Biology through Inquiry

Teacher Guide

PASCO®

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Biology through Inquiry

High School

Teacher Guide

21st Century Science

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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 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	**Enzyme Action** Use an oxygen gas sensor to understand how optimal environmental conditions, such as temperature, play a key role in enzyme function.	Data Collection System	1
		PASPORT Oxygen Gas Sensor	1
		Beaker, 1-L	2
		Beaker, 500-mL	1
		Catalase Source/Yeast Suspension	30 mL
		Distilled water	500 mL
		Graduated cylinder, 25-mL	1
		Hydrogen Peroxide, 3%	30 mL
		Warm water bath	1 L
		Sampling bottle (provided with the sensor)	1
		Test tube	2
		Tongs	1
		Water	500 mL
2	**Membrane Permeability** Use a pH sensor to explore the permeability of a cell-like membrane to hydrogen (H^+) and hydroxide (OH^-) ions. Observe that not all materials are able to pass through the membrane.	Data Collection System	1
		PASPORT pH Sensor	1
		0.1 M hydrochloric acid (HCl),15 mL	15 mL
		0.1 M sodium hydroxide (NaOH)	15 mL
		Beaker, 250-mL	1
		Binder clip	1
		Dialysis tubing, 15-cm length	2
		Distilled water	1 L
		Large Base and Support Rod	1
		Lugol's iodine	3 mL
		Magnetic Stirrer and Magnetic Spin Bar	1
		Starch solution	50 mL
		String	50 cm
		Utility clamp	2
		Wash bottle	1

Lab	Title	Materials and Equipment	Qty
3	**Organisms and pH** Use a pH sensor to determine how effective various substances are at buffering large changes in pH.	Data Collection System PASPORT pH Sensor *Beaker , 50-mL* *Beaker, 250-mL* *Erlenmeyer flask 1-L* *Graduated cylinder, 10-mL* *Disposable pipets* *Detergent solution* *Lemon juice* *Distilled water* *Liver suspension* *Buffer solution*	1 1 6 1 2 1 2 15 mL 15 mL 1 L 50 mL 50 mL
4	**Osmosis** Use a barometer/low pressure sensor to explore the concept of cell membranes and how water and other substances pass through a membrane through the process of osmosis.	Data Collection System PASPORT Barometer/low pressure Sensor (w/ Quick-Release Connector) PASPORT Sensor Extension Cable *Beaker, 100-mL* *Beaker, 400-mL* *Dialysis tubing ,15 cm* *Distilled water* *Electronic Balance* *Funnel* *Graduated cylinder, 10-mL* *Graduated cylinder, 50-mL* *Paper towels* *Plastic tubing, 5 cm* *Ring Stand with Test Tube or Three Finger Clamp* *Syrup (maple or corn)* *Thread (or dental floss) to tie dialysis tubing*	1 1 1 2 1 2 1 L 1 1 1 1 3 or 4 1 1 10 mL 1
5	**Plant Respiration and Photosynthesis** Use a carbon dioxide gas sensor to understand the comparative concentrations of CO_2 gas for a small plant in darkness and in bright light and what this says about photosynthesis and the CO_2 cycle.	Data Collection System PASPORT Carbon Dioxide Gas Sensor PASPORT Sensor Extension Cable Sampling Bottle (included with sensor) *Aluminum foil* *Lamp, 100-watt (or equivalent)* *Fresh spinach leaf*	1 1 1 1 foot 1 1 1
6	**Respiration of Germinating Seeds** Use a carbon dioxide gas sensor to understand the comparative rates of CO_2 gas production for dry, dormant seeds; for wet, germinating seeds at room temperature; and for wet, cold, germinating seeds.	Data Collection System PASPORT Carbon Dioxide Gas Sensor PASPORT Sensor Extension Cable *Beaker, 1000-mL* *Ice, cubed or crushed* *Dry beans* Sampling bottle (included with sensor) *Water*	1 1 1 1 1 L 150 1 1 L

Lab	Title	Materials and Equipment	Qty
7	**The Role of Buffers in Biological Systems** Use a pH sensor to determine which solution is the best buffer.	Data Collection System PASPORT pH Sensor *Beaker, 250 mL* *Club soda* *Distilled water* *Graduated cylinder (10 mL)* *Large Base and Support Rod* *Magnetic Stirrer and Magnetic Spin Bar* *Utility Clamp* *Vinegar, 5% acetic acid* *Wash bottle*	1 1 3 200 mL 1 L 1 1 1 1 20 mL 1
8	**Acid Rain** Use a pH sensor to determine the effect of two gases that cause acid rain on the pH of water. Prepare "acid rain" and monitor plant growth.	Data Collection System PASPORT pH Sensor *Graduated cylinder, 25-mL* *Small beaker or disposable cup with $NaHCO_3$*[2] *Small beaker or cup, 100-mL* *Beaker, 500-mL* *Storage containers for "acid rain"* *1-mL plastic pipets* *1-mL plastic pipet, cut* *0.025 M Sulfuric acid (H_2SO_4)* *Distilled water* *Vinegar* *Sodium bicarbonate ($NaHCO_3$)* *Sodium bisulfite ($NaHSO_3$)* *Water or deionized water* *Small Plants*	1 1 1 1 1 1 2 2 1 100 mL 50 mL 10 mL 5 g 5 g 60 mL 2
9	**Cellular Respiration in Yeast** Use a dissolved oxygen sensor to measure the dissolved oxygen concentration in yeast solutions in the presence and absence of sugar. Calculate the rate of oxygen consumption of yeast during aerobic cellular respiration at different temperatures.	Data Collection System PASPORT Dissolved Oxygen Sensor PASPORT Fast Response Temperature Sensor *Activated Yeast Solution* *Beaker, 250-mL* *Distilled water* *Electronic Balance* *Graduated cylinder, 25mL* Hot Plate *Ice bath (1-L Beaker filled with ice)* *Labeling tape* *Marker* *Stirring rod* *Sugar* *Weighing papers*	1 1 1 45 mL 3 1 L 1 1 1 1 1 roll 1 1 30 g 3

Lab	Title	Materials and Equipment	Qty
10	**Energy Content of Food** Use a temperature sensor to measure the change in temperature of water that is heated by burning samples of food and to compare the energy content of those samples.	Data Collection System PASPORT Temperature Sensor PASPORT Sensor Extension Cable *Aluminum can, 354-mL (12 ounce)* *Distilled water* *Electronic Balance* *Food holder (10 x 10 cm cardboard, aluminum foil, paperclips)* *Food sample* *Graduated Cylinder, 100-mL* Large Base and Support Rod *Matches* *Wood Splint*	1 1 1 1 100 mL 1 1 2 1 1 1 book 4
11	**Exploring Microclimates** Use a weather anemometer sensor and current local weather conditions to measure relevant weather conditions at different locations. Determine the impact that a location's environmental conditions have on the microclimate of a given area.	Data Collection System PASPORT Weather Anemometer Sensor (or PASPORT Weather Sensor) PASPORT Sensor Extension Cable *Cardboard box (or other covering)*	1 1 1 1
12	**Exploring Microclimates Through Temperature** Use a temperature sensor and current local weather conditions to measure relevant weather conditions at different locations. Determine the impact that a location's environmental conditions have on the microclimate of a given area.	Data Collection System PASPORT Temperature Sensor	1 1
13	**Metabolism of Yeast** Use a carbon dioxide gas sensor to measure the production of carbon dioxide gas by yeast in aerobic and anaerobic conditions. Determine if high temperatures effect the respiration of yeast.	Data Collection System PASPORT Carbon Dioxide Gas Sensor PASPORT Sensor Extension Cable *Beaker, 250-mL* *Graduated cylinder 10-mL* *Graduated cylinder, 100-mL* *Grape juice* *Hot Plate* *Mineral oil* Sampling bottle (included with sensor) *Stirring rod* *Water* *Yeast, dry*	1 1 2 1 1 150 mL 1 5 mL 1 1 1 L 1 package

Lab	Title	Materials and Equipment	Qty
14	**Rate of Photosynthesis of an Aquatic Plant** Use a dissolved oxygen sensor to understand the amount of oxygen produced through photosynthesis in an aquatic plant in ambient light, bright light and darkness.	Data Collection System PASPORT Dissolved Oxygen Sensor PASPORT Fast Response Temperature Sensor *Cloth, heavy, about 50-cm by 50-cm* *Elodea* *Lamp, 100 W (or equivalent)* *Magnetic Stirrer and Magnetic Stir Bar* Photosynthesis Tank or similar setup *Rubber stopper, #3* *Water*	1 1 1 1 5 or 6 1 1 1 1 2 L
15	**Soil pH** Use a pH sensor to understand what kinds of soil in the local community would support agricultural crops, based on pH level.	Data Collection System PASPORT pH Sensor PASPORT Sensor Extension Cable *Beaker, 250-mL* *Digging device* *Distilled water* *Graduated cylinder, 100-mL* *Marking pen* *Measuring spoons* *Paper towels* *Sealable plastic bag* *Soil sample, 60 mL* *Stirring rod* *Wash bottle*	1 1 1 3 1 400 mL 1 1 1 set 3 or 4 3 3 1 1
16	**Transpiration** Use a barometer/low pressure sensor to explore the effects of environmental factors such as air movement on the rate of transpiration.	Data Collection System PASPORT Barometer/Low Pressure Sensor PASPORT Sensor Extension Cable *Bowl* *Fan* *Glycerin* *Knife* *Large Base and Support Rod* *Petroleum jelly* *Pipet* *Plant seedling, 12 to 15 cm tall* *Three-Finger Clamp* *Utility Clamp* *Water*	1 1 1 1 1 1 mL 1 1 2 to 3 g 1 1 1 1 1 L

Lab	Title	Materials and Equipment	Qty
17	**Water and pH** Use pH and conductivity sensors to analyze the differences in how water pH changes when "acid rain" is added.	Data Collection System PASPORT pH Sensor PASPORT Conductivity Sensor *Beaker, 250-mL* *Distilled water* *Graduated cylinder, 100-mL* *Labels* *Marking pen* *Pipet* *Small container (for diluted vinegar solution)* *Stirring rod* *Water sample, 250 mL* *White vinegar*	1 1 1 4 250 mL 1 6 1 1 1 1 3 250 mL
18	**Water Purification** Use a pH sensor to understand the effectiveness of various treatments for improving the quality of water.	Data Collection System PASPORT pH Sensor PASPORT Conductivity Sensor *Beaker, 250-mL* *Coffee filter* *Distilled water* *Egg whites* *Erlenmeyer flask, 250-mL* *Funnel* *Polluted water* *Stirring rod*	1 1 1 2 2 500 mL 5 mL 1 1 1 L 1
19	**Weather in a Terrarium** Use a weather anemometer sensor in the microclimate of a terrarium to understand changes in temperature, absolute and relative humidity, dew point, and barometric pressure.	Data Collection System PASPORT Weather Anemometer Sensor PASPORT Sensor Extension Cable *Small box or other support* *Terrarium (or suitable alternative)*	1 1 1 1 1
20	**EKG and Factors that Affect the Heart** Use an EKG sensor to measure and observe the electrical activity of the heart muscle.	Data Collection System PASPORT EKG Sensor *Electrode patches (included with sensor)*	1 1 3
21	**Exercise and Heart Rate** Use a heart rate sensor to monitor the effect of physical exertion in relation to level of fitness. Determine the average heart rate before, during, and after exercise.	Data Collection System PASPORT Hand Grip Heart Rate Sensor	1 1
22	**Exercise and Respiration Rate** Use a breath rate sensor to measure the resting respiration rates of individuals and determine whether exercise causes a change in respiration rate.	Data Collection System PASPORT Breath Rate Sensor	1 1

Lab	Title	Materials and Equipment	Qty
23	**Muscle Fatigue** Use a force sensor to determine grip strength and compare muscle fatigue in hand muscles caused by isotonic ("same tension") and isometric ("same length") exercise.	Data Collection System PASPORT Force Sensor *Rubber ball, tennis ball, or equivalent (approximately 7 cm diameter)* *Timer (stopwatch or equivalent)*	1 1 1 1
24	**Regulation of Body Heat*** Use a temperature sensor to understand the extent that external conditions, such as ice water, moving air, or wearing gloves, cause changes in skin temperature. * This activity requires 2 fast response temperature probes to be connected simultaneously. Please see the Lab Preparation section for details.	Data Collection System PASPORT Fast Response Temperature Probe *Fan* *Glove or mitten* *Ice, crushed or cube* *Large bowl (or similar container)* *Tape or adhesive covers* *Paper Towel* *Water*	1 2 1 1 1 L 1 2 pieces 5 to 6 1 L
25	**Volume of Breath** Use a spirometer to explore the pulmonary function test (PFT) and the volume of breath.	Data Collection System PASPORT Spirometer Spirometer Mouthpiece	1 1 1 per student

Calibration materials

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

pH Sensor

Item	Quantity	Where Used
Buffer solution, pH (4) Buffer solution, pH (10) Beaker, small Wash bottle with deionized or distilled water	25 mL 25 mL 3 1	3,7,8,15,17,18

Dissolved Oxygen Sensor

Item	Quantity	Where Used
Clean electrode storage bottle Distilled water	1 5 mL	9,14

Oxygen Gas Sensor

Item	Quantity	Where Used
Sampling Bottle (included with the sensor)	1	2

Carbon Dioxide Gas Sensor

Item	Quantity	Where Used
Sampling Bottle (included with the sensor)	1	6,5,13

Activity by PASCO Equipment

This list shows each item needed for the activities and where the item is used.

