sinks to the ocean floor and remains there for as long as millions of years. This entombed organic carbon material is an important carbon sink in the global geochemical carbon cycle.

In this part of the carbon cycle, carbon dioxide (CO_2) from the atmosphere is captured by aquatic autotrophs and sequestered in solid form at the bottom of the ocean, removing it from the carbon cycle indefinitely. Scientists are currently trying to better quantify this carbon sink because it affects levels of atmospheric CO_2 concentrations and thus its greenhouse gas effect, as well as the level of dissolved CO_2, which affects the pH of oceans.

Aquatic plants and photosynthetic microorganisms release oxygen gas (O_2) (the byproduct of photosynthesis) into the water, where it dissolves and forms dissolved oxygen gas (DO). Water can hold only a limited amount of dissolved O_2. When the concentration of DO reaches a certain level (saturation), the DO diffuses (or out-gases) into the air as O_2 gas. When all other conditions remain constant, cold water will hold more dissolved gasses than warm water.

Primary productivity can be expressed as gross primary productivity (GPP) or net primary productivity (NPP). Net primary productivity is the total amount of carbohydrates produced in the ecosystem (the GPP) minus the carbohydrates consumed by the producers for their own aerobic cellular respiration (R). Net productivity reflects the carbohydrates available to other organisms in the ecosystem. Net primary production is the excess food produced by autotrophs that is available for consumption by other organisms in the food chain. The equation for calculating NPP is: $NPP = GPP - R$.

Pre-Lab Discussion and Activity

Hold the following discussion with your students.

Emphasize that the process of photosynthesis is the chemical pathway by which all plants, and some protists and monerans, make food, specifically carbohydrates. The entire photosynthetic pathway is a complex series of biochemical transformations that take place in association with chlorophyll. During these transformations, hydrogen from water is added to molecules of carbon dioxide to make carbohydrates. The generalized equation for photosynthesis is

$$6CO_2 + 6H_2O + \text{electromagnetic energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

(carbon dioxide + water + energy → glucose + oxygen gas).

Remind students of the generalized equation for aerobic cellular respiration:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

(glucose + oxygen gas → carbon dioxide + water + potential chemical energy + heat)

Emphasize that for every molecule of glucose produced in photosynthesis, the plant gives off 6 oxygen gas molecules. Likewise, for every molecule of glucose used in aerobic cellular respiration, the plant takes up 6 molecules of oxygen gas. Thus, tracking oxygen gas molecules is a good way to measure rates of photosynthesis and aerobic cellular respiration.

Correct a misconception: Many students do not realize that the process of cellular respiration occurs in plants (and all living things) 24 hours a day in conditions of both light and darkness, whereas photosynthesis requires light energy to drive it.

Point out the contributions to primary productivity by both terrestrial and aquatic organisms.

Brainstorm reasons it might be important to determine global primary productivity. Ask students: What would happen to life on Earth if plants did not make more food than they need for their own life processes?

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the brainstorming activity.

Help students understand the relationship between net primary productivity (NPP), gross primary productivity (GPP), and cellular respiration (R).

NPP is GPP reduced by R. In other words, NPP is what is left over from GPP after subtracting what the plant (or system) needs for its own survival (R).

In this lab, students will determine the rates of GPP, NPP, and R for the *Elodea* plants. They will be asked to determine the GPP rate as expressed as the change in dissolved oxygen concentration over time. Help students develop the formulas they will use for this calculation (rates are in "mg dissolved $O_2/(L\cdot s)$":

$$GPP_{rate} = NPP_{rate} + R_{rate}$$

Emphasize the difference between measuring an amount (such as NPP) and measuring a rate (such as NPP rate). In the lab, students will measure rates (changes over time).

Remind students of two methods for determining rate: slope of a linear fit line and the 2-point method. If students have not studied these techniques, show them examples of each procedure.

Students will then estimate from the rate the amount of glucose (NPP and GPP) produced in a period of time (24 hours), assuming the plant was kept in light for 12 hours and in darkness for 12 hours. For this calculation, students will need to know the molecular weight of oxygen gas (32) and glucose (180).

You may want to challenge students to calculate the molecular weights of glucose and oxygen gas using their chemical formulas and a periodic chart of the elements.

Depending on their background preparation, students may need help with these computations. Provide them with the following example to help them become familiar with the use of the equations.

Dissolved oxygen concentration measured over a 10-minute period

Light Setup	Initial Dissolved Oxygen Concentration ([DO]) (mg/L)	Final [DO] (mg/L)	Total Change in [DO] (mg/L)
Bright light	8	11	3 (NPP)
Darkness	8	7	–1 (oxygen gas used in respiration)

NPP: measure of the carbohydrates produced during photosynthesis, determined by the change in dissolved oxygen concentration under lighted conditions.

R: measure of the carbohydrates used during respiration to release energy needed by the cell.

It is important to note that the absolute value of the change in dissolved oxygen concentration measured with the plant in darkness (which corresponds to R), is added to NPP to determine the total amount of carbohydrate synthesized by the plant (GPP).

The GPP is the total amount of carbohydrates produced in the ecosystem in ten minutes:

$$GPP = NPP + R$$

$$GPP = 3\ mg/L + 1\ mg/L = 4\ mg/L$$

To calculate the GPP rate in mg/(L·s):

$$GPP\ rate = 4\ mg/L \div (10\ min \times 60\ s/min) = 0.0066\ mg/(L\cdot s) = 6.6 \times 10^{-3}\ mg/(L\cdot s)$$

The rates for NPP and R can be similarly calculated. Then the total GPP, NPP, and R for other time periods can be estimated by multiplying the rate (in seconds) by the length of time in question (in seconds).

To express the total amount of carbohydrate (glucose) produced in the length of time in question, multiply the GPP by the ratio of the molecular weight of glucose (180) to the molecular weight of 6 oxygen gas molecules (193). (There is one glucose molecule produced per six oxygen molecules, as indicated by the photosynthesis equation.)

Lab Preparation

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

It would be best to complete the "Cellular Respiration and the Carbon Cycle" lab before doing this lab. In that activity, students focus on the chemical reactions involved in aerobic cellular respiration they need to understand in order to interpret their findings in this lab activity.

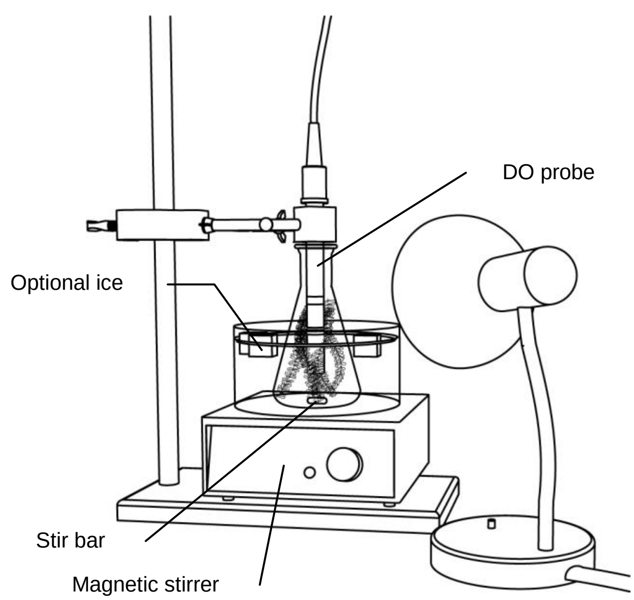
1. Obtain healthy *Elodea* plants from a store specializing in aquaria. Plan to use 1 bunch per student group. Store the plants in dechlorinated water with a pinch of $NaHCO_3$ (sodium bicarbonate, also known as baking soda). Store them near a sunny window or fluorescent light. These can be stored for several days.

Note: It is important to work with healthy *Elodea* plants.

To reduce the contribution of microorganisms to the effect measured, use fresh tap water that has been allowed to stand in an open container overnight or that has been dechlorinated (using a reagent from an aquarium supply store, for example).

2. Find the highest intensity lights that you can, such as those with a 100 W fluorescent bulb or a high-intensity halogen or incandescent light.
3. Ensure that the dissolved oxygen probes are in good working order (see the user manual for the dissolved oxygen or water quality sensor).
4. As an alternative setup, use an Erlenmeyer flask and a dish or beaker in place of the photosynthesis tank, as shown. To prevent out-gassing, drop a thin layer of mineral oil on top of the water in the flask.

Note: It is not necessary to calibrate the dissolved oxygen sensor for this activity because the measurements will be relative to each other, not related to standard measurements or intended for comparison with measurements by other groups.



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	5	1	4
Set up an airtight chamber that contains *Elodea* plants, water, and a stir bar. Position the end of the DO probe about 1 cm above the stir bar.	Add water to the cooling chamber. Position a bright light near the chamber and turn on the light. Turn on the stirrer. Record data for 15 minutes.	Determine the rate change of the DO concentration for the two experimental conditions. Determine the primary productivity of the plant.	Connect a dissolved oxygen (DO) sensor to your data collection system. (You do not need to calibrate the DO sensor.)	Turn off the light, and cover the chamber with a dark cloth. Continue data recording for 15 minutes.

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 dissolved oxygen sensor (or water quality sensor) to the data collection system. �(2.1)

3. ☐ Display Dissolved oxygen concentration (mg/L) on the y-axis of a graph with Time on the x-axis. �(7.1.1)

Note: Another way of indicating "dissolved oxygen concentration" is by using brackets around the abbreviation for dissolved oxygen, "DO" as follows: [DO].

4. ☐ Put a stir bar into the photosynthesis tank.

5. ☐ Put several sprigs of *Elodea* plant in the tank so that it is loosely full of the plant, and fill the tank to the top with dechlorinated tap water.

6. ☐ Put the large two-hole stopper into the top of the tank.

Note: Water will overflow into the outer chamber.

7. ☐ Fill the outer tank to within about 2 cm from the top with tap water.

8. ☐ Why are you putting water in the outer chamber?

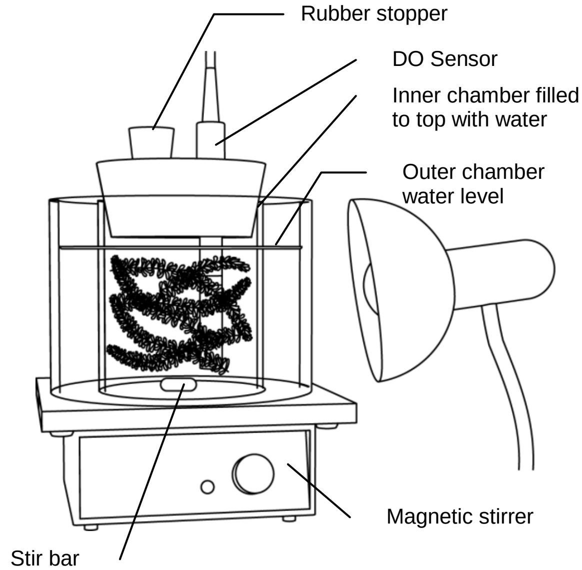
The water in the outer chamber will absorb heat from the light, maintaining a more constant temperature in the inner chamber.

9. ☐ Place the photosynthesis tank on the magnetic stirrer.

10. ☐ Remove the dissolved oxygen sensor from the storage bottle.

Be sure to remove the white cap from the sensor, being careful not to touch the membrane at the end of the sensor.

11. ☐ Insert the end of the dissolved oxygen probe carefully through the larger opening in the two-hole stopper. Push the probe down until the end is positioned just above the stir bar (within 1 cm of the stir bar) and so the end is not touching the plant.



Note: Positioning the end of the probe is important so that the vigorous motion of the water will knock any air bubbles off the end of the probe.

Note: If the plant obstructs the end of the probe, take the stopper out of the tank and rearrange the plant. You may need to add more water to ensure the tank stays completely full and to eliminate all air pockets.

12. ☐ Place the photosynthesis tank on the magnetic stirrer.

13. ☐ Put a #2 or #3 rubber stopper into the other hole of the large two-hole stopper.

14. ☐ Place the lamp very near the photosynthesis tank so the light will shine on the *Elodea* plant.

Collect Data

15. ☐ Turn on the magnetic stirrer to a high speed so that the water circulates in the tank.

16. ☐ Turn on the light to its brightest setting.

17. ☐ Why are you using a magnetic stirrer? *Hint:* Consult the user manual for the dissolved oxygen sensor.

The DO sensor uses up a small amount of DO in the process of measuring, which would create a microenvironment of reduced DO around the tip of the probe if the water were allowed to remain still.

18. ☐ Start data recording. �(6.2)

19. ☐ Adjust the scale of the graph so the data fills the graph vertically and you can better see the changes in concentration of DO while recording. �(7.1.2)

Note: The initial concentration of DO should be between 4 and 8 mg/L; if it is not in that range, check the DO sensor to be sure it is in good working order.

20. ☐ Continue to record data with the light on for 15 minutes. *Do not stop recording data!*

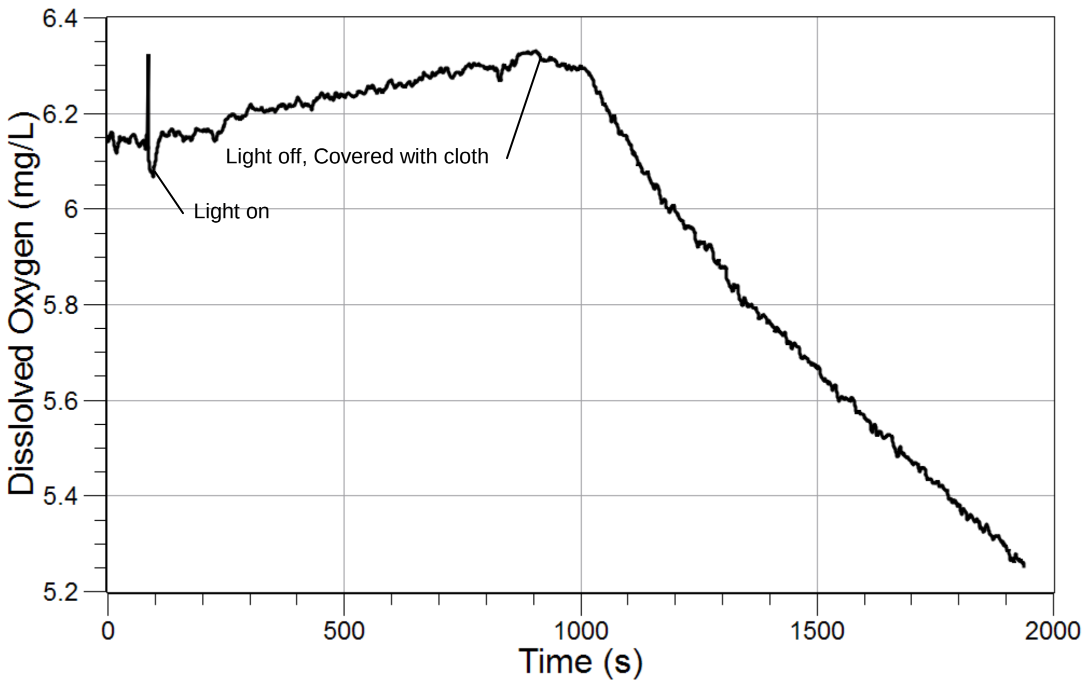
21. ☐ Turn the lamp off and carefully cover the setup with a black opaque cloth so the plant is in darkness.

22. ☐ Record data with the plant in darkness for 15 minutes, and then stop recording data. �(6.2)

23. ☐ Save your experiment. �(11.1)

Data Analysis

1. ☐ Draw a sketch of the Dissolved oxygen concentration versus Time graph. Label the x-axis and y-axis, including parameters and units as well as the point at which you turned off the light and covered the setup with the black opaque cloth.



2. ☐ Use your recorded data to find the rate of change in DO concentration when the light is shining on the plant and the rate of change in DO concentration when the plant is in darkness. Use 2 methods: 1) the slope of a linear fit line �(9.6) (7.1.4) and 2) the 2-point method. �(9.1) Show your work.

Answers will vary. Students should use the linear fit tool of the graph display to find the slope of selected regions of the graph that correspond to the two experimental conditions: light and darkness.

Answers will vary. Students should then use the graph tools to identify data points at the ends of these selected regions to do the 2-point analysis. Using the data in this example, calculating the slope using the 2-point method:

Slope = [final – initial DO concentration (mg/L)] ÷ length of time (s) between these measurements.

For this example the rate of change of dissolved oxygen concentration is:

In light: the slope is (6.3 – 6.1 mg/L) ÷ 900 s = 2.2 x 10^{-4} mg/(L·s)

In darkness: the slope is (5.4 – 6.3 mg/L) ÷ 900 s = –1.0 x 10^{-3} mg/(L·s)

3. ☐ Record these values in Table 1.

Note: The rate of change in [DO] in darkness correlates to the consumption of carbohydrates due to cell respiration. A negative slope, which indicates a decrease in the dissolved oxygen concentration, refers to a positive value of cell respiration (R). For example, if the rate of change in [DO] is –1.0 x 10^{-3} mg/(L·s), then R is 1.0 x 10^{-3} mg/(L·s).

Table 1: Rate of change of dissolved oxygen concentration comparison

Light Setup	Initial [DO] (mg/L)	Final [DO] (mg/L)	Total Change in [DO] (mg/L)	Rate of Change in [DO] (mg/(L·s) (Linear Fit)	Rate of Change in [DO] (mg/(L·s) (2-Point Method)
Bright light	6.1	6.3	0.2	2.2 x 10–4	2.2 x 10–4
Darkness	6.3	5.4	–0.9	–1.0 x 10–3	–10.0 x 10–4

Analysis Questions

1. Describe how you would find the GPP rate, and then perform the calculation.

GPP_{rate} is calculated as follows:

GPP_{rate} equals the rate of change of carbohydrate produced under lighted conditions (NPP_{rate}) plus the rate of change of carbohydrate consumed under dark conditions (R_{rate}).

(As noted above, it is important to notice that the absolute value of the change in dissolved oxygen measured in the dark, which corresponds to R, is added to NPP to determine the total amount of carbohydrate synthesized by the plant.)

Answers will vary, but an example, based on the above data, follows:

$$GPP_{rate} = NPP_{rate} + R_{rate}$$

$$GPP_{rate} = 2.2 \times 10^{-4} \text{ mg DO/(L·s)} + 10 \times 10^{-4} \text{ mg DO/(L·s)}$$

$$GPP_{rate} = 12.2 \times 10^{-4} \text{ mg DO/(L·s)} = 1.2 \times 10^{-3} \text{ mg DO/(L·s)}$$

2. Describe how you would calculate the net amount (in mg) of glucose produced (NPP) by the plant in 24 hours if the present conditions were maintained and the plant was in darkness for 12 of those hours. Then perform the calculation.

Respiration occurs when the plant is in the light as well as in the dark, and is assumed in these calculations to occur at the same rate in both conditions.

1) To find GPP, multiply GPP_{rate} by 12 h x 60 min x 60 s to find out how much oxygen gas was produced by the plant during photosynthesis during the 12 hours.

2) To find R, multiply $|R_{rate}|$ by 24 h x 60 min x 60 s to find out how much oxygen gas was used up by the plant during 24 hours.

3) To find NPP for 24 hours in terms of oxygen gas, you would subtract R from GPP.

4) To express the result in terms of glucose, multiply the result from Step 3 (NPP) by the ratio of the molecular weight of glucose (180) to the molecular weight of 6 oxygen gas molecules (192) (from the photosynthesis formula).

Calculations will vary, depending upon the experimental results. For the sample data shown:

1) $GPP_{24\ h} = 1.2 \times 10^{-3}$ mg O_2/(L·s) x 12 h x 60 min/h x 60 s/min

GPP for 1 day = 52 mg O_2/L

2) $R_{24\ h} = 1.0 \times 10^{-3}$ mg O_2/(L·s) x 24 h x 60 min/h x 60 s/min

R for 1 day = 86 mg O_2/L

3) $NPP_{24\ hr}$ = GPP – R = 52 mg O_2/L – 86 mg O_2/L

NPP for 1 day = –34 mg O_2/L

4) Net glucose produced in 24 h = –34 mg O_2/L x (180 mg/mol glucose ÷ 192 mg)/ 6 mol O_2

Net glucose produced in 1 day = –32 mg glucose/L

3. How did the rate of change calculated using the two-point method compare with the rate of change as determined by the slope at a linear region of the plotted data?

The two methods of calculating the rate of change should yield approximately equivalent answers.

4. What does a negative slope (rate of change) value indicate?

A negative slope or rate of change value indicates that the concentration of the dissolved oxygen is declining due to cellular respiration.

5. What processes are causing the change in dissolved oxygen concentration under the conditions of bright light?

Under bright light, the process of photosynthesis causes the concentration of dissolved oxygen to increase, while the process of aerobic cellular respiration causes dissolved oxygen to decrease. However, because more dissolved oxygen is being formed than consumed in this example, the net result is for the concentration of dissolved oxygen to increase.

6. What process causes the change in dissolved oxygen concentration under the conditions of darkness?

Under the condition of darkness, the process of aerobic cellular respiration causes the change in dissolved oxygen concentration.

7. Does the dissolved oxygen that you measured under lighted conditions represent the gross primary productivity (GPP) or the net primary productivity (NPP) rate? Explain.

The measured rate under the lighted condition represents the NPP rate. The NPP rate is the net result of the rate of all O_2 produced by photosynthesis (GPP) plus the rate of O_2 being consumed (which is a negative rate of O_2 production) by aerobic cellular respiration by the plant and any microbes growing in the water (R).

8. In this exploration, which is the independent variable, which is the dependent variable, and which factors are controlled?

The independent variable is the presence or absence of light. The dependent variable is the concentration of dissolved oxygen. The factors controlled include all the aspects of the experimental setup, including the equipment, temperature, rate of spin of the stir bar, dissolved oxygen sensor, and length of time of data collection.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What do you think would happen to this closed system if it were maintained for 2 weeks under these conditions?

Answers will vary. If students found a positive NPP, they would predict that the plant would grow. If students found a negative NPP, as in this example, they would predict that the plant would get smaller and perhaps die if this trend continued, because the plant wasn't producing enough food for its needs.

2. What are some of the methods currently used by scientists to determine primary production levels regionally and globally?

Currently, various methods for determining biomass are used to estimate terrestrial net primary productivity. For aquatic primary productivity, the rate of incorporation of the radioactive atom ^{14}C is commonly used. Additionally, new methods of measuring chlorophyll or carbon concentrations from satellite imagery are currently being developed.

3. What are some limitations to these methods of determining primary production?

For determining terrestrial primary production, biomass estimates are difficult to determine for all the plant growth that occurs below the surface, including roots and microscopic organisms or fallen dead plant materials. These methods are also difficult to apply to global estimates. For determining aquatic primary production, satellite methods are limited to observing activity on the surface, whereas photosynthesis can occur deeper in the water column. The method that uses ^{14}C incorporation cannot be applied globally due to practical considerations.

Multiple Choice Questions

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

1. The first trophic level in an ecosystem refers to

- **A.** Carnivores
- **B.** Consumers
- **C.** Herbivores
- **D. All autotrophs**
- **E.** B and D

2. Autotrophs responsible for primary productivity in the oceans include

- **A.** Kelp
- **B.** Zooplankton
- **C.** Photosynthetic bacteria
- **D.** Phytoplankton
- **E. A, C, and D**
- **F.** All of the above

3. Most of the primary production in the oceans occurs in the

- **A. Euphotic zone**
- **B.** Dysphotic zone
- **C.** Aphotic zone
- **D.** Abyssal zone
- **E.** Twilight zone

4. Gross primary productivity is equivalent to net primary productivity plus

- **A.** The amount of dead organic material that sinks to the bottom of a body of water or falls as litter to the ground
- **B. The amount of organic material consumed in cellular respiration**
- **C.** The amount of water transpired by plants
- **D.** None of these is true

5. In this activity, the gross primary productivity was measured by

- **A.** Determining the mass of the plant
- **B.** Determining the rate of oxygen gas consumption during cellular respiration
- **C.** Determining the rate of oxygen gas production during photosynthesis
- **D. B and C**
- **E.** All of the above

Extended Inquiry Suggestions

Ask students to research some of the new methods for estimating global primary production using satellite images. What are some of the new technologies being developed? Have students report on the patterns that are being observed in primary production using these methods. What can these studies reveal about the global environment?

Challenge students to design and conduct a study to determine the effect of light intensity on the rate of photosynthesis. How could these findings be applied to studies of primary production?

12. Photosynthesis and Cell Respiration in a Terrarium

Objectives

Students demonstrate that a terrarium, a closed system, is an excellent tool for conducting environmental studies such as determining the rates of photosynthesis and cell respiration in plants. As part of this process, students:

- Learn to use this closed system to change one variable at a time, control other variables, and monitor multiple variables
- Design additional investigations on photosynthesis and cellular respiration using the terrarium

Procedural Overview

Students gain experience conducting the following procedures:

- Designing controlled investigations
- Identifying the causes of the changes in the rates of O_2 and CO_2 gas concentration shown on the graphed results of these measurements
- Using sensor technology to monitor independent and dependent experimental variables

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	60 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Oxygen gas sensor
- Carbon dioxide gas sensor
- Temperature sensor
- Sensor extension cable
- USB hub (depending on data collection system)[1]
- EcoChamber™[2]
- Fast-growing, small, potted plant [3]
- Opaque cloth, about 1 m^3
- Strong incandescent or full-spectrum fluorescent light source

[1]To determine if a USB hub is required, refer to the data collection system Tech Tip file.

[2] PASCO's EcoChamber is specifically desgned for ease of use with sensors. If not available, use a sealed terrarium as a substitute.

[3] See the Lab Preparation section for small plant suggestions.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Most food energy comes originally from sunlight.
- Plants use light energy to make sugars from carbon dioxide and water, releasing oxygen gas as a byproduct.
- Plants can make their own food and use it immediately or store it for use later.
- Green plant cells contain chloroplasts, which are organelles in which photosynthesis takes place.
- Chlorophyll is a molecule found in chloroplasts that is required for photosynthesis; it is responsible for the green color of plants and algae.
- During photosynthesis, carbon dioxide gas is consumed and oxygen gas is released. Photosynthesis requires light energy, generally from the sun.
- During cellular respiration, oxygen gas is consumed and carbon dioxide gas is released. Cellular respiration occurs continuously in living cells.
- Human beings are part of the earth's ecosystems. The activities of people can alter the equilibrium in ecosystems.
- To identify the independent variable, ask "What do I change?"
- To identify the dependent variable, ask "What do I observe?"
- To identify the controlled variables, ask "What do I keep the same?"

Note: It would be best to have students complete the lab, “Photosynthesis and Primary Productivity,” before doing this investigation.

Related Labs in This Guide

Suggested prerequisites:

- Cellular Respiration and the Carbon Cycle
- Determining Soil Quality
- Photosynthesis and Primary Productivity

Labs conceptually related to this one include:

- Yeast Respiration

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)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Environmental studies require investigations both in the field and in the laboratory. Because the earth's environment is complex, an investigator in the field must collect a wide variety of data and look for patterns and correlations. When patterns or correlations are discovered, these can be further investigated in controlled laboratory environments. Terrariums are excellent closed systems for environmental studies, allowing the investigator to change one variable at a time, control other variables, and monitor multiple variables in an easily maintained system.

Student-designed investigations are important components of Advanced Environmental Science courses, and long-term projects are appropriate. During this activity, students become familiar with a test system, pose a hypothesis, and then design an investigation to test their hypothesis. This activity provides some ideas for investigation and a structure to get students started with their inquiries. It also includes methods for reporting results, and you can choose which are appropriate for the classroom situation.

The test system for this lab is a closed system for examining factors that affect photosynthesis and cellular respiration. The end points (dependent variables) are the rate of change in concentration of CO_2 gas and O_2 gas. The rates of change in CO_2 gas and O_2 gas are used as end points because these factors are tightly coupled with plant growth and aerobic cellular respiration, often manifesting within minutes of changing the independent variable. These types of evidence of effects on plant growth and cellular respiration can be augmented with other evidence, such as rates of increase in plant mass, visual evidence of growth, or visual evidence of disease.

Some of the independent variables that could be investigated using the terrarium include the effect on the rates of photosynthesis or aerobic cellular respiration, or both, of the following: light intensity, light wavelength, light source types, elevated CO_2 gas in the atmosphere, acidic conditions, introduced organisms, fertilizers, toxins, soil type, and temperature. No doubt your students will have many more ideas for using this test system.

Pre-Lab Discussion and Activity

Inform students they will be learning about a test system that will allow them to conduct their own investigations regarding environmental effects on photosynthesis and cellular respiration.

Help students brainstorm environmental issues that may affect plant growth.

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

Some topical environmental issues that may affect plant growth include the following: global warming, greenhouse gas emissions, acidification of soils and water, pollution of waterways with nutrients and toxins, droughts, invasive species, invasive pests, and diseases. From this list, students should be able to pick a topic that interests them.

With this list of topics, address each one and identify parameters that could serve as independent variables in an investigation. For example, if a student is interested in the effects of global warming, a test of the system at elevated temperatures would be useful. Students interested in greenhouse gas emissions might test the effect of an atmosphere with elevated CO_2 or water vapor (humidity) levels. Students interested in acid rain could test the effect of acidic water on plant growth and the side effects on the environment, and so on.

List the sensors you have available that might be used in such investigations.

Tell students that after they learn how to set up and use the test system, they will be expected to:

1. Develop a hypothesis to test, identify the independent variables, the dependent variables, and the variables they will strive to control

2. Design an experiment or set of experiments to help them develop data related to their hypothesis.

3. You can then have students write a proposal and submit it to you for your approval and guidance. They can conduct the study, collect and analyze the data, draw conclusions, and report on their study. Students could report in a variety of ways, including a formal research report, an oral presentation, or a response to a set of questions that you design.

If necessary, review the process of photosynthesis and aerobic cellular respiration with your students. Refer to the Pre-lab Discussion section of the "Photosynthesis and Primary Productivity" activity in this guide for details on such a review.

Lab Preparation

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

1. Purchase the small potted plants.

   Suggested small plants include: tomato plant, basil, mint, or other herbs in small pots. Any plant in a pot small enough to fit into the EcoChamber™ will suffice.

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.

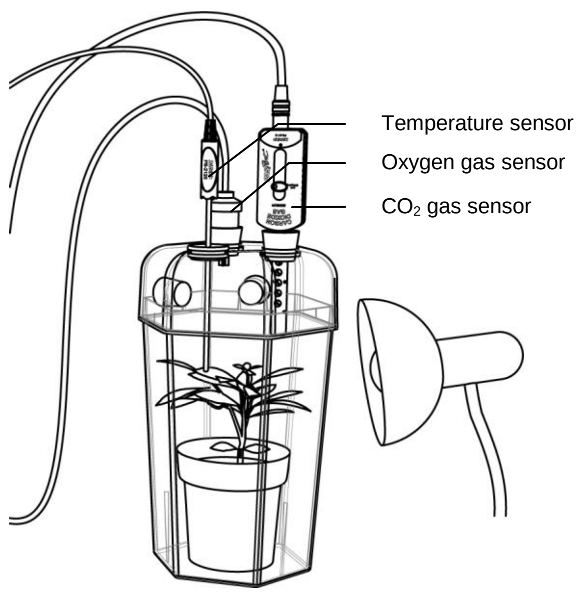
2	4	5	3	1
Set up your data collection system to monitor CO_2 gas, O_2 gas, and temperature.	Turn the light off and cover the EcoChamber with an opaque cloth. Continue recording data for another 900 seconds.	Analyze your data and develop ideas for how to use this system to investigate questions in environmental studies.	Place a light source near the EcoChamber and turn it on. Record data for 900 seconds (15 minutes.)	Set up the EcoChamber with CO_2 gas, O_2 gas, and temperature sensors, put a plant in it, and make it airtight.

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. ☐ Put a fast-growing potted plant that has moist (not wet) soil into the EcoChamber.

2. ☐ Arrange the CO_2 gas sensor, O_2 gas sensor, and temperature sensor so they can detect changes inside the EcoChamber.

3. ☐ Seal the EcoChamber so it is airtight.

Hint: One way to be sure that the EcoChamber is airtight is to exhale several times into the empty EcoChamber to raise the CO_2 level of the air in the EcoChamber relative to the room air. Then seal the EcoChamber and monitor the CO_2 level for several minutes. After the reading stabilizes, the level should not drop. If it does, you probably have a leak. Once you have learned how to make the EcoChamber airtight, use this procedure in your investigations.

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

5. ☐ Connect all three sensors to the data collection system. �(2.2)

   Note: Use the sensor extension cable to connect the CO_2 gas sensor.

6. ☐ Set up appropriate displays to view the data while it is being collected.

Note: For longer investigations, you may need to decrease the sampling rate of the sensors. Choose a time interval that will provide adequate information while limiting the number of data points collected to a practical quantity. �(5.1) For example, if you choose to monitor the EcoChamber for 24 hours, you might set the sampling rate to 1 sample every 10 minutes. Or if you choose to monitor for a week, you might set the sampling rate to 1 sample every 30 minutes.

7. ☐ Set up a strong light source near the EcoChamber and shine it directly at the plant inside.

Collect Data

8. ☐ Start data recording. �(6.2)

9. ☐ Continue to record data with the light on for 15 minutes.