Items Available from PASCO	Qty	Where Used
PASPORT Carbon Dioxide Gas Sensor (with Sampling Bottle)	1	6,5,13
PASPORT Barometer/Low Pressure Sensor	1	4,16
PASPORT Oxygen Gas Sensor	1	1
PASPORT Fast Response Temperature Probe	1	9,14
PASPORT Hand Grip Heart Rate Sensor	1	21
PASPORT Sensor Extension Cable	1	4,6,5,11,12,16,10,13,19,15
PASPORT pH Sensor	1	3,2,7,8,15,17,18
PASPORT Temperature Sensor	1	11,10,24
PASPORT Dissolved Oxygen Sensor	1	9,14
PASPORT Conductivity Sensor	1	17,18
PASPORT Force Sensor	1	23
PASPORT Breath Rate Sensor	1	22
PASPORT EKG Sensor	1	20
PASPORT Weather Anemometer Sensor	1	11,12,19
PASPORT Spirometer	1	25
Spirometer Mouthpiece	1 per student	25
Photosynthesis Tank	1	14
MyWorld GIS ™	1	12
Quick Release Connector	1	4
Large Base and Support Rod	1	2,7,16,10
Magnetic Stirrer with Magnetic Stir Bar	1	2,7,14
Electronic Balance	1	4,8,10,9
Hot Plate	1	13,9
Three-Finger Clamp	1	4,16
Utility Clamp	1	2,7,16

*Either the PASPORT Fast Response Temperature Sensor or the 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 Biology through Inquiry 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.
- Keep water away from electrical outlets.
- Remember to wear protective equipment (e.g., 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 is 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 use a buddy system in case of trouble.
- 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 your eyes and wash your hands after handling. In case of skin exposure, wash it off with plenty of water.
- Always add acids and bases to water, not the other way around, as the solutions may boil vigorously.
- Diluting acids and bases creates heat; be extra careful when handling freshly prepared solutions and glassware, as they may be very hot.
- Handle concentrated acids and bases in a fume hood; the fumes are caustic and toxic.
- Wear eye protection, lab apron, and protective gloves when handling acids. Splash-proof goggles are recommended. Either latex or nitrile gloves are suitable. Use nitrile gloves if you have latex allergy.
- Read labels on all chemicals and pay particular attention to hazard icons and safety warnings.
- When handling any bacterial species, follow aseptic techniques.
- Wash your hands before and after a laboratory session.
- If any solution comes in contact with skin or eyes, rinse immediately with a copious amount of running water for a minimum of 15 minutes.
- Follow the teacher's instructions for disposing of chemicals.
- 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

Cell Biology

1. Enzyme Action

Objectives

This activity reinforces students' understanding that enzymes act as catalysts, speeding up chemical reactions. Students also collect evidence demonstrating that enzyme activity is influenced by temperature.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Using an oxygen gas sensor to measure the amount of oxygen released during the decomposition of hydrogen peroxide:

$$2H_2O_2 \xrightarrow{\text{catalase}} 2H_2O + O_2(\text{gas})$$

- ♦ Varying the temperature of the enzyme solution and determining whether the change in temperature has an effect on the rate of oxygen production.

Time Requirement

♦ Preparation time	24 hours in advance: 30 minutes Day of the activity: 30 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	40 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Oxygen gas sensor
- ♦ Sampling bottle[1]
- ♦ Test tube, 25-mL
- ♦ Graduated cylinder, 25-mL
- ♦ Hydrogen peroxide[3,] 1.5%, 60 mL
- ♦ Warm water bath, 35 °C to 40 °C (1 per class)
- ♦ Catalase[2], room temperature, 20 mL
- ♦ Catalase[2], boiled, 10 mL

[1] Included with the oxygen gas sensor.

[2] A yeast suspension is the source of the catalase. Refer to the Lab Preparation section.

[3] To formulate 1.5% hydrogen peroxide from 3% hydrogen peroxide, refer to the Lab Preparation section.

See the Pre-lab Discussion and Activity section for materials used in the pre-lab discussion demonstrations.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- General functions of enzymes
- The "lock and key" model of enzymes
- Optimal temperature ranges exist for living things
- Temperature is a measure of average kinetic energy
- Temperature affects the frequency of collisions between particles

Related Labs in This Guide

Labs conceptually related to this one include:

- Cellular Respiration in Yeast
- Organisms and pH
- Role of Buffers in Biological Systems
- Respiration of Germinating Seeds

Using Your Data Collection System

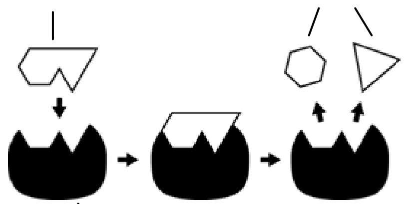
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions 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 an oxygen gas sensor �(3.5)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

Cells have to carry out many chemical reactions very quickly to sustain life. Proteins called "enzymes" are vital to this function. Enzymes act as catalysts. This means that enzymes increase the rate of the reaction. An organism's metabolism depends on thousands of different enzymes that help facilitate thousands of chemical reactions that regularly take place in a cell.

Enzymes are not consumed during the reaction, but they attach to the substrate (reactant) and help turn it into the final product. Once the final product is released from the enzyme, the enzyme can pick up additional substrate and catalyze another reaction. Enzymes are substrate-specific—only one type of molecule can fit into the active site of the enzyme. This model of enzyme function is known as the "lock and key model."



The lock and key model shows the importance of an enzyme's shape to its ability to speed up a reaction. The active site of the enzyme must be able to fit and bind to the substrate. An enzyme has an optimal temperature and pH at which it has maximum functionality. Outside of these optimum values, an enzyme's shape changes and it becomes less functional. (The specific folding and coiling of the amino acid chain is affected by these conditions.) A change in enzyme shape (called denaturing) results in a decrease in enzyme activity and, therefore, a slower reaction rate.

One example of an enzyme is lactase. Lactase catalyzes the breakdown of the disaccharide lactose (milk sugar) into the monosaccharides galactose and glucose. In order for lactose digestion to occur, lactase must be present and functioning properly. No other enzyme can do this job. People who are lactose intolerant don't produce enough functional lactase enzymes, and therefore cannot digest lactose.

Another example of an enzyme is catalase. (Many enzymes end with the letters "ase".) Catalase catalyzes (speeds up) the decomposition of hydrogen peroxide (H_2O_2). It is an important enzyme because hydrogen peroxide is a product of normal metabolism in cells, but it is toxic to a cell. It must be quickly changed into harmless substances. This change occurs rapidly in the presence of the catalase enzyme. Most living things have catalase in their cells. Sources of catalase commonly used in lab investigations are liver, potato, and yeast.

Pre-Lab Discussion and Activity

Teacher Tip: The first demonstration is best understood by students if they have some prior knowledge of disaccharides and monosaccharides. If they have no previous experience with this, it is probably best to skip to the second demonstration, "Decomposition of Hydrogen Peroxide".

Lactose Digestion

Demonstrate the lactase catalyzed reaction for students. Hold up a small beaker containing milk.

1. Does milk contain sugar? If so, what is the name of the sugar?

Yes, milk contains the sugar called lactose.

2. What molecules in your body help speed up the digestion of sugar and other food molecules?

Enzymes help the body digest food.

3. Some people are lactose "intolerant." What do you think this means?

Students are likely to say that this means the person cannot drink milk; the person cannot digest the sugar lactose. They might mention that if the person drinks milk, he or she will feel ill.

Show students a glucose test strip and explain what it does. Dip the strip into the beaker of milk. Show students that the result is negative (no glucose is present).

4. Why is the test result negative?

Milk contains only lactose sugar; it does not contain glucose as a sugar.

Show students a container of Lactaid® powder (any generic brand will also work). Explain that a person who is lactose intolerant can consume milk products if they also consume this powder. Dissolve a spoonful of Lactaid powder into the beaker of milk. Stir the sample for about 5 minutes. During this time, discuss the next few questions with students.

5. Predict what you think the powder does, so that it allows a lactose-intolerant person to consume milk products.

Answers will vary. Students may correctly predict that the powder helps break down the lactose, or helps the person digest the lactose present in milk.

6. Is lactose a monosaccharide, disaccharide, or polysaccharide? What is the basic structure of a lactose molecule?

Lactose is a disaccharide. It is composed of two linked sugars, galactose and glucose.

Draw or show a picture of lactose to students to help discuss the question above.

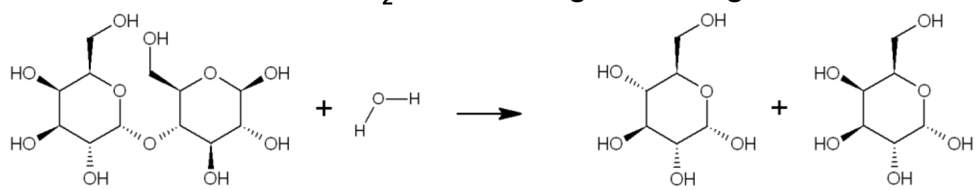
After 5 minutes of stirring the beaker of milk and Lactaid, dip a second glucose test strip into the beaker of milk. Show students that the result is positive (glucose is present).

7. Why is the test result positive? (Hint: Lactaid contains the enzyme lactase.)

The milk now contains glucose. Lactase enzymes in the powder assisted with breaking a chemical bond in lactose, producing glucose and galactose as products. (Digestion of lactose took place.)

Draw or show a picture of lactose digestion, like the one below. This will help students visualize the digestion reaction and help them understand the negative and positive glucose results seen in the demonstration.

$$\text{lactose} + H_2O \xrightarrow{\text{lactase}} \text{glucose} + \text{galactose}$$



Decomposition of Hydrogen Peroxide

Show students a bottle of hydrogen peroxide and ask them if they know what it is and what it is used for.

8. What substance is in the bottle? What are some common uses for this substance?

Students are likely to know that hydrogen peroxide is used to clean and disinfect cuts. They might say it bubbles when put on a cut. It also is good for cleaning stains, like blood stains. Some students may mention that it bleaches hair or teeth.

Pour a small amount of hydrogen peroxide into a beaker. Explain to students that the molecules are moving around, bumping into one another. Sometimes these collisions cause the molecules to react and break down so that slowly, over time, the bottle will contain less hydrogen peroxide. (Packaging hydrogen peroxide in a brown bottle prevents light from speeding up this reaction.)

Add a small piece of liver or potato to the beaker.

9. What do you observe when the piece of liver (or potato) is added to the hydrogen peroxide?

When the liver is added to the beaker of hydrogen peroxide, many bubbles are produced, creating foam within the container.

10. What is happening to create these bubbles?

Something in the liver (or potato) must be causing hydrogen peroxide to break down quickly. The normal reaction rate is so slow the reaction is not observable. Given that the reaction is now easily observed, this means it is happening much more quickly.

11. What molecule present in the liver (or potato) cells causes the rapid breakdown of hydrogen peroxide? Why is this molecule needed in cells?

Liver cells contain enzymes (including catalase) that speed up the decomposition reaction. Cells have catalase because hydrogen peroxide is produced in cells, but is toxic and needs to be quickly broken down.

Show students the equation:

$$2H_2O_2 \xrightarrow{\text{catalase}} 2H_2O + O_2\text{(gas)}$$

12. Based on the equation, what is contained in the bubbles seen in the beaker?

The bubbles contain oxygen gas.

Reinforce the concept of oxygen as a product of the reaction by performing another demonstration using a large beaker or graduated cylinder. Add hydrogen peroxide to the beaker. Add pieces of liver until a large volume of bubbles form. Light a wooden splint with a match, allowing it to burn for a short time and then blow out the flame so the splint is just glowing. Dip the splint into the bubbles so the flame reignites.

13. What happens when the wooden splint is placed in the bubbles? Why does this occur?

The wooden splint reignites; a flame is produced. The oxygen in the bubbles causes the splint to burn again.

Demonstrate the use of the oxygen gas sensor and data collection system. Perform the hydrogen peroxide–liver demonstration in a 250-mL Erlenmeyer flask. Just after adding a piece of liver to a small amount of hydrogen peroxide, plug the flask with the oxygen gas sensor and begin data collection. If you want to connect this reaction to the concept of exothermic reactions, you can also put the fast-response temperature sensor in the flask and measure the increase in temperature as the reaction occurs. Convey that the students will be using the oxygen gas sensor in their investigation.

14. If the challenge of this investigation is to see how temperature affects enzymes, why is oxygen gas the substance being measured?

Oxygen is a product of the reaction taking place. The reaction occurs rapidly due to enzymes in cells (for example, liver, potato, and yeast cells) acting as catalysts. If the enzyme's ability to work is affected by temperature, the rate of the reaction and the amount of oxygen produced will change. The enzymes, invisible within a cell, cannot be observed or measured directly. Also, the enzyme is not changed in the reaction so it cannot be directly measured, as can be done with reactants and products.

Lab Preparation

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

Teacher Tip: The instructions below make a large volume of yeast suspension sufficient for numerous class periods.

1. Twenty four hours prior to the activity, prepare the boiled yeast suspension.

  a. Add approximately 600 mL of water to a 1000-mL beaker.

  b. Add 2 packages of active dry yeast to the water and stir, creating a uniform suspension.

  c. Place the beaker of yeast suspension on a hot plate. Heat the solution for at least 30 minutes on a high setting, making sure it comes to a boil. (Alternatively, use a microwave oven to heat the solution.)

  Take care not to allow the solution to boil rapidly. Do not leave the solution unattended while it is heating.

  d. Use heat-resistant gloves to remove the beaker from the hot plate. Allow the solution to cool to room temperature. Label the beaker "boiled catalase".

2. The day of the lab, prepare the room temperature yeast suspension approximately 30 minutes before class begins.

  a. Add approximately 600 mL of room-temperature water to a 1000-mL beaker.

  b. Add 2 packages of active dry yeast to the water and stir, creating a uniform suspension.

Teacher Tip: The yeast suspension may produce foam on the surface. If the foam interferes with being able to pour the suspension for student use, remove and dispose of the foam using a spoon.

3. Before class begins, set up a water bath with a temperature between 35 °C and 40 °C. Place a test tube rack in the water bath. Set out empty test tubes.

4. Prepare a 1.5% hydrogen peroxide solution: Dilute 500 mL 3% hydrogen peroxide with 500 mL distilled water. Repeat this procedure to prepare the solution for each class period.

5. The day of the lab, set up one or more stations where students can acquire each solution needed: 1.5% hydrogen peroxide, room temperature yeast, and boiled yeast. Place a 25-mL graduated cylinder at each station and direct students to use the cylinder only at that station to prevent cross-contamination.

Teacher Tip: Over time, the yeast will settle to the bottom of the flask. Use a magnetic stir plate, or stir the yeast suspension often, to keep the suspension uniform. Direct students to stir the suspension before they remove a sample.

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

2	1	5	3	4
Measure oxygen concentration in the absence of an enzyme (in a sampling bottle containing only hydrogen peroxide).	Gather materials and equipment to find 1) the base level of O_2, 2) the effect of catalase, and 3) how temperature affects catalase.	Analyze the results and determine if temperature affects enzyme function.	Determine the effect of room temperature catalase on the decomposition rate of hydrogen peroxide.	Measure O_2 production in reactions catalyzed by warm catalase and boiled catalase.

Procedure with Inquiry

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

Set up

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

2. ☐ Connect the oxygen gas sensor to your data collection system. �(2.1)

3. ☐ Calibrate the oxygen gas sensor. �(3.5)

4. ☐ Create a display of Oxygen concentration (%) versus Time. �(7.1.1)

Collect Data

Part 1 – Decomposition of hydrogen peroxide without an enzyme

5. ☐ Measure and pour 20 mL of 1.5% hydrogen peroxide into the sampling bottle.

6. ☐ Quickly connect the oxygen gas sensor to the sampling bottle. Do NOT create a tight seal between the sensor and the bottle.

NOTE: As you collect data, hold the sampling bottle and sensor to prevent them from falling over. Pressure may build up in the sampling bottle, causing the sensor to pop off. Having a loose fit of the stopper in the bottle, and holding the sampling bottle and sensor, will prevent this from happening.

7. ☐ Start data recording. �(6.2)

8. ☐ What is happening to the O_2 concentration in the sampling bottle? Why do you think this is happening?

The concentration remains the same (no increase or decrease). The hydrogen peroxide is not decomposing into water and oxygen (or the reaction is too slow to be observed) because enzyme has not yet been added.

9. ☐ Collect data for 180 seconds, then stop data recording. �(6.2)

10. ☐ Remove the oxygen gas sensor from the sampling bottle.

NOTE: Do NOT dispose of the solution in the sampling bottle! Keep the hydrogen peroxide for use in the next part.

Part 2 – Decomposition of hydrogen peroxide with room temperature catalase

11. ☐ Predict what will happen to the oxygen concentration in the sampling bottle after catalase is added to the hydrogen peroxide. Explain your prediction.

Answers will vary. From the background and pre-lab activities, students should know that the catalase in the yeast suspension is an enzyme. Enzymes help speed up reactions, so the amount of oxygen in the bottle should increase as the enzyme helps to break down hydrogen peroxide.

12. ☐ Add 10 mL of room temperature yeast suspension (catalase source) to the hydrogen peroxide already in the sampling bottle (from Part 1).

NOTE: Stir the yeast suspension before obtaining a sample.

13. ☐ Quickly connect the oxygen gas sensor to the sampling bottle. Do NOT create a tight seal between the sensor and the bottle.

NOTE: As you collect data, hold the sampling bottle and sensor to prevent them from falling over. Pressure may build up in the sampling bottle, causing the sensor to pop off. Having a loose fit of the stopper in the bottle, and holding the sampling bottle and sensor, will prevent this from happening.

14. ☐ Start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

15. ☐ Collect data for 180 seconds, then stop data recording. �(6.2)

16. ☐ Remove the oxygen gas sensor from the sampling bottle.

17. ☐ Dispose of the solution in the sampling bottle and rinse the bottle thoroughly.

Part 3 – Decomposition of hydrogen peroxide with warm catalase

18. ☐ Measure and pour 10 mL of room temperature yeast solution into a clean test tube. Place the test tube in a warm water bath (between 35 °C and 40 °C) for 3 minutes.

NOTE: Stir the yeast suspension before obtaining a sample.

19. ☐ Predict how the oxygen concentration in the sampling bottle containing warm catalase will compare with that of the room-temperature catalase.

Answers will vary. Students may correctly predict that the reaction will occur more quickly because the enzyme and substrate will collide more often if they are moving faster, due to a warmer temperature.

20. ☐ Remove the test tube with the warm yeast suspension from the water bath.

21. ☐ Measure and pour 20 mL 1.5% hydrogen peroxide into a clean sampling bottle.

22. ☐ Pour the warm yeast suspension from the test tube into the sampling bottle.

23. ☐ Quickly connect the oxygen gas sensor to the sampling bottle. Do NOT create a tight seal between the sensor and the bottle.

NOTE: As you collect data, hold the sampling bottle and sensor to prevent them from falling over. Pressure may build up in the sampling bottle, causing the sensor to pop off. Having a loose fit of the stopper in the bottle, and holding the sampling bottle and sensor, will prevent this from happening.

24. ☐ Start data recording. �(6.2)Adjust the scale of the graph to show all data. �(7.1.2)

25. ☐ Collect data for 180 seconds, then stop data recording. �(6.2)

26. ☐ Remove the oxygen gas sensor from the sampling bottle.

27. ☐ Dispose of the solution in the sampling bottle and rinse the bottle thoroughly.

Part 4 – Decomposition of hydrogen peroxide with boiled catalase

28. ☐ Predict what will happen to the oxygen concentration in the sampling bottle containing catalase that was heated to 100 °C.

Answers will vary. Students may predict that 100 °C would denature the enzyme, making the enzyme not functional. so it has little or no affect on the reaction.

29. ☐ Measure and pour 20 mL 1.5% hydrogen peroxide into the clean sampling bottle.

30. ☐ Pour 10 mL of boiled yeast suspension into the sampling bottle.

31. ☐ Quickly connect the oxygen gas sensor to the sampling bottle. Do NOT create a tight seal between the sensor and the bottle.

NOTE: As you collect data, hold the sampling bottle and sensor to prevent them from falling over. Pressure may build up in the sampling bottle, causing the sensor to pop off. Having a loose fit of the stopper in the bottle, and holding the sampling bottle and sensor, will prevent this from happening.

32. ☐ Start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

33. ☐ Collect data for 180 seconds, then stop data recording. �(6.2)

34. ☐ Remove the oxygen gas sensor from the sampling bottle.

35. ☐ Dispose of the solution in the sampling bottle and rinse the bottle thoroughly.

36. ☐ Save your experiment, �(11.1)and clean up your workspace.

Data Analysis

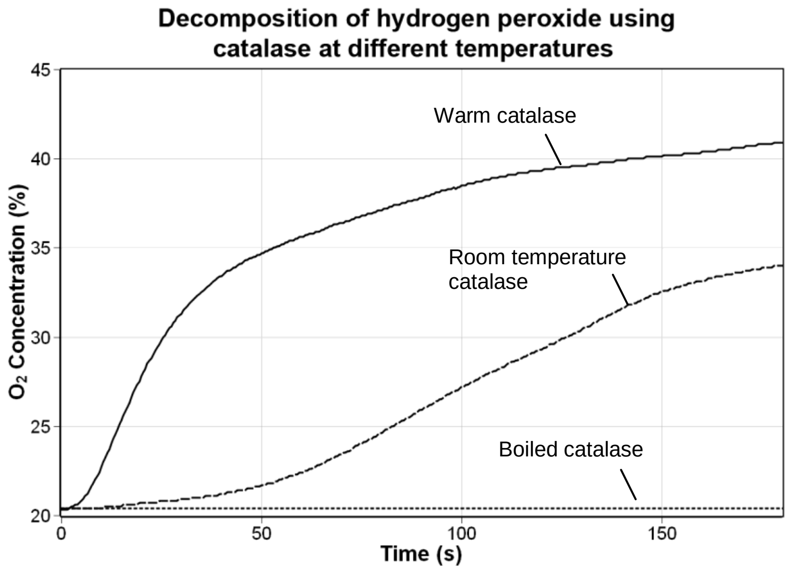
1. ☐ Use available tools on the data collection system to find values for the initial and final oxygen gas concentration. �(9.1) Record these values in Table 1.

2. ☐ Determine the change in the oxygen concentration in the sampling bottle. To calculate the "Rate of O_2 Production," divide the change in the O_2 concentration by the time. Record these values in Table 1.

Table 1: Oxygen gas production due to decomposition of hydrogen peroxide with and without catalase

Catalase Sample	Initial O_2 Concentration (%)	Final O_2 Concentration (%)	Change in O_2 Concentration (%)	Time (s)	Rate of O_2 Production (% /s)
None	20.4	20.4	0.00	180	0.00
Room temperature	20.3	34.0	13.7	180	0.08
Warm (35 °C to 40 °C)	20.4	40.9	20.5	180	0.11
Heated to 100 °C	20.4	20.4	0.00	180	0.00

3. ☐ Graph Oxygen concentration (%) versus Time. Label the overall graph and each axis. Include appropriate units on each axis. Plot data for: room-temperature catalase, warm catalase, and boiled catalase. Label each data curve.



Analysis Questions

1. Which best describes hydrogen peroxide in this reaction: substrate, product, or enzyme? Explain.

Hydrogen peroxide is the substrate. A substrate is a reactant; it is acted upon by the enzyme and changed into products.

2. Which best describes catalase (present in the yeast suspension): substrate, product, or enzyme? Explain.

Catalase is the enzyme. It helps speed up the breakdown of hydrogen peroxide. When it was absent, no detectable reaction occurred.

3. What happened to the amount of oxygen in the sampling bottle when room temperature yeast suspension was added to hydrogen peroxide?

The amount of oxygen gas inside the bottle increased after the addition of the yeast suspension.

4. Why does the addition of the yeast suspension cause a change in the oxygen concentration inside the sampling bottle?

Adding yeast to the sampling bottle increases the amount of oxygen gas because the yeast contains an enzyme called catalase. Catalase speeds up the breakdown of hydrogen peroxide. Oxygen is a product of this reaction.

5. Is enzyme activity affected by temperature? Use evidence from this investigation to support your answer.

Enzyme activity is affected by temperature. After being heated to a high temperature, 100 °C, the catalase enzyme showed little to no activity. When warmed to a temperature between 35 °C and 40 °C, there was greater activity than at room temperature.

When the temperature of the enzyme was changed, there was a significant difference in the oxygen produced in the bottle. When enzymes are at maximum functionality, the reaction will occur at its fastest rate. If enzymes become less active, the reaction is slower and less oxygen is produced.

6. At the molecular level, what is the difference between a room temperature (21 °C) solution and a warm (35 °C to 40 °C) solution?

In a warm solution, the molecules have a greater average kinetic energy, meaning that on average, those molecules are moving faster compared to the molecules in the room temperature solution.

7. Why would enzyme activity in the room temperature yeast cells be different than the enzyme activity in the warm yeast cells?

In the warm yeast cells, the greater kinetic energy of the molecules results in more collisions between enzyme and substrate. The enzyme is able to bind to the substrate more frequently, causing the reaction rate to be greater.

8. After being boiled, the catalase enzymes are not functional. Keeping in mind the lock and key model, explain why extreme temperatures would affect the function of an enzyme.

In the lock and key model, the enzyme and substrate bind together due to having complementary shapes. Extreme temperatures cause the enzyme to change shape. This renders the enzyme nonfunctional, being unable to bind to the substrate molecules.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Why are enzymes important to organisms? What would happen to cells if enzymes were not present?

An organism has to carry out thousands of chemical reactions to sustain life. Enzymes catalyze these biological reactions so they occur at a rapid rate. If enzymes were not present, the reactions would occur too slowly to maintain life, and the organism would die.

2. What temperature would you predict is optimal for enzymes in the human body? Explain your reasoning.

Enzymes in the human body would have an optimal temperature at 37 °C (98.6 °F), since this is the temperature maintained by homeostasis in the human body.

3. Explain why fevers over 40.5 °C (105 °F) are so dangerous in humans.

The enzyme in this experiment became denatured at a high temperature. In humans, a temperature of 40.5 °C is the upper limit of enzyme tolerance. At temperatures higher than that, the enzymes in our cells become denatured and stop functioning. Without functioning enzymes, cells cannot work properly and will die.

4. What does the term "denature" refer to? Why are enzymes nonfunctional when they become denatured?

"Denature" refers to the loss of shape by a protein. Proteins have complex 3-dimensional shapes that result from the folding and coiling of the amino acid chain(s). Enzymes become nonfunctional when denatured because without its proper shape an enzyme is unable to bind to the substrate and cannot catalyze the reaction.

5. Do you think pH affects enzyme activity? Explain. How could you test this?

Answers will vary. Some students may make the connection to enzymes in the saliva, stomach, and small intestine, knowing that the pH of these areas differ. Experiments to test the affect of pH on enzyme activity should focus on adding an acid or a base to solution samples, changing only that variable. Students should indicate that other variables, such as temperature and amount of substrate, are held constant.

Multiple Choice Questions

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

1. Which of the following describes an accurate enzyme–substrate relationship?

- **A.** Lactose–catalase
- **B.** **catalase–hydrogen peroxide**
- **C.** Bile–protease
- **D.** Glucose–polymerase

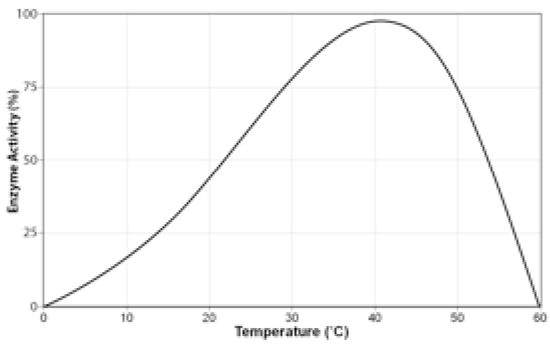
2. Which of the following is NOT true regarding enzymes and enzyme function?

- **A.** Enzymes are affected by changes in temperature.
- **B.** **An enzyme can be used only once.**
- **C.** Enzymes are specific and can only catalyze a specific reaction.
- **D.** The enzyme "catalase" is found in many types of cells.