10. ☐ After 15 minutes, turn the lamp off and carefully cover the setup with an opaque cloth so the plant is in darkness. *Do not stop recording data.*

11. ☐ Record data with the plant in darkness for 15 minutes, and then stop data recording. �(6.2)

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

Data Analysis

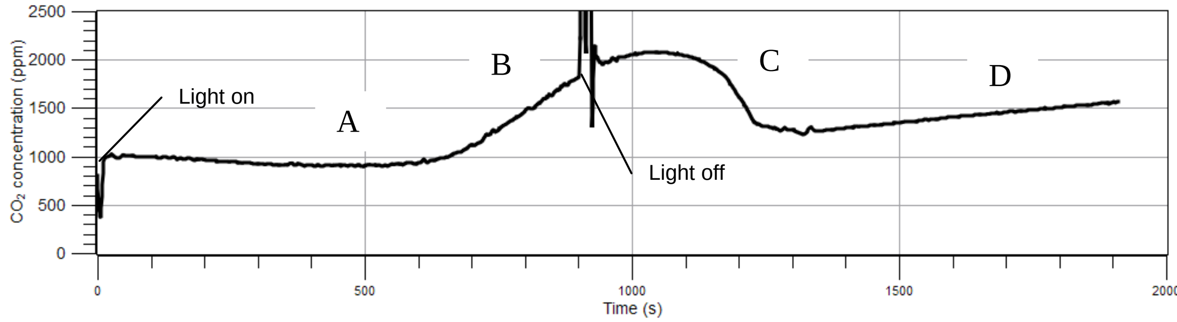
1. ☐ Display your data as graphs. �(7.1.1)

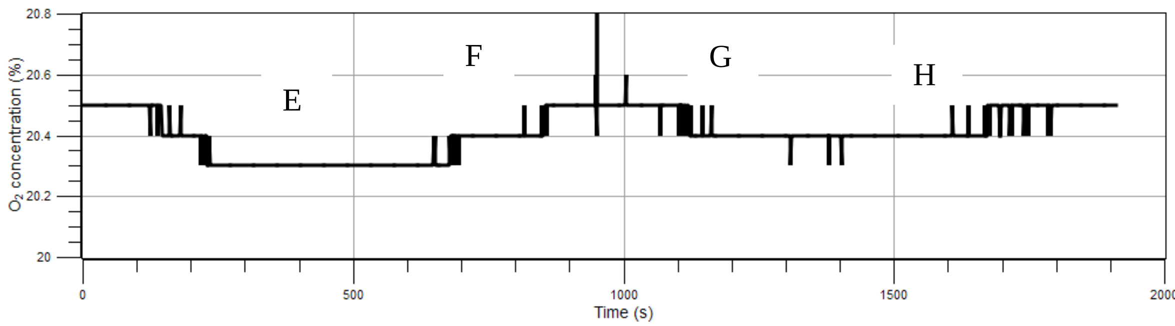
2. ☐ Adjust the graphs to fill the screen vertically, and adjust the x-axis to make the time scales equivalent between graphs. �(7.1.2)

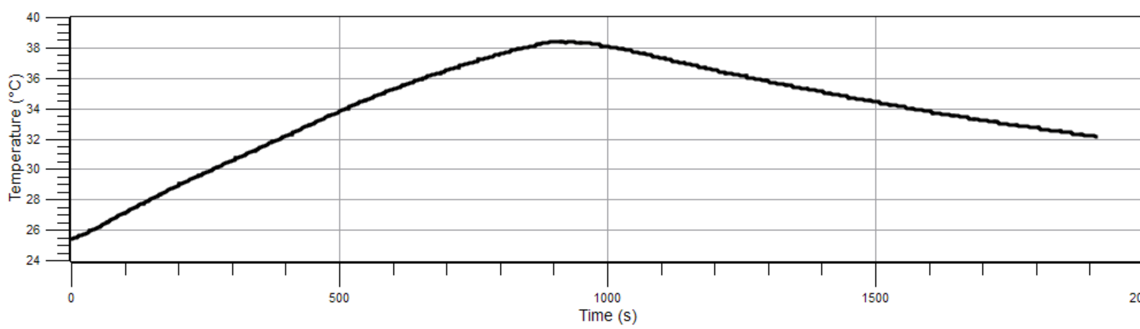
3. ☐ Sketch your graphs. Label the overall graph, the x-axes, the y-axes, and include units on your axes.

4. ☐ Indicate on your graphs where you turned on the bright light and where you turned the light off and covered the EcoChamber with a cloth.

5. ☐ Label the areas on the graphs where the pattern of data changes with numbers or letters.







Analysis Questions

1. Which does the CO_2 gas concentration represent: the rate of aerobic cellular respiration, the rate of photosynthesis, or the combination of rates of aerobic cellular respiration and photosynthesis? Why?

The CO_2 level represents the combination of aerobic cellular respiration and photosynthesis rates. This is because the plant is consuming CO_2 during photosynthesis, and at the same time, the plant and the soil organisms are producing CO_2 during cellular respiration. This can be accurately measured in a closed system.

2. Which does the O_2 gas level represent: the rate of aerobic cellular respiration, the rate of photosynthesis, or the combination of rates of aerobic cellular respiration and photosynthesis? Why?

The O_2 level represents the combination of rates of aerobic cellular respiration and photosynthesis. This is because the plant is producing O_2 during photosynthesis, and at the same time, the plant and the soil organisms are consuming O_2 during cellular respiration. This can be accurately measured in a closed system.

3. Why are the changes in CO_2 gas concentration more apparent than those of O_2 gas? *Hint:* Think about the relative levels of these gases in the atmosphere.

The changes in CO_2 gas concentration are more apparent than those of O_2 gas because of the relative amounts of these gases in the atmosphere to start with. In air at sea level, CO_2 constitutes about 0.033% of the molecules in air, while O_2 constitutes 21%. To view an equivalent change in the absolute number of molecules of these gases, the scale of the graph showing O_2 concentration needs to be significantly more sensitive than the scale showing CO_2 concentration. For example, the CO_2 concentration in this example showed changes that more than doubled the concentration, while the O_2 concentration changed by 0.1%.

4. Discuss what was occurring in the areas where the pattern of data changed (label or letter the areas on your graph for easy reference).

Answers may vary. For this example:

A. This area represents the net productivity of the system under lighted conditions. Since the concentration of CO_2 gas is decreasing, it seems that the rate of photosynthesis under lighted conditions is slightly greater than the rate of cellular respiration.

B. This area really surprised me at first. I expected the CO_2 concentration to continue to go down under lighted conditions. Then I remembered that the CO_2 concentration represents a combination of the processes of photosynthesis and cellular respiration. So apparently, the rate of cellular respiration has increased more than the rate of photosynthesis. Taking into account that the temperature rose during the light period, this makes sense. The microorganisms in the soil could have contributed significantly to the levels of CO_2 concentration and their metabolic processes and those of the plant speed up under the warmer temperatures.

C. This area was the most interesting to me. After putting the EcoChamber in darkness, all of a sudden the CO_2 concentration dropped. This was the opposite of what I expected, because I thought photosynthesis would stop when I turned off the light. However, could this be evidence of the dark reaction of photosynthesis?

D. This area is more like what I expected when the EcoChamber was placed in darkness. This area shows only the effects of aerobic cellular respiration. It seems that the energy absorbed during the light reaction of photosynthesis has all been consumed during the dark reaction, so photosynthesis has shut down. Cellular respiration is free to drive up the CO_2 concentration, but at lower rates than in area B because the temperature is lower.

E, F, G, and H. These areas are interesting, but it is difficult to assess whether they have any real meaning because the changes are so small and are close to the limits of the oxygen gas sensor's reliability.

5. What was the independent variable in this activity?

The independent variable in this activity was light energy (presence or absence of it).

6. What were the dependent variables in this activity?

The dependent variables were O_2 gas concentration, CO_2 gas concentration, and temperature.

7. What factors did you try to hold constant during this activity?

Factors that were held constant included the volume of the container, the plant, the soil, and the closed nature of the system. It would be best to hold the temperature constant, but it rose under lighted conditions and fell under dark conditions.

8. How could you design an investigation that controls the change in temperature?

You could place the EcoChamber in a room-temperature or controlled-temperature water bath. The water would absorb much of the heat energy from the bright light, reducing considerably the change in temperature during the experiment. Also, using a fluorescent light source would generate less heat than an incandescent light source.

Synthesis Questions

Use available resources to help you answer the following questions.

Begin designing an experiment that investigates an aspect of the weather, using the EcoChamber. These questions will assist you in developing a proposal.

1. What question would you like to investigate using this system?

Here is where students will propose how they want to use this test system in their own investigation.

An example: I would like to remove the variables of soil organisms and change in temperature to get a better picture of what the plant itself is doing regarding photosynthesis.

2. What independent variables will you test to investigate the question? Why?

Students need to think about which factor they will change to find out its effect on the system.

In this example: the presence or absence of soil would be the independent variable and the use of a fluorescent light and water bath would help keep the temperature constant.

3. What will be the hypothesis to test this issue using the EcoChamber?

Students need to state the hypothesis they intend to test. The following are some examples of appropriate hypotheses:

- Using this test system, increased light intensity will result in increased rates of photosynthesis.
- Using this test system, increased acidity of the water in the soil will result in decreased rates of photosynthesis.
- Using this test system, increased air temperature will result in increased rates of aerobic cellular respiration.
- Using this test system, increased levels of carbon dioxide gas added to the atmosphere will result in increased rates of photosynthesis.
- Using this test system, removing the soil will reduce the amount of cellular respiration in the system and result in a better understanding of the photosynthesis in the plant.

You may need to guide students to create an appropriate hypothesis.

4. How will you design the investigation to test your hypothesis?

Students should state exactly what they plan to do in their investigation. The exact specifications of how they will change their independent variable should be stated. Examples of appropriate plans include the following:

- To vary the light intensity reaching the EcoChamber, the distance of the light source from the EcoChamber will be varied by set amounts. We will run 4 trials with the light source being pulled back from the EcoChamber 2 cm each time. We will run each trial for 15 minutes. We will put the plant in darkness for 5 minutes before starting each trial. The light sensor will record the effect on light intensity of this action, which will quantify our independent variable, light intensity. We will record carbon dioxide gas and oxygen gas levels to determine rates of photosynthesis and aerobic cellular respiration.

- The concentration of CO_2 gas will be increased by injecting a blast of it into the EcoChamber using a CO_2 cartridge bike tire inflator. We will run 2 trials, one at an ambient CO_2 gas concentration and one at an elevated CO_2 gas concentration. We will run each trial for 15 minutes. We will put the plant in darkness for 5 minutes before starting each trial. We'll use the CO_2 gas sensor to quantify our independent variable: CO_2 gas concentration. We will record CO_2 gas (which will become a dependent variable once the light is turned on) and O_2 gas concentrations to determine the rates of photosynthesis and aerobic cellular respiration.

- To control the soil and temperature variables, all the soil from the plant will be removed and a little water will be put in the bottom of the EcoChamber. The EcoChamber will be placed in a controlled water bath. Then we will conduct the experiment exactly as the first one was conducted.

You will need to guide students to create an appropriate design plan for their investigations.

5. How will you analyze the results of your experiment?

Students should state the types of comparisons and statistical analyses they will use.

For this example, you would compare rates of CO_2 gas production in both lighted and dark conditions with those in the first experiment.

6. What materials and equipment will you need to conduct your investigation?

Students should specify the materials and equipment they will need to a similar level of detail as that in the Materials and Equipment sections of these lab activities.

Multiple Choice Questions

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

1. The design of a research study generally includes:

A. A hypothesis to test
B. A defined test system that controls variables
C. A controllable independent variable
D. A measurable dependent variable
E. Control or baseline measurements
F. All of the above

2. In a scientific experiment, an independent variable is:

A. A variable that has nothing to do with other variables
B. Something that changes in response to another variable
C. Something that you change to affect another variable
D. Something that you try to keep constant

3. In a scientific experiment, a dependent variable is:

- **A.** A variable that has nothing to do with other variables
- **B. Something that changes in response to changes in another variable**
- **C.** Something that you change to affect another variable
- **D.** Something that you try to keep constant

4. In the test system in this activity, the independent variable is:

- **A.** Temperature
- **B. Light energy**
- **C.** Carbon dioxide gas level
- **D.** Oxygen gas level
- **E.** Both C and D

5. In the test system in this activity, the dependent variable is:

- **A.** Temperature
- **B.** Light energy
- **C.** Carbon dioxide gas level
- **D.** Oxygen gas level
- **E. A, C, and D**

Extended Inquiry Suggestions

Have students conduct the experiment they designed in the Synthesis Questions section. Have students report on their experiment, including the hypothesis, the method, the results, and conclusions regarding why the results did or did not support their hypothesis.

Provide the opportunity for more than one student-designed experiment. In science, the answer to one question usually leads to more questions that seem interesting to explore.

13. Cellular Respiration and the Carbon Cycle

Objectives

Students explore the relationships between cellular respiration, photosynthesis, and the carbon cycle by:

- ♦ Analyzing the process of aerobic cellular respiration, particularly the release of CO_2, in dormant and germinating seeds
- ♦ Explaining the contribution of cellular respiration to the global carbon cycle.
- ♦ Recognizing some of the different forms carbon can take.

Procedural Overview

Students use germinating bean seeds as a model to represent cellular respiration in a closed system, and conduct the following procedures:

- ♦ Observe, sketch, label, and compare the gross morphology of dormant and germinating bean seeds.
- ♦ Use a carbon dioxide sensor to measure and compare the carbon dioxide concentration in the air of a closed system containing first dormant and then germinating bean seeds.

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
- ♦ CO_2 gas sensor
- ♦ Sensor extension cable
- ♦ Sampling bottle or Erlenmeyer flask (2), 125-mL
- ♦ Dissecting microscope or magnifying glass
- ♦ Knife or scalpel
- ♦ Parafilm® (if using an Erlenmeyer flask)
- ♦ Dry bean seeds (11)[1]
- ♦ Germinating bean seeds (11)[1]

[1] Dried pinto beans work well for this activity.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Food provides molecules that serve as fuel and building material.
- ♦ Organisms get energy from oxidizing their food.
- ♦ The processes of extracting energy from food and getting rid of waste are carried out primarily in cells, which function similarly in all organisms.
- ♦ An independent variable in an experiment is the condition the scientist controls and changes.
- ♦ A dependent variable in an experiment is the condition that changes when the scientist changes the independent variable. The scientist is interested in how the dependent variable changes when the independent variable is changed.
- ♦ A controlled variable in an experiment is a condition, such as temperature, light, and volume, that the scientist keeps the same from one trial to another.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Photosynthesis and Primary Productivity
- ♦ Photosynthesis and Cell Respiration in a Terrarium

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)
- ♦ 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 two data runs in a graph �(7.1.3)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Saving your experiment �(11.1)

Background

In the germinating seed, cells within the growing plant embryo use energy-storage molecules (oils, starches, and sugars) stored in the seed for food to fuel its life processes. The energy from the food is extracted through a process of cellular respiration. In a series of hundreds of biochemical reactions, the carbon atoms that are initially bound in the large energy-storage molecules combine with oxygen gas to produce carbon dioxide gas. Water vapor and energy, vital to living processes, are also products of these biochemical reactions that break down the large energy storage molecules.

During cellular respiration, part of the energy in the complex energy-storage molecules is captured as potential chemical energy in a molecule called ATP. The remainder of the energy is released as heat into the cell and ultimately into the surrounding environment. The ATP molecules provide energy to fuel the life processes of growth and reproduction. They also power the process of creating food used later by the organism to produce additional ATP molecules for life processes. Organisms, especially warm-blooded vertebrates, use the heat energy released by cellular respiration to maintain their internal temperature in the range needed for their life processes.

The carbon dioxide gas released into the environment becomes available to plants for use in photosynthesis. During photosynthesis, plants trap energy from the sun to convert carbon dioxide gas and water into complex sugar molecules that store potential chemical energy. The carbon dioxide gas and water vapor molecules released into the atmosphere during cellular respiration also function as natural "greenhouse gases," causing the atmosphere to retain more of the sun's energy through the natural greenhouse effect.

Pre-Lab Discussion and Activity

Hold a brain-storming discussion regarding seed germination. What do students already know? During the brainstorming activity, accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

Ask students the following questions as appropriate:

1. What do students think that seed germination is? Have students ever noticed seeds germinating?

Answers will vary based on student experience.

2. How many have seen bean sprouts in the store? What happens inside the bean seed to change it from a hard, seemingly inert object to a green, growing plant?

Answers will vary based on student experience. It may be a good idea to bring in some bean sprouts to show students. Typically, a series of complex chemical reactions takes place within the seed to begin germination.

3. What do seeds need in order to germinate?

Germination usually begins after the seed has been exposed to adequate levels of moisture (water) and are at the proper temperature, have a sufficient amount of oxygen and light levels. The amount of water needed and the proper temperature vary from species to species.

4. **Where does the energy come from to power this change? What kind of energy is it?**

The embryo inside the seed has lipids, proteins, and carbohydrates stored in it. This provides the energy for the growing seedling until it can begin to make its own carbohydrates through photosynthesis. Those macromolecules are broken down in the mitochondria of the plant cells to produce ATP. The energy stored in the chemical bonds of the ATP molecule is then used as an energy source for the plant.

5. **What is the process called that generates the energy that the plant needs to grow?**

The process that creates ATP is called *cellular respiration*.

Review an illustration that summarizes the global carbon cycle.

6. **What is the role of living things in the carbon cycle? Brainstorm ideas, recording them for class viewing.**

Plants use the carbon dioxide in the environment during the process of photosynthesis to create carbohydrates. All living organisms then use the carbon stored in the carbohydrates as an energy source during the process of cellular respiration. An end product of cellular respiration is carbon dioxide.

Ask students to observe the water covering the germinating seeds. Ask them if they can see evidence of chemical activity.

7. **How would you determine what kind of gas is in the bubbles?**

Students may recommend adding a dissolved oxygen sensor to the water with the seeds, to see if the oxygen level is increasing or decreasing. They may also recommend a variety of other chemical tests

Teacher Tip: Students may have the misconception that plants do not undergo aerobic cellular respiration, giving off CO_2 in the process, but rather only undergo the process of photosynthesis, giving off only O_2 in the process. At this stage, don't correct these misconceptions. Let them find out for themselves during the laboratory activity!

Teacher Tip: Many high school students have difficulty grasping the concept that matter can be transformed during a chemical reaction from a solid form into an invisible gas. By using a CO_2 sensor, students can extend their senses to enable them to detect CO_2 gas, which is odorless and invisible to the human eye.

Teacher Tip: To make better use of time, students could evaluate seed morphology and collect data simultaneously, either dividing the tasks or using the data collection time to perform the morphologic evaluation.

Lab Preparation

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

- ♦ Twenty-four to 48 hours before starting the lab activity, place the seeds (11 per student or group) in a large beaker and cover them with water. Put the beaker in a dark location.

Safety

Add this important safety precaution to your normal laboratory procedures:

- ♦ Use care with the knife or scalpel.

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
Insert the sensor into the bottle and seal the chamber to create a closed system.	Put dry seeds in one bottle and soaked seeds in the other.	Analyze data, comparing test conditions.	Measure the concentration of CO_2 inside the bottle containing dry seeds.	Repeat the measurement of CO_2 in the bottle containing soaked seeds.

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 and comparing the morphology of dormant and germinating bean seeds

1. ☐ Obtain one dry seed and one soaked seed. Use a knife or scalpel to bisect the seeds longitudinally into halves.

2. ☐ Use a magnifying glass or dissecting microscope to observe the interior of the seed.

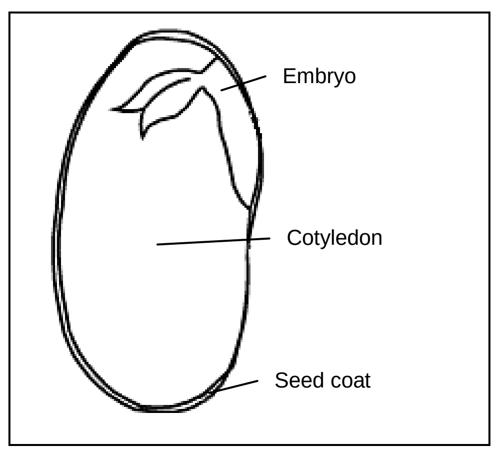
3. ☐ Sketch the major morphologic features of the bean seed. Label the cotyledon, embryo, and seed coat.

4. ☐ List some differences you observe in the appearance of the dry versus the soaked seed.

The seed coat of the soaked seed is softer and wrinkled.

The embryo is larger in the soaked seed.

The cotyledon is softer in the soaked seed.



5. ☐ What is a sign that the seed has changed from a dormant state to a growing state, in other words, that the seed is germinating?

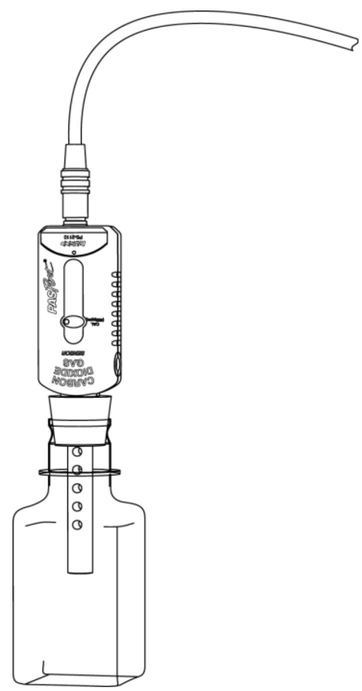
The primary sign that the seed is growing is that the embryo is larger in the soaked seed. Also, the fact that the cotyledon is softer may suggest some changes associated with germination.

Part Two – Comparing the CO_2 gas concentrations of a closed system containing dormant seeds versus a closed system containing germinating seeds

Set Up

6. ☐ Start a new experiment on the data collection system. �[1.2]

7. ☐ Connect a CO_2 gas sensor to the data collection system using an extension cable. �[2.1]



8. ☐ Display CO_2 gas concentration on the y-axis of a graph with Time on the x-axis. �[7.1.1]

9. ☐ Why is a parameter versus time graph chosen to view the data? What is another way to view the data?

The parameter versus time graph was chosen to display the data because it gives the best overall graphical representation of an activity in which data for a parameter is collected over time. Another way to view that data would be on a table.

10. ☐ Put 10 dry seeds into one sampling bottle and 10 soaked seeds in the other sampling bottle.

11. ☐ Insert the end of the CO_2 gas sensor into the sampling bottle containing the dry seeds and firmly plug the end of the sampling bottle with the rubber stopper.

Note: If you are using an Erlenmeyer flask rather than a sampling bottle, seal the top with Parafilm®.

12. ☐ Why are you using dry and soaked seeds?

Dry seeds are being used because they are dormant and presumably not undergoing cellular respiration. Soaked seeds are being used because water has softened the seed coat and entered the cells of the seed so the process of cellular respiration can start. Therefore, it will be possible to compare seeds that are not undergoing cellular respiration with seeds that are.

13. ☐ Why are you sealing the bottles with a rubber stopper or Parafilm?

The rubber stopper or Parafilm is used to seal the sample bottles to prevent any gas from escaping, thus creating a closed system.

14. ☐ Predict what will happen to the CO_2 concentration during data recording? Why?

Answers will vary, but students should predict what they expect to happen to the level of CO_2 in the bottle, and they should relate this to what they think is different in the two experimental situations.

Collect Data

15. ☐ Start data recording and record data for 10 minutes. �(6.2)

Note: Avoid bumping the equipment because jarring or bumping the sensor might cause the sensor to record erratically.

16. ☐ Stop data recording. �(6.2)

Write the run number here____1_____.

17. ☐ Switch the sensor to the other sampling bottle, seal with Parafilm if necessary.

18. ☐ Record data for 10 minutes. �(6.2)

19. ☐ Stop data recording. �(6.2)

Write the run number here_____2_____.

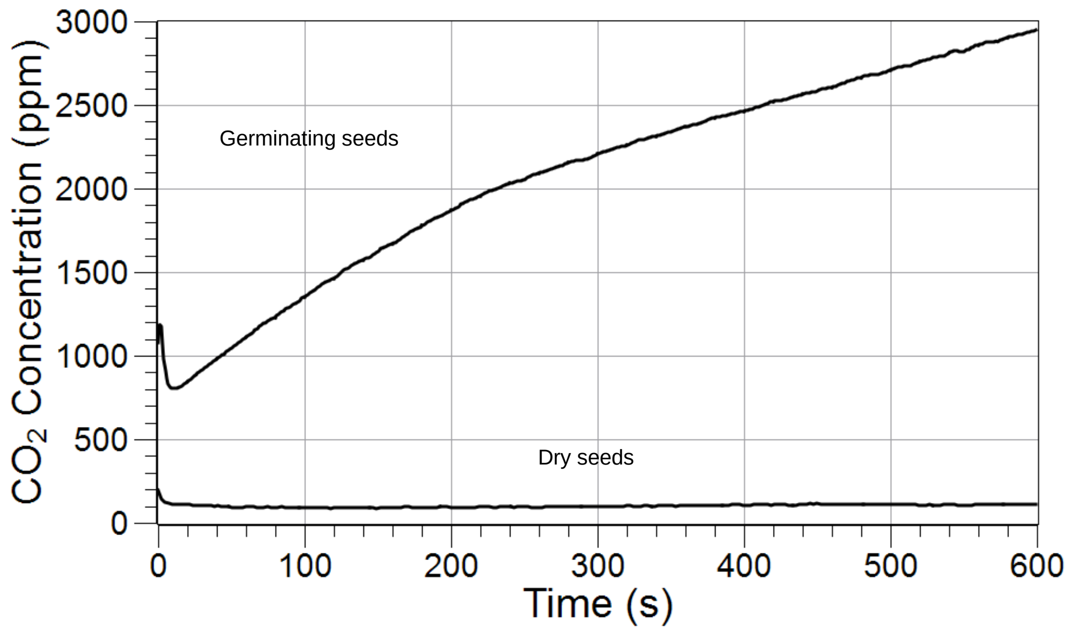
20. ☐ Save your experiment, �(11.1) and clean up according to your teacher's instructions.

Data Analysis

1. ☐ Display both data runs on the graph display. �(7.1.3)

2. ☐ Adjust the scale of the graph to show all data. �(7.1.2)

3. ☐ On the graph below, sketch the plotted data on your graph display. Be sure to label the x-axis and y-axis regarding parameter and units of measurement. Label each data run.



CO_2 gas concentrations versus time graphs of germinating seeds and dry, dormant seeds

4. ☐ Find the initial and final CO_2 concentrations for each run �(9.1) and record them in the data table.

5. ☐ Calculate the change in CO_2 concentration for each experimental condition and record these values in Table 1.

Table 1: CO_2 concentration of dry seeds and germinating seeds

	Initial CO_2 Concentration (ppm)	Final CO_2 Concentration (ppm)	Change in CO_2 Concentration (ppm)
Dry seeds	111	108	–3
Germinating seeds	810	2935	2125

Analysis Questions

1. Compare the change in CO_2 concentration for dry seeds versus soaked seeds.

The concentration of CO_2 did not change much in the sample bottle containing dry seeds. In contrast, the concentration of CO_2 increased in the sample bottle containing soaked seeds.

2. What can you conclude about the soaked seeds regarding CO_2?

The dry seeds don't seem to affect the concentration of CO_2 in the air, but soaked seeds seem to release (give off) CO_2.

3. Compare your prediction to the data you collected. Were you correct or incorrect in your prediction? Explain.

Students should tell whether their prediction was correct or not. Expect more than just a "yes" or "no" answer. Answers should include reasons related to cellular respiration.

4. In this experiment, what is the independent variable and what is the dependent variable?

The independent variable is the presence or absence of germination, and the dependent variable is the level of CO_2 gas in the bottle. Students may state that the independent variable is water, but the important variable is whether or not germination is occurring.

5. What would you expect to happen to the concentration of oxygen gas in the bottle? Why? How could you test this hypothesis?

The concentration of oxygen gas should go down in the bottle because oxygen gas is being used up during the process of cellular respiration. You could test this by measuring the oxygen gas in the bottle using an oxygen gas sensor.

6. What are the gaseous products of cellular respiration that are released from the cells of the germinating seeds?

The gaseous products of cellular respiration that are released from the cells of the germinating seeds are carbon dioxide gas (CO_2) and water vapor (H_2O).

7. Where did the seed get the fuel (glucose) for cellular respiration?

The seed got the fuel (glucose) for cellular respiration from the plant that produced it. The green plant, through photosynthesis, made sugar molecules from carbon dioxide gas and water (using energy captured from the sun). The plant stored the fuel as oils, starches, or sugars in the seed's cotyledons.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Consider the following overall summary equation of the hundreds of biochemical reactions involved in aerobic cellular respiration:

$$C_6H_{12}O_6 + 6O_2 + ADP + P_{inorganic} \rightarrow 6CO_2 + 6H_2O + ATP$$

Write this equation using words instead of chemical symbols. Write an equation for this process using chemical notation.

glucose (energy storage molecule) + oxygen gas +ADP (low-energy molecules) + phosphate →
carbon dioxide gas + water vapor + ATP (high-energy molecules)

2. In this activity, a germinating seed is used as a model to represent cellular respiration in all living things. Why is it reasonable to create a model for cellular respiration?

Using a germinating seed as a model to represent cellular respiration in all living things is possible because the process of cellular respiration is essentially the same for most organisms.

3. What is the effect of cellular respiration on the atmosphere? How is the natural greenhouse effect influenced?

The effect of cellular respiration on the atmosphere is to increase the concentration of carbon dioxide gas and water vapor in the air. Carbon dioxide gas and water vapor are natural greenhouse gases, so cellular respiration contributes to the natural greenhouse effect of the atmosphere. Therefore, these gases cause the atmosphere to retain some of the sun's energy in the form of heat, causing the atmosphere to be warmer than it would be without cellular respiration.

4. What role does cellular respiration in plants and other living organisms play in the carbon cycle?

Cellular respiration in plants, animals, and microbes helps keep carbon circulating in the environment so it can be available as a building block for life processes. Cellular respiration is responsible for converting carbon, bonded in solid forms, to carbon dioxide gas that is released to the atmosphere or into bodies of water, including the ocean, lakes, and rivers. Carbon dioxide gas in the atmosphere is available to plants for the photosynthetic process which converts carbon from the atmosphere into carbon bonded in molecules that exist in solid forms within organisms.

Multiple Choice Questions

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

1. The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. In this activity, which of the following is an example of a chemical element being recombined as it passes through a link in the food web?

- **A.** Carbon dioxide is being passed from the energy storage molecule in the bean seed to the atmosphere.
- **B.** Carbon from the energy storage molecule (glucose) in the bean seed is being recombined with oxygen and passed as CO_2 gas into the atmosphere.
- **C.** Oxygen gas (O_2) from the atmosphere is being recombined in the bean seed into different molecules (H_2O and CO_2).
- **D. Both B and C are examples.**

2. How did the energy-storage molecules in the bean seed get there?

- **A.** The bean seed gathered these molecules from its surrounding environment.
- **B. The plant that made the seeds gathered energy from the sun through photosynthesis and stored it in the energy-storage molecules in the seed.**
- **C.** The germinating seed gathered energy from the sun and stored it in the energy-storage molecules.
- **D.** Both B and C are correct answers.

3. The food energy that the plant uses for cellular respiration is stored in the seed's

- **A.** Cell wall
- **B.** Embryo
- **C. Cotyledons**
- **D.** DNA

4. Beans and coal both have stored energy. Where did the energy originally come from that is stored in beans and coal?

- **A.** From the earth's gravity
- **B.** **From the sun's light**
- **C.** From the heat in the earth's core
- **D.** From the carbon dioxide in the air

5. What natural "greenhouse gases" were produced by the bean seeds during cellular respiration?

- **A.** Carbon dioxide gas
- **B.** Oxygen gas
- **C.** Water vapor
- **D.** **Both A and C are correct**

Extended Inquiry Suggestions

Ask students to plant the seeds in a PASCO EcoChamber and continue monitoring the CO_2 gas concentration. When green leaves appear, what effect does photosynthesis have on CO_2 gas concentration?

Challenge students to design an experiment using an O_2 gas sensor to answer the question: Is the cellular respiration by the bean seeds an aerobic or anaerobic process?

Challenge students to carry out an Internet investigation concerning the magnitude of the contribution of cellular respiration by marine plants and animals to the total carbon cycle.

Challenge students to investigate the current understanding of the magnitude of the role of cellular respiration in contributing to greenhouse gases and climate change. Conduct a classroom debate focused on the question: Does cellular respiration play a significant part in climate change?

14. Energy Content of Food

Objectives

Students investigate and compare the energy content of energy-rich substances (foods) to determine:

- How much energy is stored in some common food items
- What type of food contains the most concentrated amounts of energy

Procedural Overview

Students measure the energy released from different types of foods by oxidative combustion (burning) through energy transfer into water in a closed container (calorimeter). From this they

- Calculate the amount of heat released from the food item based on the change in temperature of the water in the calorimeter
- Calculate the total amount of energy stored in each piece of food

Time Requirement

♦ Preparation time	15 to 60 minutes (shopping may be required)
♦ Pre-lab discussion and activity	45 minutes
♦ Lab activity	75 minutes (less if testing fewer items or if items are divided among groups)

Materials and Equipment

For each student or group:

- Mobile data collection system
- Temperature sensor
- Fast-response temperature probe
- Electronic balance
- Large base and support rod, rod and clamp
- Graduated cylinder, 100 mL
- One-hole rubber stopper (4), ~1 1/2" top diameter
- Aluminum pie pan (4)
- Marking pen
- Plastic straw
- Food sample[1] (4)
- Wooden matches or starter wand
- Paperclip, large (5)
- Aluminum soda can (4)
- Water, 200 mL
- Tape
- Cardboard box, large[2]

[1]Use a small marshmallow, a piece of popped popcorn, a peanut, and a cashew.

[2]If no ventilated hood is available indoors, a box serves as a wind break for burning food samples outdoors.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Food provides molecules that serve as fuel and building material for all organisms.
- Thermal energy is transferred by the collisions of atoms.
- Thermal energy transfers from warmer objects to cooler ones.
- Energy appears in different forms and can be transformed within a system.
- Whenever energy appears in one place, it must have disappeared from another.