3. Enzymes are what kind of macromolecule?

- **A.** Lipids
- **B.** Carbohydrates
- **C.** Nucleic Acids
- **D.** **Proteins**

4. The graph below shows enzyme activity at different temperatures. What is the



optimal temperature for this enzyme?

- **A.** 20 °C
- **B.** 30 °C
- **C.** **40 °C**
- **D.** 60 °C

Key Term Challenge

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

1. Enzymes are found in the cells of living organisms. Their main function is to **catalyze,** or speed up, chemical reactions that occur in the cell. Enzymes are not **consumed** during the reaction and therefore are available to catalyze another reaction immediately. Each enzyme has a different job, and many enzymes work together to keep an organism alive and healthy. Enzymes have an optimal **temperature** and pH range in which they can function properly. In your body, for example, enzymes work best when your temperature is normal (about 37 °C). If the environmental conditions are outside the normal range, enzymes lose their ability to catalyze reactions. They become **denatured** and cannot function if they are not in the proper shape.

2. In the human body, the liver has several enzymes that act on certain toxic compounds by removing hydrogen atoms from the poisons and transferring them to oxygen molecules. This detoxifies the poison, but it creates a new compound, hydrogen peroxide (H_2O_2), which is also **dangerous** to the organism. Fortunately, another enzyme in the liver catalyzes the decomposition of hydrogen peroxide into **water** and **oxygen.** This enzyme is **catalase.** Most living organisms have catalase inside their cells.

Extended Inquiry Suggestions

Alter other environmental conditions, such as salinity, pH, or presence of a heavy metal to determine their effect on enzyme functionality.

Investigate what happens when using different substrate or enzyme concentration.

To solidify the concept that enzymes are re-usable and that the reaction stops when all substrate has been used up, let the reaction go to completion (until there is no bubbling, about five minutes), and then add additional yeast suspension and gather data. Next add additional hydrogen peroxide and continue to observe and gather data.

Research the toxic effects of hydrogen peroxide in the human body and discuss why there is such an abundance of catalase produced by liver cells (the liver being the “detox” center in our bodies).

Research enzymes involved in digestion and compare the optimal pH for each.

Research cases where people have been frozen, or close to frozen, and have survived. Then do comparative research on cases where people have been extremely overheated. Consider and explain, in biological terms, which group has a better survival rate and why.

2. Membrane Permeability

Objectives

This activity is designed to provide students with an understanding of semi-permeable membranes. Students:

- Explore the permeability of a cell-like membrane to hydrogen (H^+) and hydroxide (OH^-) ions.
- Observe that not all materials are able to pass through the membrane.

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the change in pH in water when a dialysis tubing bag (representing a cell membrane) filled with either a strong acid or strong base is immersed in the water
- Calculating the rate of change of pH per minute
- Observing whether starch can permeate the membrane

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Beaker, 250-mL
- Large base and support rod
- Clamp, utility (2)
- Magnetic stirrer and spin bar
- Lugol's iodine
- 0.1 M hydrochloric acid (HCl),15 mL
- 0.1 M sodium hydroxide (NaOH), 15 mL
- Starch solution[1]
- Dialysis tubing, 15-cm length (2)
- Wash bottle
- Water, distilled, 1 L
- Binder clip
- String

[1] To formulate using cornstarch and water, refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Cell membrane structure
- Diffusion and equilibrium
- Definition of acids and bases

Related Labs in This Guide

Labs conceptually related to this one include:

- Organisms and pH
- Acid Rain
- Osmosis

Using Your Data Collection System

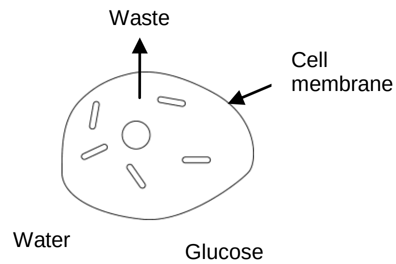
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions 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 on a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Displaying two data runs in a graph �(7.1.3)
- Adding a note to a graph �(7.1.5)
- Naming a data run �(8.2)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

The contents of a cell are separated from the outside environment by a membrane. A biological membrane is the cellular organelle that isolates biochemical reactions, enzymes, and genetic material essential to the vitality of the individual cell from the outside world.

In some cases, the cell membrane acts as a passive barrier. When the membrane acts passively, the materials migrate in or out due to a difference in concentration (or osmotic gradient) between the inside and outside of the membrane.



Cell diagram - membrane permeability

In other cases, the membrane can be very selective about what passes from one side to the other. It is through the membrane that essential nutrients pass into and waste products pass out of the cell. An active membrane is also the anchorage for many enzymes and coenzymes. The cell membrane is not a simple bag holding cell parts. The active nature of a biological membrane makes it a living part of the cell.

While cell membranes are selectively permeable, this experiment investigates a cell membrane's role as a passive diffusor of materials from one side of the membrane to the other.

The cell membrane, also called the plasma membrane, is a highly organized structure consisting primarily of phospholipid (fat) molecules and proteins. The phospholipids are comprised of a specific hydrophilic head portion with a hydrophobic tail region. They form a bilayer by arranging themselves tail-to-tail so that only their hydrophilic heads are exposed to the aqueous environment inside and outside of the cell, thus forming a barrier to everything that cannot permeate it.

The protein molecules, which are embedded in the phospholipids, function as passageways for the movement of materials through the cell membrane. A membrane unit is not static; it is a continuously changing structure, responding to changes in the environment.

Cellular homeostasis is dependent upon processes involving the movement of substances across the membrane, specifically gaseous exchange (typically CO_2 and O_2), water regulation, mineral and nutrient uptake, and the elimination of wastes. Molecules that may pass (unaided) through the membrane include water, carbon dioxide, oxygen gas, cholesterol (lipid), and other very small polar molecules (for example, ammonia). Most substances, however, require specific mechanisms to be transported across the membrane.

Each process occurs by either passive or active transport. Passive transport includes simple diffusion (for example, osmosis), and does not require energy consumption. In contrast, active transport requires energy to move substances from a lower to higher concentration, traveling against a concentration gradient.

Pre-Lab Discussion and Activity

Review the structure of the plasma membrane and ask students:

1. Can all molecules diffuse through the cell membrane?

Typically, there will be a handful of students who indicate that everything is able to pass through the membrane.

2. How do the organelles remain inside the cell; what prevents the organelles from diffusing out of the cell?

Students should indicate that the size of the structure/molecule affects its ability to pass through the membrane.

Giving students an analogy, or visual representation of the membrane is often helpful. A common analogy is that the cell membrane is like a chain link fence. Tell students: "Some things are small enough to pass directly through the 'holes' or pores, and some larger items that need to move into or out of the cell need to pass through a 'gate' or protein channel. In today's activity, we are going to try to determine what is able to pass through the "fence" or pores only, via passive transport, or diffusion."

Lab Preparation

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

1. Cut the pieces of dialysis tubing to 15-cm lengths, and pre-soak these prior to class.
2. Prepare the starch solution by adding 7 g of cornstarch per 100 mL of water. Heat the solution to a boil, stirring occasionally. Allow the solution to cool to room temperature and then cover. You can store the prepared solution at room temperature for up to 24 hours.

Safety

Add these important safety precautions to your normal laboratory procedures.

- Wear safety glasses and lab coats or aprons.
- Dispose of chemicals and solutions as instructed.

CAUTION: Hydrochloric acid and sodium hydroxide are irritants and can ruin clothing. Avoid contact to eyes and skin. Do not ingest. Notify your teacher of any contact with the chemicals.

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	5	1	2
Determine the change in pH. Observe any change in color in the beaker or inside the bag.	Lower the dialysis tubing containing the HCl and starch into the water, and add iodine to the water.	Repeat the procedure for the bag containing NaOH.	Prepare 2 dialysis bags. Set up your data collection system.	Add distilled water to the beaker, and turn on the magnetic stirrer.

Procedure with Inquiry

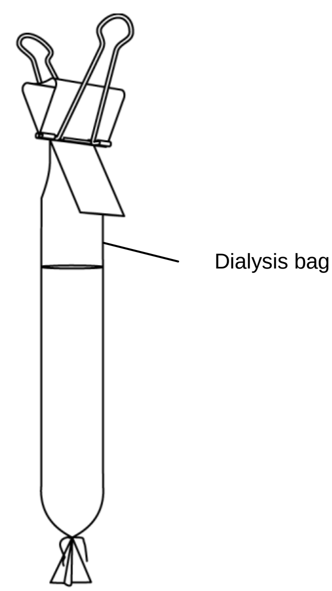
After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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 Equipment

Prepare the Dialysis Bag

Tips for working with dialysis tubing:



- ♦ Wash your hands. The oils on your skin can clog the pores of the tubing.
- ♦ Keep the tubing moist. If it dries out, it can crack and give invalid results.
- ♦ Tie multiple *tight* knots in the string at the end of the bag to ensure that it is sealed off.

1. ☐ Tie one end of a piece of dialysis tubing with string to form the tubing into a bag. Rub the tubing between your fingers to open the top of the bag.

2. ☐ Pour 15 mL of 0.1 M hydrochloric acid (HCl) and 5 mL of the 10% starch solution into the dialysis tubing bag.

CAUTION: Hydrochloric acid and sodium hydroxide are irritants and can ruin clothing. Avoid contact to eyes and skin. Do not ingest. Notify your teacher of any contact with the chemicals.

3. ☐ Fold over the open end of the bag.

4. ☐ Place a binder clip over the folded end, or you can tie off this end using string as well.

5. ☐ Place the bag under a gentle stream of running water to wash off any acid that may have fallen on the exterior of the bag.

6. ☐ Tie off one end of the second piece of dialysis tubing with string.

7. ☐ Add 15 mL of 0.1 M sodium hydroxide (NaOH) to the bag.

8. ☐ Fold over and clip or tie off the other end of the bag (as with the first bag).

9. ☐ Rinse the outside of the second bag.

Note: Do not allow the exteriors of the bags to come in contact with each other.

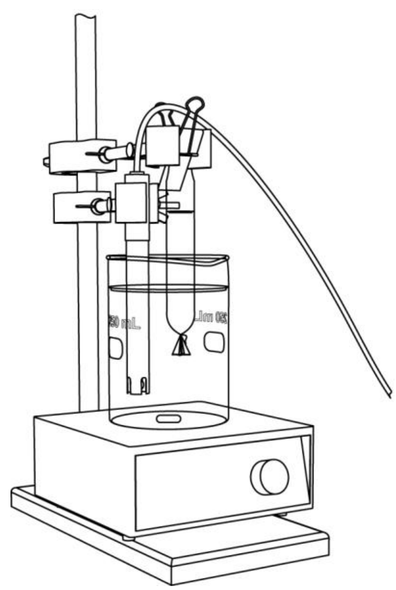
10. ☐ Set your bags aside on a labeled paper towel.

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

12. ☐ Connect a pH sensor to the data collection system. �(2.1)

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

14. ☐ Adjust the scale of the graph to show all data as needed. �(7.1.2)



15. ☐ Put a spin bar into a 250-mL beaker and place the beaker on the magnetic stirrer.

16. ☐ Use a clamp and a base and support rod to position the pH sensor so that it is near the edge of the beaker but is not touching the spin bar.

Part 1 – Migration of hydrogen ions (H^+) through a membrane

Set Up

17. ☐ Use a clamp to suspend the dialysis tubing bag containing hydrochloric acid above the beaker.

18. ☐ Add 100 mL of distilled water to the beaker.

19. ☐ Turn the magnetic stirrer on low.

20. ☐ Add 25 drops of iodine to the water.

21. ☐ Position the pH sensor so it is in the water in the beaker but does not hit the spin bar.

Collect data

22. ☐ Start data recording. �(6.2)

23. ☐ After 60 seconds, lower the dialysis tubing containing the hydrochloric acid into the water.

24. ☐ Allow the experiment to run for 300 seconds.

25. ☐ Stop data recording. �(6.2)

26. ☐ Name the data run "HCl". �(8.2)

27. ☐ Add a note to the graph of any color changes in the beaker water, or the color of the water inside the bag. �(7.1.5)

28. ☐ Dispose of the dialysis tubing bag and hydrochloric acid as directed.

29. ☐ Raise the pH sensor out of the water.

30. ☐ Use a wash bottle to thoroughly rinse the end of the pH sensor.

31. ☐ Remove the spin bar from the beaker and dispose of the beaker contents as directed.

32. ☐ Rinse and dry the beaker.

Part 2 – Migration of hydroxide ions (OH^-) through a membrane

Set Up

33. ☐ Add 100 mL of fresh distilled water to the beaker.

34. ☐ Add the spin bar and place the beaker on the magnetic stirrer.

35. ☐ Turn on the magnetic stirrer.

36. ☐ Position the pH sensor so it is in the water in the beaker, but does not hit the spin bar.

37. ☐ Display both data runs. �(7.1.3)

Collect Data

38. ☐ Start data recording. �(6.2)

39. ☐ After 60 seconds, lower the dialysis tubing containing the sodium hydroxide into the water.

40. ☐ Allow the experiment to run for 300 seconds.

41. ☐ Stop data recording. �(6.2)

42. ☐ Name this data run "NaOH”. �(8.2)

43. ☐ Dispose of the dialysis tubing bag and sodium hydroxide as directed.

44. ☐ Raise the pH sensor out of the water.

45. ☐ Use a wash bottle to thoroughly rinse the end of the pH sensor and store it properly

46. ☐ Remove the spin bar from the beaker and dispose of the beaker contents as directed.

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

Data Analysis

1. ☐ In Table 1, record the initial and final colors seen in the beaker and the bag for the HCl run. Also indicate whether or not starch was present in the results column.

Table 1: Initial and final colors

	Initial Color	Final Color	Result
Beaker	Yellow	Yellow	No starch
Bag	White	Blue/black	Starch present

2. ☐ Find the initial and final pH for each data run and record in Table 2. �(9.1)

3. ☐ Calculate the change in pH for both data runs and record in Table 2.

Final pH – initial pH = Change in pH

1.1 – 6.7 = –5.6

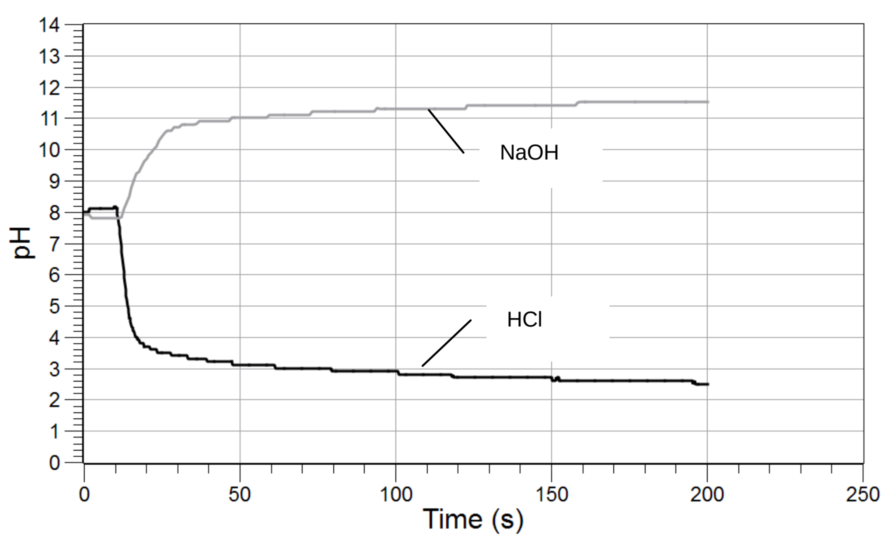
4. ☐ Calculate the rate of change of pH (change in pH / time) for each run and record in Table 2.

–5.6/300 = –0.0187

Table 2: Change in pH

Part	Run	Initial pH	Final pH	Change in pH	Rate of Change of pH
HCl	1	6.7	1.1	–5.6	–0.0187 pH/s
NaOH	2	6.8	10.5	+3.7	0.0123 pH/s

5. ☐ Sketch pH versus Time for both data runs. Be sure to label your runs.



Analysis Questions

1. Describe what happened to the pH in the beaker during the soaking of the HCl bag. What does this indicate about the permeability of the membrane by the H^+ ions?

Due to CO_2 being dissolved in solution and forming carbonic acid, pure water actually has a pH in the range of 6.5 to 6.9, so the pH of the distilled water starts at slightly less than 7. After the dialysis tubing is added, the pH drops rapidly for the first 25 seconds and then continues to slowly drop to a pH of 2.5 at 200 seconds. This indicates that H^+ can easily move through the membrane and cause the water in the beaker to become acidic.

2. Describe what happened to the pH in the beaker during the soaking of the NaOH bag. What does this indicate about the permeability of the membrane by the OH^- ions?

Due to CO_2 being dissolved in solution and forming carbonic acid, pure water actually has a pH in the range of 6.5 to 6.9, so the pH of the distilled water starts at slightly less than 7. After the dialysis tubing is added, the pH rises rapidly for the first 25 seconds and then continues to slowly rise to a pH of 11.5 at 200 seconds. This indicates that OH^- can easily pass through the membrane and cause the water in the beaker to become basic.

3. Describe what happened between the starch solution and iodine. Was iodine able to move into the bag? Was starch able to move out of the bag? Explain your answer, and support it with data.

When starch and iodine interact, it gives a blue/black color indication. The starch started off inside the bag and the iodine started off in the beaker. At the end of the run, the blue/black color was inside the bag, indicating that iodine had moved into the bag. The fact that the water was still yellow in the beaker shows that starch was not able to move out of the bag. In other words, the membrane was not permeable by starch.

4. This lab is demonstrating diffusion and semi-permeable membranes. Define these concepts.

In the absence of other forces, a substance diffuses from where it is more concentrated to where it is less concentrated.

Membranes are semi-permeable, which means that some things can pass through the membrane and some things cannot.

Synthesis Questions

Use available resources to help you answer the following questions.

1. How could the diffusion rate be increased?

The diffusion rate could be increased by increasing the concentration difference across the membrane. Higher concentration differences cause a higher rate of diffusion. Also, increasing temperature could increase the rate of diffusion.

2. How could you use a series of molecules to determine the size of the pores in the membrane?

Acidic or basic ions having the same electrical charge but a different size could be used to check the pore size of the membrane. Once again, the size of the ion is determined not just by the size of the individual charged atom but also the water molecules that surround the ion.

If samples are taken at standard time intervals, the relative concentrations of the ions as they migrate through the membrane can be determined. At a particular ion/solvent size, the migration across the membrane ceases. The size of the pore is approximately the size of the ion/solvent combination.

3. Were there any sources of experimental error that may have altered your results?

Answers can include: hole in the bag, leaking bag, and substance on the outside of the bag that clogged the pores.

4. How does this membrane model differ from a real cell membrane? What structures are present in a real cell membrane that regulate what can enter and exit the cell?

Answers should include: dialysis tubing does not have proteins and is limited to pore size. Real membranes are fluid and dynamic.

5. What types of molecules can readily enter and exit cells by passing directly through the lipid bilayer?

Molecules that can readily enter and exit cells by passing directly throug the lipid bilayer include CO_2, O_2, water, cholesterol, and small polar molecules.

6. List several examples of substances that *must* move through a membrane protein. Explain why it is necessary for these substances to use a protein for transport.

Large molecules including proteins, starches, and sugars must move through a membrane protein. Molecules that are too large to fit directly though the membrane are still needed by the cell. Also, some molecules are needed in such large quantities that they need to be pumped in against the concentration gradient. Active transport requires a protein channel.

7. Does the model illustrated in this experiment demonstrate active or passive transport? Explain.

The model illustrates passive transport. Passive transport is accomplished without the expenditure of energy. Substances diffuse from an area of greater concentration to lesser concentration. A substance diffuses down its concentration gradient.

Multiple Choice Questions

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

1. The membrane of a cell will allow water, oxygen, CO_2, and glucose to pass through. However, other substances are blocked from entering. This type of membrane is called:

- **A. Semi-permeable**
- **B.** Perforated
- **C.** Permeable
- **D.** Non-permeable

2. Despite differences in cell types, all cells have a:

- **A.** Cell wall
- **B. Cell membrane**
- **C.** Mitochondrion
- **D.** Nucleus

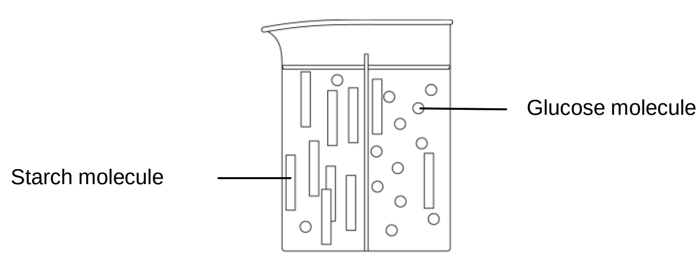
3. Cell membranes are constructed *mostly* of:

- **A.** Protein channels
- **B.** Carbohydrate channels
- **C. Lipid bilayers**
- **D.** Hydrophobic regions

4. Look at the diagram below and choose the correct statement:

- **A. Glucose will move from right to left.**
- **B.** Starch will move from right to left.
- **C.** Salt will move from right to left.
- **D.** No molecules will move in any direction.

The membrane is permeable to glucose but not permeable to starch.



Key Term Challenge

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

1. **Cells** are the basic unit of all living organisms. The one common attribute of all cells is that they are surrounded or bounded by a **plasma membrane.** Because of its chemical makeup, it is **selectively permeable**, which means that some particles pass easily through it and others cannot pass through at all. The plasma membrane forms an extremely effective seal around the cell. A cell uses two methods to move substances from one side of the plasma membrane to another. **Passive transport** is accomplished without the expenditure of energy. **Active transport** requires a cell to expend energy.

2. Water and selected solutes move passively though the cell and cell membranes by **diffusion**, a physical process in which molecules move from an area where they are in high concentration to one where their concentration is lower. The rate at which molecules of a particular substance cross a plasma membrane defines **membrane permeability**. Permeability is dependent on the **type of molecule** and the composition of the membrane, the number and **size of pore**s, or the number of specific carrier proteins in the membrane.

3. The plasma membrane is composed primarily of two types of molecules: **lipids**, which are fatty or oily molecules, and **proteins**. The basic structural framework of the plasma membrane is formed by two sheets of lipids, each sheet a single molecule thick. The protein molecules are embedded within this double layer, or **bilayer**, of lipids.

Extended Inquiry Suggestions

What is the effect of water temperature on membrane permeability? Challenge students to vary the temperature of the distilled water and determine the effect of temperature change on the rate of ion migration. Students may use water that is higher and lower than room temperature.

Students may use various amounts of distilled water, or acid/base concentrations to determine the effect this has on membrane permeability

3. Organisms and pH

Objective

Students explore pH and its impact on biological organisms by:

- Determining the importance of pH and the use of chemical buffers to organisms
- Indicating the effects of pH on the function of biological molecules and other various common compounds

Procedural Overview

Students gain experience conducting the following procedures:

- Testing changes in pH after adding a variety of substances to a solution
- Testing the effects of buffers on the pH of substances
- Analyzing the results and applying to living systems and organisms

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Beaker (6), 50-mL
- Beaker, 250-mL
- Erlenmeyer flask (2), 1-L
- Graduated cylinder, 10-mL
- Disposable pipets (2)
- Detergent solution[1]
- Lemon juice
- Distilled water
- Liver suspension[2]
- Buffer solution[3]

[1]To formulate using household detergent and water, refer to the Lab Preparation section.
[2]To formulate using fresh liver and water, refer to the Lab Preparation section.
[3]To formulate using sodium bicarbonate and water, refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Measurement
- Macromolecules—carbohydrates, proteins, lipids, and nucleic acids.

Related Labs in This Guide

Labs conceptually related to this one include:

- Enzyme Action
- Water and pH
- Soil pH

Using Your Data Collection System

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

- Starting a new experiment with your data collection system �(1.2)
- Connecting a sensor to the data collection system�(2.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a digits display �(7.3.1)
- Saving your experiment �(11.1)

Background

pH is a measure of the acidity or alkalinity of water. Solutions with very low pH are highly acidic; solutions with very high pH are highly alkaline (basic). A sample with a pH equal to 7 is neutral, that is, neither acidic nor basic. The pH number is the negative log of the the concentration of H^+ ions in a water solution at a given time, as shown in the following equation:

$$pH = -\log [H^+].$$

Therefore, a pH of 2 corresponds to a concentration of H^+ ions of 10^{-2}, or 1 H^+ ion per 100 molecules of H_2O. Accordingly, a pH of 8 corresponds to a concentration of H^+ ions of 10^{-8}, or 1 H^+ ion per 100,000,000 of H_2O molecules. (Note that in aqueous solutions, free H^+ ions are bound to water molecules in the form of H_3O^+. However, for the purpose of this explanation, the idea of H^+ ions is used.)

Solutions that are acidic produce a large number of H^+ ions, which can affect biological molecules in the solution. Proteins and other biological molecules can undergo changes in shape or solubility when there are too many (or too few) H^+ ions in the surrounding solution. Enzymes may lose their effectiveness if the pH of the organism is not tightly controlled. Organisms may lose the ability to maintain homeostatic equilibrium if the pH is changed too much.

The effect of pH on biological molecules can be demonstrated by the visual change in the anthocyanin pigment found in red cabbage. Changing pH affects the optical absorption characteristics of the purple compound, resulting in an observable color change, turning red in acidic conditions and blue in basic conditions.

One way an organism's pH can be changed is by adding carbon dioxide (CO_2) to the bloodstream. Mammals have an enzyme in the bloodstream called carbonic anhydrase. This enzyme combines CO_2 with H_2O to form carbonic acid (H_2CO_3). Carbonic acid increases the amount of CO_2 the blood can hold and transport. Some of the carbonic acid molecules break down, releasing H^+ ions. The more an organism exerts itself, the more carbonic acid is produced, decreasing blood pH. When CO_2 is removed from the bloodstream, pH increases. Low blood pH triggers a breathing response in the brain, causing the lungs to expel CO_2. Breathing is one way an organism controls pH.

Another way organisms control pH is through the use of buffers. A buffer is a compound that can combine with the free H^+ ions, removing them from the solution. When extra H^+ ions are added to a solution, they are removed by the buffer, so the pH does not change. A buffer may also produce free H^+ ions when combined with an alkaline (basic) substance. Therefore, if an acidic or basic substance is added to a buffered solution, the solution's pH will not be significantly changed—until the buffer cannot absorb or produce any more ions. One common buffer is sodium bicarbonate (baking soda, Na_2CO_3).

Pre-Lab Discussion and Activity

Many students are familiar with pH indicators. They have most likely worked with litmus paper or pH paper in the past. They may not be as familiar with probeware or other indicator options. In this quick demonstration, you will test the pH of various substances using a pH sensor and red cabbage as an indicator. Use the following procedure to show the differences between the substances. Directions for preparing the red cabbage indicator are located in the Lab Preparation section. Students enjoy the red cabbage indicator demonstration because it is something they can potentially do at home.

Procedure for the red cabbage demonstration

1. **Connect a pH sensor to the data collection system.** �[(2.1)]

2. **Place 25 mL of the red cabbage extract into four 50-mL beakers, and label them "A" to "D".**

3. **Rinse the pH probe with distilled water, and place it in beaker A.**

4. **Monitor data on a digits display without recording.** �[(6.1)]

5. **Wait a few seconds until the pH reading stabilizes, then measure the pH of the solution and record it and the color in the Sample results table below.**

6. **Add 5 mL of distilled water to the beaker and stir gently with a glass stirring rod.**

Note: Do not use the pH sensor to stir the solution. Be careful of the pH sensor while using the glass stirring rod.