Related Labs in This Guide

Labs conceptually related to this one include:

- Cellular Respiration and the Carbon Cycle
- Photosynthesis and Primary Productivity
- Investigating Specific 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)
- 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)
- Naming a data run �(8.2)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

The entire food web depends on the primary productivity of autotrophs. Plants, for instance, consume much of the energy they capture by photosynthesis. They also store some of this energy in large energy-storage molecules. These are formed into energy-rich substances known as food. Other organisms eat this food to supply themselves with energy.

Living organisms convert this chemical energy to a chemical form that they can use for their life processes. This complex series of chemical reactions is known collectively as cellular respiration. The aerobic form of cellular respiration (which consumes oxygen gas) is summarized as follows:

$$C_6H_{12}O_6 + 6O_2 + 30ADP + 30Pi \rightarrow 6CO_2 + 6H_2O + 30ATP$$

The entire process of energy transfer during cellular respiration is tightly controlled by cellular enzymes. This efficient process results in a minimum amount of energy being released as heat. The chemical energy from the food is primarily stored in ATP molecules, which can be used by organisms for their life processes.

This same energy can be released from the food by the process of oxidative combustion, also known as burning. That is, energy-rich molecules containing carbon plus oxygen yield carbon dioxide plus water plus a lot of heat.

Combustion is similar to aerobic cellular respiration in that it releases chemical energy from food molecules. However, it differs from cellular respiration in that it requires a high temperature to initiate it. Such burning is wildly uncontrolled, causing all the energy to be lost as heat.

The amount of energy stored in food is measured in terms of calories. One calorie is equal to the amount of heat energy required to increase 1 gram (g) of water by 1 degree Celsius (°C). One calorie equals 4.186 joules (J), another unit used to measure energy.

How can we determine how much energy is stored in food? Theoretically, the amount of thermal energy from burning food equals the amount of thermal energy transferred to water. This statement assumes that no energy is lost to the surrounding environment. The following equation describes this concept:

$$Q = m \times c \times \Delta T$$

- Q is thermal energy (J)
- m is mass of water (g)
- c is specific heat of water (4.186 J/g °C)
- ΔT is the change in temperature of the water (°C)

Once Q is known, the energy in the food can be expressed as calories; Q (in Joules) divided by 4.186 Joules/calorie converts the energy from joules to calories.

The energy in food is commonly expressed in terms of kilocalories (1000 calories). A kilocalorie is also known as a large Calorie (a Calorie with an upper case "C"). Thus, declaring that an average adult man needs 2000 Calories of food each day means that he needs 2,000,000 calories. Gram calories, or small calories, are terms for calories with a lower case "c".

Pre-Lab Discussion and Activity

Engage students by holding a contest called "Guess How Many Calories."

1. After announcing the contest, make distinctions about calories.

- A calorie (lower case "c") is also known as a small calorie. It equals the amount of heat energy required to increase 1 gram (g) of water by 1 degree Celsius (°C). This equals 4.186 joules (J).
- A Calorie (upper case "C") is also known as a large calorie or a kilocalorie, which is 1000 small calories (lower case "c"). A Calorie (large calorie) is what people mean by the calories they are eating or avoiding. For instance, 200 calories in an "energy bar" means 200 kilocalories or two hundred thousand calories. Commonly, people may not pay attention to the distinction between the upper case and lower case "c" in the word calorie.

2. Show students one of each food sample they will use in the lab: a small marshmallow, a piece of popped popcorn, a peanut, and a cashew.

3. Ask students to write their guesses about how many Calories (kilocalories) are stored in each of these pieces of food.

4. Tell them that at the end of the lab, they will compare their guesses with the lab results. For each food, the smallest difference between the guesses and the lab results wins.

5. Draw a diagram of the experiment setup, and then ask the students the following questions.

a. Describe how the energy released from the burning of the food will be transferred to the calorimeter. Use the terms oxidative combustion, radiation, and conduction in your answer.

The burning (oxidative combustion) of the food releases heat energy that is primarily radiated upwards to the aluminum can. The can absorbs the radiated heat energy and transfers it to the water by conduction. The heat energy is distributed throughout the water by convection.

b. Do you expect all of the energy from the burning food to be transferred into the calorimeter? Why or why not.

No. Some of the heat energy will be lost to the air through radiation and not transferred to the aluminum can. Since the aluminum can is a highly efficient conductor of heat, some of the heat will radiate into the surrounding air in addition to transferring to the water in the can.

c. What parameter will be measured to quantify the amount of energy that is transferred?

The parameter that will be measured is the temperature of the water.

6. Introduce students to the formula $Q = m \times c \times \Delta T$ they will use to calculate the amount of energy transferred to the water in the calorimeter. (Refer to the Background information.)

7. Demonstrate how to convert energy in terms of *Q* (joules) to energy in terms of calories.

Divide Q by 4.186 joules/calorie.

Lab Preparation

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

1. Shop for the food items.
2. Pop some popcorn.
3. Have students bring in clean, empty aluminum soda cans.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Use appropriate caution with burning and hot materials, such as matches, starter wands, and foods.
- ♦ Conduct the lab in a well-ventilated area, preferably outside or under a ventilated hood.

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	5
Collect temperature data while burning each of the food samples.	Determine the mass of the water, food sample, paper clip, rubber stopper and pie pan before burning.	Set up the equipment, including items to hold the food, hang the can of water, and secure the probe.	Take the equipment to set up outside or to a ventilated hood.	Analyze the data, and determine who won the contest.

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 – Preparation

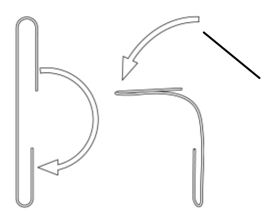
Set Up

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)

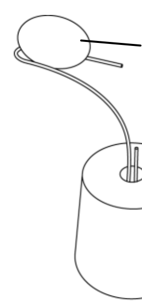
3. ☐ Display data on the graph to show Temperature versus Time. � (7.1.1)

4. ☐ Label each of four aluminum soda cans with one of the following: marshmallow, popcorn, peanut, and cashew.



5. ☐ Open a large paper clip, and bend the top half so it is perpendicular to the bottom half.

Note*:* Bend the paper clip over the side of a piece of cardboard or cover of a hard-cover book. The paper clip should form a flat platform to hold the food piece.



6. ☐ Insert one end of the paper clip into a one-hole rubber stopper as shown in the illustration.

7. ☐ Make three more paper clip platforms and insert each one in a rubber stopper.

Note: For the following instructions, use the balance to determine mass, and use Table 1 in the Data Analysis section when instructed to record data.

8. ☐ Determine the mass of each empty aluminum can, and record the data in Table 1.

9. ☐ Pour 50 mL of water into each can.

10. ☐ Determine the mass of each can plus water, and record the data in Table 1.

11. ☐ Determine the mass of each sample of food, and record the data in Table 1.

12. ☐ For each food sample, put a paper clip, rubber stopper and the sample of food into a pie pan.

13. ☐ Determine the mass for each set of a paper clip, a rubber stopper, a sample of food, and a pie pan, and record the data in Table 1.

14. ☐ Make a hanger for the soda can by bending open another paper clip.

15. ☐ Tape a plastic straw to the cord just above the bulb of the quick-response temperature probe.

Note: The straw taped to the sensor cord helps prevent the sensor from touching the can. This helps assure accurate measurements.

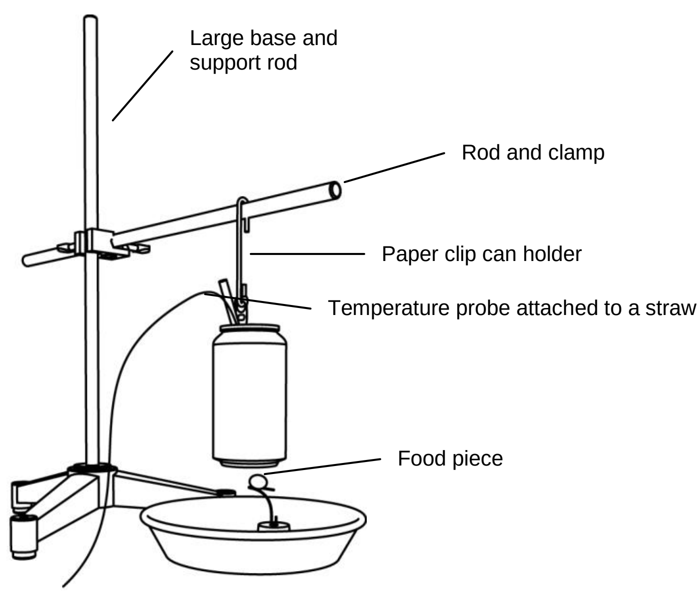
16. ☐ Take the setup to a ventilated hood inside or, alternatively, use a cardboard box outside as a wind break.

Note: The setup includes the data collection system, temperature sensor with a straw taped to the cord, and four sets of food samples with a paper clip and rubber stopper in a pie pan.

Part 2 – Measure the energy content of the marshmallow

17. ☐ Hang a soda can to the rod with the paper clip, and adjust the height of the rod stand so the bottom of the can is about one centimeter above the food sample on the paper clip platform in the pie pan.

Equipment setup



Note: Testing this adjustment before proceeding helps assure that the flame of the burning food sample will directly heat the can of water.

18. ☐ Hang the soda can labeled "marshmallow" on the rod with a paper clip.

19. ☐ Insert the straw taped to the sensor cord into the water, and tape the cord to the can so that the end of the probe does not touch the bottom or sides of the can.

20. ☐ Put the paper clip and rubber stopper in a pie pan close to the aluminum can, but not directly under it, and place the marshmallow on the paper clip platform.

Collect Data

CAUTION: Keep hair, clothing, and other items away from open flames.

Note: Whether indoors or outdoors, minimize air circulation when the food is burning. This helps assure that the flame stays lit and remains in contact with the bottom of the aluminum can. You can use a large cardboard box set on its side with the lid flaps extended to shelter the burning food from air movement. If the day is windy, consider postponing the activity until a day when the winds are calm.

21. ☐ Start data recording. �(6.2)

22. ☐ Adjust the scale of the graph to show all data. �(7.1.2)

23. ☐ Using the wooden match or starter wand, begin burning the food sample.

24. ☐ Adjust the rod with the hanging soda can so the bottom of the soda can is directly over the burning food sample on the paper clip above the pie pan as shown in the equipment setup graphic.

25. ☐ Immediately after the food sample stops burning, gently twirl the can to stir the water with the probe still in it.

26. ☐ Stop recording data when the temperature stops rising, which may be about 30 seconds after the food sample stops burning. �(6.2)

27. ☐ Name the data run "Marshmallow". �(8.2)

28. ☐ Remove the sensor from the soda can, and take the hanging soda can off the paper clip hanger.

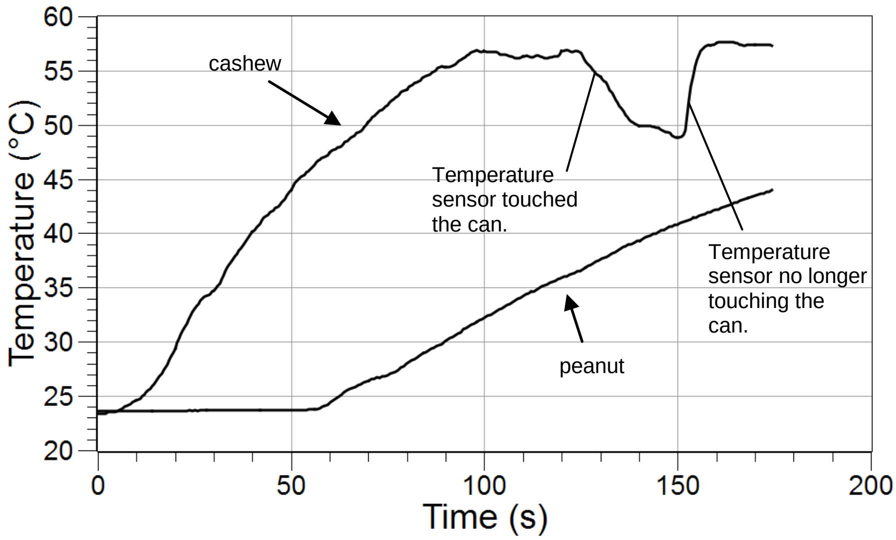
Part 3 – Popcorn, peanut, and cashew

29. ☐ Repeat the steps in Part 2 for the popcorn, the peanut, and the cashew.

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

Sample Data

This graph shows the temperature of the water in the calorimeter while food samples (peanut and cashew) are burning.



Data Analysis

For each food sample, many of the rows in Table 1 were filled in while completing the steps in the Procedure section. The following instructions help you calculate the remaining rows.

1. ☐ Display your run named “Marshmallow” on a graph of Temperature versus Time. �(7.1.7) Adjust the scale of the graph to show all data. �(7.1.2)

2. ☐ Find the initial and final temperatures �(9.1) and record these values in Table 1.

3. ☐ Repeat this procedure for your other three data runs.

4. ☐ For each food trial, determine the following and record the values in Table 1:

- **a.** mass of the water
- **b.** change in mass of the food sample after burning
- **c.** change in temperature of the water
- **d.** heat Q (in joules) transferred to the water ($Q = m \% c \% \Delta T$)
- **e.** the energy content (calories) of the burned food sample in terms of calories, that is, the portion of the heat that was transferred to the water, which is equal to Q/(4.186 calories/joule)
- **f.** energy (Calories) per gram of food burned
- **g.** total energy (Calories) contained in the food piece

Table 1: Mass, temperature, and energy data for food samples

Item	Marsh-mallow	Popcorn	Peanut	Cashew
Mass of empty can (g)	48.0	48.4	15.6	14.9
Mass of can + water (g)	98.0	98.3	63.6	62.1
Mass of water (g)	50.0	49.9	48.0	47.2
Mass of food sample (g)	0.5	0.3	1.1	1.7
Before burning, mass of food sample + clip + rubber stopper + pie pan (g)	7.7	7.4	32.4	31.8
After burning, mass of food sample + clip + rubber stopper + pie pan (g)	7.3	7.2	31.9	31.3
Change in mass of food sample (g)	0.4	0.2	0.5	0.5
Water temperature before burning (°C)	22.8	23.3	23.6	23.6
Water temperature after burning (°C)	24.2	30.7	47.3	57.5
Change in temperature, ΔT (°C)	1.4	7.4	23.7	33.9
Heat Q transferred to the water (joule)	293	1546	4762	6698
Energy content of burned food (calorie), Q/(4.186 calories/joule)	70	369	1138	1600
(Large) Calories/gram of food sample	0.2	1.8	2.3	3.2
Total Calories in food sample (Calorie)	0.1	0.6	2.5	5.4

Analysis Questions

1. According to the United States Department of Agriculture (USDA), there are about 5.9 Calories in 1 gram of peanuts. What percentage of this accepted value was measured in your calorimeter?

Answers will vary, but in this example, the calorimeter captured 39% of the total energy in the peanut:

(2.3 measured Calories/gram ÷ 5.9 USDA Calories/gram) X 100 = 39%

2. Assume you had similar percentage for the other food items. What would be the accepted value for the other food samples?

For this example data:

- Marshmallow: 0.2 ÷ 0.39 = 0.5 Calories/gram
- Popped popcorn: 1.8 ÷ 0.39 = 4.6 Calories/gram
- Peanut: 2.3 ÷ 0.39 = 5.9 Calories/gram
- Cashew: 3.2 ÷ 0.39 = 8.2 Calories/gram

3. Compare your predictions with your data.

Answers will vary, but students should mention predicted and actual findings of the food samples with the highest and lowest number of Calories.

4. For the contest, add the total (adjusted) Calories from the four samples. Add this total to the total of every experiment in the class. Divide this grand total by the number of experiments in the class to calculate the average number of Calories for these four samples. The guess that came closest to this average wins the contest.

For this example, the total number of Calories contained in the 4 food pieces is 19.2 Calories.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Carbohydrates and proteins contain 4 Calories/gram, whereas fats contain 9 Calories/gram. From this information, what can you say about the composition of the 4 food items you tested?

To answer this question, the calculated value of Calorie/gram must be corrected for the calculated efficiency of the calorimeter (39% in this example). For this example, the corrected values would be the following:

Marshmallow = 0.2 ÷ 0.39 = 0.5 Calories/gram

Popped popcorn = 1.8 ÷ 0.39 = 4.6 Calories/gram

Peanut = 2.3 ÷ 0.39 = 5.9 Calories/gram

Cashew = 3.2 ÷ 0.39 = 8.2 Calories/gram

An answer based on results like the one in this example would be something like the following: Based on the equivalent reference of Calories per gram, marshmallows probably have no fat. Popcorn has some fat. Peanuts have more fat than popcorn. Cashews have the most fat. There is no way from this experiment to make any comparison of carbohydrates versus protein since they contain the same Calories per gram.

2. What happened to the heat that was not captured in this calorimeter?

Some of it was transferred directly to the surrounding air by radiation. Since the aluminum can is a highly efficient conductor, most of the heat that did not transfer to the water radiated into the air.

3. What happened to the mass that was lost during burning?

During combustion (oxidation) of the carbohydrates and fats, the carbon, oxygen, and hydrogen in these molecules, together with the oxygen gas, were recombined into carbon dioxide and water vapor and released into the air. A small amount of unburned carbon was also released into the air in the form of smoke.

4. Conduct research on the process using bomb calorimetry that is usually used to determine the caloric content of food. Describe the process.

In a bomb calorimeter, electrical energy is used to ignite the food piece. The calorimeter is pressurized with excess pure oxygen. The energy released by the combustion of the food raises the temperature of the steel bomb, its contents, and the surrounding water jacket. The temperature change in the water is then precisely measured. This temperature rise, along with a bomb factor (which is dependent on the heat capacity of the metal bomb parts) is used to calculate the energy produced by the fuel burnt. A small correction is made to account for the electrical energy input and the burning fuse.

5. Discuss the role of plants in the energy cycle of living organisms. Why is the productivity of plants of concern to other organisms?

The process of converting CO_2 and water into energy-rich organic molecules is called primary production. Autotrophs, through the process of photosynthesis, are the most important primary producers in any food web. Most other organisms in food webs depend on the primary productivity of plants. Primary consumers eat plants or their fruits and seeds, as the source of their food energy, while secondary consumers eat primary consumers for their food energy.

6. Discuss the similarities and differences of aerobic cellular respiration and oxidative combustion (burning).

During both aerobic cellular respiration and oxidative combustion, energy-rich organic molecules are converted to CO_2 and water with the release of energy. Both involve oxidation that requires oxygen. However, oxidative combustion is an uncontrolled process. The energy is released rapidly as heat directly into the environment. In contrast, aerobic cellular respiration is a highly controlled process. It occurs more slowly in multiple biochemical steps. The energy released is captured in chemical bonds in ATP molecules. These ATP molecules can then fuel biosynthetic reactions in a living cell.

Multiple Choice Questions

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

1. A calorie is defined in terms of a certain amount of what?

- **A.** Food
- **B.** Weight in milligrams
- **C.** **Heat**
- **D.** Fat
- **E.** Carbohydrate

2. Which foods have the greatest density of calories?

- **A.** Carbohydrates
- **B.** Sugars
- **C.** Starches
- **D.** **Fats**
- **E.** Proteins

3. When foods are burned by combustion or oxidized during cellular respiration, in what form is the mass lost to the environment?

- **A.** Energy
- **B.** Carbon dioxide
- **C.** Water vapor
- **D.** Oxygen gas
- **E.** **Both B and C**

Extended Inquiry Suggestions

Challenge students to design and test calorimeters that are more efficient in capturing the energy released during the combustion of foods.

15. Weather in a Terrarium

Objectives

Students demonstrate that a terrarium, a closed system, is an excellent tool for conducting environmental studies such as weather investigations. As part of this process, students

- Learn to use this closed system to change one variable at a time, control other variables, and monitor multiple variables
- Design additional investigations of weather using the terrarium

Procedural Overview

Students gain experience conducting the following procedures:

- Designing controlled investigations
- Determining the effect of a plant on the weather inside a terrarium
- Using sensor technology to monitor independent and dependent experimental variables

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Weather sensor
- Light sensor
- Sensor extension cable (2)
- EcoChamber
- Strong incandescent or full-spectrum fluorescent light source
- Fast-growing, small, potted plant

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The difference between climate and weather
- To identify the independent variable, ask "What do I change?"
- To identify the dependent variable, ask "What do I observe?"
- To identify the controlled variables, ask "What do I keep the same?"

Related Labs in This Guide

Labs conceptually related to this one include:

- Investigating Specific Heat
- Insolation and the Seasons
- Photosynthesis and Cell Respiration in a Terrarium

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)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Environmental studies require investigations both in the field and in the laboratory. Because the earth's environment is complex, an investigator in the field must collect a wide variety of data and look for patterns and correlations. When patterns or correlations are discovered, these can be further investigated in controlled laboratory environments. Terrariums are excellent closed systems for environmental studies, allowing the investigator to change one variable at a time, control other variables, and monitor multiple variables in an easily maintained system.

Student-designed investigations are important components of Advanced Environmental Science courses, and long-term projects are appropriate. During this activity, students become familiar with a test system, pose a hypothesis, and then design investigations to test the hypothesis. This activity provides some ideas for investigation and a structure to get students started with their inquiries. It also includes methods for reporting results, and you can choose which are appropriate for the classroom situation.

The test system for this activity is a closed system for examining factors that affect weather. The terrarium functions as a model for the earth and its troposphere. The dependent variables are temperature, barometric pressure, relative humidity, absolute humidity, and dew point. Some topics that could be investigated include the effect on the dependent variables of the following: light intensity, vegetation, water bodies, and land materials. No doubt your students will have many more creative ideas for what they would like to test.

Pre-Lab Discussion and Activity

Inform students they will be learning about a test system that will allow them to conduct their own investigations regarding environmental effects on aspects of weather.

Note: This is a good "starter" activity to help students learn to design scientific investigations because it is simple to set up and execute.

Help students brainstorm environmental issues that may affect weather.

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

Some environmental issues that may affect weather include the following: diurnal changes, seasonal changes, deforestation, local water bodies, and urbanization. From this list, students should be able to pick a topic that interests them.

With this list of topics, address each one and identify parameters that could serve as independent variables in an investigation. For example, a student interested in the effects of deforestation could compare the effects on weather of dirt and a potted plant versus dirt without the potted plant. Students interested in effects of urbanization might test the effect of ground cover versus dark gravel. Students interested in seasonal variations could test the effect of the intensity of the light source, and so on.

Tell students that after they have a chance to learn about the test system, they will be expected to develop a hypothesis to test, identify the independent variables, the dependent variables, and the variables they will strive to control. They will be expected to design an experiment or set of experiments to help them develop data related to their hypothesis. They will be expected to write a proposal and submit it to you for your approval and guidance. Then they will conduct the study, collect and analyze the data, draw conclusions, and report on their study. Students could be expected to report in a variety of ways, including a formal research report, an oral presentation, or response to a set of questions that you design.

Lab Preparation

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

1. Purchase the small potted plants.

Suggested small plants include: tomato plant, basil, mint, or other herbs in small pots. Any plant in a pot small enough to fit into the terrarium will suffice.

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.

4	1	5	3	2
Add a potted plant to the terrarium. Continue recording data for another 5 minutes.	Set up a weather sensor so it can measure the temperature, humidity, barometric pressure, and dew point inside a terrarium.	Determine the effects of light energy and vegetation on the weather variables in the terrarium.	Seal the terrarium airtight. Collect data for 5 minutes. Turn on the light and collect data for another 5 minutes.	Set up a strong light source so it will shine into the terrarium.

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. ☐ Arrange the weather and light sensors so they can detect changes inside the terrarium.

2. ☐ Seal the terrarium so it is airtight.

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

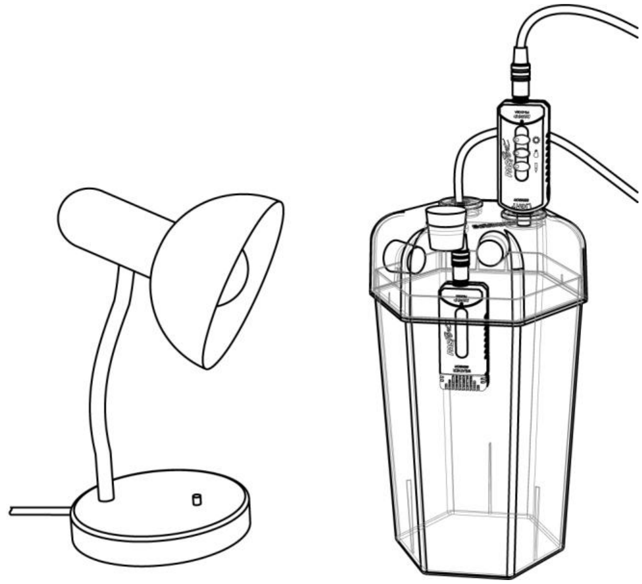
4. ☐ Connect the sensors to the data collection system using the sensor extension cables. �(2.2)

5. ☐ Set up appropriate displays to view the data while it is being collected.

6. ☐ Set up a strong light source near the terrarium to shine directly at it. *Do not turn it on yet.*

7. ☐ What is the light source a model for? What is the terrarium a model for?

The light source is a model for the sun. The terrarium is a model for the earth and its troposphere.



Collect Data

8. ☐ Start recording data. �(6.2)

9. ☐ Continue to record data with the light off for 5 minutes. *Do not stop recording data.*

10. ☐ Turn the light on and continue recording data for 5 minutes. *Do not stop recording data.*

11. ☐ Open the terrarium and add a potted plant. Close the terrarium. Continue recording data for 5 minutes.

12. ☐ Stop recording data. �(6.2)

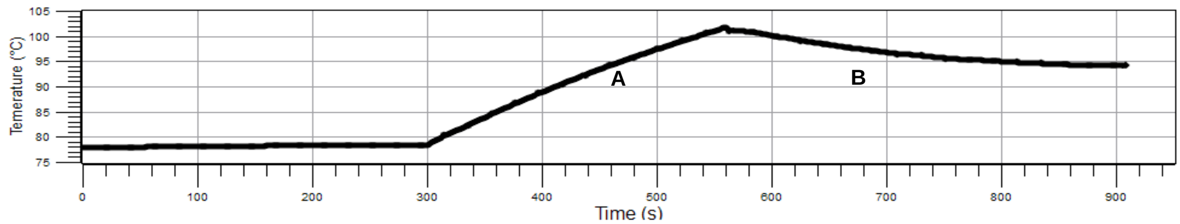
13. ☐ Turn off the light.

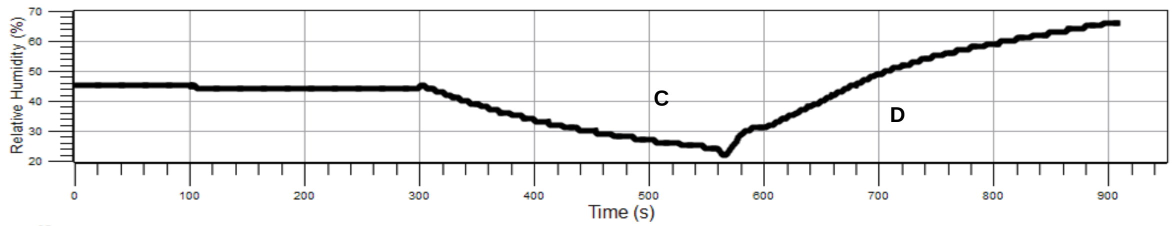
14. ☐ Save your experiment �(11.1) and clean up according to your teacher's instructions.

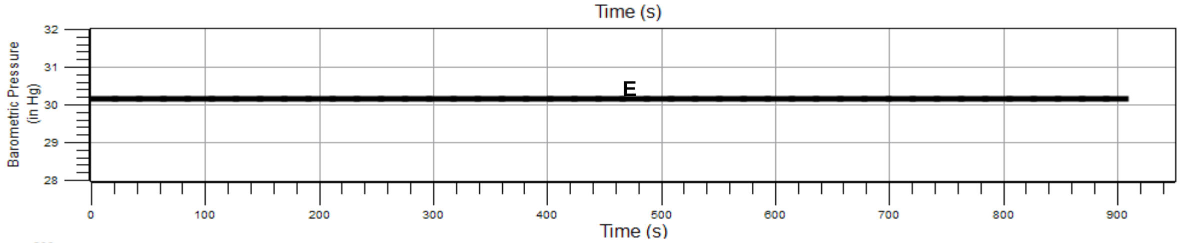
Data Analysis

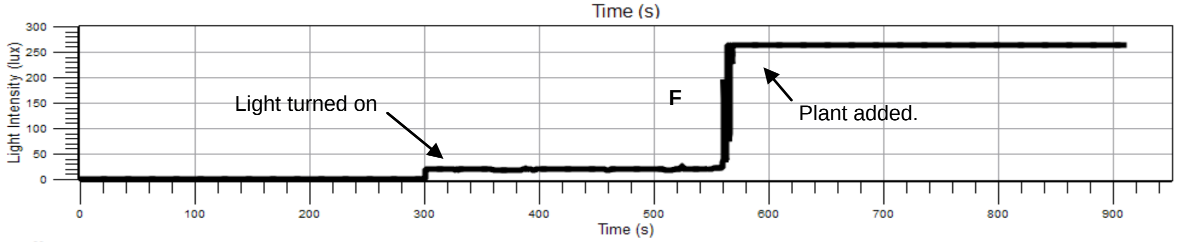
1. ☐ Display your data as graphs, and adjust the graphs to fill the screen vertically. �(7.1.1)
Adjust the x-axis to make the time scales equivalent between graphs. �(7.1.2)

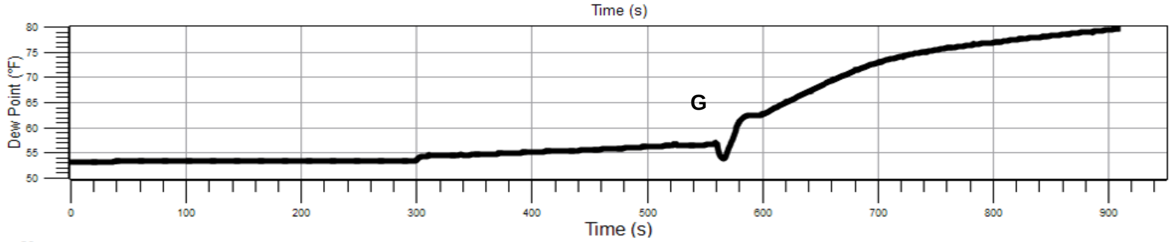
2. ☐ Sketch the graphs of light intensity, temperature, barometric pressure, relative humidity, absolute humidity, and dew point. Label the graphs and the axes, including the units and scales.

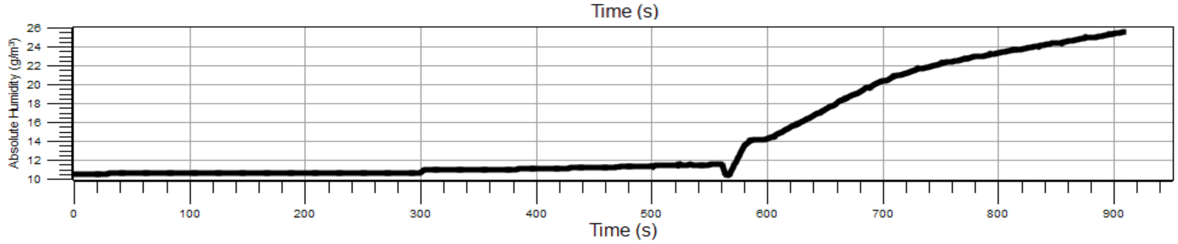












3. ☐ Indicate on the graph where you turned on the bright light and where you added the plant.

4. ☐ Label the areas you think are interesting on the graphs with numbers or letters.

Analysis Questions

1. Discuss the different patterns on the graphs. What do you think are explanations for the patterns?

For this example:

A. When we turned the light on, the temperature inside the chamber rose, probably because the light energy is converted to heat energy inside the chamber. Note: temperature variation will depend upon the type of light used.

B. After we added the plant, the temperature went down, probably because the plant absorbed the light energy for photosynthesis, so some of the light energy was converted to chemical energy in the plant rather than heat energy. Also, the plant was transpiring, adding water to the air as shown by the increase in relative humidity and absolute humidity when the plant was added. Energy is absorbed by the water as it changes phase from liquid to gas during transpiration.

C. When we turned on the light, the relative humidity went down. However, the dew point and absolute humidity went up a little. This might be because relative humidity depends on the temperature. Relative humidity is the percentage of water vapor that the air can hold at a given temperature.

D. After we added the plant, the relative humidity, absolute humidity, and dew point all went up dramatically. This is due to plant transpiration, respiration, and possibly evaporation of water in the soil.

E. The barometric pressure didn't change, because we didn't do anything to significantly change the number of molecules in the air inside the chamber.

F. It was interesting that when we put the plant in the chamber, the light intensity went up dramatically. I would have thought the light intensity would have gone up dramatically when we turned on the light and would have decreased when we added the plant. The increase is probably due to the position of the light sensor, which was out of the direct path of the light. The light that was not changed to heat energy just passed through the chamber (the chamber is relatively transparent to visible light. When we put the plant in it, it scattered the light rays so some of them bounced up to be detected by the light sensor. So even though the plant was absorbing a lot of the light, it looked like the light intensity increased because light rays were reflected towards the light sensor.

G. The dew point and the absolute humidity curves look identical. This could be because they basically are measuring the same thing: the amount of water vapor in the atmosphere. The dew point just reports this in terms of the temperature at which the water vapor would be at 100% saturation, whereas, the absolute humidity is in grams of water vapor/m^3.

2. What were the independent variables in this activity?

The independent variables in this activity were light energy (less or more of it) and vegetation (absence or presence of it).

3. What were the dependent variables in this activity?

The dependent variables were temperature, humidity, absolute humidity, barometric pressure, and dew point.

4. What factors did you try to hold constant during this activity?

Factors that were held constant included the volume of the container and the closed system.

Synthesis Questions

Use available resources to help you answer the following questions.

Begin designing an experiment that investigates an aspect of the weather, using this test system. These questions will assist you to develop a proposal.

1. How could you use the data you collected in this activity in additional investigations?

You could use the data you collect in this activity as a control, or to provide baseline values for comparison when you introduce experimental variables.

2. What question would you like to investigate using this system?

This is where students will propose how they want to use this test system in their own investigation.

3. What independent variables will you test to investigate the question? Why?

Students need to think about and should state which factor they will change to find out its effect on the system.

4. What will be a hypothesis for a test of this issue using this system?

Students need to state the hypothesis they intend to test. The following are some examples of appropriate hypotheses:

- Using this test system, increased light intensity will result in increased temperature.
- Using this test system, the addition of light-colored rocks will result in a lower air temperature than the addition of dark-colored rocks.
- Using this test system, the addition of water will result in lower temperature and higher humidity.
- Using this test system, condensation will occur if the system is cooled below its dew point.

You may need to guide students to create an appropriate hypothesis.

5. How will you design the investigation to test your hypothesis?

Students should state exactly what they plan to do in their investigation. The exact specifications of how they will change their independent variable should be stated. Examples of appropriate plans include the following:

- To vary the light intensity reaching the terrarium in a manner that mimics the sun, the intensity of the light source will be varied by set amounts. We will run 3 trials with the light source being positioned progressively further away from the terrarium. Each trial will last 5 minutes, allowing the chamber to cool for 15 minutes between trials. The light sensor will record the effect on light intensity of this action, which will quantify our independent variable, light intensity. We will record temperature, humidity, barometric pressure, and dew point to determine the effect on these weather parameters.
- To determine the effect of a water body on weather, we will add 1 L of room-temperature water to an empty terrarium. We will run 2 trials, one with an empty terrarium, and the other with water. Each trial will last 5 minutes, allowing the chamber to cool for 15 minutes between trials. We'll keep the amount of light entering

the system constant as verified by the light sensor. We will record temperature, humidity, barometric pressure, and dew point to determine the effect of the water on these weather parameters.

You will probably need to guide students to create an appropriate design plan for their investigations.

6. How will you analyze the results of your experiment?

Students should state the types of comparisons and statistical analyses they will use.

7. What materials and equipment will you need to conduct your investigation?

Students should specify the materials and equipment they will need to a similar level of detail as that in the Materials and Equipment sections of these lab activities.

Multiple Choice Questions

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

1. The design of a research study must include:

- **A.** A hypothesis to test
- **B.** A defined test system that controls variables
- **C.** A controllable independent variable
- **D.** A measurable dependent variable
- **E.** Control or baseline measurements
- **F.** **All of the above**

2. In a scientific experiment, an independent variable is:

- **A.** A variable that has nothing to do with other variables
- **B.** Something that changes in response to another variable
- **C.** **Something that you change to affect another variable**
- **D.** Something that you try to keep constant

3. In a scientific experiment, a dependent variable is:

- **A.** A variable that has nothing to do with other variables
- **B.** **Something that changes in response to changes in another variable**
- **C.** Something that you change to affect another variable
- **D.** Something that you try to keep constant

4. In the test system in this activity, an independent variable is:

- **A.** Temperature
- **B.** Light energy
- **C.** Vegetation
- **D.** Humidity level
- **E.** **Either B or C**

5. In the test system in this activity, a dependent variable is:

- **A.** Temperature
- **B.** Light energy
- **C.** Vegetation
- **D.** Humidity level
- **E. Either A or D**
- **F.** Either B or C

Extended Inquiry Suggestions

Have students conduct the experiment they designed in the Synthesis Questions section. Have students report on their experiment, including the hypothesis, the method, the results, and conclusions regarding why the results did or did not support the hypothesis.

Provide the opportunity for more than one student-designed experiment. In science, the answer to one question usually leads to more questions that seem interesting to explore.

16. Yeast Respiration

Objectives

Students use yeast cells as a simple model for studying both aerobic and anaerobic cellular respiration. As part of this investigation, they:

- Analyze evidence of aerobic and anaerobic respiration by yeast cells
- Discuss the role of cellular respiration in the carbon and oxygen cycles
- Explain the role yeast cells play in scientific exploration

Procedural Overview

Students gain experience conducting the following procedures:

- Creating a closed-system for collecting and interpreting data collected by CO_2 gas and dissolved oxygen sensors
- Using a microscope to observe and describe yeast cells

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 to 30 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dissolved oxygen sensor
- Carbon dioxide gas sensor
- Stainless steel temperature sensor
- EcoChamber
- Beaker, 1-L
- Graduated cylinder, 500-mL or 1-L
- Pipet, disposable
- Microscope with magnification to 400x
- Microscope slide and cover slip
- Activated baker's yeast, 7-g packet
- Sugar, 100 g
- Hot plate with magnetic stirrer and stir bar
- Magnetic stir plate with stir bar
- Water, 1 L

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Food provides molecules that serve as fuel and building material.
- ♦ Organisms get energy from oxidizing their food.
- ♦ The processes of extracting energy from food and getting rid of wastes are carried out primarily in cells, which function similarly in all organisms.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Cellular Respiration and the Carbon Cycle
- ♦ Determining Soil Quality
- ♦ Toxicology Using Yeast

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 your data collection system �(2.2)
- ♦ 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)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Saving your experiment �(11.1)

Note: Provide a copy of the user manual for the carbon dioxide and dissolved oxygen sensors for student reference.

Background

The term "respiration" refers to the exchange of gases between an organism and its environment. This intake of oxygen gas and exhalation of carbon dioxide gas is closely linked to the production of ATP at the cellular level, a process called cellular respiration. ATP is generated by mitochondria within the cell. During cellular respiration, the energy stored within macromolecules such as glucose is released and harnessed to phosphorylate ADP, producing ATP.

In the presence of oxygen, glucose can be fully oxidized releasing large amounts of energy. The process of cellular respiration also produces water and carbon dioxide gas as waste products.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{energy}$$

Organisms that obtain their energy primarily by utilizing oxygen for the breakdown of glucose are called aerobic organisms. Plants and animals are both examples of aerobic organisms. Even dormant plant seeds undergo respiration, although at a much lower level than after germination starts.

Yeasts are actually facultative anaerobes, organisms that have the ability to undergo aerobic respiration and anaerobic respiration. With oxygen present, yeast will preferentially undergo aerobic respiration. If no oxygen is present, yeast cells use an anaerobic respiration. These reactions are summarized as follows:

glucose + ADP → carbon dioxide gas + ethanol + ATP

Yeast cells participate in the carbon cycle by breaking down large, organic molecules, releasing carbon into the environment as carbon dioxide gas. The carbon dioxide gas is then available to plants for use in the photosynthesis process. Yeast cells participate in the oxygen cycle by using oxygen gas during aerobic cellular respiration to oxidize glucose, producing carbon dioxide gas and water vapor.

Pre-Lab Discussion and Activity

Engage your students by discussing the historical role that yeast has played in the progress of science.

You may be able to find a multimedia presentation on the discoveries of Louis Pasteur as related to the French beer and wine industries in the 1860s. If not, you can present the following information:

Only 150 years ago, nobody knew how important the single-celled fungi called yeasts are to humankind. We now know that yeast cells are involved in common medical conditions and are promising genetic research tools. Yeast also turns grape juice into wine; converts sugar, water, and hops into beer; and causes bread dough to rise. However, until 1860, people thought that magic or "the grace of God" was responsible. Beer makers knew that they needed to stir the wort (the sugar, hops, and water) with a special stick that they handed down from generation to generation in order to get the proper fermenting action. Bread makers knew they had to preserve a culture that they carefully kept fresh with regular additions of sugar. Wine makers knew that when they crushed the grapes and let the juice sit in vats with the grape skins for awhile, the juice would ferment and turn into wine.

Louis Pasteur was the scientific genius who discovered that yeast cells cause these changes. When the French government called on him to figure out why the wine and beer industries were literally going sour, he used classic microbiological methods to determine that rogue bacteria had invaded the beer and wine, preventing the yeast cells from growing and doing their job of fermenting sugar into alcohol. He invented the pasteurization process to kill the bacteria, and then he inoculated the sterile solutions with the proper kinds of yeast cells.

Review the chemical reactions involved in aerobic respiration and anaerobic respiration as they occur in yeast cells.

Point out that the process of aerobic respiration in yeast cells is virtually identical to that of human cells. However, the process of anaerobic respiration in yeast cells is different from that occurring in human muscle cells. In yeast cells, ethanol is produced as a waste product of anaerobic respiration. In human muscle cells, lactic acid is produced as a waste product of anaerobic respiration.

Ask students*:*

Do you think your cells undergo anaerobic respiration?

Students may be surprised to learn that every time they exercise until their muscles get sore, their muscle cells have used the process of anaerobic respiration. The lactic acid that is produced as a byproduct of anaerobic respiration makes their muscles feel sore.

If necessary, review with your students the proper use of microscopes.

Lab Preparation

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

Teacher Tip: It is not necessary to calibrate the sensors in this activity because it is not concerned with accuracy but rather with relative levels within the data run.

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	5	2	3	4
Heat sugar water, make an activated yeast solution, and set up your data collection system to show CO_2 and DO.	Observe the activated yeast solution and the sugar and water solution under a microscope.	Set up an airtight transparent chamber in which you can measure dissolved oxygen (DO) and carbon dioxide (CO_2) gas simultaneously.	Pour sugar water into the chamber, seal it from air, and collect data. Stir the solution slowly with the magnetic stirrer.	Put the yeast solution into the collection chamber and keep 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.

Set Up

1. ☐ Heat a liter of water and 100 g sugar solution in the 1-L beaker on a hot plate to about 40 °C.

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

b. Insert the temperature sensor into the solution and adjust the hot plate temperature control until 40 °C is reached.

Note: Make sure the sensor is not in contact with the bottom of the beaker when you measure the temperature.

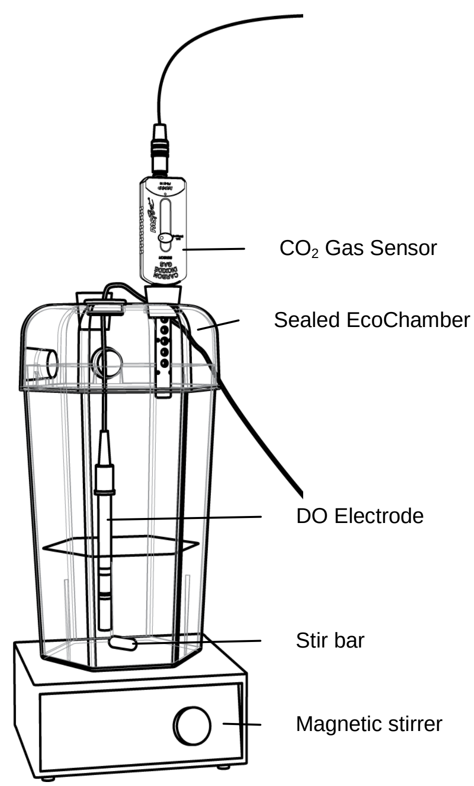
c. Adjust the temperature control on the hot plate to maintain the solution at 40 °C. Monitor the temperature for two minutes to make sure it has stabilized.

2. ☐ Set up the EcoChamber to measure dissolved oxygen (DO) and carbon dioxide (CO_2) gas simultaneously.

a. Place a stir bar in the chamber and set it on a magnetic stirrer.

b. Make sure the end of the dissolved oxygen sensor is about 1 cm above the bottom of the chamber.

c. Arrange the CO_2 gas sensor so the end is completely inside the container but will not get wet.



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

4. ☐ Connect the DO and CO_2 sensors to your data collection system. �(2.2)

5. ☐ Display both DO and CO_2 on the y-axis of the graph, with time displayed on the x-axis. �(7.1.10)

6. ☐ Pour 500 mL of the sugar water into the chamber, and seal the chamber airtight.

7. ☐ Turn on the magnetic stirrer.

8. ☐ Maintain the remaining solution at about 40 °C.

Note: The goal is to pour enough liquid into the chamber to allow the dissolved oxygen sensor to be submerged up to the silver ring.

9. ☐ What do you predict will happen to the levels of dissolved oxygen and CO_2 gas with this setup?

Answers will vary. However, students should mention what kind of change they expect for both dissolved oxygen and CO_2 gas. Note: The dissolved oxygen concentration will decrease and the carbon dioxide concentration will stay approximately the same.

Collect Data

10. ☐ Start data recording. �(6.2) Record data for about 10 minutes, but *do not stop recording data.*

11. ☐ Adjust the scale of the graph so the data fills the screen. �(7.1.2)

Note: While you record data, you can continue with the next two steps.

12. ☐ Pour a package of activated baker's yeast into the remaining sugar-water, and stir until the yeast is dissolved in the water.

13. ☐ Observe the yeast solution, and describe its appearance and any activity in it. What do you think is happening?

Students should see gas bubbles forming. They may be able to guess that these are bubbles of CO_2 gas.

14. ☐ After recording data for 10 minutes, pour about 250 mL of this mixture into the chamber, and re-seal the chamber so that it is airtight.

Note: The goal is to pour about half of the yeast solution into the chamber.

15. ☐ Why do you seal the chamber to isolate it from the surrounding air?

You seal the chamber to create a closed system so that all of the carbon dioxide gas produced by the yeast cells will remain in the chamber to be measured.

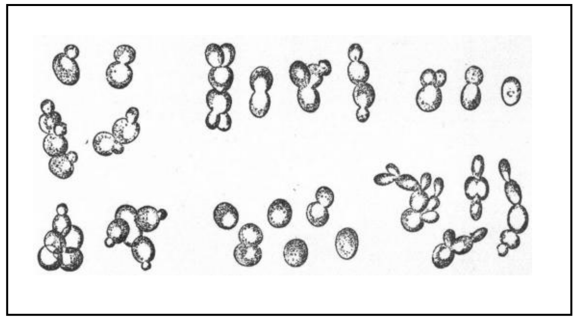
16. ☐ What do you predict will happen to the levels of dissolved oxygen and CO_2 gas with this setup?

Answers will vary, but students should mention what kind of change they expect for both dissolved oxygen and CO_2 gas as a result of adding yeast cells to the system. Note: The dissolved oxygen concentration will go down and the carbon dioxide concentration will go up.

17. ☐ Continue recording data for 20 minutes. While data is recording, perform the following three steps.

18. ☐ Using the pipet, put a drop of the yeast solution on a glass slide and cover it with a cover slip.

19. ☐ Examine this preparation under a microscope at up to 400x magnification. Record your observations below, including a sketch of what you see at the highest magnification.



Students should record their observations of the yeast solution.

20. ☐ In studying cellular respiration in yeast, why would you measure dissolved oxygen and carbon dioxide gas?

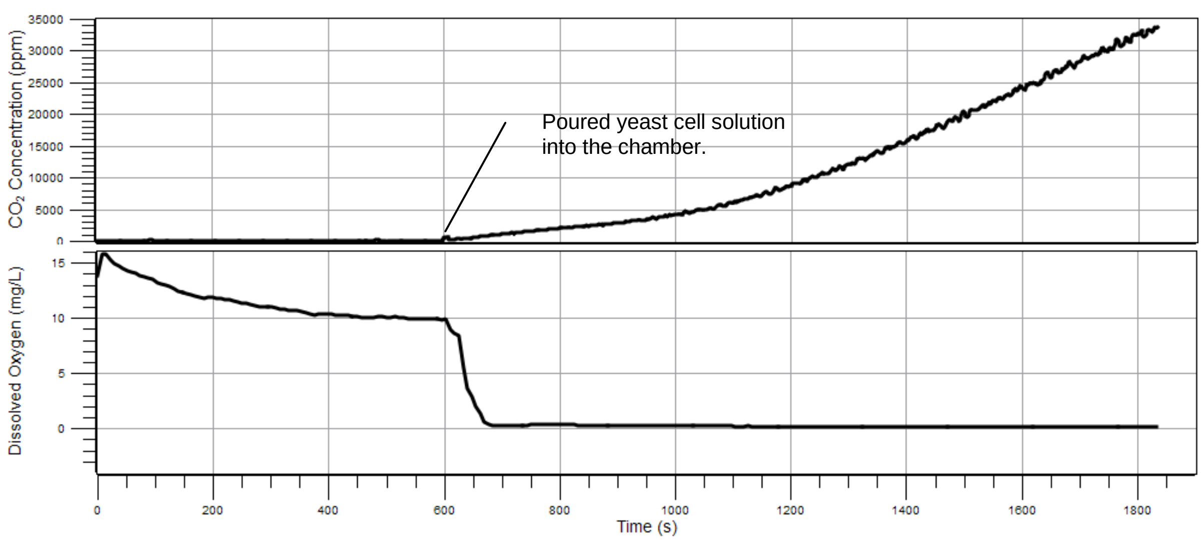
You would measure dissolved oxygen and CO_2 gas as evidence that cellular respiration is occurring.

21. ☐ After 20 minutes, stop recording data �(6.2) and save your experiment. �(11.1)

Data Analysis

1. ☐ Sketch graphs of your recorded data in the spaces provided, including the appropriate scale. Indicate when the yeast cell solution was added.

Graph of [DO] in sugar-water and CO_2 gas concentration, before and after activated baker's yeast is added.



2. ☐ Use graph tools to identify the data points �(9.1) to complete Table 1.

Table 1: Change in dissolved oxygen and carbon dioxide gas concentrations

	Dissolved Oxygen (mg/L)			CO_2 gas (ppm)		
	Initial	**Final**	**Δ**	**Initial**	**Final**	**Δ**
Sugar water	15.9	10.0	-5.9	14	55	31
Sugar water with yeast	10.0	0	-10.0	55	33768	33763

Analysis Questions

1. How do the results of the data compare with your predictions?

Answers will vary. However, students should specifically mention what actually happened to carbon dioxide gas concentrations and dissolved oxygen concentrations compared with what they predicted.

2. The following summarizes the chemical reactions during aerobic cellular respiration:

oxygen gas + glucose → carbon dioxide gas + water vapor + energy (ATP)

Did you see any evidence that aerobic cellular respiration took place? Record all kinds of evidence, including visual observations.

When the yeast cells are first poured into the chamber, the level of dissolved oxygen drops off precipitously. At the same time, the level of CO_2 gas starts rising. This combination of events suggests that aerobic respiration is occurring.

3. The following summarizes the chemical reactions during anaerobic cellular respiration:

glucose → carbon dioxide gas + ethanol + energy (ATP)

Did you see any evidence that anaerobic cellular respiration took place? Record all kinds of evidence, including visual observations.

After the dissolved oxygen seems to be consumed, the level of CO_2 gas continues to rise. In fact, it seems to rise at a faster rate.

Synthesis Questions

Use available resources to help you answer the following questions.

1. How do yeast cells participate in the carbon cycle?

Yeast cells participate in the carbon cycle by breaking down large, complex organic (containing carbon) molecules and releasing the carbon into the environment as carbon dioxide. The carbon dioxide gas is then available to plants for use in the process of photosynthesis.

2. How do yeast cells participate in the oxygen cycle?

Yeast cells participate in the oxygen cycle by using oxygen gas during cellular respiration, causing the oxygen to combine with carbon atoms to form carbon dioxide and to combine with hydrogen atoms to form water molecules.

3. List one reason why yeast cells are frequently used as models in medical and scientific research.

Answers might include one of the following: Yeast cells have many metabolic processes that are similar to those of organisms higher in phylogeny, including humans. Yeast cells are easy to grow. Most yeast cells are not pathogenic. Yeast cells are relatively simple organisms yet are eukaryotic.

4. List one way that yeast cells are now being used in medical or scientific research.

Answers might include one of the following: Yeast cells are currently being used in genetic engineering studies, toxicology studies, and molecular biology studies.

Multiple Choice Questions

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

1. Yeasts are

- **A.** Single-celled organisms containing chlorophyll
- **B.** Single-celled organisms that do not have a nucleus
- **C. Single-celled organisms that have a nucleus and organelles typical of eukaryotes**
- **D.** Single-celled bacteria
- **E.** Multicellular organisms

2. Yeasts get their energy for life processes from

- **A.** Aerobic cellular respiration
- **B.** Anaerobic cellular respiration
- **C.** Alcoholic fermentation
- **D.** Only A and B are correct
- **E. A, B, and C are all correct**

3. Yeasts release the following as byproducts of cellular respiration:

- **A.** Oxygen gas
- **B.** Carbon dioxide gas
- **C.** Ethanol
- **D.** Water
- **E.** Only B and C are correct
- **F.** **Only B, C, and D are correct**

4. Yeasts participate in the carbon cycle by

- **A.** Decomposing complex carbohydrates
- **B.** Capturing CO_2 gas from the atmosphere and incorporating it into sugars
- **C.** Incorporating elemental carbon into foods that other organisms can use
- **D.** Fermenting sugars, releasing CO_2 gas
- **E.** A and B are correct
- **F.** **A and D are correct**

5. Yeasts participate in the oxygen cycle by

- **A.** Decomposing complex carbohydrates
- **B.** Capturing O_2 gas from the atmosphere and incorporating it into sugars
- **C.** Incorporating elemental carbon into foods that other organisms can use
- **D.** Fermenting sugars, releasing CO_2 gas
- **E.** A and B are correct
- **F.** **A and D are correct**

Extended Inquiry Suggestions

Challenge students to design a more detailed inquiry into yeast cellular respiration by adding oxygen gas and ethanol sensors to the experimental system. Have them look for additional evidence of aerobic and anaerobic cellular respiration.

Ask students to investigate the role of yeast in the creation of biofuel.

Pollution

17. Properties of Water

Objectives

Students explore how the properties of water can be explained by the molecular structure of water. Through this investigation, students:

- Explain that hydrogen bonding allows water, unlike other molecules, to change from one state of matter to another at the temperatures and pressures experienced on Earth
- Observe adhesion and cohesion of water molecules on polar and non-polar surfaces and explain these observations by describing the intermolecular attractions involved
- Design an experiment to determine how the volume of ice compares to the volume of liquid water. The students will base their predictions on their understanding of the molecular structure of water
- Describe how the unique properties of water are important to processes on Earth such as physical erosion and the hydrologic cycle

Procedural Overview

Students gain experience conducting the following procedures:

- Collecting temperature data as ice is melted and water is boiled
- Classifying substances as polar or non-polar based on their ability to absorb water
- Designing an experiment to determine the effect of freezing on the volume of water

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activities	60 minutes
♦ Lab activity	90 minutes (or two 45 minute blocks)

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Stainless steel temperature sensor[1]
- ♦ Beaker, 600-mL
- ♦ Beaker, 100-mL
- ♦ Utility clamp
- ♦ Ring stand
- ♦ Hot pads or mittens
- ♦ Hot plate
- ♦ Crushed ice, 300 mL
- ♦ Eye dropper or disposable pipet
- ♦ Paper towel
- ♦ Wax paper
- ♦ Foam tray
- ♦ Other materials to test[2]
- ♦ Water, 50 mL

[1]A fast-response temperature probe is not appropriate for this lab

[2] Any materials can be tested such as waxy leaves, cement, sand paper, glass, cloth, overhead transparencies, brick, rocks, and plastic wrap.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ States of matter and changes of state
- ♦ Covalent bonding
- ♦ Hydrogen bonding
- ♦ Polar and non-polar substances
- ♦ Cohesion
- ♦ Adhesion

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Specific Heat of Sand versus Water
- ♦ Monitoring the Quality of Water
- ♦ Water Treatment

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)
- Saving your experiment �(11.1)
- Printing �(11.2)

Background

Properties of Water and Earth Processes

Compared with other substances on Earth, water is quite unusual. Water is the only substance that naturally exists on Earth as a solid, a liquid, and a gas. Water is also the only substance whose solid state is less dense than its liquid state. Water is attracted to some surfaces (adhesion) causing a water drop on these surfaces to spread out and be absorbed into the surface. On other surfaces, however, water is repelled and beads ups in small drops (cohesion).

These unusual properties of water are vital to many processes on Earth. Water evaporation plays a critical role in the distribution of fresh water over the earth's surface. Water deposited high in mountains or in cold climates accumulates and erodes rocks through freeze-thaw cycles, glacial erosion, or typical erosion as it melts on its way back to the sea. Water both wets solid surfaces and is drawn into spaces between rocks and soil. The water dissolves minerals, allowing microorganisms in the soil to absorb these nutrients. Various molecules and compounds in air, such as oxygen or carbon dioxide, dissolve in water and are important for the survival of aquatic organisms, decomposing organic matter, or creating acid rain.

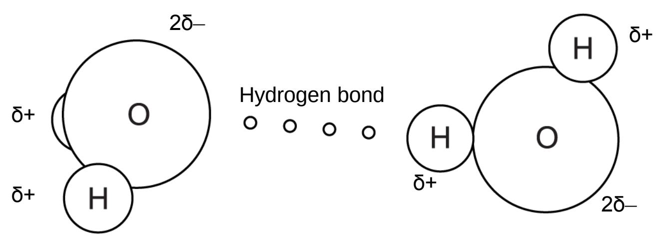
Molecular Structure of Water

The molecular structure of water explains its unusual properties. Each water molecule is made up of one oxygen atom covalently bonded to two hydrogen atoms. The covalent bond is formed by the sharing of electrons between each hydrogen atom and the oxygen atom. The sharing of electrons, however, is not equal. Oxygen attracts the electrons more strongly than hydrogen and therefore has a partially negative charge, leaving the hydrogen atoms with a partially positive charge. Covalent bonds that exhibit unequal sharing are called polar bonds.

In addition to containing polar bonds, the entire water molecule is also polar. The H–O–H bond angle in water is 105° which gives water a bent shape. This shape along with the polar O–H bonds causes the side of the water molecule containing the hydrogen atoms to have a partial positive charge while the oxygen side of the molecule has a partial negative charge. Most chemicals that involve two atoms of one element and one atom of another are symmetrical (such as CO_2) and are gases at room temperature, but water is asymmetrical and this asymmetry causes water to be a liquid at room temperature.

In the liquid and solid state water molecules are attracted to one another. The polar nature of water molecules cause water molecules to be attracted to each other. This attraction between molecules is called an intermolecular attraction. The type of intermolecular attraction involved is called hydrogen bonding. Hydrogen bonding occurs when a hydrogen atom covalently bonded to a highly electronegative atom is attracted to a highly electronegative atom of another molecule (highly electronegative atoms include oxygen, fluorine, and nitrogen). Compared to other intermolecular forces, hydrogen bonds are very strong. But when compared to covalent or ionic bonds, hydrogen bonds are very weak.

Hydrogen bonds in liquid water are constantly being broken and reform as the water molecules move around. This is why water flows and does not have a definite shape. As a solid, however, the hydrogen bonds holding water molecules together are fixed between the same molecules. Although the water molecules vibrate, they do not move around and thus a crystal lattice is formed.



Pre-Lab Discussion and Activities

Materials and Equipment for Pre-lab Activities:

- Latex balloon
- Dripping stream of water
- Glass bottle with a screw cap
- Water, enough to fill the glass bottle
- Toothpicks (24)
- Gumdrops (24), white[1]
- Gumdrops (12), red[1]

[1]Any color gumdrops can be used, but you should use the 24 of the same color to represent hydrogen atoms and 12 of the same color to represent oxygen atoms.

The Polar Nature of Water

Demonstrate the polar nature of water by rubbing a comb or latex balloon in your hair and placing it next to a dripping stream of water (this words best if the air in the room is very dry). Engage the students in a discussion about what they observe and have them explain why this is happening.

1. What do you think will happen if a charged balloon is placed next to a dripping stream of water?

The charged balloon causes the stream of water to alter its direction of fall and be attracted to the balloon.

2. Why does this happen?

This occurs because of the dipole nature of water molecules. Water molecules have a partially positive side (the hydrogen atoms) and a partially negative side (the oxygen atom). The charged balloon causes the water molecules to align themselves so that the positive side of each water molecule is pointed toward the balloon (which is negative).

3. What is a water molecule made up of and why is it considered to be a polar molecule?

A water molecule is made up of one oxygen atom and two hydrogen atoms covalently bonded together (electrons are shared). Unequal sharing of electrons between O–H causes the hydrogen atoms to have a partially positive charge and the oxygen to have a partially negative charge. The atoms are arranged in a bent shape with an H–O–H bond angle of 105° which gives the molecule an asymmetrically bent shape. The bent shape and the polar bonds causes the water molecule to be polar.

Hydrogen Bonding in Water

Discuss with the students how water is different when it is a solid, a liquid, and a gas. Use this discussion to review changes of state, hydrogen bonding, and covalent bonding.

4. How is the molecular structure of ice, water, and water vapor similar?

Ice, water, and water vapor are all made up of the same molecule, H_2O.

5. How is the molecular structure of ice, water, and water vapor different?

Water vapor is made up of quickly moving, independent water molecules. Water, as a liquid, is made up of water molecules that are moving more slowly and are held together with other water molecules by hydrogen bonding. Ice is made up of water molecules that are only vibrating and are locked in a crystal structure by hydrogen bonds between the molecules.

6. Why is a water molecule a liquid at room temperature, but most other small molecules (CO_2, NO_2, O_2, N_2) are all gases at room temperature?

Water is a liquid at room temperature because of the hydrogen bonding between its polar molecules. The energy that is provided at room temperature is not strong enough to overcome this attraction. The other small molecules are non-polar and are held together by dispersion forces (a much weaker type of intermolecular force). These weaker forces are easily overcome by the energy provided at room temperature.

7. What is hydrogen bonding? How does it compare to covalent bonding?

Hydrogen bonding occurs when a hydrogen atom covalently bonded to a highly electronegative atom is attracted to a highly electronegative atom of another molecule (highly electronegative atoms include oxygen, fluorine, and nitrogen). Hydrogen bonding holds one molecule of water to another and therefore is called an intermolecular force.

Covalent bonding is a much stronger force and is the attraction that holds the hydrogen atom and oxygen atom within a water molecule together. The attraction is formed by the sharing of electrons.

8. How does the density of ice compare to the density of water? Is this unusual?

Ice is less dense than water. This is because the hydrogen bonding in ice forces the molecules farther apart and thus water, as ice, takes up more volume than liquid water. Water molecules as a liquid can get closer together because they are always moving forming hydrogen bonds between different water molecules.

This is very unusual. In general, the solid state is always the most dense out of the three states of matter because the atoms or molecules that make up the substance are closer together.

9. What will happen to a glass bottle that is completely filled with water, capped, and placed in the freezer overnight? Why?

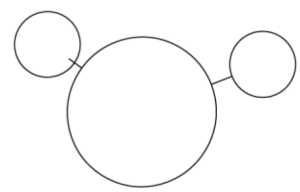
The glass bottle will break because ice takes up more space than liquid water.

Teacher tip: Show the students a bottle and fill it with water. Place the bottle in a plastic bag and then freeze it over night. Show the students the results the next day.

Model the difference in density between liquid and solid water:

Have the students model the structure of liquid water compared to the structure of solid water (ice). The important earth science application here is the space taken up for liquid water molecules compared to the space taken up by solid water molecules. This has implications for the erosive effect of freezing water on rock.

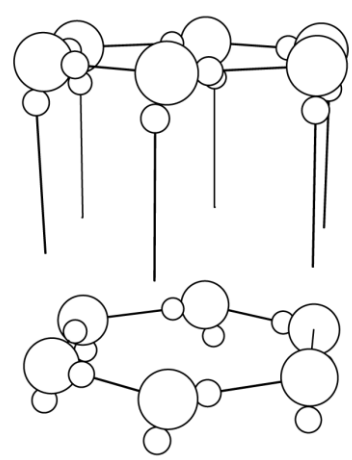
Have the students build twelve water molecules from colored gumdrops.



- Use half-toothpicks to hold the atoms together in a single molecule (covalent bonds).
- One color gumdrop should be used for hydrogen and a second color for oxygen.
- Make sure that students build the molecule in the correct "bent" shape.
- Have students pile their molecules together and observe that the molecules can tumble around each other, and take up a small amount of space.

10. What causes the twelve water molecules to stay close together? What state of matter does this represent?

The water molecules are weakly held together by hydrogen bonds that are quickly forming and reforming as the molecules move around (in this model the hydrogen bonds are invisible). The water molecules are very close together and are held together by hydrogen bonds. This represents a liquid.



11. In this model what do the half-toothpicks represent?

The half-toothpicks represent the covalent bonds within the water molecule.

Have the students attach the water molecules together to create a crystal of ice.

- Use whole toothpicks (representing hydrogen bonds) to connect six water molecules together in a hexagon alternating -H-O-H-O-. Create two of these hexagons.
- Stack the two hexagons together using whole toothpicks to complete the ice crystal.

12. What do the whole toothpicks represent?

The whole toothpicks represent hydrogen bonds between water molecules.

13. What state of matter does this model represent?

This model represents ice.

14. Does the model of ice or water take up more space? Why?

The ice takes up more space. This is because the water molecules are in a set position and are not free to move around.

15. How do these models help you understand the difference in density between ice and water?

Ice is less dense than water because the same number of molecules (same mass) takes up more space when position in a crystal lattice. In ice the H_2O molecule are farther apart than they are in liquid water.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Do not touch the hot plate or hot glassware.
- ♦ Do not allow the temperature sensor's wires to touch the hotplate at any time.

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 – Phase change of water

2	1	3	4	5
Place the beaker with ice on a hot plate with a temperature sensor positioned in the ice.	Fill the beaker with ice.	Start collecting Temperature versus Time data.	Stop collecting data after the water has boiled for approximately 10 minutes.	Mark the following features on your graph: ice only, ice and water, water only, water and water vapor, melting, and boiling.

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 – Phase change of water

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

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

5. ☐ Plug in the hotplate and turn it on to its highest setting.

CAUTION: Ensure that papers and wires do not touch the hot plate.

6. ☐ Fill the 600-mL beaker with crushed ice to approximately 300 mL.