7. **Wait a few seconds until the pH reading stabilizes, and then have the students observe the color and pH of the solution in the beaker. Record observations in the table below.**

8. **Repeat steps 3, to 6 for beakers B, C, and D, substituting lemon juice, white vinegar, and detergent for the distilled water in step 5.**

Sample red cabbage demonstration results

Beaker	Solution added	Resulting Color	Measured pH
	None – initial condition	Purple/Red	6.5
A	Distilled water	Purple	7
B	Lemon juice	Red	2
C	White vinegar	Red	2
D	Detergent solution	Green/Blue	9

Lab Preparation

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

1. Prepare red cabbage pH indicator: Slice a red cabbage into 1-cm slices. Place the slices in a pot and cover with boiling water (perhaps 3 cups, 750 mL). Boil for 15 to 20 minutes. Strain out the cabbage pieces using a colander. Save the purple water for use as indicator solution. The solution is very pungent. Allow your students to smell the indicator to convince them that it does, indeed, come from cabbage.

2. Prepare detergent solution: Dilute 1 part of a household liquid detergent with 2 parts water. Select an undyed brand of detergent to prevent confusing the color change of the red cabbage indicator solution. Test your detergent solution before using in this lab. For best results, you should select a detergent with an approximate pH of 10 or higher.

3. Prepare the liver suspension: Place about 75 g (2 to 3 oz) of fresh beef liver and 250 mL (1 cup) of distilled water in an electric blender. Blend at high speed until the liver is liquefied.

4. Set up one ring stand with clamp at the front of the room so students can see how to properly set up their test station.

5. Prepare the buffer solution: In a large Erlenmeyer flask, add 4 tablespoons of baking soda (sodium bicarbonate, Na_2CO_3) to 500 mL of distilled water.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Wear safety glasses and lab coats or aprons.

♦ Dispose of chemicals and solutions as instructed.

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
First, measure the pH of the various solutions.	Connect a pH sensor to the data collection system.	Next, add detergent to water, buffer, and liver and measure the change in pH.	Graph the change in pH versus Time as a base is added to three substances.	Compare the measurements to determine if any biological solutions are good buffers.

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 – Testing the pH of water + lemon juice

Set Up

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

2. ☐ Connect a pH sensor to the data collection system. �(2.1)

3. ☐ Display pH in a digits display. �(7.3.1)

4. ☐ Pour 25 mL of distilled water into a 50-mL beaker.

5. ☐ Rinse the pH sensor with distilled water and place it into the beaker.

Collect Data

6. ☐ Wait a few seconds until the pH reading stabilizes, and then start data recording. �(6.2)

7. ☐ Record the initial pH in Table 1 in the Data Analysis section of this worksheet.

8. ☐ What do you predict will happen to the pH of the water if lemon juice is added to the beaker?

Lemon juice contains citric acid, so it should introduce H^+ ions to the solution and reduce the pH.

9. ☐ Continue recording data as you add 30 drops of lemon juice using a clean pipet. Use the glass stirring rod to gently mix the solution in the beaker while the lemon juice is being added.

10. ☐ Wait 30 seconds following the last drop of lemon juice, and then stop data recording. �(6.2)

11. ☐ Record the final pH in Table 1 in the Data Analysis section of this worksheet.

Part 2 – Testing the pH of water + detergent

Set Up

12. ☐ Pour 25 mL of distilled water into a 50-mL beaker.

13. ☐ Rinse the pH sensor with distilled water and place it into the beaker.

Collect Data

14. ☐ Wait a few seconds until the pH reading stabilizes, and then start data recording. �(6.2)

15. ☐ Record the initial pH in Table 1 in the Data Analysis section of this worksheet.

16. ☐ What do you predict will happen to the pH of the water if detergent solution is added to the beaker?

Detergent solution is alkaline (basic), so it should neutralize some of the H+ ions in the water and add OH^- ions, increasing the pH.

17. ☐ Continue recording data as you add 30 drops of detergent using a clean pipet. Use the glass stirring rod to gently mix the solution in the beaker while the detergent is being added.

18. ☐ Wait 30 seconds following the last drop of detergent, and then stop data recording. �(6.2)

19. ☐ Record the final pH in Table 1 in the Data Analysis section of this worksheet.

Part 3 – Testing pH of buffer + lemon juice

Set Up

20. ☐ Pour 25 mL of buffer into a 50-mL beaker.

21. ☐ Rinse the pH sensor with distilled water and place it into the beaker.

Collect Data

22. ☐ Wait a few seconds until the pH reading stabilizes, and then start data recording. �(6.2)

23. ☐ Record the initial pH in Table 1.

24. ☐ What do you predict will happen to the pH if lemon juice is added to the beaker with the buffer?

The pH will decrease, but not with as large a change as when it was added to water.

25. ☐ Continue recording data as you add 30 drops of lemon juice using a clean pipet. Use the glass stirring rod to gently mix the solution in the beaker while the lemon juice is being added.

26. ☐ Wait 30 seconds following the last drop of lemon juice, and then stop data recording. �(6.2)

27. ☐ Record the final pH in Table 1 in the Data Analysis section of this worksheet.

Part 4 – Testing the pH of buffer + detergent

Set Up

28. ☐ Pour 25 mL of buffer into a 50-mL beaker.

29. ☐ Rinse the pH sensor with distilled water and place it into the beaker.

Collect Data

30. ☐ Wait a few seconds until the pH reading stabilizes, and then start data recording. �(6.2)

31. ☐ Record the initial pH in Table 1 in the Data Analysis section of this worksheet.

32. ☐ What do you predict will happen to the pH if detergent is added to the beaker with the buffer?

The pH will increase, but not with as large a change as when it was added to water.

33. ☐ Continue recording data as you add 30 drops of detergent using a clean pipet. Use the glass stirring rod to gently mix the solution in the beaker while the detergent is being added.

34. ☐ Wait 30 seconds following the last drop of detergent, and then stop data recording. �(6.2)

35. ☐ Record the final pH in Table 1 in the Data Analysis section of this worksheet.

Part 5 – Testing the pH of liver + lemon juice

Set Up

36. ☐ Pour 25 mL of liver suspension into a 50-mL beaker.

37. ☐ Rinse the pH sensor with distilled water and place it into the beaker.

Collect Data

38. ☐ Wait a few seconds until the pH reading stabilizes, and then start data recording. �(6.2)

39. ☐ Record the initial pH in Table 1 in the Data Analysis section of this worksheet.

40. ☐ What do you predict will happen to the pH if lemon juice is added to the beaker with the liver?

Many students will predict that the liver will work better than the chemical buffer, and that little to no change will occur. However, it is likely that you will see a decrease in pH, with results that show more buffering than the water sample, but less than the buffered sample.

41. ☐ Continue recording data as you add 30 drops of lemon juice using a clean pipet. Use the glass stirring rod to gently mix the solution in the beaker while the lemon juice is being added.

42. ☐ Wait 30 seconds following the last drop of lemon, and then stop data recording. �(6.2)

43. ☐ Record the final pH in Table 1 in the Data Analysis section of this worksheet.

Part 6 – Testing the pH of liver + detergent

Set Up

44. ☐ Pour 25 mL of liver suspension into a 50-mL beaker.

45. ☐ Rinse the pH sensor with distilled water and place it into the beaker.

Collect Data

46. ☐ Wait a few seconds until the pH reading stabilizes, and then start data recording. �(6.2)

47. ☐ Record the initial pH in Table 1 in the Data Analysis section of this worksheet.

48. ☐ What do you predict will happen to the pH if detergent is added to the beaker with the liver?

Many students will predict that the liver will work better than the chemical buffer and that little to no change will occur. However, it is likely that you will see an increase in pH, with results that show more buffering than the water sample, but less than the buffered sample.

49. ☐ Continue recording data as you add 30 drops of detergent using a clean pipet. Use the glass stirring rod to gently mix the solution in the beaker while the detergent is being added.

50. ☐ Wait 30 seconds following the last drop of detergent, and then stop data recording. �(6.2)

51. ☐ Record the final pH in Table 1 in the Data Analysis section of this worksheet.

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

Data Analysis

1. ☐ Calculate the change in pH for each substance, and record in Table 1.

Table 1: pH test results

Beaker	Solution added	Initial pH	Final pH	Change in pH
Water	Lemon juice	6.9	4.7	–2.2
Water	Detergent solution	6.9	8.9	+2.0
Buffer	Lemon juice	8.1	7.5	–0.6
Buffer	Detergent solution	8.1	8.4	+0.3
Liver	Lemon juice	6.8	5.4	–1.4
Liver	Detergent solution	6.8	8.2	+1.4

Analysis Questions

1. What is significant about the pH change in the liver suspension? What does it tell us about biological compounds, in general?

The physical properties of the indicator are changed by pH. The properties of other important biological molecules are also probably affected by changes in pH.

2. List the following common compounds in order from most acidic to most basic: distilled water, detergent solution, lemon juice.

Lemon juice, distilled water, detergent solution.

3. Do organisms appear to have effective ways to avoid large changes in pH? Give an example using experimental evidence.

Organisms can manufacture buffering agents to reduce the effect of acids and bases on pH. The liver suspension is less affected by the addition of an acid or base than plain water is.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In what ways does pH play a role in the digestive system of humans?

pH plays a role in digestion through the enzymes pepsin and trypsin. Pepsin is an enzyme located in the stomach that functions best in an environmental pH around 2. Trypsin is an enzyme in the small intestine and best functions in an environmental pH around 8. Each of these enzymes will not function in the other environment due to the specific pH that would denature their protein structure.

2. There are buffers in the human blood system. How might that be important for you?

Simply put, the buffering capacity of the blood helps to maintain a stable pH. Without this stability, the body could not function efficiently and might suffer damage or even death due to radical changes in acid or alkaline conditions.

3. Hemoglobin is the compound in red blood cells that caries oxygen. Hemoglobin binds to oxygen in the lungs and somehow "knows" to let go of the oxygen when the blood is transported near the tissues that need oxygen. How is this possible?

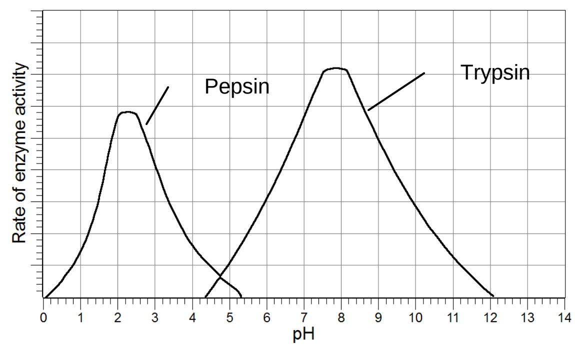
Much like the red cabbage indicator, hemoglobin is affected by changes in pH. CO_2 is removed from the body in the lungs, so the concentration of CO_2 and carbonic acid is low there. Blood pH in the lungs is relatively high. CO_2 is produced where O_2 is being used up, so anywhere O_2 is in short supply there will be plenty of CO_2 and carbonic acid. Blood pH is lowest where the need for O_2 is greatest. Hemoglobin binds to O_2 when the pH is high and releases O_2 when the pH is low.

Multiple Choice Questions

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

1. Which of the following biochemical substances located in the human body is not maintained at a neutral pH?

- **A.** Blood
- **B. Stomach fluids**
- **C.** Internal material of living cells
- **D.** Lymph



2. According to the graph above, which statement is true?

- **A.** More enzymes are present at a higher pH.
- **B.** Pepsin is less sensitive to pH than trypsin.
- **C.** Pepsin is less effective at low pH than trypsin.
- **D. pH affects the activity rate of enzymes**.

3. Five mL of lemon juice was added to 10 mL of each of the following substances. According to the table below, which has the best buffering capacity?

- **A.** Milk
- **B.** Liver
- **C.** Tap water
- **D. Egg whites**

	Change in pH
Milk	–3.2
Liver	–3.0
Tap Water	–4.0
Egg Whites	–2.8

Key Term Challenge

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

1. The pH scale is a logarithmic scale representing the concentration of **H^+** ions in a solution. As the H^+ ions increase in a solution, the **OH^-** ions decrease and vice versa. The pH scale goes from a pH of 0 to 14, with 7 being **neutral** pH, where the concentration of H^+ ions is equal to that of the OH^- ions. The **acidic** portion of the scale comprises pH values less than 7 while the **alkaline** (basic) part of the scale comprises pH values greater than 7. The pH of some common items include stomach acid with a pH of 2, tomatoes with a pH of 4, baking soda with a pH of 9, and oven cleaner with a pH of 13.

2. Water tends to **disassociate** into H^+ and OH^- ions. Pure water has the same number (or concentration) of H^+ as OH^- ions. Acidic solutions have **more** H^+ ions than OH^- ions. Basic solutions have the opposite. An acid causes an increase in the number of H^+ ions, and a base causes an increase in the number of OH^- ions.

3. A **buffer** is a substance in a solution that increases the amount of acid or alkali (basic) that must be added to cause a change in pH. Thus, buffers are very important in all living systems in order to maintain **homeostasis**. The pH of mammalian **blood** is maintained close to 7 by a wide variety of buffers.

Extended Inquiry Suggestions

Students can determine the pH of aqueous solutions taken from nearby water sources and draw conclusions as to the type of organisms that could exist in that environment.

Observe the effect of pH on various living organisms such as the aquatic plant, duckweed.

Discover the optimum pH condition for enzymes by testing with hydrogen peroxide at various pH levels the activity of the enzyme catalase that has been extracted from liver.