7. ☐ Place the beaker with crushed ice onto the hot plate.

8. ☐ Lower the stainless steel temperature sensor into the ice, positioning the tip of the sensor approximately 2 cm below the surface of the ice. Make sure the sensor does not touch the bottom or the sides of the beaker.

Collect Data

9. ☐ Start data recording. �(6.2)

10. ☐ Adjust the scale of the graph as needed. �(7.1.2)

11. ☐ Collect data until the water has been boiling for 10 minutes. Be sure that the tip of the sensor is always under the ice or the water. You may have to adjust its position as the experiment continues.

12. ☐ What changes do you expect to happen that may cause the volume of ice and water in the beaker to decrease as the beaker is heated?

When the ice melts, the spaces between the ice cubes will be filled with water. Ice also has a slightly larger volume than liquid water, so when it melts the water will take up less space than the ice did. When water evaporates the gaseous water molecules escape into the air and thus the volume of water in the beaker decreases.

13. ☐ Record the elapsed time when each of the changes listed in Table 1 occurred.

Table 1: Phase changes

Change	Elapsed Time (s)
Ice started melting	10
The last piece of ice melted	80
Water started boiling	780

14. ☐ Describe the characteristics (in regard to volume and shape) of ice that make it a solid.

Ice is classified as a solid because it has a definite volume and a definite shape.

15. ☐ What is hydrogen bonding and how does it explain the properties of ice listed above?

Hydrogen bonding is the attractive force that holds certain types of molecules, such as water, together. Molecules that involved hydrogen bonds have hydrogen atoms attached to an atom of oxygen, nitrogen, or fluorine.

In ice, the water molecules are held in a rigid crystal structure by hydrogen bonds. The molecules vibrate, but remain in the same location (attracted to the same molecules) which gives ice its definite shape and definite volume.

16. ☐ Describe the characteristics of water that make it a liquid. Explain how hydrogen bonding is involved.

Water is classified as a liquid because it has no definite shape (it takes the shape of its container) and it has a definite volume.

Water molecules are held together by hydrogen bonding, which gives water a fixed volume. The water molecules are constantly moving, however, so the hydrogen bonds are constantly being formed between different molecules. This constant motion and rearrangement of the hydrogen bonds give water its ability to change shape and take the shape of its container.

17. ☐ Describe the characteristics of water vapor that make it a gas. Explain whether or not hydrogen bonding occurs.

Water vapor is a gas because it does not have a definite volume and it does not have a definite shape.

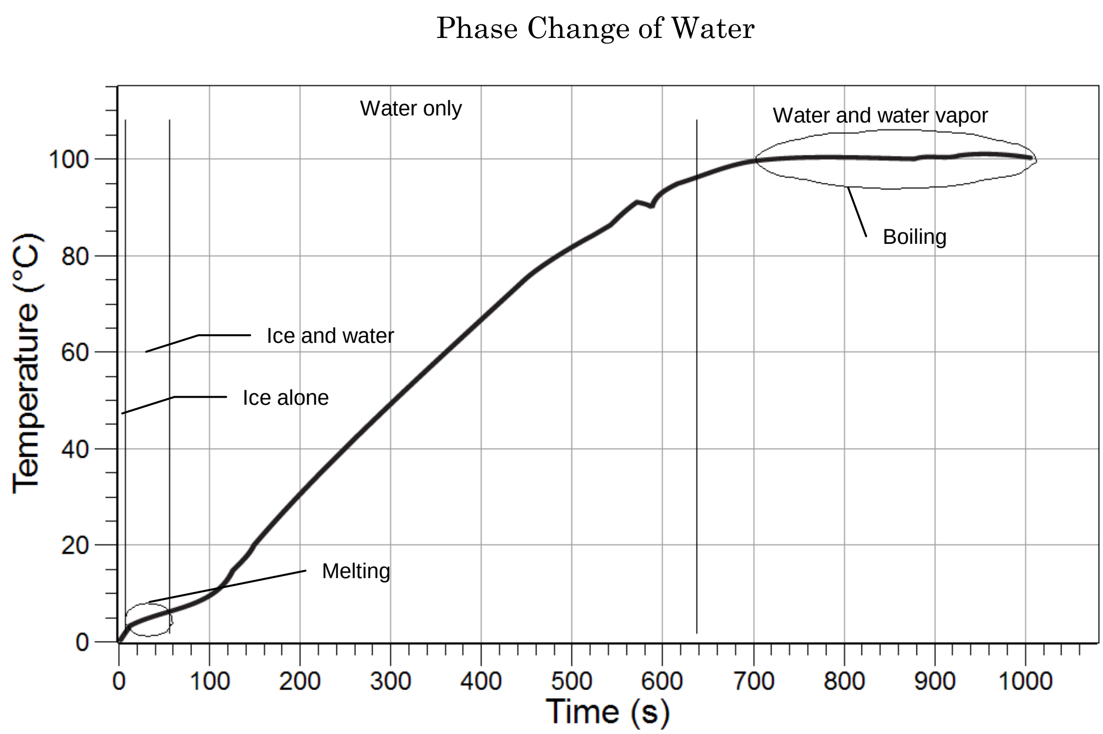
Hydrogen bonding does not occur in water vapor. Each water molecule is alone and is not attracted to other water molecules (as a gas, water molecules have more than enough energy to overcome the force of attraction).

18. ☐ When the water has been boiling for approximately 10 minutes, stop data recording. �(6.2)

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

Analyze Data

20. ☐ Print or sketch a graph of Temperature versus Time where heat is added to allow ice to change to water and then to water vapor. Label the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



21. ☐ Label the items below on your temperature versus time graph above.

a. Ice alone

b. Ice and water

c. Water only

d. Water and Water Vapor

e. Melting

f. Boiling

22. ☐ In this lab, what was added to the ice in order to make it melt and then make the water boil? On Earth, what causes these processes to occur?

Heat, from the hotplate, was added to the ice to make it melt to water and then to make the water boil. On Earth, the Sun provides the heat energy that makes ice melt and water evaporate.

23. ☐ What needs to happen for the reverse process to occur (water vapor to turn to water, and water to change to ice? Does this occur on earth? Explain.

Heat needs to be removed from water vapor to turn it to water and heat needs to be removed from water to make it turn into ice. These processes occur on earth all the time in the hydrologic cycle. Water vapor in the air condenses in clouds and falls to earth as rain. On cold days, water often freezes.

Part 2 – Waters behavior on different surfaces

24. ☐ Fill a 100-mL beaker with approximately 50 mL of water.

25. ☐ Place 10 drops of water on a piece of wax paper.

26. ☐ Slightly lift the edges of the wax paper and slowly move the water from side to side. Record your observation in Table 2.

Table 2: Behavior of water on known surfaces

Surface	Molecular Structure	Observations
Wax paper	Non- polar	Water moves together from one side to another and does not get the wax paper wet.
Foam food tray	Non-polar	Water moves together from one side to another and does not get the wax paper wet.
Paper towel	Polar	Water is absorbed into the paper towel. The water does not move over the surface.
Untreated wood	Polar	Water is absorbed into the wood. The water makes the wood wet.

27. ☐ Repeat the process for a foam food tray, a paper towel, and an untreated piece of wood:

a. Place 10 drops of water on the surface.

b. Slightly life the edges of the surface and slowly move the water from side to side.

c. Record your observation in Table 2.

28. ☐ How does water behave when placed on non-polar surfaces? Explain using the terms cohesion, adhesion, and hydrogen bonding.

Water beads up on non-polar surfaces. The water does not absorb into the material but is repelled from the material. The cohesive forces of attraction (hydrogen bonding between water molecules) are stronger than the adhesive forces of attraction between the water molecules and the molecules in the non-polar surface.

29. ☐ How does water behave when placed on polar surfaces? Explain using the terms cohesion, adhesion, and hydrogen bonding.

Water spreads out on and absorbs into polar surfaces. This causes the surface to become wet. This occurs because the adhesive forces of attraction between the water molecules and the molecules in the surface material are stronger than the cohesive forces (hydrogen bonding) between the water molecules.

30. ☐ How does the polarity of water affect the behavior of water on different surfaces? Provide evidence to support your answer.

Water is a polar substance. Polar molecules mix well with other polar molecules but do not mix with non-polar molecules. In the four substances tested water mixed into the polar surfaces, but was repelled by the non-polar surfaces.

31. ☐ Pick 5 different surfaces and predict the polarity of these surfaces. Record the name of each surface and your prediction in Table 3.

Table 3: Determining the polarity of unknown surfaces

Surface	Polarity Prediction	Observations	Polarity
Fresh waxy leaf	Non-polar	Water beaded up	Non-polar
Paper	Polar	Water soaked in	Polar
Brick	Polar	Water soaked in	Polar
Overhead sheet	Non-polar	Water beaded up	Non-polar
rock	Polar	Water soaked in	Polar

32. ☐ Test each of your surfaces to determine how water behaves on each and record your observation in Table 3.

33. ☐ Use your results to determine the polarity of each surface. Record your answers in Table 3.

34. ☐ Were your predictions correct? Explain why or why not.

The predictions were correct. Polar substances tend to have waxy or shiny surfaces whereas polar substances tend to be dull and dry.

35. ☐ Clean up according to your teacher's instructions.

Part 3 – Volume of ice versus water

Complete the following steps to design an experiment to determine how the volume of ice compares to the volume of water (with equal mass).

36. ☐ How do you think the volume of ice compares to that of water? What physical evidence do you have to support your prediction?

The volume of ice is greater than the volume of an equal amount of water. This is known because when placing water in the freezer the water takes up more space when it is frozen than when it was a liquid. An example of this is how ice in an ice cube tray expands and is raised above the rim of the tray, whereas when the tray is filled with water, the level of the water is below the rim of the tray.

37. ☐ Explain your prediction using what you know about the molecular structure of water. The following terms should be used in your explanation: hydrogen bonds, crystal structure, and water molecule.

In the liquid state water molecules attracted to other water molecules by an intermolecular force called hydrogen bonding. These hydrogen bonds are constantly being broken and reformed with other water molecules. This constant motion allows the water molecules to be very close together and slip past each other. When water is frozen, however, the water molecules are trapped in a rigid crystal structure that forces the water molecules to be farther apart than in the liquid state. The "frozen" molecules stay in this rigid structure and their only movement is vibration. The hydrogen bonding that traps the water molecules in this crystal structure causes ice to take up more space than liquid water.

38. ☐ Explain how you plan to test your prediction.

One way to test this prediction is to place water in a small water balloon and use the circumference of the balloon to calculate its volume. Then freeze the balloon and repeat the calculation.

39. ☐ Write a procedure for the plan you described.

Answers will vary. The procedure should be very specific so that other students in the class could follow the same procedure and reproduce the same results.

40. ☐ If time permits your teacher may allow you to perform your experiment.

Analysis Questions

1. List two behaviors of water you observed in this lab and explain how hydrogen bonding is involved in each.

Water can be changed from one state to another by adding or removing heat. Hydrogen bonding is what holds water molecules together in the liquid and solid state. When the molecules get too much energy the hydrogen bonding is too weak and water vapor forms.

When placed on non-polar surfaces water beads us. This is caused because the hydrogen bonding between the water molecules is stronger than the attraction between the water molecule and the molecules of the surface.

2. List one behavior of water that you experimented with in this lab and explain why it is unique compared to other chemicals on Earth.

Water exists as a liquid at room temperature. This is unique because most small molecules (like carbon dioxide, oxygen gas, and nitrogen gas) exist as gases at room temperature. Water is different than these other molecules because it is polar and is held together by a stronger form of intermolecular attractions called hydrogen bonds.

3. Explain how one (or more) of the properties you observed in this lab is involved in a physical process on Earth.

Physical erosion occurs when water absorbs into rocks (part 2) and freezes (part 1). When the water freezes it expands (part 3) and causes the rock to crack. This cracking causes the rock to break down or erode.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Are changes of state physical or chemical changes? How do you know?

Changes of state are physical changes. This is because no new chemical substance is formed. Water, whether it is a solid, a liquid, or a gas, is still made up of H_2O. In order for a chemical change to occur the covalent bonds between H–O would have to be broken.

2. How can the cohesive forces between water molecules be reduced? Why might this be necessary?

Something can be added to the water to break up its bonding. For example, soap can be added to water. This will allow water to wet surfaces like greasy pots and pans that need to be cleaned.

3. Does it take more energy for ice to melt or for water to evaporate? Why is this important on Earth?

It takes a lot more energy for water to evaporate than for ice to melt. This is important on Earth because water is of more use to us in the liquid state than as a solid or as a liquid. We depend on liquid water to hold lots of energy on Earth. This helps in the moderation of earth's climate worldwide.

Multiple Choice Questions

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

1. What type of attractions hold water molecules to other water molecules?

- **A.** **Hydrogen bonds**
- **B.** Covalent bonds
- **C.** Adhesion
- **D.** Application
- **E.** All of the above

2. Water will absorb into __________________________.

- **A.** Non-polar surfaces
- **B.** **Polar surfaces**
- **C.** All surfaces
- **D.** Surfaces that are already wet
- **E.** None of the above

3. What happens to the temperature of boiling water when more heat is added?

- **A.** The temperature of the water increases.
- **B.** The temperature of the water decreases.
- **C.** **The temperature of the water stays the same.**
- **D.** Heat cannot be added to water that is boiling.
- **E.** None of the above.

4. What is the molecular structure of water vapor?

- **A.** H_2 gas molecules
- **B.** O_2 gas molecules
- **C.** **H_2O gas molecules**
- **D.** A mixture of A and B
- **E.** None of the above

5. Which of the following properties of water increase the rate of physical erosion?

- **A.** **Water expands as it freezes.**
- **B.** Water molecules are polar.
- **C.** Water is odorless and colorless.
- **D.** Water boils at 100 °C.
- **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. Water has many unique properties. These properties are derived from water's ability to **hydrogen bond** to neighboring water molecules. This happens because water is a **polar** substance, meaning it has a partially positive and partially negative side to it. Water's partially **positive** side in one molecule is attracted to water's partially negative side in **another** water molecule. This attraction is what holds water molecules together in the liquid and **solid** state. This attraction is also the reason that **heat** must be added or removed to change water from one state to another. The polarity of water also explains why water absorbs into some surfaces, but **beads up** on other surfaces.

2. The unique properties of **water** enable life to exist on Earth. Ice is less dense than water which means that ice **floats** in water. This allows fish and other aquatic animals to survive in the extremely **cold** regions. The properties of water are also responsible for many of the processes on Earth such as **physical erosion**. The polar nature of water enables it to be absorbed into **rocks**. When the water freezes it **expands** inside the rock and causes the rock to break apart. This is an important process in the rock cycle and helps to create soil. The **hydrologic cycle** is also a result of hydrogen bonding in water. Water is constantly cycled from one area to another. Solar radiation causes ice to melt and water to **evaporate**. Cool weather causes water vapor to **condense** and water to freeze.

Extended Inquiry Suggestions

Explore and explain other unusual properties of water such as its high specific heat, high heat of vaporization, and water's role as the “universal” solvent.

Compare the melting points and boiling points other small molecules such as oxygen gas, nitrogen gas, and carbon dioxide with the melting and boiling points of water.

Determine the effect solutes such as salts and soap have on the surface tension of water.

Compare the cohesive forces of water with other liquids such as rubbing alcohol and salt water.

Explore the quantitative values a phase diagram can give including the melting point, boiling point, heat of fusion, specific heat, and heat of vaporization.

18. Air Pollution and Acid Rain

Objectives

In this activity, students investigate chemical reactions that are important in the formation of acid rain to better understand the relationship between certain types of man-made (anthropogenic) emissions and problems arising from acid rain. During this investigation, students:

- Determine the effect of different anthropogenic gases on the pH of water
- Discuss the effect of changes in the pH of water on the environment

Procedural Overview

Students gain experience conducting the following procedures:

- Learning the chemical reactions involved in generating three types of gases (CO_2, SO_2, and NO_2) that are common anthropogenic emissions
- Measuring the effect of CO_2, SO_2, and NO_2 on the pH of water using a pH sensor
- Analyzing the chemical reactions that lower the pH of 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
- 1-hole rubber stopper for flask
- Beaker, 40-mL
- Graduated pipet, 4-mL and pipet bulb
- Glass tubing for rubber stopper
- Flexible Teflon® tubing to fit glass tubing, 20 cm
- Graduated cylinder, 50- or 100-mL
- Sodium bicarbonate ($NaHCO_3$), 5 g
- Sodium bisulfite ($NaHSO_3$), 5 g
- Sodium nitrite ($NaNO_2$), 5 g
- 1 M HCl (15 mL)[1]
- Water or deionized water, 1 L
- Wash bottle containing distilled or deionized water

[1] To formulate using 6 M HCl, refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Most cells function best within a narrow range of acidity.
- pH is a logarithmic measurement of the concentration of hydrogen ions in water. ($pH = -\log_{10}[H^+]$)
- pH measurements can range from 0 through 14. The lower the value, the higher the concentration of hydrogen ions.
- pH can be a measure of acidity, with values below 7 becoming increasingly acidic as the value approaches 0. Therefore, the lower the pH, the higher the concentration of hydrogen ions and the higher the acidity.
- A pH of 7 is neutral—neither acidic nor basic.
- pH values greater than 7 are considered basic. Practically speaking, a pH of 6 to 8 is considered to be in the neutral zone.

Related Labs in This Guide

Labs conceptually related to this one include:

- Acid Deposition and Natural Water Bodies
- Determining Soil Quality
- Monitoring Water Quality

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)
- Start and stopping data recording �(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)

- Viewing statistics of data �(9.4)

- Saving your experiment �(11.1)

Background

The Creation of Acid Rain

Acid rain is rain, or 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), nitrogen dioxide (NO_2), and nitrous oxide (N_2O), 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 dissolves in water, producing bisulfite and hydrogen ions. Students will explore this reaction of sulfur dioxide in this lab activity.

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

Engage your students by having them research adverse effects of acid rain worldwide. Brainstorm for a variety of examples and record them for class viewing. If local examples can be found, these are excellent for focusing and stimulating interest.

Point out that anthropogenic emissions are responsible for some of the acidity in the atmosphere that results in acid rain. Tell students they will be generating some of these gases and testing their effect on the pH of water.

Review the chemical reactions that produce the gases you will be studying:

Sodium bicarbonate + hydrochloric acid + water → sodium ion + chloride ion + water + carbon dioxide gas:

$$NaHCO_3(s) + HCl(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l) + CO_2(g)$$

Sodium bisulfite + hydrochloric acid + water → sodium ion + chloride ion + water + sulfur dioxide gas:

$$NaHSO_3(s) + HCl(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l) + SO_2(g)$$

Sodium nitrite + hydrochloric acid + water → sodium ion + chloride ion + water + sulfur dioxide gas:

$$NaNO_2(s) + HCl(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l) + NO_2(g)$$

If necessary, review the pH scale and how it is determined.

Lab Preparation

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

1. Prepare the 1.0 M hydrochloric acid solution by adding 16.6 mL of 6 M HCl per 100.0 mL of solution. Pour the concentrated HCl into about 80 mL of water, bring the solution up to 100 mL with water, and pour 15 mL into a beaker for each group.

Note: Do not pour water into the concentrated acid.

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. This 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 to measurements within this lab, the factory calibration is sufficient.

If your classroom does not have a vented hood, student groups or the teacher can generate the SO_2 and NO_2 under the vented hood in the chemistry lab. It is safe for students to generate the CO_2 at their workbenches in the classroom. Each group can then present its results to the class for analysis.

For students generating CO_2 at their workbench, you can substitute household white vinegar if you don't have 1M HCL.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Consult the manufacturer's material safety data sheets (MSDS) for instructions on handling, storage, and disposing of hydrochloric acid, sodium bisulfite, and sodium nitrite. (You can find these on the Internet.) Keep these instructions available in case of accidents.
- Students creating sulfur dioxide and nitrogen dioxide should work under a vented hood.
- Do not touch the hydrochloric acid (HCl). Handle the pipet with HCl with extreme care.
- Do not remove the rubber stopper from the Erlenmeyer flask once the reaction has started.
- After completing the lab, wash your hands.
- Wear safety glasses and lab coats or aprons.

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.	Rinse out the gas generation bottle, beaker, and tubing.	Generate CO_2 gas and collect data as it's bubbled through water.	Determine the changes in the pH of the water for each gas.	Set up the equipment. Open the 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.

Create gas generators, and measure pH

You will create CO_2, NO_2, and SO_2, as follows:

Mix sodium bicarbonate ($NaHCO_3$) with hydrochloric acid (HCl) to produce carbon dioxide gas (CO_2).
Mix sodium nitrite ($NaNO_2$) with hydrochloric acid (HCl) to produce nitrogen dioxide (NO_2).
Mix sodium bisulfite ($NaHSO_3$) with hydrochloric acid (HCl) to produce sulfur dioxide gas (SO_2).

1. ☐ Make predictions: What do you think will happen to the pH of the water when you dissolve these gases in it? Which gas will produce the largest change in pH?

Answers will vary according to student predictions. Answers should include the prediction about the gas that will create the largest change in pH.

Part 1 – Making carbon dioxide (CO_2) gas and measuring its effect on the pH of water

Set Up

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

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

4. ☐ Display pH on the y-axis of a graph with time on the x-axis. �(7.1.1) (7.1.2)

5. ☐ Measure 20.0 mL of water using the graduated cylinder.

6. ☐ Pour the water into the 40-mL beaker.

7. ☐ Thoroughly rinse the pH electrode with distilled water.

8. ☐ Place the rinsed pH electrode in the beaker.

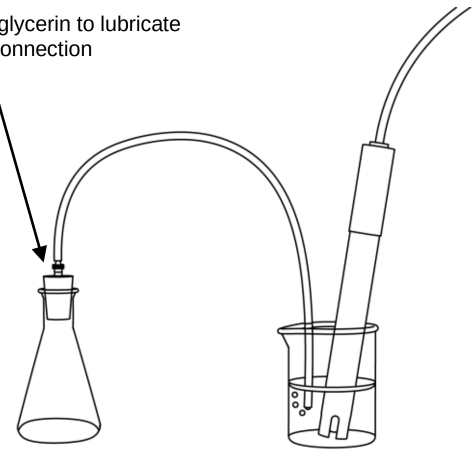
9. ☐ Obtain a sample of powdered sodium bicarbonate ($NaHCO_3$) from the teacher.

10. ☐ Measure 5 grams of $NaHCO_3$

11. ☐ Place the measured $NaHCO_3$ in the Erlenmeyer flask.

12. ☐ Assemble the stopper, glass tubing or barbed connector, and flexible tubing.

Note: If necessary, use glycerin to lubricate the connection so that the connector or glass tubing is well seated in the rubber stopper



13. ☐ Pipet 4 mL of 1.0 M hydrochloric acid (HCl) into the Erlenmeyer flask, and immediately stopper the flask.

CAUTION: Hydrochloric acid is a strong acid. Handle with care. Flush any spillage with a lot of water.

Collect Data

14. ☐ Place the free end of the flexible tubing in the water in the beaker, and immediately start recording data. �(6.2)

15. ☐ Record data for about 200 seconds (until the change in pH stops or stabilizes), and then stop recording. �(6.2)

16. ☐ Name your run to reflect the sample type. �(8.2)

17. ☐ Dispose of the contents of the flask and beaker as directed by your instructor.

18. ☐ 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

19. ☐ Repeat the steps in Part 1 using 5 g $NaHSO_3$ instead of $NaHCO_3$.

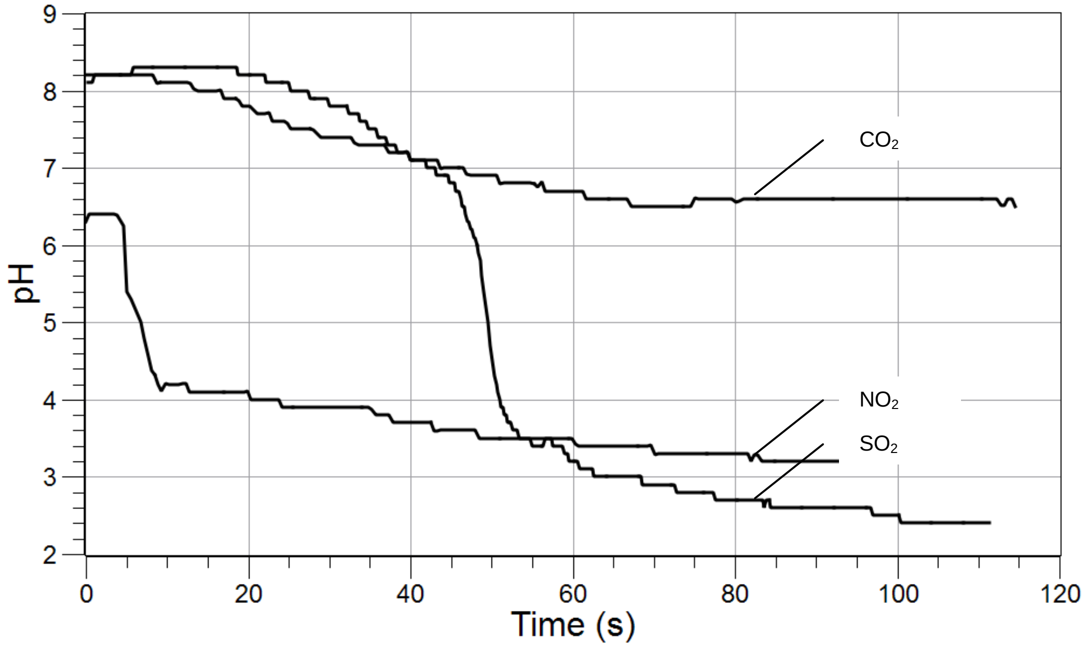
Part 3 – Making nitrogen dioxide (NO_2) gas and measuring its effect on the pH of water

20. ☐ Repeat the steps in Part 1 using 5 g $NaNO_2$ instead of $NaHCO_3$.

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

Sample data

The following graph shows pH versus time as CO_2, SO_2, and NO_2 are bubbled into distilled water.



Data Analysis

1. ☐ From the graph display for each run, determine the maximum and minimum pH values, and record them in Table 1. �[(9.4)]

2. ☐ Complete Table 1.

Table 1: pH change due to gases dissolved in water

Gas	Final pH	Initial pH	Change in pH (pH_{final} - $pH_{initial}$)
Carbon dioxide	6.5	8.2	–1.7
Sulfur dioxide	2.9	8.3	–5.4
Nitrogen dioxide	3.2	6.4	–3.2

Analysis Questions

1. Was your prediction correct regarding what would happen to the pH when you dissolved the gases in it? Why or why not?

Answers will depend on what students predicted. Answers should briefly discuss why they were correct or not correct.

2. The following chemical reactions are involved in this lab. Write each formula using chemical notation.

a. One molecule of carbon dioxide gas dissolves in water to form one bicarbonate ion and one hydrogen ion.

$CO_2 + H_2O \rightarrow HCO_3^- + H^+$

b. Two nitrogen dioxide gas molecules dissolve in water to form one nitrate ion, one nitrite ion, and two hydrogen ions.

$2NO_2 + H_2O \rightarrow 2H^+ + NO_3^- + NO_2^-$

c. One sulfur dioxide gas molecule dissolves in water to form one bisulfite ion and one hydrogen ion.

$SO_2 + H_2O \rightarrow HSO_3^- + H^+$

3. Which gas created the smallest change in pH of the water?

The carbon dioxide gas produced the smallest decrease in pH.

4. Compare your results with those from other groups. What factors might have caused some of the variability in the change of the observed pH?

Some factors that might contribute to experimental variability include: 1) variations in the mass of reactants used; 2) variations in the amount of water used; 3) variations in the efficiency of collecting the gases; 4) variations in pH sensors, which may not have been calibrated for this experiment.

5. For the three reactions of gas dissolving in water, what caused the reduction of the pH of the water in which these gases are dissolved?

The pH is lowered because hydrogen ions are formed. When the concentration of hydrogen ions increases, the pH decreases.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What industrial or other man-made (anthropogenic) gases emitted into the atmosphere are considered the primary gases that cause acid rain? What are some sources of these gases?

The primary gases involved in producing acid rain are sulfur dioxide and the nitrogen oxides. The primary sources of these gases are the burning of fossil fuels, smelting of metals, and paper pulp production.

2. Scientists have found that sulfuric acid is the primary acid that causes acid rain. What are some of the chemical reactions that produce sulfuric acid in the atmosphere? Why does radiation from the sun speed up this reaction?

$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ (this reaction requires an oxidizer, such as ozone)

$SO_3(g) + H_2O(l) \rightarrow H^+(aq) + HSO_4^-(aq)$

The sun's radiant energy, particularly ultraviolet energy, produces oxidizing molecules from ozone, water molecules, and oxygen gas. These oxidizing molecules speed the reaction.

3. Coal from states in the western United States, like Montana and Wyoming, has a lower percentage of sulfur impurities (lower sulfur content) than coal found in the eastern United States. How would burning low-sulfur coal change acid rain?

Burning low-sulfur coal would decrease the amount of acid rain by reducing the amounts of sulfur oxides (the reactants required to produce sulfuric acid) emitted into the atmosphere.

4. Discuss the relationship between acid rain and the sulfur and nitrogen cycles.

Sulfur and nitrogen trapped in solid materials enter the atmosphere through oxidative chemical reactions. These reactions combine the sulfur or nitrogen with oxygen atoms, creating gas oxide molecules. Examples of these oxidation reactions include: 1) combustion of sulfur-rich and nitrogen-rich fossil fuels; 2) oxidative decay of sulfur- and nitrogen-containing plant and animal matter by microorganisms; and 3) oxidation of sulfur- or nitrogen-containing organic matter during certain industrial processes, such as converting wood to paper pulp.

While in the atmosphere, the sulfur and nitrogen oxide gas molecules are converted to sulfuric acid and nitric acid. These acid molecules are then deposited back on the surface of the earth via dry or wet deposition. Wet deposition is in the form of rain, fog, sleet, or snow. The sulfate, nitrate, and nitrite ions of the acids then serve as nutrients for protein and DNA synthesis by living organisms. Thus, the sulfur and nitrogen are again bound in solid matter, completing the cycle.

5. What are some ways to treat the effects of acid rain?

1) Buffer lakes by adding lime. 2) Add vegetation to the watershed so that water does not run off as rapidly into the body of water. That way, the water seeps into the soil, dissolving buffers contained in the soil. 3) Add large amounts of water that have neutral or basic pH.

6. What are some ways to prevent the formation of acid rain?

Ways to prevent the formation of acid rain include: 1) Burning a lower sulfur-containing fuel will result in less SO_x emissions; 2) Install scrubbers (or other technology) on smoke stacks to reduce SO_x 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, thus reducing NO_x emissions; 6) Develop energy-producing methodologies that do not emit sulfur and nitrogen oxides.

7. Although carbonic acid produces only a small decrease in the pH of water, why is it of concern in the environment?

In the oceans, CO_2 is taken from the atmosphere and is converted to carbonic acid. There is concern that as CO_2 levels increase in the atmosphere, more CO_2 will become dissolved in the oceans. This forms more carbonic acid, which might decrease the pH of ocean water and adversely affect many forms of life there.

Multiple Choice Questions

1. Which of the following is true about acid rain?

- **A.** Acid rain is linked to NO_x and SO_x 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 to decrease to a level outside their tolerance.
- **C.** Acid rain affects soil chemistry and the ability of plant roots to take in nutrients.
- **D.** Acid rain increases the mobility of toxic metals in ecosystems.
- **E.** **All of the above are true.**
- **F.** Only A, B, and C are true.

2. Which of the following play important roles in the formation of acid rain?

- **A.** Solar radiation
- **B.** Buffers in soils and water
- **C.** Water in the atmosphere
- **D.** Nitrogen gas (N_2) in the atmosphere
- **E.** All of the above
- **F. Only A and C**

3. In general, rain exerts harmful effects on ecosystems when it falls below a pH of

- **A.** 3.6
- **B.** 4.6
- **C. 5.6**
- **D.** 6.6
- **E.** 7.6

4. Acid rain has been linked to

- **A.** Contamination of fish with highly toxic methylmercury
- **B.** Damage to fish through reactions that create high aluminum concentrations in the water.
- **C.** Reduced nutrient uptake by tree roots
- **D.** Weakening trees, so they become more susceptible to other types of damage
- **E. All of the above**

Extended Inquiry Suggestions

What is the pH of your local rainwater? Challenge students to design a method for collecting rainwater and then measure the pH of the sample using a pH sensor.

What is the pH of a local water system? Ask students to 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. 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 unpolluted rain). Acid rain would accelerate this damage.

Ask students to write, produce, and direct a “weather special” segment for TV on how weather patterns affect 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.

Encourage students to contact a local natural resource specialist at your local zoo or park. Ask that person about the impact, if any, of both acid rain and dry acid deposition in the local lakes.

19. Monitoring Water Quality

Objectives

Students monitor the quality of a natural body of water in several locations to determine how water quality changes in response to changes in environmental factors. They also:

- ♦ Make measurements that can be reliably compared to measurements made with different equipment or at other times, or both

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Calibrating electronic sensors
- ♦ Measuring parameters of water quality and interpreting the results
- ♦ Comparing the results of measuring water quality factors in situ with measurements of water samples removed from the source

Time Requirement

♦ Preparation time	First water quality monitoring field trip: several hours; otherwise, 1 hour
♦ Pre-lab discussion and activity	45 minutes
♦ Lab activity	90 minutes

Materials and Equipment

For each student or group:

- ♦ Mobile data collection system
- ♦ Water quality sensor
- ♦ Turbidity sensor
- ♦ Weather/anemometer sensor
- ♦ GPS sensor (optional)
- ♦ Sensor extension cable
- ♦ Sensor user guides with calibration instructions and tables
- ♦ Chemical test kit (optional)
- ♦ Buffer solution, pH 4, 25 mL[1]
- ♦ Buffer solution, pH 10, 25 mL[1]
- ♦ Wide-mouth sampling jar or small plastic bucket with a handle
- ♦ Long-handled sampling device[2]
- ♦ Duct tape and scissors
- ♦ Wash bottle containing distilled or deionized water
- ♦ Wading boots (optional)

[1]Used for pH sensor calibration.

[2]Available commercially, or can be made from a tree-pruning pole. Refer to the Lab Preparation section for details.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Renewable and non-renewable resources
- ♦ Waste material disposal
- ♦ Cations and anions
- ♦ Conductivity
- ♦ Cell function and pH
- ♦ Measuring pH
- ♦ Measuring turbidity

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Determining Soil Quality
- ♦ Water Treatment

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 dissolved oxygen sensor �(3.3)
- ♦ Calibrating a pH sensor �(3.6)
- ♦ Calibrating a turbidity sensor �(3.7)
- ♦ Setting up a conductivity sensor for a particular range �(4.2)
- ♦ Monitoring live data without recording �(6.1)
- ♦ Starting and stopping data recording �(6.2)

♦ Displaying data in a graph �(7.1.1)

♦ Finding the values of a point in a graph �(9.1)

Background

Water quality is the suitability of water for a given use. Water in a natural ecosystem has to have the right balance of dissolved oxygen, nutrients, temperature, pH, salts, and light penetration to sustain a healthy aquatic ecosystem. Drinking water must have acceptable levels of contaminants to be deemed safe. Treated wastewater must also be of acceptable quality before it is released into the environment.

Natural bodies of water have many chemical and physical characteristics that can vary from one location to another. Water quality indicators can fluctuate depending on the characteristics of the surrounding watershed as well as from varying weather conditions. Water quality at a given point in a stream or river reflects the effects of upstream activities. We can measure different aspects of water quality at different locations to assess the health of a natural body of water and to locate possible sources of pollution.

The World Health Organization publishes guidelines for water quality worldwide. These are available in full text on the Internet. For the United States, standards for the water quality of natural bodies of water supportive of aquatic organisms are specified by the US Environmental Protection Agency (EPA) in their Red Book and Gold Book, the full text of which is available on the Internet. The US EPA also publishes Primary and Secondary Drinking Water Standards, available on the Internet. These specify the maximum lawful level of contaminants in the United States for drinking water supplied by municipal water treatment facilities and are good references to have on hand.

Pre-Lab Discussion and Activity

Engage students by presenting information about a local body of water that has been in the news due to water quality issues. This could be a fish kill that occurred because of accelerated (cultural) eutrophication or due to low water levels in the summertime. Or it could be an industrial accident that caused a point-source pollution crisis. Work on a local dam can cause water quality problems that affect fish and other aquatic organisms. A local beach may have been closed for a part of the summer due to elevated levels of pathogenic bacteria.

If no local news related to water quality is available, choose an example from other parts of the country, or even worldwide. Alternatively, there may be a good example of a successful water quality cleanup project. An Internet search will produce a number of good options.

1. Brainstorm with students regarding a suitable local body of water to monitor. One that is within walking distance would be ideal.

Teacher Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

Continue the discussion by asking students these questions:

2. **How is water quality monitored?**

Water quality is monitored using sensors and chemical tests that have been calibrated to external references and give reliable, repeatable measurements.

3. **How can we ensure that measurements are accurate and can be compared with each other over time?**

Measuring instruments must be calibrated to external standards, and standard sampling and testing techniques must be used.

Demonstrate the correct techniques for calibrating the dissolved oxygen, pH, and turbidity sensors.

Point out that water samples should be obtained away from shoreline and below the surface of water.

Ask students:

4. **Why is it important to take measurements from samples obtained away from the shoreline?**

It is important to take measurements away from the shoreline to avoid contamination by mud or other materials that might reduce the accuracy of measurements.

Demonstrate proper sampling technique with your sampling equipment (see the Lab Preparation section).

Teacher Tip: The *Water Quality Field Guide*, published by PASCO scientific, is a thorough and concise reference that can help add meaning to your water quality measurements.

Teacher Tip: Consider doing additional field work to maximize the value of the field trip. For example, part of the day could be used to do the "Biodiversity and Invasive Species" or "Biodiversity and Native Species" activities, or both. These additional investigations would give a more complete picture of the watershed of your natural body of water.

Lab Preparation

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

1. Plan how students are to obtain water samples away from the shoreline and below the surface of the water. If they use a wide-mouth sampling jar, they will need to dip it into the water. Wading boots would be useful in this case.

   Special sampling devices are made specifically for this purpose; they are generally cylinders with closable ends, weights, and attached to long ropes.

   Alternatively, use a long pole (such as a telescoping tree-pruning pole) with a device (such as duct tape) on the end to hold a sensor extension cable, plastic water bottle, or bucket. You can make these poles with supplies from the local hardware store, or you can order them ready-made from companies specializing in such gear.

   For beginning studies, the homemade equipment works well. More advanced studies may require specially made equipment.

2. Think through the requirements for your field trip, including safety considerations and necessary permissions needed.

   You should visit the site beforehand and note safety issues to alert your students to.

   Prepare the instructions for student behavior at the testing site based on this survey.

Teacher Tip: Point out hazards you noticed during your survey of the site.

Teacher Tip: Require students to use a buddy system and specify the procedure to use in case of trouble.

3. The following is a checklist of equipment you may choose to take, depending on the nature of the field trip:

- Water sampling device
- Field microscope
  Digital camera or camcorder
- Binoculars
- Seine or kick nets for collecting macro invertebrates
- Ice chest and ice (for storing collected water samples)
- Rain gear
- Wading boots
- Plastic sample storage bottles with caps (for samples to be brought back to the school lab for testing)
- Water bottles for collecting samples
- Extra clothing if contact with water is anticipated
- Non-perishable snacks
- Sunscreen
- Mosquito repellent
- First aid kit with a pocket knife and snake bite kit

4. The following are tips for increasing the success of the field trip.

- Establish a base to bring samples back to for testing and analyzing.
- If samples can be brought back to the school lab, do so.
- For multiple outings, develop a packing routine.
- Establish a clean-up routine for coming off the field.
- Use a GPS sensor to enable mapping of data.
- Emphasize the need to develop a story, that is, a description of the water quality based on the surrounding environment. Encourage collaboration between student pairs or groups.
- Measure other aspects of the environment such as temperature, humidity, barometer, rainfall, wind, insolation, light intensity, and challenge students to incorporate these findings into the overall story.

5. Consider bringing samples back to the classroom to analyze for pollutants using colorimetric chemical test kits. If you plan to do this, be sure to take extra sampling bottles and an ice chest. Alternatively, take test kits to the site and set up a lab area to complete the analyses there.

Safety

Add these important safety precautions to your normal outdoor class procedures:

- Practice appropriate caution around bodies of water, steep terrain, and harmful plants or animals. Point out hazards you observe at the site.
- Use a buddy system and follow the established procedure in case of trouble.

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	2	6	1	7
Measure the turbidity of the water, the pH, temperature, conductivity, and dissolved oxygen. Compare with the in situ measurements you made.	Determine the barometric pressure and temperature, and then calibrate the pH and dissolved oxygen sensors.	Find a second location on the body of water and repeat the measurement procedure.	Find a suitable place to collect water samples and take measurements. Make note of the surrounding environment and appearance of the water.	(Optional) Repeat the monitoring activity in a different season of the year.

4	3
Collect a water sample from at least 1 meter away from the shore and from below the surface level of the water	Take in situ measurements of temperature, pH, conductivity, and dissolved oxygen at least 1 meter from the shoreline.

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.

Work with your teacher to find a good place to take your measurements.

Set Up

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

2. ☐ Connect the weather/anemometer sensor to the data collection system. �(2.1)

3. ☐ Monitor live data without recording. �(6.1)

4. ☐ Determine the current barometric pressure and record below:

Barometric pressure:_____________.

5. ☐ Why is it necessary to determine the barometric pressure?

The barometric pressure is needed to calibrate the dissolved oxygen sensor. The amount of dissolved oxygen that can be held in water depends on the barometric pressure and the temperature of the water. The greater the air pressure, the more dissolved oxygen water can contain.

6. ☐ Connect the water quality sensor, using a sensor extension cable, to the data collection system. �(2.1)

7. ☐ Make sure the conductivity sensor is adjusted to measure the quality of fresh (not salt) water. �(4.2)

8. ☐ Calibrate the dissolved oxygen sensor. �(3.3)

Note: Determine the 100% saturation point for the dissolved oxygen sensor with the sensor's storage bottle submerged in the water you plan to monitor.

9. ☐ Why is it important to calibrate the dissolved oxygen sensor at the same temperature as the water you are testing?

The amount of dissolved oxygen (mg/L) that can be held in water depends on the barometric pressure and the temperature of the water. The calibration should be related directly to the test temperature and air pressure conditions.

10. ☐ Use pH 4 and pH 10 buffer solutions to calibrate the pH sensor. �(3.6)

11. ☐ Why is it necessary to calibrate the pH, dissolved oxygen, and turbidity sensors?

You need to calibrate the pH, dissolved oxygen, and turbidity sensors with an external standard so measurements can be reliably compared between groups and when collected at different times or using different sets of equipment.

Note: Keep the file open that contains this calibration information. The sensor calibration remains with the file that was open when you performed the calibration.

12. ☐ Use duct tape to secure the data collection system and the sensor cables to the extension pole so the probes dangle from the end of the pole.

Collect Data – In situ

13. ☐ Start data recording, �(6.2) and gently lower the probes into the water at least 1 meter from the shoreline and to at least 1/3 meter below the surface of the water. If the water is stagnant, gently move the sensors back and forth for 1 minute.

CAUTION: Do not let the data collection system get wet!

14. ☐ Carefully remove the probes from the water, return them to the shore, and stop data recording. �(6.2)

Write the run number here ____________ .

15. ☐ Remove the sensors and recording device from the extension pole.

Collect Data – From a water sample

16. ☐ Use duct tape to attach a clean bucket or other container to the end of the extension pole.

17. ☐ Collect a sample of water from the same spot that you just monitored with the sensors.

18. ☐ Test the quality of the water in the bucket (measure the temperature, pH, conductivity, and dissolved oxygen) using the same procedure used for the in situ sample.

Record the run number here ____________ .

19. ☐ Calibrate the turbidity sensor. �(3.7)

20. ☐ Stir the water in the bucket and measure the turbidity of the water.

Record the run number here ____________ .

21. ☐ Record the turbidity in Table 1.

22. ☐ (Optional) Test other water quality parameters as indicated by your teacher, using the water in the bucket as your sample.

23. ☐ (Optional) Record the GPS coordinates.

24. ☐ Find another site to monitor the water quality (Site 2), repeating the data collection procedure above.

Data Analysis

1. ☐ Show your first data run in a graph. �(7.1.1)

2. ☐ Complete Table 1 as follows:

a. Use the graph tools to identify the value of each parameter that best represents the measured parameter. �(9.1)

Note: This is a value in the area of the graph where the measurements have stabilized.

b. Record these values in Table 1.

c. Repeat this process for your second data run.

Table 1: Water quality measurements from two locations

Test	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)
Site 1: In situ	22.7	8.0	637	0.8	
Site 1: Sample	22.4	8.0	646	1.9	7.5
Site 2: In situ	22.7	7.7	806	0.9	
Site 1: Sample	22.3	7.7	813	3.1	4.5

3. ☐ Describe the first test site. (For example, note the presence and types of surrounding vegetation, shade or full sun, signs of soil erosion, presence or absence of insects or other animals, and evidence of point-source pollution.)

Answers will vary. In this example, the test site was a small, slow-running, shallow creek flowing through a field. There was a mixture of shade and sun surrounding the creek. The vegetation surrounding the creek and in the creek was fairly dense, composed of bushes, grasses, and trees. The creek showed signs of accelerated eutrophication, including lots of algae growing on the surface water; weeds and reeds growing in the water; and a green, slightly turbid color.

When we sampled the water, we pulled up a lot of dead vegetation. There were a lot of tadpoles and frogs, dragon flies, and flies present. We saw 4 river otters swimming by. We did not see any fish. There did not seem to be erosion of the soil. The field next to the stream was very dry, largely comprising grasses, bushes, and thistles. We saw squirrels, woodpeckers, and ants in this area.

4. ☐ Describe the second test site.

Answers will vary. For this example, Site 2 was a little upstream from Site 1. There seemed to be more dead vegetation in the water, and the water seemed shallower. Otherwise, it looked similar to Site 1.

Analysis Questions

1. Was there a sizable difference between measurements made in situ and measurements of the water sample? Do you think it is worth the effort to take measurements in situ?

Answers will vary. For this example, we saw a big difference in the dissolved oxygen level between the in situ measurement made about 1/2 meter under water compared with the sample we collected. The in situ samples had much lower dissolved oxygen concentrations. We think the in situ measurements were more accurate, reflecting the almost anoxic conditions of this creek that was clearly in a state of accelerated eutrophication.

The higher levels of dissolved oxygen in the bucket sample could have occurred because air mixed with the sample during the collection process and while sitting in the bucket before we could measure it. Also, the temperature measurement was somewhat lower for the measurements of the sample, and again, we thought the in situ measurements were more representative of the creek. So we would conclude that it is worth the effort to take measurements in situ.

2. What do you think could be responsible for any differences you found between sites?

Answers will vary. For this example, the main difference between our sites occurred in the conductivity. We did not see any obvious reason for it, like point-source pollution. However, there seemed to be a lot of decaying vegetation on the bottom of the creek, and that could have been contributing dissolved solids to the water.

3. Dissolved oxygen levels below 3 mg/L indicate low water quality for many aquatic animals. Do you think the water you tested had enough dissolved oxygen to support most aquatic animals? Explain.

Answers will vary. For this example, the water we tested did not contain enough dissolved oxygen to support fish and many other aquatic animals that cannot gather oxygen from the air. The mean dissolved oxygen level for our two sites was 0.85 mg/L, which is a very low concentration.

4. Dissolved oxygen levels above 9 mg/L indicate accelerated eutrophication and low water quality, due to rapid algae growth in nutrient-dense, warm water. These algal blooms are usually followed by very low dissolved oxygen levels. The algae die and are decomposed by bacteria, which consume the dissolved oxygen during aerobic cellular respiration. Does the body of water you investigated show evidence of accelerated eutrophication? Explain.

Answers will vary. For this example, there were multiple signs of accelerated eutrophication that had progressed to the point where bacteria were decomposing the algae and plants. Some of the evidence included the low dissolved oxygen levels, the presence of dead vegetation on the bottom of the creek, and the abundance of algae and weeds growing in and on the creek.

5. Does the body of water show signs of acid rain or other acid deposition? Explain.

Answers will vary. For this example, there was no sign of acid deposition, since the pH at both sites was greater than 7.

6. Conductivity is a measure of salts dissolved in the water. Conductivity levels above 200 to 300 µS/cm in a fresh-water surface body of water may indicate pollution by runoff from cities or agricultural regions. Does the body of water you investigated show signs of pollution? If so, what do you think might be contributing to this pollution?

Answers will vary. For this example, there was evidence of pollution from runoff, since the conductivity levels were relatively high (between 600 and 800 µS/cm) and there were signs of accelerated eutrophication.

7. In the United States, turbidity levels higher than 1 nephelometric turbidity unit (NTU) in drinking water are unlawful, and the World Health Organization recommends levels lower than 1 NTU for drinking water. If the body of water you investigated served as a drinking water source, would the water have to be filtered to remove suspended solids? Explain.

Answers will vary. For this example: to be used as drinking water, this water would have to be filtered to remove suspended solids, since turbidity levels were between 4.5 and 7.5 NTU.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Design an additional study to determine levels of pollutants in the body of water you tested. Use the evidence you collected in the field study to identify 3 additional tests you think would be useful to conduct, and explain why you picked these.

Answers will vary. For this example, we think it would be interesting to look at nutrient pollutants, including nitrates, phosphorous, and potassium. We chose these tests because the evidence from the test site—low dissolved oxygen measurements and a lot of algae and vegetation growing on and in the creek—suggests that these pollutants may be present at high levels, causing accelerated eutrophication.

2. Design a water quality monitoring process to test whether point-source pollution is significantly affecting the body of water you investigated. If this body of water does not have an obvious point source for pollution, create a hypothetical one.

(Examples of point-source pollution include heat from power plants; nitrogen-, phosphorous-, and phosphate-containing effluent from agricultural sources or runoff from cities; salt-containing effluent; and treated or untreated sewage.)

Answers will vary. For this example, the creek we monitored runs through an industrial area just before it gets to the monitored sites. We would pick two or three pollutants that we found at high levels at our site. We would go to a site on the creek upstream before it gets to the industrial area and, using the same techniques, monitor levels at that point. We would include the GPS coordinates with our data.

Based on our findings there, we would move further up or down the creek and repeat the testing procedure to see if we could find a specific point where levels rose sharply. If such a point was found, we would evaluate the adjacent watershed to determine whether we could identify a point source for the pollution.

Multiple Choice Questions

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

1. Which of the following statements is true?

- **A.** A watershed delivers runoff, sediment, and dissolved substances into the body of water.
- **B.** A coastal delta is an example of a watershed.
- **C.** A watershed is the land area bordering a body of water
- **D.** **Both A and C are true.**
- **E.** A, B, and C are true.

2. Point-source pollution:

- **A.** Can usually be identified within a given area
- **B.** Is dispersed and difficult to identify
- **C.** Is more easily controlled than non-point-source pollution
- **D.** **A and C**
- **E.** A, B, and C

3. Fish kills can be caused by:

- **A.** Decreased dissolved oxygen levels due to decomposition of sewage by bacteria
- **B.** Decreased dissolved oxygen levels due to high summer temperatures
- **C.** Excessive cultural (or accelerated) eutrophication, in which plant matter is decomposed by bacteria
- **D.** A and C
- **E.** **A, B, and C**

4. Nitrates, potassium, and phosphorous found in plant fertilizers are considered water pollutants because they:

- **A.** Directly reduce the dissolved oxygen in water
- **B.** Form toxic compounds in water
- **C.** **Cause increased algae growth rates**
- **D.** Are harmful to fish and humans
- **E.** None of the above

5. Cultural (or accelerated) eutrophication can be caused by:

- **A.** Plant nutrients found in fertilizers
- **B.** Organic wastes from waste treatment facilities
- **C.** Human recreational activities such as swimming or boating
- **D.** **A and B**
- **E.** All of the above

6. Bodies of water that are eutrophic or hypereutrophic typically exhibit:

- **A.** High turbidity
- **B.** High nutrient levels
- **C.** Low turbidity
- **D.** A low level of primary productivity
- **E.** **A and B**

Extended Inquiry Suggestions

Have students collect samples of water at your test sites. Keep them on ice and take them back to school. Analyze them for levels of pollutants you suspect may be present. Use colorimetric chemical test kits or do a biological oxygen demand study, or both. Relate the results to the characteristics of the watershed.

Conduct water quality monitoring field trips several times during the year and examine seasonal differences in water quality and in the watershed

20. Toxicology Using Yeast

Objectives

Students demonstrate how yeast cells can serve as simple models to assess chemical hazards. They also:

- Evaluate the role of pH in toxicity
- Evaluate the role of cell culture in toxicology studies

Procedural Overview

Students determine the relative toxicity of half-strength bleach and full-strength vinegar using a yeast cell culture system. They gain experience completing the following procedures:

- Conducting toxicology studies of yeast cell cultures in a closed system, measuring the carbon dioxide gas level as the indicator of toxicity, and correlating pH with toxicity
- Extrapolating the median effective dose (ED_{50}) for half-strength bleach and full-strength vinegar from experimental data

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	90 minutes or two 45-minute sessions

Materials and Equipment

For each student or group:

- Data collection system
- CO_2 sensor
- pH sensor
- Sensor extension cable
- EcoChamber
- Magnetic stir plate and stir bar
- Beaker, 100-mL (for vinegar)
- Beaker, glass, 2-L
- Graduated cylinder, 25-mL or 10-mL
- Graduated cylinder, 1-L or 500-mL
- Erlenmeyer flask, 125-mL (for bleach)
- Rubber stopper for Erlenmeyer flask
- Stirring rod
- Rapid-rise activated baker's yeast, 7-g packet
- Sugar, 100 g
- White vinegar, 50 mL
- Household bleach, half-strength, 50 mL
- Water, 1 L

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Basic biochemistry of cellular respiration
- The role of closed systems in evaluating change
- Most cells function best within a narrow range of acidity
- pH is a logarithmic measurement of the concentration of hydrogen ions in water. ($pH = -\log_{10}[H^+]$)
- pH measurements can range from 0 through 14. The lower the value, the higher the concentration of hydrogen ions.
- pH can be a measure of acidity, with values below 7 becoming increasingly acidic as the value approaches 0. Therefore, the lower the pH, the higher the concentration of hydrogen ions and the higher the acidity.
- A pH of 7 is neutral—neither acidic nor basic.
- pH values greater than 7 are considered basic. Practically speaking, a pH of 6 to 8 is considered to be in the neutral zone.
- Standard deviation is a simple measure of the variability of a data set.

Related Labs in This Guide

Prerequisites:

- Yeast Respiration

Labs conceptually related to this one include:

- 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 your experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)

- Displaying multiple graphs simultaneously �(7.1.11)
- Naming a data run �(8.2)
- Finding the value of a point on a graph �(9.1)
- Viewing statistics of data �(9.4)
- Find the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)

Background

Toxicologists must concern themselves with the degree of toxicity—that is, the capacity to cause harm or death to living organisms—that exists for chemicals in the environment. Their studies must consider the dose (the amount of the substance that organisms are likely to be exposed to). They must also consider the genetic makeup of a species that might cause it to be sensitive to damage by a given chemical.

Toxicologists must select organisms for toxicity testing that are genetically similar to the organisms they want to protect from toxic chemical effects. Because of ethical considerations, substitutes for the organism of concern are often needed. Organisms further down in phylogeny that, nevertheless, have critical genetic characteristics similar to those of humans, are preferred test subjects.

Yeasts are good candidates for toxicology screening tests because 1) they are easy to grow, 2) they are relatively simple single-celled organisms yet are eukaryotic, 3) they have many metabolic processes that also occur in humans and other organisms further up in phylogeny, and 4) they have a known genetic code.

Pre-Lab Discussion and Activity

Engage your students by examining a Material Safety Data Sheet (MSDS) of sodium fluoride, a toxic chemical that might be familiar to them and one they might encounter in their everyday lives. Sodium fluoride is a chemical that is sometimes added to drinking water at low levels to increase its fluoride content.

Note: MSDS documents are available on the Web in PDF format. They are easily found using a Google search. Students might not be aware that such information is freely available.

Note: You may find a bottle of sodium fluoride in your chemistry storage area to use as a visual aid.

Examine the MSDS for toxicity study information. For sodium fluoride, environmental toxicity data is listed in terms of lethal dose (LD_{50}). The LD_{50} for a goat and wild bird are listed.

Engage students in the following questions and discussion items:

1. Based on the LD_{50} information given for sodium fluoride, find the mass of sodium fluoride that would be expected to kill 50% of rats weighing 500 g.

The LD_{50} of sodium fluoride for a rat is 52 mg/kg. Therefore, 26 milligrams would be required to kill 50% of the rats weighing 500 g (52 mg/kg x 0.5 kg = 26 mg).

2. Discuss the ethical issues of testing the toxicity of substances. What would be the advantages of finding cell-culture systems that could produce toxicity information that could be directly applied to humans?

Conduct a brainstorming session to identify the criteria that such a test system would need to satisfy.

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. Prepare 2 liters of a 1:1 household bleach:water solution (equal parts of bleach and water).
2. For each group, pour a 60-mL aliquot of the half-strength bleach solution into a 125-mL Erlenmeyer flask.

Note: Put stoppers in the Erlenmeyer flasks to minimize the amount of chlorine that vaporizes from the solution.

Safety

Add these important safety precautions to your normal laboratory procedures:

- If the room is not well-ventilated, handle open containers of bleach and bleach solutions under a ventilated hood.
- Wear safety glasses and a lab coat.
- Have running water or an eyewash station in close proximity.

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	5	2	3	1
At 3-minute intervals, add 10 mL of vinegar. Continue collecting data until the CO_2 levels stop rising.	Repeat the test procedure using a 1:1 solution of bleach and water. Compare the toxicity of bleach and vinegar. Evaluate the role of pH in toxicity.	Set up the airtight EcoChamber to measure carbon dioxide gas (CO_2) and pH. Have a removable plug that will allow addition of toxins.	Pour half of the yeast solution into the EcoChamber and seal it from air. Slowly stir the solution with the magnetic stirrer. Collect data for 3 minutes.	Heat sugar and water, make the yeast solution, and set up your data collection system to show CO_2 and pH measurements.

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 – Prepare the yeast culture

Set Up

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

2. ☐ Connect the CO_2 sensor and the pH sensor to the data collection system to record pH and CO_2 gas simultaneously. �(2.2)

3. ☐ Display pH on the y-axis of a graph and CO_2 gas on the y-axis of another graph; show Time on the x-axes of these graphs. �(7.1.11)

4. ☐ Heat 1 L of water and 100 g of sugar in a 2-L beaker to about 40 °C on a hot plate.

5. ☐ Remove the beaker from the hot plate and turn off the heat.

6. ☐ Add a package of activated yeast, and stir thoroughly.

7. ☐ Allow the mixture to activate for 15 minutes, stirring occasionally.

Note: The formation of bubbles indicates the yeast is activating.

Part 2 –Test the toxicity of vinegar

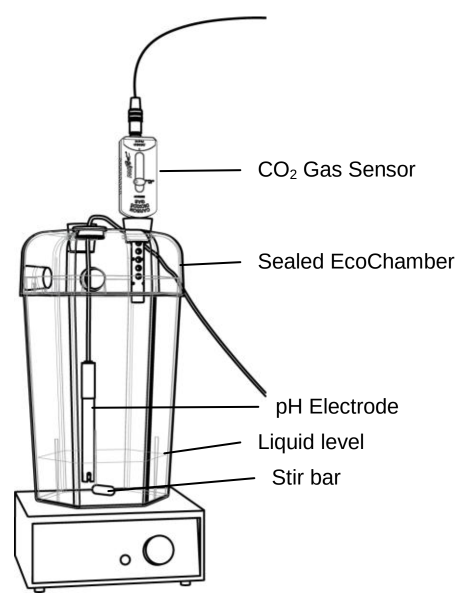
Set Up

8. ☐ Set up the EcoChamber to measure pH and CO_2 gas simultaneously, as follows:

   a. Place a stir bar in the chamber and set it on a magnetic stirrer.

   b. Make sure the end of the pH probe is about 1 cm above the bottom of the chamber.

   c. Arrange the CO_2 gas sensor so the end is completely inside the container, but will not get wet.



d. Using the graduated cylinder, measure and pour 500 mL of the yeast cell culture solution into the chamber and seal it airtight.

e. Turn on the magnetic stirrer.

Collect Data

Important! Record data continuously until you have added all 50 mL of vinegar.

9. ☐ Start data recording. �(6.2) Adjust the scale of the graph so the data fills the screen. �(7.1.2)

10. ☐ Measure 10 mL of vinegar using the graduated cylinder while data is recording.

11. ☐ After recording data for 3 minutes, remove the stopper from a port at the top of the chamber and add the 10 mL of vinegar. Replace the stopper.

Note: Do not stop recording data!

12. ☐ Record data for 3 additional minutes and again add 10 mL of vinegar.

Note: Do not stop recording data!

13. ☐ Repeat this procedure until a total of 50 mL of vinegar has been added.

14. ☐ Record data for 3 additional minutes.

15. ☐ Stop recording data. �(6.2)

16. ☐ Name the data run appropriately. �(8.2)

17. ☐ Discard the yeast solution as instructed by your teacher, and rinse the chamber and pH sensor.

18. ☐ Predict which will be more toxic to the yeast cells—half-strength bleach or full-strength vinegar? Explain your reasoning.

Answers will be either half-strength bleach or full-strength vinegar. Students may think an acidic solution is more harmful than a basic one, or vice versa; or that half-strength bleach may not be as strong as full-strength vinegar.

19. ☐ Why are you measuring the CO_2 gas concentration?

Carbon dioxide gas is being used as an indicator of cellular respiration by the yeast cells. Reduction in the rate of CO_2 gas production should indicate a reduced level of cellular respiration, indicating toxic stress on the yeast cells.

20. ☐ Why are you measuring the pH of the solution?

Vinegar is acidic, and so the acidity of the solution can be correlated with the toxicity of the dose of vinegar. Also, the effect of bleach on the pH of the yeast solution can be investigated and compared with the results of the vinegar trial.

Part 3 – Test the toxicity of half-strength bleach

Set Up

21. ☐ Set up the EcoChamber to measure pH and CO_2 gas simultaneously, as follows:

- **a.** Place a stir bar in the chamber and set it on a magnetic stirrer.
- **b.** Make sure the end of the pH probe is about 1 cm above the bottom of the chamber.
- **c.** Arrange the CO_2 gas sensor so the end is completely inside the container, but will not get wet.
- **d.** Using the graduated cylinder, measure and pour 500 mL of the yeast cell culture solution into the chamber and seal it airtight.
- **e.** Turn on the magnetic stirrer.

Collect Data

Important! You should record data continuously until you have added all 50 mL of half-strength bleach.

22. ☐ Start data recording. �(6.2) Adjust the scale of the graph so the data fills the screen. �(7.1.2)

23. ☐ Measure 10 mL of half-strength bleach using the graduated cylinder while data is recording.

24. ☐ After recording data for 3 minutes, remove the stopper from a port at the top of the chamber and add the 10 mL of vinegar. Replace the stopper.

Note: Do not stop recording data!

25. ☐ Record data for 3 additional minutes and again add 10 mL of half-strength bleach.

Note: Do not stop recording data!

26. ☐ Repeat this procedure until a total of 50 mL of half-strength bleach has been added.

27. ☐ Record data for 3 additional minutes.

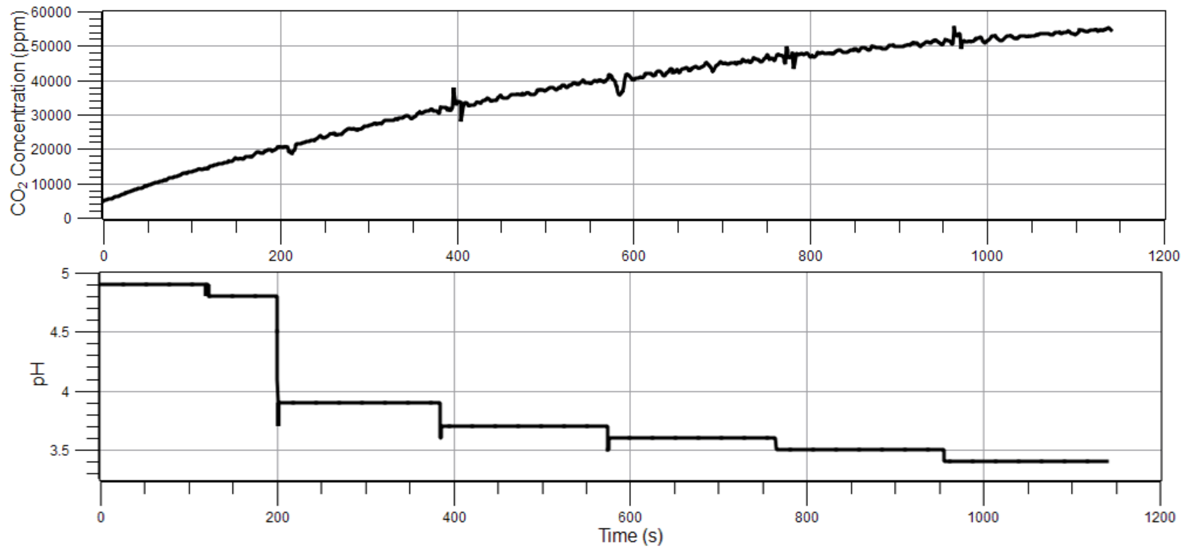
28. ☐ Stop recording data. �(6.2)

29. ☐ Name the data run appropriately. �(8.2)

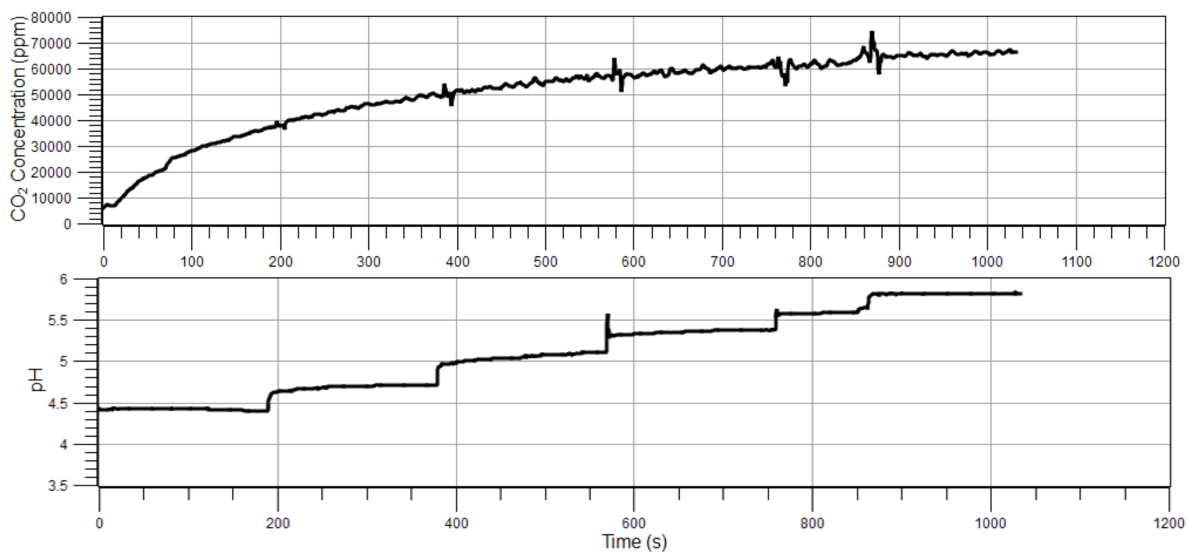
30. ☐ Discard the yeast solution as instructed by your teacher, and rinse the chamber and pH sensor.