4. Osmosis

Objectives

Students explore the concept of cell membranes and how water and other substances pass through a membrane through the process of osmosis. Students:

- Demonstrate an understanding of how water moves across a cell membrane through osmosis
- Explain how the flow of water is impacted by the concentration of solute within the cell
- Analyze how the cell membrane is a semipermeable membrane that allows molecules to move through based on size and charge

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the change in mass and gas pressure for various dialysis bags containing different syrup concentrations

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Barometer/Low Pressure sensor
- Electronic balance
- Sensor extension cable
- Beaker, 400-mL
- Quick-release connector
- Beaker (2), 100-mL
- Graduated cylinder, 10-mL
- Graduated cylinder, 50-mL
- Funnel
- Ring stand with test tube or 3-finger clamp
- Dialysis tubing (2), 15 cm
- Thread (or dental floss) to tie dialysis tubing
- Plastic tubing, 5 cm
- Syrup (maple or corn), 10 mL
- Distilled water
- Paper towels

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Cell Membrane
- ♦ Diffusion
- ♦ Characteristics of water
- ♦ Hypertonic, hypotonic, isotonic

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Membrane Permeability
- ♦ Organisms and pH

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 using a sensor extension cable �(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)
- ♦ Naming a data run �(8.2)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Saving your experiment �(11.1)

Background

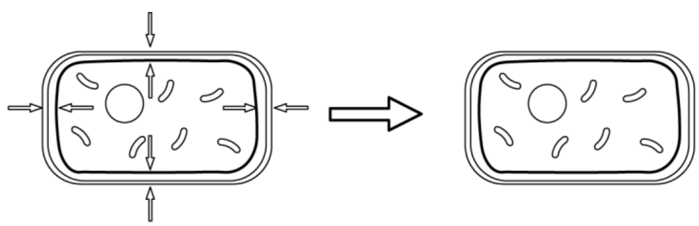
Living cells have a cell membrane. The primary function of this membrane is to separate what is inside the cell from the outside. All portions of the cell necessary for life, such as ribosomes, DNA, and enzymes, are prevented from drifting away by the cell membrane. Once captured, energy sources are not allowed to escape. Competing organisms and dangerous enzymes are prevented from damaging critical components of the cell.

If the membrane locked everything out, the amount of energy expended just to bring water into the cell would be fatal. Since a cell is able to transfer water and other substances in and out, its membrane is considered semipermeable. This means that certain small things, like water molecules and H^+ ions, can pass through the membrane. Most larger molecules cannot pass through the membrane without utilizing a channel.

A cell is mostly water, but it also contains a large quantity of protein, nucleic acid, sugars, and trace elements. The environment inside a cell is often quite different from the environment outside a cell. The cell may come in contact with salty sea water or a fresh water pond. One side of the membrane will have more water and less dissolved substances (solutes); the other side will have relatively less water and more solutes. Since sea water has much more dissolved salt than pond water, it has less space for water. A liter of pond water has more water molecules in it than a liter of sea water does.

If we examined a small space on either side of the membrane, we might see 50 water molecules on one side and only 45 on the other. That means 50 molecules are trying to pass through one side of the membrane and only 45 are attempting from the other side. This difference is called a gradient.

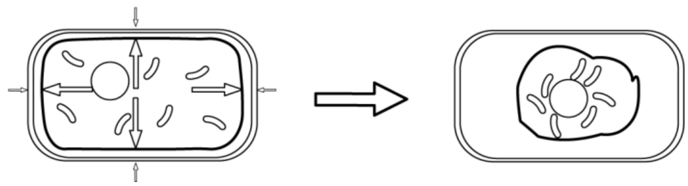
The side with more water loses water faster. Eventually, the inside and outside will balance or become very close to balanced. Just as heat tends to have a net movement from hot to cold places, water tends to have a net movement from greater to lower concentration. This is called moving along a gradient.



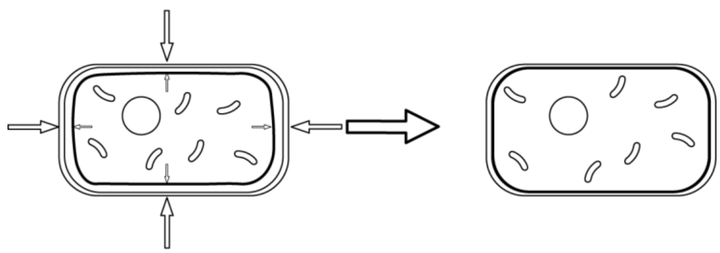
The passage of water through a semipermeable membrane along a concentration gradient is called osmosis. Osmosis is the process cells use to balance the concentration of water on both sides of the cell membrane. Osmosis does not require any input energy to proceed. When the concentration of water inside the plant cell and the concentration of water outside the plant cell are the same, equilibrium is achieved. In this case, the solution outside the cell is said to be isotonic to the cytoplasm inside the cell, and there is no net movement of water.

However, if you place that cell into a salt water solution, now, the concentration of water is higher on the inside of the cell. Even though the volume of actual water outside the cell may be greater, the fact is that the water outside the cell (salt water) contains a greater concentration of solutes. The salt water solution is said to be hypertonic to the cytoplasm of the cell.

In an attempt to "dilute" the concentrated salt water solution, water from the cytoplasm will diffuse across the membrane, out of the cell. Most of the solutes that were dissolved in the cytoplasm are too large to pass through the membrane, so they stay inside the cell. So there is only a net movement of water out of the cell. This loss of water is what causes a carrot to become limp over time.



On the other hand, if that cell is placed into a pure water solution, such as distilled water, the concentration of water outside the cell is much greater than the concentration inside. Water will flow into the cell in an attempt to "dilute" the cytoplasm. In this case, the solution outside the cell is said to be hypotonic to the inside of the cell. In plants cells, the cell wall provides a solid structure that prevents the cell from popping like an over full water balloon. As water flows in, it creates turgor pressure in plant cells. Animal cells, however, have no such protection. A crisp carrot is an example of plants cells in a hypotonic solution.



It is very difficult to do experiments on cell membranes. Dialysis tubing is a larger substitute for a cell membrane. Like a cell membrane, dialysis tubing has very small pores that allow water and other small substances to pass through. The pores are too small for proteins, blood cells, and other larger substances to pass through. By artificially creating a difference in solute concentration between two sides of a semipermeable membrane, we can direct the movement of water through the membrane. Living cells do the same thing.

Pre-Lab Discussion and Activity

Engage your students by showing them a crisp, fresh vegetable and a limp one (carrots work well). Discuss the principles of osmosis and ask the following questions:

1. What is the main factor that makes one of these crisp and one limp?

Many students will indicate that one has more water content than the other. Call on students and have them indicate whether they think water has moved into or out of each of the vegetables. Many will indicate that water must have moved out of the limp carrot.

2. Ask students to provide evidence as to why they think water moved out of the limp carrot.

Their evidence may include: "it seems drier" or "it's not juicy" or "it looks like dehydrated food". At this point, you should draw a typical plant cell, including a cell wall and the plasma membrane, on the board.

Have students brainstorm answers to the following questions:

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

3. Predict what you believe will be the changes in mass and the movement of water through osmosis in the following instances:

Dialysis bag containing distilled water submerged in distilled water

There should be no net change. The solutions are isotonic to each other.

Dialysis bag containing 100% syrup submerged in distilled water

There should be a large increase in the mass of the bag because the syrup inside the bag is being placed in a hypotonic solution. Therefore, water molecules will cross the membrane into the bag to attempt to achieve equilibrium in concentration.

4. How does osmosis play a role in maintaining homeostasis in living organisms?

Osmosis plays a role by maintaining appropriate water and solute concentration inside and outside of cells.

Lab Preparation

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

Approximately 30 cm of dialysis tubing will be required for each group. Cut this into two 5-cm pieces, and have them soaking in water before the lab begins.

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

2	1	5	3	4
Pour 10 mL of syrup solution into the dialysis bag,	Obtain a piece of dialysis tubing, and tie one end of the bag with thread.	Remove the dialysis bag, rinse the bag with distilled water, blot the outside of the bag, and measure the final mass of the bag.	Rinse the dialysis bag with distilled water, blot the excess water off the bag, measure the initial mass of the bag, and place it in the beaker.	Connect the bag to the barometric pressure sensor. Record the barometric pressure 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 a barometer sensor to the data collection system using a sensor extension cable. �(2.1)

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

4. ☐ Adjust the scale of the graph to show all data as needed. �(7.1.2)

5. ☐ Mount the barometer sensor on a ring stand with a clamp.

Note: Keep the barometer sensor completely still throughout the experiment.

Part 1 – Measuring osmosis with hypertonic and hypotonic solutions.

6. ☐ Pour 300 mL of distilled water at room temperature into a 400-mL beaker.

7. ☐ Obtain a 15-cm piece of dialysis tubing, and tie one end closed with thread.

8. ☐ Open the other end of the tubing by rubbing your fingers together over the end.

Note: If it is difficult to open the dialysis bag, run it under water while rubbing your fingers over the end.

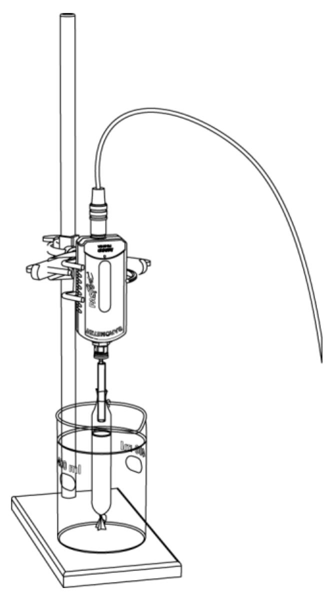
9. ☐ Using a funnel, fill the dialysis bag with 10 mL of syrup.

10. ☐ Rinse the outside of the dialysis bag with distilled water, and blot it dry with a paper towel. Make sure no water enters the bag and that you do not to spill any contents of the open bag.

11. ☐ Measure the initial mass of the bag and record it in Table 1.

12. ☐ Insert the 2-inch piece of plastic tubing into the dialysis bag, and seal the bag around the tubing by tying tightly with thread.

13. ☐ Blow some air into the bag through the tubing to inflate the bag.



14. ☐ Insert the barbed end of the quick-release connector into the plastic tubing.

15. ☐ Connect the quick-release connector to the barometer sensor.

16. ☐ When the dialysis bag with syrup is submerged in the beaker of distilled water, will it increase or decrease in mass? What if the bag contained distilled water? Explain your answers.

The dialysis bag will increase in mass due to osmosis. Water will move into the bag, causing an increase in mass. However, if distilled water were in the bag and also in the beaker, there would be no change in mass because the solutions would be isotonic.

17. ☐ When the dialysis bag with syrup is submerged in the beaker of distilled water, will the pressure inside the bag increase, decrease, or stay the same? What if the bag contained distilled water? Explain your answers.

When water moves into the bag, it occupies volume that was previously occupied by air. The air molecules in the bag are then compressed and the pressure in the bag rises. The more water that moves into the bag, the greater the pressure will increase. The bag with the syrup solution will have a dramatic increase in pressure because a lot of water will move into it. There would be no change of pressure in the distilled water bag because there would be no net movement of water.

18. ☐ Submerge the dialysis bag in the beaker with distilled water.

Collect Data

19. ☐ Start data recording. �(6.2)

20. ☐ After 15 minutes, stop data recording. �(6.2)

21. ☐ Find the initial and final pressures of the data run. �(9.1)

22. ☐ Record these pressures in Table 2.

23. ☐ Name the data run “Syrup”. �(8.2)

24. ☐ Remove the dialysis bag from the beaker.

25. ☐ Remove the plastic tubing.

26. ☐ Blot the dialysis bag.

27. ☐ Measure the final mass of the bag and record in Table 1.

Part 2 – Measuring osmosis with isotonic solutions

28. ☐ Repeat Part 1, adding distilled water to the bag, instead of syrup.

29. ☐ Name this second data run "Distilled."

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

Data Analysis

1. ☐ Calculate the difference between the initial and final masses for 100% syrup (Part 1) and distilled water (Part 2), and record in Table 1.

Table 1: Mass

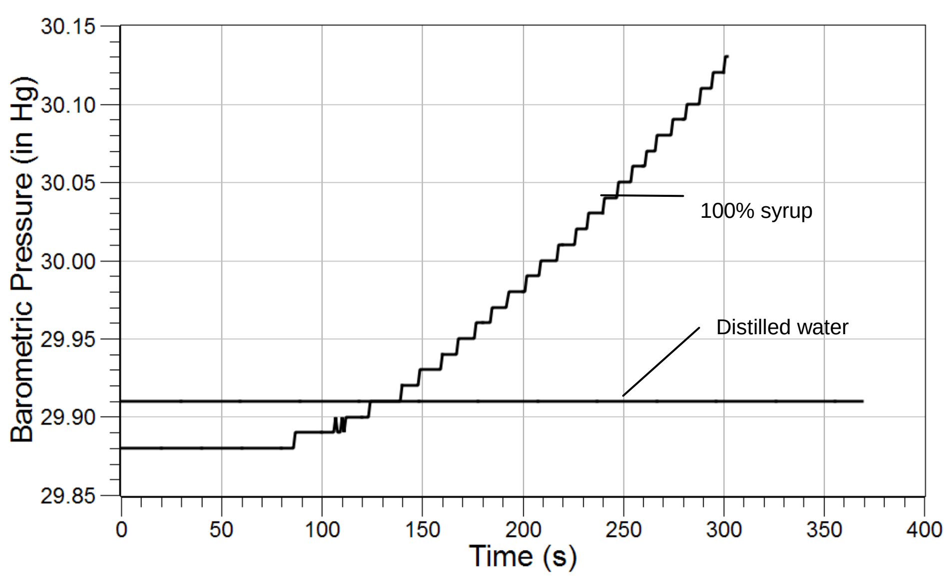
Sample	Contents	Initial Mass	Final Mass	Difference (g)
1	100% Syrup	23.10 g	27.98 g	4.88 g
2	Distilled water	18.95 g	18.97 g	0.02 g

2. ☐ Calculate the difference between the initial and final pressure for 100% syrup (Part 1) and distilled water (Part 2), and record in Table 2.

Table 2: Pressure

Sample	Contents	Initial Pressure	Final Pressure	Difference (in Hg)
1	100% syrup	29.88 in Hg	30.13 in Hg	0.25 in Hg
2	Distilled water	29.91 in Hg	29.91 in Hg	0 in Hg

3. ☐ Sketch a graph of Pressure versus Time for both the syrup and distilled water runs. Use a key to differentiate your runs.



Analysis Questions

1. In which bag did the pressure increase the most? In which bag did the mass increase the most? What does this indicate about which direction water was moving?