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

Sample Data



Effect of full-strength household vinegar on CO_2 gas concentrations and pH of a yeast cell culture system



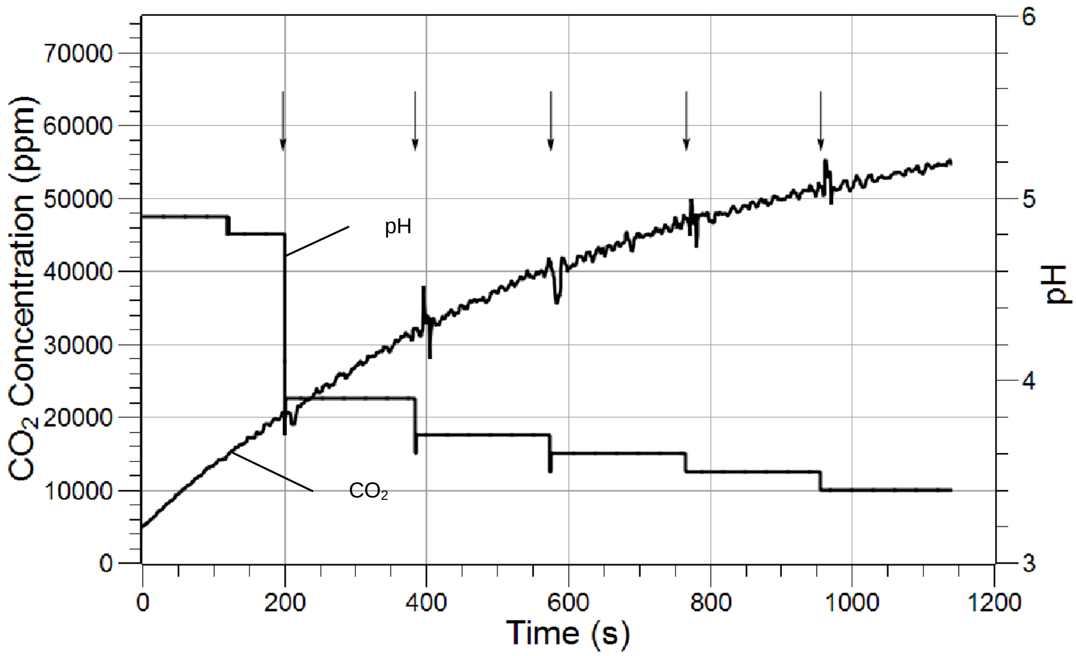
Effect of half-strength household bleach on CO_2 gas concentrations and pH of a yeast cell culture system

Data Analysis

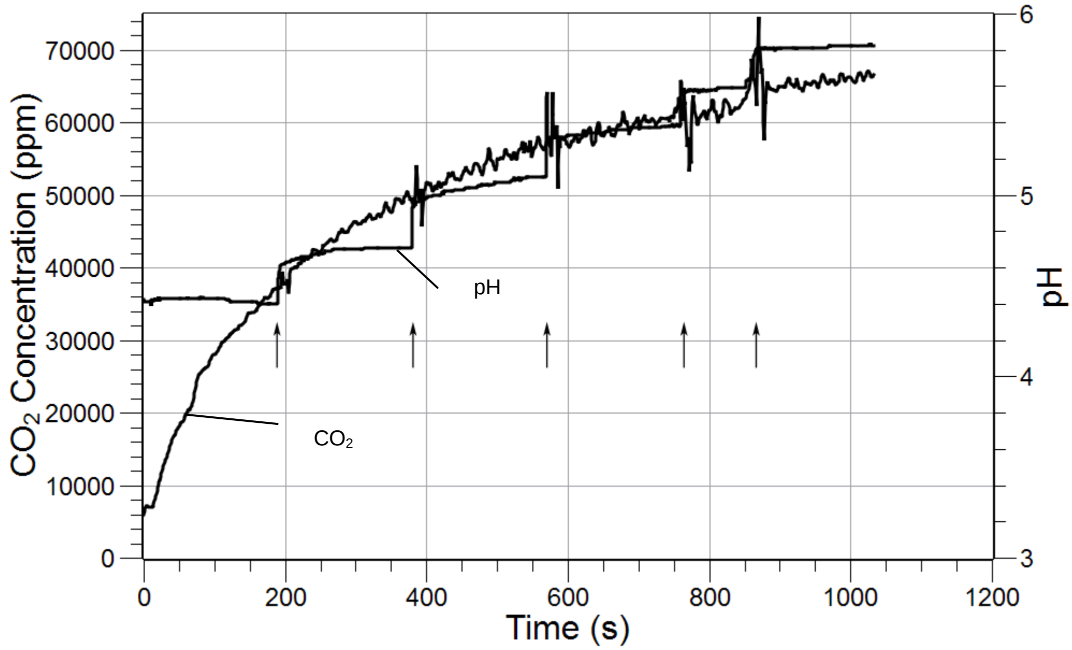
1. ☐ Display the dependent variable on the y-axis of a graph and time on the x-axis for both measurements (pH and CO_2 gas concentration) for each toxin. �(7.1.11)

2. ☐ Adjust the scale of the graph so the data fills the screen. �(7.1.2)

3. ☐ Sketch the graphs on the blank graphs. Sketch one graph for the vinegar trial and one graph for the half-strength bleach trial. Indicate the appropriate scale on the axes. Indicate the points at which the toxins were added to the system.



Effect on CO_2 concentration and pH of adding aliquots of full-strength vinegar



Effect on CO_2 concentration and pH of adding aliquots of half-strength bleach

4. ☐ Use graph tools to find the value of data points to complete Table 1. �(9.1)

Hint: To find the rate of CO_2 production (parts per million/second) for selected regions of the CO_2 data plot, use the linear fit tool to determine the slope of a best-fit line. �(9.6) To find the pH value for selected regions of the pH plot, use the statistics tool to find the mean value. �(9.4)

Table 1: Enter the rate of production of CO_2 gas and the pH change for each of the toxins

	Rate of production of CO_2 gas (ppm/s)						**pH**					
Toxin (total volume added)	**0 mL**	**10 mL**	**20 mL**	**30 mL**	**40 mL**	**50 mL**	**0 mL**	**10 mL**	**20 mL**	**30 mL**	**40 mL**	**50 mL**
White Vinegar	76	64	46	35	25	20	4.9	3.9	3.7	3.6	3.5	3.4
Bleach: water 1:1	144	59	37	20	14	11	4.4	4.7	5.0	5.4	5.6	5.8

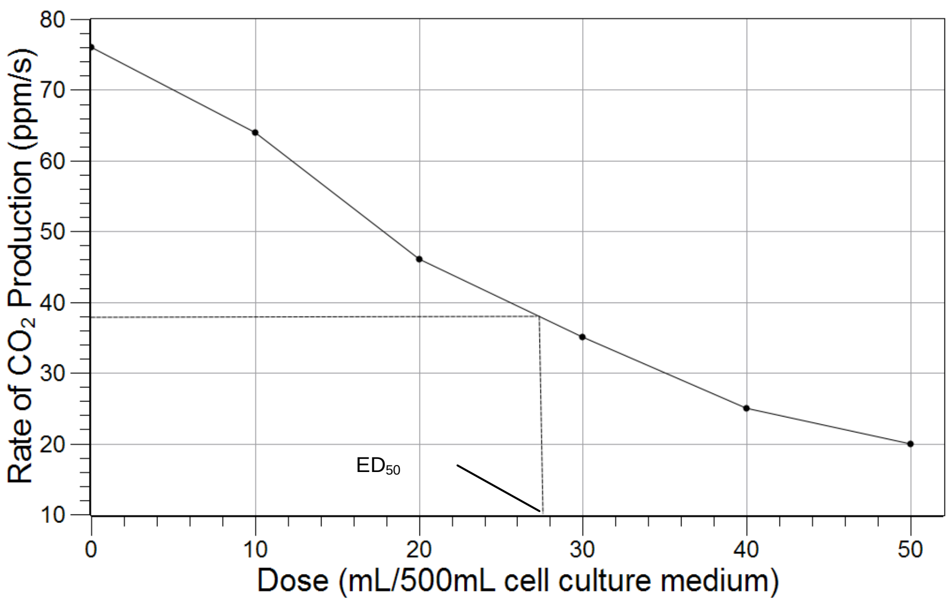
5. ☐ Toxicologists often report the strength of a toxin in terms of LD_{50} or ED_{50}. Which of these terms is most appropriate for the results of this experiment? Explain.

Note: The LD_{50} is the dose of a substance at which 50% of the organisms are killed—that is, the lethal dose for 50% of exposed organisms. In many cases, the end point of interest is a sublethal effect, such as affecting the ability to reproduce or inhibiting metabolism. In these cases, the strength of a toxin is reported in terms of ED_{50}—that is, the effective dose causing 50% inhibition.

To evaluate the relative toxicity of substances using this yeast cell culture, the best measure would be the ED_{50}. This is because it is impossible to know in this experimental design whether the yeast cells are dead or whether they are just temporarily inhibited.

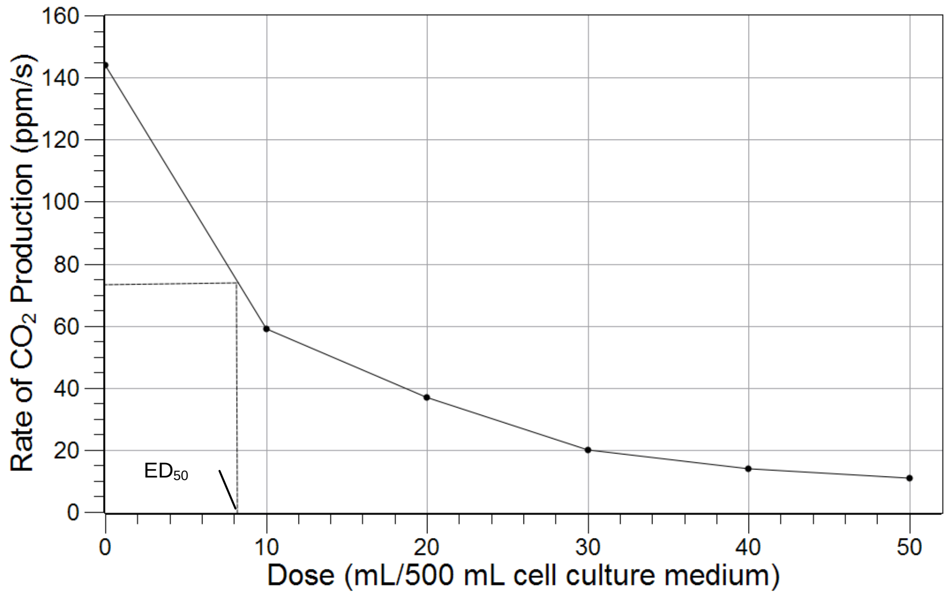
6. ☐ Use your data to extrapolate the ED_{50} of the half-strength bleach solution and the full-strength vinegar solution. To do this:

- **a.** Plot the rate of CO_2 gas production versus the dose administered (mL toxin solution/500 mL).
- **b.** Then connect the points and use this curve to extrapolate the volume of toxin (mL toxin/500 mL yeast culture) required to reduce the rate of CO_2 gas production in half (ED_{50}).
- **c.** Adjust the dose calculation to terms of mL toxin/L yeast culture.



The ED_{50} of full-strength vinegar is **56 mL/L**

Toxicity of full-strength vinegar



The ED_{50} of half-strength bleach is **16 mL/L**

Toxicity of half-strength bleach

ED_{50} of full-strength vinegar: ___56 mL/L___

ED_{50} of half-strength bleach: ___16 mL/L___

Answers will vary. For this example, the ED_{50} of half-strength bleach is 16 mL/L of yeast culture medium, and the ED_{50} of full-strength vinegar is 56 mL/L yeast culture medium.

7. ☐ Using the ED50 values as indices of toxicity, how does the toxicity of bleach compare to the toxicology of vinegar?

For this example, the ratio of toxicity of half-strength bleach to full-strength vinegar, as expressed in terms of ED_{50}, was 56:16. Using the ED_{50} values as indices of toxicity, half-strength bleach was 56/16 or 3.5 times more toxic than full-strength vinegar. That would mean that full-strength bleach is 3.5 x 2 = 7 times more toxic for yeast cells than full-strength vinegar.

Analysis Questions

1. What is the independent variable in this experiment?

The independent variable in this experiment is the toxin being tested.

2. What are the dependent variables?

The dependent variables are the rate of CO_2 gas production and the pH of the solution.

3. What are the controlled variables in this experiment?

The controlled variables are the volume of yeast cell culture added to the EcoChamber, the volume of vinegar and half-strength bleach added to the yeast culture, and the time between the additions of the toxins.

4. How do the data compare with your prediction?

Students should mention the relative response of yeast cells to toxins and should identify which toxin they predicted would be strongest and which actually was strongest.

5. What does the rate of CO_2 gas production indicate regarding the yeast culture? Explain why the rate of CO_2 gas production by a yeast culture can be used as an indicator of the toxicity of an added substance.

Yeast cells produce CO_2 gas during cellular respiration. Therefore, the production of CO_2 is an indicator that the yeast cells are metabolically active. A toxic substance would inhibit the metabolism of yeast, or perhaps even kill the yeast. In the presence of a toxic substance, their cellular respiration would be reduced, resulting in a decreased rate of CO_2 production.

6. Why do you think pH was measured in this experiment? What was the relationship of pH to toxicity? Was a large change in pH necessary for a toxic effect to occur?

pH was measured to correlate the pH of the yeast cell culture to the rate of cellular respiration. Cells function in a limited range of pH, therefore, lowering pH should inhibit cell function. However, a change in pH is not the only mechanism that can cause cells to reduce the rate of cellular respiration. The evidence from this experiment shows that bleach was more toxic than vinegar and raised the pH slightly, rather than lowering it.

7. For the best interpretation of the data, what additional test should be run with this assessment? Explain.

A control trial with water as the independent variable should be run to support the assumption that there is a constant rate of CO_2 production by the yeast culture. If students have performed the Yeast Respiration lab before performing this lab, they can use the evidence from that activity to support this assumption. If time permits, consider performing this control trial.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Determine the mean and standard deviation (SD) of the ED_{50} data obtained from the several trials conducted in your class. Compare the results of your trial to that of your classmates. Discuss possible reasons for the variations seen. Which value do you think is closest to the true value?

Answers will vary according to class results. Possible sources of experimental variation include variation in the number of active yeast cells in the cell culture and variations in measuring accuracy. Generally, the mean is the value that is closest to the true value, given enough trials. In general, from a large number of trials, the true mean is highly likely to fall within the range of the mean ± 2SD.

2. In what ways are yeast cells good subjects for toxicity studies?

Yeast cells are good subjects for toxicity studies because they are eukaryotic cells, so they are more like cells of organisms higher in phylogeny than bacteria are. Baker's yeast cells are easy to grow, and they are not pathogenic. Yeasts have many metabolic pathways that are like those of humans, and their genetic code is largely known.

3. What are some limitations of using yeast cells as subjects for toxicity studies?

Yeasts are single cells, so they do not have many of the complex mechanisms for detoxifying chemicals that exist in humans. Yeast reproduction has almost no characteristics that are similar to humans. Yeasts do not have differentiated cells and tissues, such as neurons and brains, that could be uniquely affected by a toxin.

Multiple Choice Questions

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

1. The toxicity of a substance depends on

- **A.** Genetic makeup or sensitivity of the organism
- **B.** Frequency of exposure
- **C.** Ability of the body to detoxify
- **D.** The amount or dose
- **E. All of the above**

2. An LD_{50} is a determination of

- **A.** The amount of a toxin required to inhibit growth by 50%
- **B.** The amount of a toxin required to inhibit reproduction by 50%
- **C. The amount of a toxin required to kill 50% of a population**
- **D.** The lethal dose of a chemical after 50 days of exposure

3. An ED_{50} is a determination of

- **A.** The amount of a toxin required to inhibit growth by 50%
- **B.** The amount of a toxin required to inhibit reproduction by 50%
- **C.** The amount of a toxin required kill 50% of a population
- **D.** The lethal dose of a chemical after 50 days of exposure
- **E. Both A and B could apply**

4. Yeast cells can be useful in toxicology studies because

- **A.** They are eukaryotic.
- **B.** They have many metabolic pathways that are similar to those of humans.
- **C.** They are easy to grow.
- **D.** Their genetic code is largely mapped.
- **E. All of the above.**

5. Which of the following characteristics of baker's yeast is *not* a limitation in using yeast cells for toxicology studies?

- **A.** They have some metabolic pathways that are not found in humans.
- **B. They are not pathogenic.**
- **C.** They do not have similar detoxification mechanisms compared with those of humans.
- **D.** They are single-cellular organisms.
- **E.** They reproduce differently than humans.

6. In this activity, the rate of CO_2 gas production was used as an indicator of toxicity to yeast cells because

- **A. It indicates the relative amount of cellular respiration by actively growing yeast cells.**
- **B.** CO_2 is consumed by yeast cells during aerobic cellular respiration.
- **C.** Yeast cells release CO_2 gas when they die.
- **D.** The toxin reacts to substances in the yeast cells to produce CO_2 gas.
- **E.** A and D are correct.
- **F.** None of the above.

Extended Inquiry Suggestions

Toxicologists have identified two basic models of dose-response curves for toxicity: those with no threshold and those with a threshold. Toxins that have no threshold are ones that are toxic at any level. Toxins that have a threshold are ones that are not toxic until a certain threshold of dose is achieved. Refer to available resources for examples of these models. Which model seems to apply to the toxicity of bleach for yeast cells? Which model seems to apply to the toxicity of vinegar for yeast cells?

Design additional trials using smaller doses of the toxins to determine whether bleach or vinegar have a threshold effect and the level of that threshold effect. What is the relationship of pH of the yeast cell culture to any threshold you discover?

Research the toxicity of sodium hypochlorite (active ingredient in bleach) and acid. Ask students to report on some possible mechanisms by which these toxins inhibit the rate of cellular respiration in yeast cells.

21. Water Treatment

Objectives

Students demonstrate how water treatment processes such as filtration, flocculation, and sedimentation improve water quality.

Procedural Overview

Students will gain experience conducting the following procedures:

- Evaluating water treatment processes using direct observation and by measuring conductivity, pH, and turbidity.
- Using test results to design, build, test, and evaluate a water treatment process.

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	45 minutes
♦ Lab activity	90 minutes or two, 45-minute sessions

Materials and Equipment

For each student or group:

- Data collection system
- Water quality sensor (or pH and conductivity sensors)
- Turbidity sensor
- Beaker (4), 150-mL
- Beaker, 50-mL
- Beaker, large ("wastewater" container)
- Test tube, 18-mm OD or greater
- Graduated pipet, 50-mL, and bulb
- Graduated cylinder, 100-mL
- Transfer pipet, 2 mL
- Stirring rod
- Balance (1 per class)
- Buffer solution pH 4, 25 mL
- Buffer solution pH 10, 25 mL
- Soda bottle (2), empty, 500-mL
- Paper napkins (12), dinner, white, smooth
- Paper towels(4), white
- "Wastewater" sample, 500 mL[1]
- Swimming pool water clarifier solution, 4%, 2 to 4 mL
- Wash bottle containing water
- Activated charcoal, 2 g
- Water, 300 mL
- Lint-free lab tissue

[1]To formulate using tap water, soil with a high clay content or crushed kitty litter, and coffee, refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Renewable and non-renewable resources
- Measuring conductivity
- Measuring pH
- Measuring turbidity

Related Labs in This Guide

Labs conceptually related to this one include:

- Monitoring Water Quality
- Determining Soil Quality

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)
- Calibrating a pH sensor �(3.6)
- Calibrating a turbidity sensor �(3.7)
- Monitoring live data without recording. �(6.1)
- Displaying data in a digits display �(7.3.1)

Background

There are several steps in the water treatment process common to both drinking water and wastewater treatment. Among these processes are coagulation, flocculation, and filtration.

Filtration technology is abundant and can be used to remove nearly any impurity from water. However, using only filtration devices is not cost effective, so usually filtration is combined with other water treatment methods.

Both types of water treatment—for drinking water and for wastewater—start by passing the water through a screen to remove larger objects. Then, a coagulant is added to the water. Salts of aluminum (alum) or water-soluble organic polyelectrolytes are often used as coagulants. Coagulants cause suspended particles to form clumps. Next, these clumps aggregate into larger clumps, or flocs. These flocs are dense enough to settle out of the water in a process called sedimentation. The water is then filtered through a variety of media of varying porosities, including activated carbon, sand, and gravel. Filtration works by trapping impurities in the spaces between the granules of the media and allowing the water to flow through it.

While the water looks clean at this point, several precautions must be taken to eliminate viruses or bacteria in the water that can cause disease. Three of the most common ways to disinfect water include: 1) treatment with chlorine, 2) bubbling with ozone, or 3) exposure to ultraviolet light. More advanced (and expensive) filtration methods use membranes—for example, reverse osmosis and micropore filtration—for special purposes.

The United States Environmental Protection Agency (EPA) publishes the Primary and Secondary Drinking Water Standards on the Internet. These specify the maximum level of contaminants in the United States for drinking water supplied by municipal water treatment facilities and are good references to have on hand.

The United States standards for the water quality of natural bodies of water that support aquatic organisms are also specified by the United States EPA in their Red Book and Gold Book. These are also available on the Internet. Treated wastewater must ensure that these standards are maintained when wastewater is discharged back into the ecosystem.

Pre-Lab Discussion and Activity

Many students have not thought carefully about how the water they drink and the water they put into the sewer system is processed. Discuss water usage and waste in the home and community by asking the following questions:

1. How does water get into the home?

The water that is pumped into residences has to meet water quality standards. A better term for what we usually just call "water" is "drinking water." This is what comes out of the faucet, spigot, and garden hose. Although drinking water is also used for things like bathing, cooking, and car washing, the idea remains the same: it is safe to drink and contains no offensive taste, odors or color.

In order to provide homes with drinking water, communities have developed water treatment plants to ensure the water is safe. Water comes into the home via a distribution network that includes a watershed, a collection point (such as a reservoir, tower, or tank), and the water treatment facility. From there, water is piped to businesses and homes served by the water treatment facility.

2. Where does it come from?

Water that is ultimately fed into the home can come from a variety of sources. Raw, untreated water is obtained from the large bodies of water, like lakes and rivers, of a local or distant watershed.

3. How, generally, does it leave the residence?

Answers will vary based on your location and local water and sewage treatment facilities.

Bring in water samples from various sources and discuss whether treatment is necessary to improve quality. Help build students' understanding of humans' interactions with the water cycle and their effects on the environment by asking the following questions:

4. How does proximity to industries and to areas affected by the presence of people alter water quality?

Industries that introduce pollutants into the water or air have the potential to adversely affect water quality. Also, the way people use the land can affect water quality. For example, when rain hits the land or the structures, such as roads and parking lots, that people build, the rainwater picks up substances such as pesticides, fertilizers, and car fluids that have leaked and brings them as part of the runoff into a creek, lake, or other body of water.

5. What can be done to prevent water pollution from industries?

One of the following will have to occur: industry has to stop operations, trap and dispose of pollutants before they are introduced to the environment, or treat water to remove the pollutants.

Engage students and prepare them for a successful lab activity by doing a demonstration and asking them to predict the outcome. You can turn this into a contest.

Tell students you will analyze the local tap water for its pH, conductivity, and turbidity. Have them write down their predictions regarding these parameters. Tell them that these predictions will be used to determine the winner of your contest.

Demonstrate how to properly calibrate the pH and turbidity sensors and then test the pH, turbidity, and conductivity of the local tap water.

Note: The conductivity sensor does not need calibrating because the possible calibration error is small compared to the magnitude of conductivity being measured.

Note: Model the correct method for handling the cuvettes of the turbidity sensor.

Note: Highlight the need to submerge the conductivity sensor so the holes on the end of the sensor are submerged, and emphasize the need to wash the sensor with water between measurements.

Note: Emphasize the need to rinse containers between trials.

Discuss the results with students. Try to relate these to what you know about the source of the water or the water treatment procedures in your area. For example, if your local water is taken from a valley river or well, it is likely to have higher levels of dissolved solids, and thus higher levels of conductivity, than water that is taken from a river flowing through a mountain. (This is because the water in the well or river valley has been exposed to more runoff from the watershed or for more time to minerals in the ground.)

Turbidity will be low or not measurable because water treatment facilities are required to remove suspended solids for sanitation reasons. So even if your water source is turbid, the water delivered from your tap will not be turbid.

The pH will be in the neutral zone because water treatment facilities are required to adjust the pH to neutral. That is because pH that is too acidic or basic is corrosive to water pipes. So even if your area has acidic water, the pH will be adjusted by the water treatment facility so the water flowing through the pipes has a pH in the neutral zone.

Have students find the total numerical value of the difference between their guesses and your measurements, with the winner being the students with the lowest difference for each of the three parameters.

Lab Preparation

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

1. Purchase dinner napkins, paper towels, swimming pool water clarifier, and activated charcoal at local stores.

- ♦ Swimming pool water clarifier is widely available at hardware/home improvement stores.
- ♦ Activated charcoal is widely available at health food stores as loose powder or in 250-mg capsules. Both forms work well, but the capsules take longer and are messier to use, because a total of 8 capsules for each group will have to be opened.

Note: Activated charcoal can get messy if students are careless with it. Have plenty of paper towels and soap handy.

2. Consider having students bring in empty 500-mL disposable plastic bottles. Otherwise, save them yourself or find a source of them.

3. Prepare the "wastewater" sample (about 500 mL are required per group): Fill a large container (for example 2 to 3 gallons) with water, and add the following:

- ♦ Two to three handfuls of potting soil (Make sure the soil has a high clay or silt content. If not, add some crushed kitty litter.) Strive for a turbidity of about 400 NTU.
- ♦ Coffee or instant coffee granules. Add enough until you can detect a coffee odor.

4. Prepare the 4% solution of swimming pool water clarifier: Mix 4 mL of clarifier solution with 96 mL of water. This will create enough for approximately 50 groups.

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	2	5	1	4
Make a paper membrane filter. Make an activated charcoal-paper membrane filter.	Set up your data collection system to monitor pH, conductivity, and turbidity. Calibrate the pH and turbidity sensors.	Design a water treatment technique selecting from the techniques just tested. Test your design and evaluate the results.	Set up the samples and set aside the sedimentation and coagulation samples for at least 30 minutes.	Test the various filtration systems and treatments for effectiveness in purifying the 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 – Determining effects of different water treatment processes

Set Up

1. ☐ Stir the "wastewater" sample to uniformly mix it.

2. ☐ Pour 100 mL of the well-mixed "wastewater" sample into each of four 150-mL beakers.

3. ☐ Label the beakers as follows:

- Beaker 1, "#1 Untreated"
- Beaker 2, "#2 Activated Charcoal"
- Beaker 3, "#3 Sedimentation"
- Beaker 4, "#4 Coagulation"

4. ☐ Set Beaker 3 aside for at least 30 minutes. Enter the starting time: __________

5. ☐ Put 2 mL of the 4% swimming pool clarifier solution in Beaker 4 and use the stirring rod to stir vigorously.

6. ☐ Note any changes in appearance and record these in Table 1 in the Data Analysis section.

7. ☐ Periodically during the next 30 minutes, slowly stir this solution.

Note: Swimming pool clarifier solution contains coagulating agents similar to those used in municipal water treatment facilities.

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

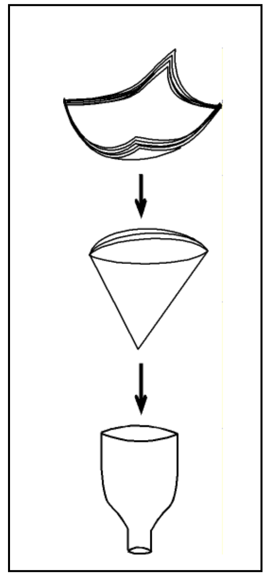
9. ☐ Connect a water quality sensor (or pH and conductivity sensors) and a turbidity sensor to the data collection system. �(2.2)

10. ☐ Display pH, conductivity, and turbidity in a digits display. �(7.3.1)

11. ☐ Use pH 4 and pH 10 buffer solutions to calibrate the pH sensor. �(3.6)

12. ☐ Calibrate the turbidity sensor. �(3.7)

Note: It is not necessary to calibrate the conductivity sensor for this activity.



13. ☐ Prepare a paper membrane filter as follows:

a. Cut off the top half of a 500-mL soda bottle to use as a funnel.

b. Fold a paper towel in half, and then fold it in half again. Separate the layers to make a funnel-shaped filter.

c. Stack 3 paper napkins together, and shape them into a shallow bowl. Tuck these into the paper funnel, and push the entire paper membrane construction into the funnel, forming a bowl to hold the filtrant.

14. ☐ Prepare an activated charcoal–paper membrane filter as follows:

a. Make another paper membrane filter as described in the previous step.

b. Measure and add 1 gram of activated charcoal to 100 mL of tap water and stir.

c. Pour this slurry into the filter.

d. After that aliquot has been filtered, slowly pour another 100 mL of tap water into the filter.

e. You should now have a paper membrane filter covered with a layer of activated charcoal. If the water filtering through it is not clear, filter an additional 100 mL of tap water.

Note: This step ensures that the activated carbon becomes fixed inside the filter and is not leaking into the filtrate.

Note: Activated charcoal is specially prepared so that it is extremely porous and can thus trap and remove molecules from water, especially large organic molecules such as those responsible for odors and colors. The activated charcoal must also be filtered out of the water.

15. ☐ Which water treatment method do you think will have the greatest effect on the following?

Odor ______________________________

Color ______________________________

pH ________________________________

Conductivity ______________________

Turbidity _________________________

16. ☐ Which water treatment method do you think will have the least effect on the following?

Odor ____________________________

Color ____________________________

pH ______________________________

Conductivity ____________________

Turbidity ________________________

Collect Data – Untreated waste water

17. ☐ Examine the untreated "wastewater" sample (Beaker 1). Note its odor, color, and general appearance, and record these in the Table 1 in the Data Analysis section.

18. ☐ Monitor live data without recording. �(6.1)

19. ☐ Determine the pH, conductivity, and turbidity, and record them in Table 1.

Collect Data – Paper membrane filtration

20. ☐ Now test the effect of filtration on the untreated wastewater sample.

a. Slowly pour the untreated sample into the paper filter, being careful to keep the liquid contained inside the paper napkin "bowl".

b. Collect the filtrate in the 50-mL beaker.

21. ☐ Determine the odor, color, and general appearance of the filtrate, and record these in Table 1.

22. ☐ Transfer the filtrate to a large test tube.

23. ☐ Determine the pH, conductivity, and turbidity, and record them in Table 1.

24. ☐ Rinse the beakers and test tube.

Collect Data – Activated charcoal-paper membrane filtration

25. ☐ Using the activated charcoal–paper membrane filter you prepared earlier, filter 100 mL of the "wastewater" from Beaker 2 into the graduated cylinder.

26. ☐ Discard the first 30 mL of filtrate. Collect the remaining filtrate in the 50-mL beaker.

27. ☐ Note the odor, color, and general appearance of the filtrate, and record these in Table 1.

28. ☐ Transfer the filtrate to the large test tube.

29. ☐ Determine the pH, conductivity, and turbidity, and record them in Table 1.

30. ☐ Rinse the beakers, graduated cylinder, and test tube.

31. ☐ What effects did adding activated charcoal to the paper membrane filtration have on the results of the filtration?

In our sample, the water had less of an odor and it appeared cleaner. The conductivity dropped significantly, so the charcoal was effective at removing dissolved solids.

Collect Data – Coagulation plus paper membrane filtration

32. ☐ Observe the coagulated sample (Beaker 4). Compare it with an untreated sample and record your observations here:

Students should see that the coagulated sample is cloudier than the untreated sample. They may see flecks of white floc on the surface. When they swirl the water, they will see coagulated clumps moving in the water.

33. ☐ Determine the pH, conductivity, and turbidity and record the data in Table 1 (in the row labeled "Coagulation").

34. ☐ Prepare another paper membrane filter as described previously.

35. ☐ Filter the coagulated sample using this paper membrane filter.

36. ☐ Note the odor, color, and general appearance of the filtrate, and record these in Table 1.

37. ☐ Transfer the filtrate to the large test tube.

38. ☐ Determine the pH, conductivity, and turbidity, and record them in Table 1.

39. ☐ Rinse the beakers and test tube.

Collect Data – Sedimentation

40. ☐ From Beaker 3, carefully pipet a 30-mL sample from the top of the solution, being careful not to disturb the solution.

41. ☐ Place the sample in the test tube.

42. ☐ Note the odor, color, and general appearance of the sample, and record these in Table 1.

43. ☐ Determine the pH, conductivity, and turbidity, and record them in Table 1.

44. ☐ Rinse the beakers and test tube.

Part 2 – Designing and testing a water treatment system

Set Up

45. ☐ Design a water treatment procedure using the techniques presented in Part 1 of this activity.

46. ☐ Record the water treatment steps in your design and explain why you chose this design. Refer to your test results in Part 1.

Designs will vary, but students should include at least 2 treatments and have good reasons for their process design that are based on the data they collected in Part 1. An example of an effective design is as follows:

1) Add a coagulating agent to the sample.

2) Allow coagulation to proceed for 30 minutes.

3) Prepare an activated charcoal-coated paper membrane filter.

4) Filter the coagulated sample.

Given this example, an explanation might be as follows:

I ruled out using sedimentation because it is too slow for the amount of time I have to test my system. I reasoned that if I add a coagulating agent, the suspended solids will clump. The activated charcoal forms a more non-porous surface on the paper filter, as shown when it allowed water to filter at a slower rate. So by using the activated charcoal-coated paper membrane filter, I can have more effective removal of suspended solids as well as better removal of odor and color.

Collect Data

47. ☐ Treat 100 mL of the "wastewater" using the system you designed.

48. ☐ Note the odor, color, and general appearance of the sample, and record these in Table 2.

49. ☐ Transfer the filtrate to the large test tube.

50. ☐ Determine the pH, conductivity, and turbidity, and record them in Table 2.

51. ☐ Clean up according to your teacher's instructions.

Data Analysis

Table 1: Water treatment process results

Water Treatment Type	pH	Conductivity (µS/cm)	Turbidity (NTU)	Odor	Appearance (Color, Transparency, Other Observations)
Untreated "wastewater"	6.4	449	357	noticeable coffee odor	brown, turbid, organic material floating on top
Paper membrane filtration	6.7	448	348	noticeable coffee odor	brown, a little less turbid, no large pieces of organic material
Activated charcoal + paper membrane filtration	6.6	217	173	coffee odor very slight or absent	clearer than untreated, less color
Coagulation	6.5	414	700	noticeable coffee odor	extremely turbid, cloudy
Coagulation + paper membrane filtration	6.6	460	300	noticeable coffee odor	clearer than untreated, but not as clear as activated charcoal filtered
Sedimentation	6.4	401	409	noticeable coffee odor	looked a lot like the untreated water, but had more large insoluble pieces sitting on the bottom

1. ☐ Compare the data obtained from your designed water treatment system with the data collected in Part 1 and complete the "Best Individual Test System" row in Table 2.

2. ☐ Share the data from your designed water treatment system with those collected by classmates and then complete the "Best Designed System in the Class" row in Table 2.

Table 2: Results of the designed water filtration systems

Water Treatment Data Set	pH	Conductivity (µS/cm)	Turbidity (NTU)	Odor	Appearance (Color, Transparency, Other Observations
My designed treatment system	6.6	235	15	Not detectable	clear, slight tint of brown
Best individual test system (from Part 1)	6.6	217	103	Very slight	somewhat turbid, slight tint of brown
Best designed system in the class					

Analysis Questions

1. Compare your predictions with your results. Which result surprised you the most?

Answers will vary, but students should include reference to their test results.

2. What was the effect of filtration using a paper membrane?

Membrane filtration using paper filters removed only the large, medium, and somewhat small suspended material.

3. What was the effect of treatment with the activated charcoal and membrane filtration?

Membrane filtration through a layer of activated charcoal worked the best of all the treatments, but it was also the slowest. Most of the coffee odor was removed as was some of the color. Additionally, some of the conductivity and turbidity was removed.

4. What was the effect of treatment with a coagulating agent? What was the effect of coagulation and paper membrane filtration?

Treatment with a coagulating agent caused the solution to become cloudy and even more turbid than before. Conductivity and pH did not seem to be affected much.

After filtering, the filtrate was somewhat clearer than the untreated sample, but not as clear as the activated charcoal–paper membrane filtered sample. There did not seem to be a reduction in the odor.

5. What was the effect of treatment with sedimentation?

Sedimentation for 30 minutes had a limited effect, with only the largest pieces settling out. If the water was filtered first before the sedimentation step and then allowed to sit for a day, the results would probably improve.

6. What quality of water is measured with the conductivity sensor?

Conductivity is a measurement of the ability to conduct electricity. In water, it is a measure of the concentration of ions and can be roughly related to total dissolved solids (TDS) measurement, which is much more cumbersome to perform. Total dissolved solids (mg/L) can be estimated from its conductivity (µS/cm) by dividing the conductivity measurement by 2.

7. Which treatment method worked best for odors?

The treatment that worked best for odors was filtration through the activated charcoal–paper membrane.

8. Which treatment worked best for removing turbidity? Which was least effective?

The treatment that worked best for removing turbidity was filtration through the activated charcoal–paper membrane. Sedimentation was the least effective treatment.

9. What was the effect of the various treatments on pH?

In this example, all of the treatments raised the pH slightly.

10. Compare the results obtained with your custom-designed filtration process to those you got with the individual filter media. Be sure to make comparisons regarding the rate of filtration. (Why might this be important?)

An example: My custom-designed filtration process worked better than any of the individual processes alone. Most notably, the filtrate was much clearer than for any of the other processes. However, I noticed that my designed filtration technique was slow, much like the activated charcoal–paper membrane filtration process. This is important because water treatment facilities have to treat huge amounts of water in a short period of time. Some way would have to be found to speed up this process if it were to be used on a large scale.

11. Based on your results and those of your classmates, which combination of treatments produced the best results? Explain, using your data to support.

The best combination is likely to include coagulation and filtration through an activated charcoal filter. Student data should be included in the answer.

12. How did your class's best design measure up to the United States Environmental Protection Agency's Drinking Water Standards? Describe one way you might improve your system or the evaluation of your system.

The United States Environmental Protection Agency's Drinking Water Standards specify the following maximum contamination levels for the parameters you measured:

- pH: 6.5 to 8.5
- Conductivity: total dissolved solids, 500 mg/L (which corresponds to a conductivity of approximately 1000 µS/cm)
- Turbidity: 1 NTU
- Odor: 3 threshold odor number (a threshold odor number is defined as the greatest number of dilutions of a sample with "odor-free" water yielding a definitely perceptible odor)

For this example, the designed system met the requirements for pH and conductivity, it was close to meeting the requirement for turbidity, but it was not determined whether the odor requirement was met. To improve the testing procedure, an evaluation test for odor that includes determining the threshold odor number should be included.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What are some differences between water treatment for human consumption compared with wastewater treatment for discharge into the environment?

Water treated for human consumption has to be disinfected. For this purpose, chlorine or a chemical that chlorinates is added to drinking water. Chlorine may not be added to wastewater unless coliform bacteria persist after the treatment process.

Water that is being treated for human consumption cannot be turbid, but some turbidity is allowed for wastewater.

Wastewater may be held in holding tanks and treated with decomposers, such as certain types of bacteria.

Wastewater undergoes more sedimentation treatment, with the sediment (sludge) being hauled to landfills or being used for some purpose.

Wastewater may be filtered through organic filters like a natural estuary.

Odors are not monitored for wastewater.

2. What treatment methods would you include if you had to design a wastewater treatment system that resulted in drinking water? Explain.

Students should incorporate the data they collected in this activity into their reasoning. Answers should also demonstrate that students have read about and understand water treatment processes.

Multiple Choice Questions

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

1. The main purpose of sewage treatment is to:

- **A.** Kill pathogenic bacteria and reduce odor
- **B. Remove biodegradable materials from the water and to kill pathogenic bacteria**
- **C.** Kill pathogenic bacteria and remove plant nutrients
- **D.** Kill pathogenic bacteria, remove biodegradable materials, and make the water safe for human use
- **E.** None of the above

2. The main purpose of drinking water treatment is to:

- **A.** Kill pathogenic bacteria and reduce odor
- **B.** Remove biodegradable materials from the water and kill pathogenic bacteria
- **C.** Kill pathogenic bacteria and remove plant nutrients
- **D. Kill pathogenic bacteria, remove biodegradable materials, and make the water safe for human use**
- **E.** None of the above

3. What factor is NOT generally included in treating water for human use?

- **A.** Cost effectiveness
- **B.** Killing microorganisms
- **C.** Removing suspended solids
- **D.** **Removing dissolved solids**
- **E.** A and C

Extended Inquiry Suggestions

Take a field trip to a local water treatment facility.

Invite an outreach person from a local water treatment facility to come to your classroom or interact via conference call to answer questions regarding the methodologies used for local water treatment as well as to discuss career opportunities in water treatment.

Have students research some current challenges in water treatment, such as how to economically remove salts from ocean or irrigation water, whether or not to add fluoride to drinking water, or what to do about new water contaminants, such as low levels of prescription drugs and pesticides, that are not removed by current methods.

Have students research global initiatives that seek to provide people in developing nations with safe, clean water systems. Use search terms such as water treatment, developing countries, and new technology to find information about treatment systems that have been recently designed to help worldwide purification of water. Discuss simple water treatment procedures and civil engineering strategies that can improve water quality and how these might be implemented.

22. Greenhouse Gases

Objectives

Determine the effect of a man-made organofluorine compound, a greenhouse gas, on the trapping of heat in an isolated system. During this investigation, students:

- Reproduce and study a greenhouse gas environment
- Describe the relationship between the type of gas in a system and its ability to absorb energy
- Consider the impact of human-made solutions to global warming and ozone-depletion

Procedural Overview

Students gain experience conducting the following procedure:

- Simulating a greenhouse gas environment using difluoroethane

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Fast-response temperature probe
- EcoChamber with stoppers
- Size 5 or 5 1/2 solid stoppers (2)
- Dark aquarium rocks or dark sand (approximately 200 g)
- Heating lamp
- Ring stand
- Balance (1 per class)
- Canned keyboard duster[1] (fresh)
- Heavy-duty tape

[1]The propellant difluoroethane used in store-bought keyboard dusters is the greenhouse gas used to conduct this experiment. If you can find it, tetrafluoroethane may be found in one brand of duster and is ideal for this activity.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Atmospheric layers

- Atmospheric composition
- Greenhouse effect
- Greenhouse gases and their effect on global climate

Related Labs in This Guide

Labs conceptually related to this one include:

- Radiation Energy Transfer
- Air Pollution and Acid Rain

Using Your Data Collection System

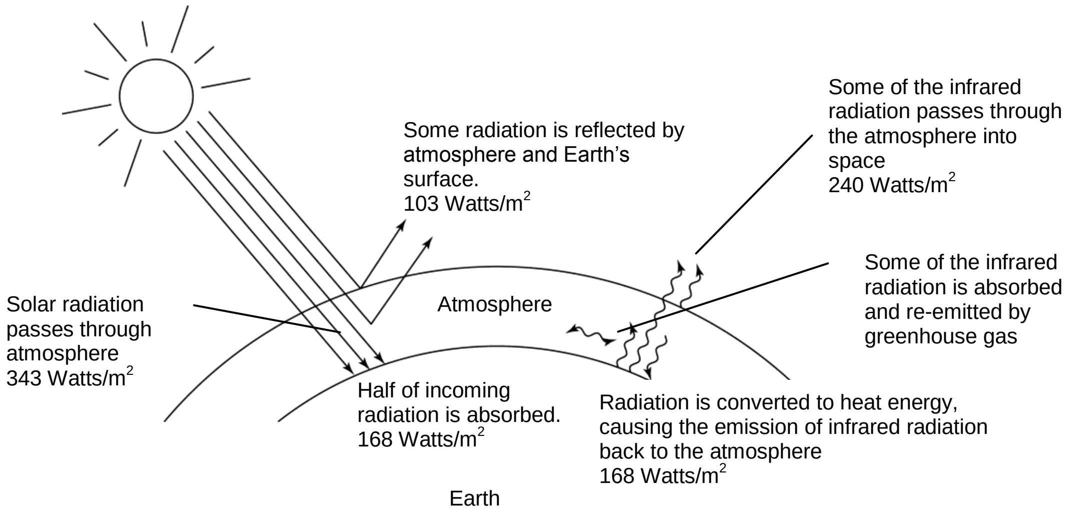
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions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

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to your 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 �(7.1.10)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

Greenhouse Gases Absorb Incoming Solar Radiation

Greenhouse gases are atmospheric gases that absorb heat energy radiated from Earth's surface, trapping the heat in the atmosphere. Solar radiation from the sun passes through the atmosphere and is partially absorbed by the earth's surface. That absorbed energy is converted to heat and is re-emitted by the ground in the form of long wavelength infrared energy (IR). Some of this radiation passes through the atmosphere and into space, while greenhouse gases absorb the remainder and re-radiate it, trapping heat in the atmosphere. This is called the greenhouse effect. Water vapor, carbon dioxide, methane, and ozone are examples of naturally occurring greenhouse gases, and are listed here in the order of their percent contribution to atmospheric warming. Carbon dioxide is especially effective at trapping heat, and the burning of fossil fuels, especially methane, produce more carbon dioxide and water as byproducts. However without greenhouse gases the Earth's climate would be extremely cold, dropping to temperatures that would be intolerable to most living organisms.



Many other types of greenhouse gases exist whose ability to trap heat in the atmosphere far exceeds carbon dioxide, methane, or water vapor. Chlorofluorocarbons (CFCs), for example, were used throughout the 20th century as a refrigerant and in common aerosol cans but were found to contribute heavily to ozone(O3) depletion by binding with oxygen atoms. In cases where CFCs were used as a propellant, they were replaced by difluoroethane and tetrafluoroethane. These compounds do not contribute to ozone-depletion, but they are efficient greenhouse gases.

Layers of Atmosphere

The layer of atmosphere closest to the Earth's surface is the troposphere. When rocks and water, even plant matter, is warmed by the sun, heat is radiated back into the troposphere throughout the day and into the night. The greater the surface's ability to absorb radiant energy, the greater is its ability to warm the troposphere. Climate is moderated by this process.

Above the troposphere is the stratosphere, which contains the ozone layer. Ozone serves to reflect short wavelength radiant solar energy. Ozone also is a greenhouse gas, helping to trap IR energy in the atmosphere, but ozone can be depleted by CFC's. Scientists study the ozone layer carefully to see if man-made propellants are diminishing ozone. Beyond this layer is the mesosphere and finally the thermosphere, neither of which are affected directly by greenhouse gases.

Ozone-Depletion versus Global Warming Potential

Ozone-depletion and global climate change are two very distinct and different issues. Concerns over ozone-depletion are almost entirely biological and are directed at the effect of decreased protection against cancer-causing UV rays and decreased health of the Arctic environment rather than any increase in global temperatures. Gases that contribute to ozone depletion are rated for their Ozone Depletion Potential (ODP). The ODP of difluoroethane is 0.065, whereas the ODP of CFC's is between 1 and 0.6, which is 60 to 100 times greater than difluoroethane.

While one compound may be a greenhouse gas, it may not also be an ozone-depleting gas and vice versa. The latter is true in the case of tetra- and difluoroethane. Neither of these compounds have the ozone-depletion potential of CFCs, but their ability to trap heat in the atmosphere far exceeds that of carbon dioxide, with difluorethane having a global warming potential (GWP) of 122 ± 43 and tetrafluoroethane having a GWP of 1420 ±490, according to the Intergovernmental Panel on Climate Change (IPCC 1995). The global warming potential (GWP) of a compound is its estimated contribution to global warming, relative to a scale that compares that compound to carbon dioxide (whose GWP is 1 by definition). NOAA (National Oceanic and Atmospheric Administration) estimates that global surface temperatures have risen between 0.5 °C and 0.9 °C during the 20th century, and in the last 50 years there has been an increase of 0.13 °C per decade. These increases are small but they are significant.

Pre-Lab Discussion and Activity

Discuss greenhouse gases and the greenhouse effect with students. A diagram of the layers of the atmosphere and Earth's Energy Budget would be useful for this discussion. Ask the following questions:

1. Explain how the greenhouse effect works. How does the global climate benefit from this process?

Solar radiation from the sun passes through the atmosphere and is partially absorbed by the earth's surface. This radiant energy is converted to heat and is re-emitted to the atmosphere as long wave radiation. Some of this radiation passes through the atmosphere and into space, while greenhouse gases, such as carbon dioxide and methane, absorb the remainder and re-emit it, trapping heat in the atmosphere. Without this process, all of the heat from the sun's rays would be lost to space, and the earth's climate would be far too cold to sustain life.

2. A system in science includes all the contributing elements that interact to produce the effect being studied. Define what is in the "system" of the artificial greenhouse we are creating in this lab.

The system for this experiment includes the EcoChamber and all its parts and the nonliving elements we are adding to the EcoChamber including the air and rocks. The system will be defined because it will not be open to the surrounding environment. Any heat loss through the walls of the chambers will be negligible and will be the same for both tests.

3. Why are rocks being added to the system?

Rocks are being added to the system to simulate the Earth's surface that absorbs the sun's energy (in this case, the lamp) and re-emits this energy to help warm the air.

4. How will a loose seal affect your data?

A loose seal will cause the difluoroethane to leak from the experimental chamber and, depending on the size of the leak, will cause the data to look increasingly more like the control chamber.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

- Pressurized cans of difluoroethane can become very cold, especially when inverted, and may burn your hands or even cause frostbite if propellant is continually released for long periods of time. Activate the can in short bursts only. Hold the can upright, and do not shake the can.

- Inhaling excessive concentrations of difluoroethane causes dizziness and can be fatal. Avoid direct inhalation. In addition, it is flammable. Use in a well-ventilated area and follow all safety precautions printed on the can.

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	5
Seal off all remaining holes in the Ecochamber with stoppers and heavy duty tape.	Set up the EcoChamber and insert one fast-response temperature probe into one hole on the top of the chamber.	Collect data for 5 minutes of heating and 5 minutes of cooling.	Introduce the tetrafluoroethane into the chamber and reseal it tightly.	Collect data again for 5 minutes of heating and 5 minutes of cooling. Compare your 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.

Part 1 – Control

Set Up

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

2. ☐ Set up the EcoChamber as indicated in the following steps.

3. ☐ Place 3 flat stoppers into the holes on the top of each EcoChamber. These stoppers have small holes to accommodate the temperature sensor. Plug two of these holes with the small rubber dowels.

4. ☐ Thread the temperature sensor through the hole in the last stopper on the lid of the chamber. Pull the temperature sensor through the stopper until the sensor hangs down approximately halfway in the chamber.

5. ☐ Once the temperature sensor is in place, cover the hole with heavy-duty tape.

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

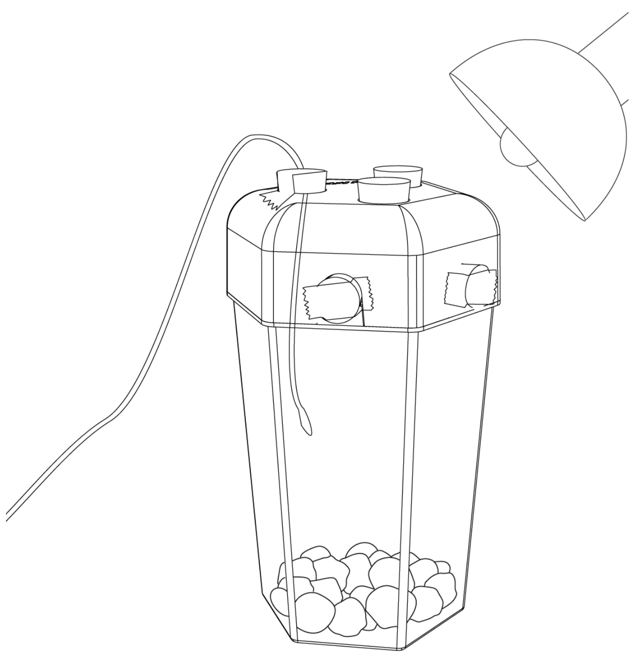
7. ☐ Measure out approximately 200 grams of aquarium rocks or enough to cover the bottom of each chamber. Place these in the chamber.

8. ☐ Place the lid on the chamber, and stopper the holes on the sides of the chamber with solid stoppers (size 5 or 5 1/2 will work). If the stoppers are not solid, cover them with heavy-duty tape to ensure a good seal.

9. ☐ Why do you think the holes in the sides need to be sealed, as well as the extra hole in the top?

Stopper all holes to make the system inside the chamber a closed system. Then all effects will be related to changes in the system, not changes from outside the system.

10. ☐ Position the heating lamp so that it will shine on the chamber, angled slightly downward to increase the amount of solar radiation hitting the rocks. Do not turn the light on yet.



Collect Data

11. ☐ Display Temperature on the y-axis of a graph with Time on the x-axis. �(7.1.10)

12. ☐ Turn on the lamp and begin recording data. �(6.2)

13. ☐ After 5 minutes, turn the lamp off and continue to record data for 5 minutes more.

14. ☐ Stop recording data. �(6.2)

15. ☐ Adjust the scale of the graph. �(7.1.2)

Part 2 – Experiment

Set Up

16. ☐ Open the EcoChamber and allow it to cool completely. You may want to replace the rocks with room temperature rocks, but use the same mass of rocks as you did before.

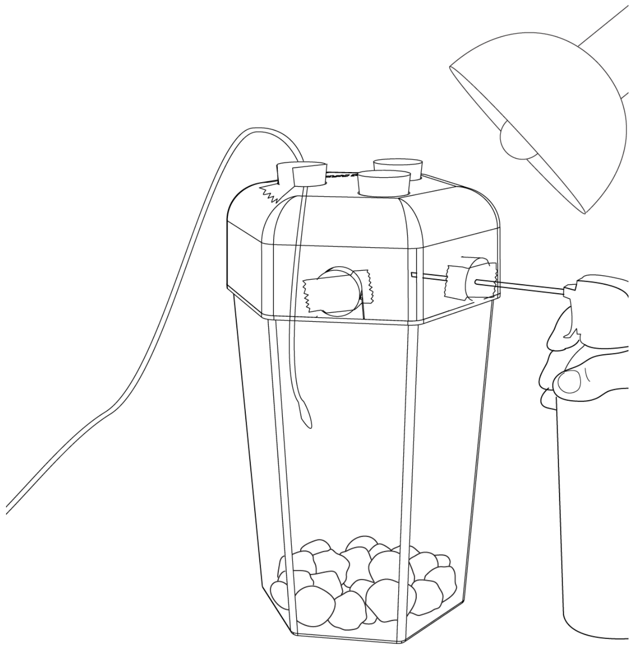
17. ☐ If you decide to replace the rocks, why is it necessary to use the same amount of rocks as you used the first time?

You want to control all the variables. More rocks than before could change the amount of radiated heat inside the chamber .

18. ☐ Replace the lid on the EcoChamber. Ensure that the temperature probe is hanging as it was in the first trial, and that the lamp and the chamber are positioned exactly as they were in the first trial.

19. ☐ Place the plastic straw that accompanies the keyboard duster into the nozzle of the can. Do not shake the can. When the trigger is pulled, the propellant should leave the can in a steady, concentrated stream.

20. ☐ Peel back the tape on the rubber stopper on the side of the chamber and place the straw of the keyboard duster into the hole. Fill the chamber with difluoroethane by pulling the trigger on the can in a series of short bursts. Keep the can upright while dispensing.



21. ☐ Begin recording data without turning on the lamp �(6.2) and continue to dispense the difluoroethane in short bursts.

22. ☐ Watch the data carefully. Once the temperature inside the chamber is below the starting temperature of the control run, stop dispensing difluoroethane.

23. ☐ Remove the straw and immediately plug the hole.

24. ☐ Watch the temperature on the graph. When the temperature is 2 to 3 degrees below the starting point of the first run, stop recording data. �(6.2)

25. ☐ Why is it necessary to wait for the experimental chamber to reach room temperature, or at least the same temperature as the control chamber?

It is necessary for the chambers to start out at approximately the same temperature to eliminate the variable of different starting temperatures as a cause of the final effect we will see.

26. ☐ Hide this last run of data. �(7.1.7) You will not need it.

Collect Data

27. ☐ Turn on the light and begin data recording. �(6.2)

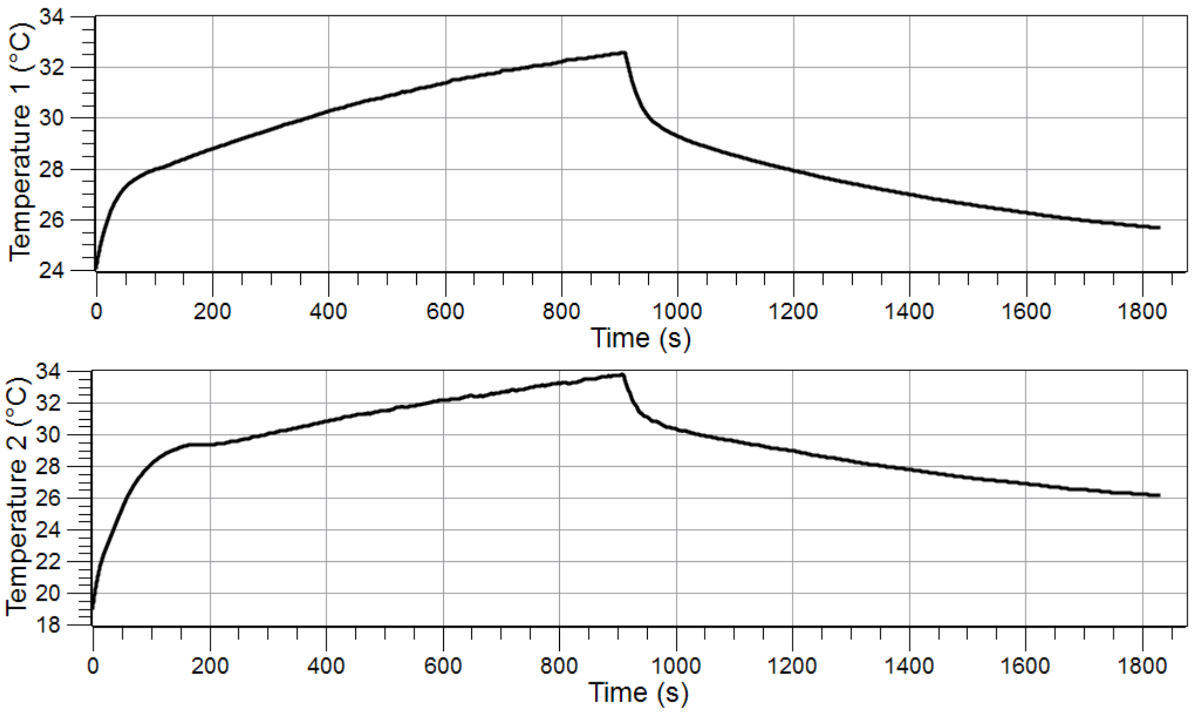
28. ☐ Collect data for 5 minutes under the lamp. Then, turn off the light and continue to collect data for an additional 5 minutes while the chamber cools.

29. ☐ Stop data recording. �(6.2)

30. ☐ Adjust the scale of the graphs if necessary. �(7.1.2)

31. ☐ Save your experiment. �(11.1)

Sample Data



Data Analysis

1. ☐ Find the initial, final, maximum, and change in temperature for both chambers �(9.1) and enter this data in Table 1.

Table 1: Temperature data

Chamber	Initial Temp. °C	Maximum Temp. °C	Increase in Temp. °C	Final Temp.	Change in Temp.
Control (air)	24.2	27.2	3.0	26.3	2.1
Experimental (difluoroethane)	24.0	28.6	4.6	27.1	3.1

2. ☐ What is the change in temperature for the heat gain in both cases after the light was turned on?

The Control gained 3.0°C while the Experimental gained 4.6°C.

3. ☐ What was the change in temperature for the heat loss in both cases after the light was turned off?

The Control lost 0.9°C while the Experimental lost 1.5°C .

4. ☐ Which system retained heat longer? How do you know?

The experimental chamber retained heat longer, not just because it ended up hotter than the control tank, but because its change in temperature from the maximum temperature to the final temperature is greater than that for the control tank.

5. ☐ How did the change in temperature from initial to final temperature for the experimental run compare to the change in temperature for the control run?

The change in temperature in the experimental chamber was1.5 times greater than that of the control chamber.

Analysis Questions

1. How significant are the differences that you observed in heat retention and maximum temperature?

The differences are significant when considering that even though we are studying a small volume of air, the change occurs relatively quickly.

2. In analyzing this data, which of the following is more valuable to compare: the overall change in temperature, the heating change in temperature, the cooling change in temperature, or the difference in maximum temperatures? Explain your reasoning.

Student responses to this question can vary. However, they should reference controls. For example, if you compare the difference in maximum temperatures, are the starting temperatures the same? Probably the differences between the heating rates and the cooling rates are the most valuable data.

3. In what ways can you use the results from this demonstration to predict the effects of this gas on the atmosphere?

We may predict that this type of gas, when included in the atmosphere, can trap heat as it did inside this chamber. Therefore it would be a greenhouse gas.

4. In what ways does this demonstration fail to predict what effect this gas would have on the atmosphere?

We cannot know from this demonstration the volume of difluoroethane that would be detrimental in the atmosphere.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Considering the severity of the IR absorption of the difluoroethane and its increased ability to trap heat, why are scientists so concerned about carbon dioxide and not gases like difluoroethane and other man-made gases?

Difluoroethane lingers in the atmosphere at such trace amounts that its concentration is an insignificant contributor to the greenhouse gas effect on a global scale. Carbon dioxide exists in the atmosphere at 384 ppm by volume (approximately 0.0384% by volume), compared to nitrogen, which comprises approximately 78% of the atmosphere. Though this volume may not sound significant compared to that of nitrogen, the concentration of difluoroethane is even more insignificant at approximately 0.000049 ppm by volume (as of 07/2009: the Carbon Dioxide Information Analysis Center)). Additionally, sources of carbon dioxide are abundant whereas sources of difluoroethane are limited to electronic dusters and insecticides.

2. In some cases, one solution to an environmental problem can result in another environmental problem. In this case, ozone-depleting chlorofluorocarbons (CFCs) were replaced by tetrafluoroethane, which contributes to global warming. What are some ways to avoid this situation?

Answers will vary. Many students may suggest greener industrial practices to avoid or minimize the use of ozone-depleting compounds and greenhouse gases. Some students may suggest that the need for these chemicals is assessed more closely to determine how necessary they are and what alternatives exist. If it is found that these compounds are absolutely necessary, then other greenhouse gas concentrations must be more strictly regulated to allow for the limited use of CFCs.

3. At your home, examine canisters and other sources of propellants to see what, if any, greenhouse gases discussed in this lab may be contained within those canisters. Make a list of the products here, and the propellants they contain.

Students may list such products as hair spray, bug spray, cooking oil spray, or spray paint, not all of which contain harmful propellants. Constructing a classroom list of harmful and non-harmful products may be enlightening for students.

Multiple Choice Questions

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

1. Which of the following is NOT true of chlorofluorocarbons (CFCs)?

- **A.** CFCs were commonly used as propellants and refrigerants.
- **B.** **CFCs are extremely toxic and harmful to human health.**
- **C.** CFCs cause ozone-depletion and contribute to the growing of the hole in the ozone layer.
- **D.** CFCs are greenhouse gases associated with increased global warming trends.
- **E.** All of the above are true.

2. Atmospheric pollution affects which area(s) of the atmosphere?

- **A.** Mesosphere
- **B.** Stratosphere
- **C.** Troposphere
- **D.** Ionosphere
- **E.** **B and C**

3. What makes a gas an ozone-depleting gas?

- **A.** The gas will re-radiate longwave infrared energy into the ozone.
- **B.** The gas will absorb ozone molecules.
- **C.** **The gas will bind with one of the oxygen atoms in the molecule, reducing it to O_2.**
- **D.** Ozone-depletion only occurs when temperatures rise and the atmosphere warms up.
- **E.** Any gas can become an ozone-depleting gas if there is enough of it.

4. What is the main cause of atmospheric warming from greenhouse gases?

- **A.** Greenhouse gases usually have a high specific heat and get very hot.
- **B.** Greenhouse gases make the atmosphere much thicker and more polluted, so they trap the sun's direct rays and warm the air.
- **C.** Greenhouse gases absorb and re-emit IR waves that enter the atmosphere from the sun.
- **D.** **Greenhouse gases absorb and re-emit IR waves that are radiated from Earth's surfaces.**
- **E.** None of the above are true.

5. Why is difluoroethane used in place of chlorofluorocarbons today as a propellant?

- **A.** Difluoroethane is much less of an ozone-depleter than chlorofluorocarbons.
- **B.** Difluoroethane is much less of a greenhouse gas than chlorofluorocarbons.
- **C.** Even though difluoroethane is more of a greenhouse gas, it was chosen because it is less of an ozone-depleter than chlorofluorocarbons.
- **D.** All of the above are true.
- **E.** **Both A and C are true.**

Key Term Challenge

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

1. Carbon dioxide and methane are greenhouse gases – atmospheric gases that absorb reradiated energy from the earth's surface and trap heat in the atmosphere. Solar radiation from the sun passes through the **atmosphere** and is partially absorbed by the earth's surface. The heat that is absorbed by the ground is radiated to the atmosphere in the form of **longwave** radiation (IR), It is this longwave **radiant** energy that greenhouse gases can trap and re-emit to **warm** the atmosphere even further.

2. Many other types of greenhouse gases exists whose ability to trap heat in the atmosphere far exceeds **carbon dioxide**, **methane**, or **water vapor**. Chlorofluorocarbons, for example, were used throughout the 20th century as refrigerants and in common **aerosol** cans but were found to contribute heavily to ozone-depletion. In cases where CFCs were used as a propellant, they were replaced by **difluoroethane** and tetrafluoroethane.

3. It is possible that a compound may be a greenhouse gas, without actually depleting the **ozone** layer as badly as CFC's. This is true for **tetrafluoroethane** and difluoroethane. Neither of these compounds have the ozone-depletion potential of CFCs, but their ability to trap **heat** in the atmosphere far exceeds that of carbon dioxide, with **difluorethane** having a global warming potential **(GWP)** of 1800. The global warming potential of a compound is its estimated **contribution** to global warming. Many other types of greenhouse gases have a GWP greater than that of **carbon dioxide**, but they are available in such **small** quantities that they are not considered an immediate **threat** to global warming.

Extended Inquiry Suggestions

Consider running this experiment with carbon dioxide in the control chamber and discuss the results as they pertain to greenhouse gas efficiency. If available, dry ice can be used as it eliminates the introduction of water vapor into the system. If dry ice is not available, a CO_2 canister, such as those used with small bike pumps, can also be used.