The pressure and mass increased the most in the bag filled with syrup. A large amount of water moved across the membrane into the bag, thus causing an increase in the air pressure. Since water molecules are matter and thus have mass, more water inside the bag resulted in an increase in mass as well.

2. What happened to the pressure and mass of the distilled water bag? Explain why this happened.

There was little or no change in pressure or mass inside the distilled water bag. Because the water inside and outside the bag are at equilibrium; there is no net movement of water.

3. What would happen to the mass of the samples if they were each placed in a solution of 50% syrup and 50% water?

The syrup solution would be hypertonic in relation to the distilled water bag. Therefore, the bag containing distilled water would lose mass, because the water inside the bag would move out of the bag in an attempt to dilute the syrup outside of the bag.

On the other hand, the 50% syrup solution would be hypotonic in relation to the 100% syrup in the other bag. In this case, the syrup bag would increase in mass because the water from the 50% syrup solution would move into the bag, attempting to have both sides reach equilibrium.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In what ways does the dialysis tubing behave like an actual cell membrane? In what ways does it differ?

The dialysis bag behaves like an actual cell membrane in that it is porous and allows molecules based on size to pass through the bag. It is not like the cell membrane because it only controls passage based on size. A cell membrane will also control movement based on charge; hydrophobic and hydrophilic properties; and other properties.

2. When a person is given fluid intravenously in the hospital, the fluid is typically a saline solution that is isotonic to human body tissues. Explain why this is necessary?

Keeping the saline solution and human body tissue isotonic ensures that water will diffuse into and out of the cell at the same rate. This will keep the contents of the IV moving into the body tissue at a constant rate, causing neither dehydration nor edema.

3. A patient is given an intravenous infusion of distilled water in it rather than of saline solution. Describe what would happen to the red blood cells in the patient and why it would happen?

The red blood cells would take up too much water and rupture due to the distilled water creating a hypotonic environment.

4. When roads become icy during the winter months, salt is added to the roads to make them less icy and slippery, but the salt also kills many plants alongside the road. What causes the plants to die?

The plants along the road go from a hypotonic to a hypertonic environment with the salt dissolving into the water that runs off the road. This causes the plants to go through plasmolysis and lose their water to the environment.

Multiple Choice Questions

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

1. Some peeled pieces of apple were placed in distilled water and some in very salty water. The cells in the apple pieces will:

- **A.** Lose water in both solutions
- **B.** Gain water in both solutions
- **C.** Lose water in distilled water and gain water in the salty water
- **D. Gain water in the distilled water and lose water in the salty water**

2. When there is a lower concentration of water outside of a plant cell than inside, the plant will tend to:

- **A.** Grow toward the sun
- **B. Lose water and wilt**
- **C.** Gain water and become rigid
- **D.** Increase its rate of photosynthesis

3. The movement of water across a membrane is referred to as:

- **A.** Endocytosis
- **B.** Diffusosis
- **C. Osmosis**
- **D.** Exocytosis

Key Term Challenge

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

1. **Osmosis** is the diffusion of water across a **semipermeable** membrane. The presence of a solute **decreases** the water potential of a substance, meaning there is more water per unit of volume in a glass of fresh water than there is in an equivalent volume of sea water. In a cell, which has many organelles and other large molecules, the water flow is generally **into** the cell.

2. The movement of water across the membrane is based on **water** concentration as well as **solute** concentration. **Hypertonic** solutions contain more solute and less water than the cell, while **hypotonic** solutions contain less solute and more water than the cell. **Isotonic** solutions have equal concentrations of solute and water. Human **blood** relies on an isotonic environment to ensure that water is moving equally in and out of the cell.

Extended Inquiry Suggestions

Create various syrup solution concentrations and use the same procedure to determine whether the concentration of solute affects the rate of osmosis.

Evaluate different unknown sugar concentrations and their movement in and out of the dialysis bag. Then rank the unknown solutions in increasing concentrations.

Observe onion or elodea cells under a microscope. Investigate osmosis in a living environment by adding a drop of 15% salt solution to the cells on a microscope slide, and observe the effects on the cells. Then add a drop of distilled water and observe the cells again.

5. Plant Respiration and Photosynthesis

Objectives

Students understand the relationship between carbon dioxide, respiration, and photosynthesis in plants. During this investigation students determine:

- The change in carbon dioxide concentration in a closed system when a plant is carrying out photosynthesis.
- The change in carbon dioxide concentration in a closed system when a plant is carrying out cellular respiration.

Procedural Overview

Students gain experience conducting the following procedures:

- Using a carbon dioxide gas sensor to monitor the carbon dioxide concentration when a plant is carrying out photosynthesis.
- Monitoring the change in carbon dioxide concentration when a plant is carrying out cellular respiration.
- Relating the changes in carbon dioxide concentration under each condition to the cell's photosynthesis and cellular respiration activities.

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Carbon dioxide gas sensor
- Sensor extension cable[1]
- Sampling bottle[1]
- Aluminum foil (30 cm long, from dispenser)
- Lamp, 100-W (or equivalent) fluorescent or halogen light bulb, to fit a standard socket
- Fresh spinach leaves, 1 or 2 [2]

[1]Included with the carbon dioxide gas sensor.

[2]Refer to the Lab Preparation section for details.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Plants capture sunlight to acquire energy needed to produce their own food.
- ♦ Photosynthesis uses light energy to convert water and carbon dioxide into glucose and oxygen.
- ♦ Cellular respiration provides usable energy for the cell in the form of ATP.
- ♦ Water and carbon dioxide are products of cellular respiration.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Rate of Photosynthesis for an Aquatic Plant
- ♦ Respiration of Germinating Seeds
- ♦ Cellular Respiration in 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 a sensor to your data collection system �(2.1)
- ♦ Calibrating a carbon dioxide gas sensor �(3.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Naming a data run �(8.2)
- ♦ Measuring the distance between two points in a graph �(9.2)
- ♦ Saving your experiment �(11.1)

Background

Carbon dioxide is a reactant in the process of photosynthesis and a product of cellular respiration. Plants take in carbon dioxide from the atmosphere and use it as a source of carbon for the sugars they produce, such as glucose ($C_6H_{12}O_6$). Sunlight captured by the plant during photosynthesis is stored as chemical potential energy within the glucose molecules (and other organic compounds) made by the plant. Although photosynthesis consists of a number of biochemical pathways within chloroplasts, a chemical equation can be used to summarize the overall process:

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

All organisms use food molecules, like glucose, to produce adenosine triphosphate (ATP). Made during cellular respiration, ATP provides cells with the energy needed for cell activities. Some organisms are autotrophs, like plants, and make their own food; others are heterotrophs and consume other organisms as food. In either case, to release the stored energy contained within the food molecules, the organism carries out respiration. Cellular respiration occurs within mitochondria, and like photosynthesis, the process consists of multiple biochemical pathways. The overall process is summarized as:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{ATP}$$

Photosynthesis and cellular respiration are important components of the carbon cycle. As a result of these processes, carbon is exchanged between living things and the nonliving environment.

Pre-Lab Discussion and Activity

If time allows, set up the first demonstration for students a few days before beginning this investigation. If you do not perform this demonstration, skip to the next part of this section.

Effect of a plant on carbon dioxide dissolved in water

Perform the steps below, in front of students.

a. **Fill a test tube half full with water. Add enough bromothymol blue (BTB) to the water to turn it dark blue.**

b. **Bubble your breath through a straw into the test tube until the solution turns bright yellow. Place a rubber stopper on the test tube. This is the control.**

c. **Fill a second test tube half full with water and repeat steps "a" and "b" from above.**

d. **Place a 5 cm piece of *Elodea* into the second test tube. Seal the test tube with a rubber stopper.**

e. **Place both test tubes near a window or under direct light for one or two days. Have students observe any color changes that occur.**

Explain to students that Joseph Priestly (1733-1804) hypothesized that plants clean the air. Priestly thought that air became polluted by the exhalation of animals, and that plants could "repair" the air. He performed a number of experiments related to this hypothesis.

1. What does a person's breath contain that causes the bromothymol blue (BTB) to change from blue to yellow?

A person breathes out carbon dioxide. When the carbon dioxide gas dissolves into the water it causes the BTB to change to yellow.

2. What is the color of the water in the control test tube after two days? Why is it this color?

The water in the control test tube is yellow after two days. The carbon dioxide dissolved in the water remains in the water. The tube was sealed and the gas was not able to escape.

3. What is the color of the water in the test tube containing *Elodea* after two days? Why is it this color?

The water in the test tube containing *Elodea* turned blue (or it may be green-blue in appearance). The plant removed the carbon dioxide from the water, returning it to the color it initially was before the person breathed into it.

Photosynthesis, respiration, and cell structure

Show students some fresh spinach leaves to begin an open-ended discussion to elicit students' prior knowledge.

4. What do you know about leaves?

Answers will vary. Students might refer to the color of the leaves and say they are green due to chlorophyll. Students are likely to state that leaves are the site of photosynthesis, which is the process plants use to make food.

Show students a diagram of the cells that compose a leaf. This might be an image of a leaf cross-section. Then show students a diagram of a single, generalized plant cell.

5. What structures or organelles of the plant cell can you identify?

Answers will vary. Students are likely to identify the cell wall, cell membrane, and nucleus. They may also identify chloroplasts and the vacuole. Some students might recall the endoplasmic reticulum or other organelles.

6. Which organelle is responsible for photosynthesis?

The chloroplasts are the site of photosynthesis.

7. Photosynthesis converts the energy from light into chemical potential energy in glucose. Does any other organelle in the cell have a function that involves energy conversion?

The mitochondria are the site of cellular respiration, in which oxygen is combined with glucose to produce ATP, the primary energy source for the cell.

Show students the carbon dioxide gas sensor. Explain that they will use this sensor and a spinach leaf to investigate the effect of a plant on carbon dioxide levels in a closed system.

8. Is carbon dioxide involved in photosynthesis? Explain your answer.

Yes; carbon dioxide is a reactant in photosynthesis. It provides a plant with the carbon atoms needed to make sugar molecules. This relates to the first demonstration, which used *Elodea* and bromothymol blue (BTB). Students can connect the color change in the water (from yellow to blue) to the uptake of carbon dioxide by the plant during photosynthesis.

9. Is carbon dioxide involved in cellular respiration? Explain your answer.

Yes; when sugar is broken down to release energy, the carbon contained in the sugar is released and used in carbon dioxide molecules. CO_2 is a product of respiration. This relates to the first demonstration, in which a person breathes into a test tube with water and BTB and the color changes (from blue to yellow) as carbon dioxide is added to the water. The carbon dioxide the person exhales is a product of cellular respiration.

Lab Preparation

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

1. Acquire fresh spinach leaves, like those found in the bulk section of a produce department in a grocery store. If the leaves have long stems, remove the stems from the leaves so the leaves will fit in the sampling bottle and can lay flat along its side.
2. Obtain 100-watt fluorescent or halogen light bulbs which can screw into a standard light socket. Do NOT use an incandescent light bulb. You will need one lamp per student group.
3. Cut a 30-cm piece of aluminum foil from the dispensing box for each student group.
4. If it is not possible to use the power adapter of the data collection system while carrying out the experiment, ensure that the data collection system is fully charged.

Note: The carbon dioxide gas sensor requires more power than other sensors. A fully charged data collection system provides about 30 minutes of data recording time.

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	4	1	5
Collect CO_2 data in darkness, by wrapping aluminum foil around the sampling bottle.	Attach the CO_2 sensor to the sampling bottle and measure the CO_2 concentration in direct light.	Remove the spinach leaves from the sampling bottle and discard them.	Add one or two spinach leaves to a sampling bottle.	Finally, use analysis tools to determine the change of concentration of CO_2 gas in the sampling bottle.

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

Note: During data collection, avoid bumping the equipment. Jarring or bumping the carbon dioxide gas sensor may cause it to record erratically.

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

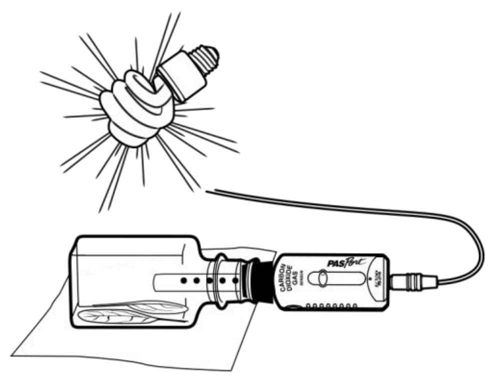
2. ☐ Connect the carbon dioxide gas sensor to your data collection system using the sensor extension cable. �(2.1)

3. ☐ Calibrate the carbon dioxide gas sensor. �(3.1)

4. ☐ Create a display of carbon dioxide gas (ppm) versus time (s). �(7.1.1)

5. ☐ Obtain one or two dry, fresh spinach leaves.

6. ☐ Position the sampling bottle on its side and arrange the leaf to rest flat inside of the bottle. (If using two small leaves, do not overlap the leaves.)



Note: Use the blunt end of a pencil or pen to push the leaf into proper position in the bottle.

7. ☐ Why do you think it is important for the leaf to be flat and the bottle to be on its side during data collection?

Having the leaf flat and the bottle on its side maximizes the leaf surface area exposed to the light to provide for optimum photosynthesis.

8. ☐ Place the carbon dioxide gas sensor into the sampling bottle so the rubber stopper makes an airtight seal.

Collect Data

Part 1 – In light

9. ☐ Obtain a 30-cm long piece of aluminum foil and rest the sampling bottle on its side, on top of the foil.

10. ☐ Position the light source 15 cm directly above the sampling bottle.

11. ☐ What do you think will happen to the carbon dioxide level in the bottle while the plant is exposed to bright light? Explain your answer.

Answers may vary. Most students will predict that the CO_2 level will decrease over time because plants use carbon dioxide during photosynthesis.

12. ☐ Turn on the light source.

13. ☐ Start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

14. ☐ Record data for 8 minutes, and then stop data recording. �(6.2)

15. ☐ Name the data run "Light".�(8.2)

Part 2 – In darkness

16. ☐ Keeping the sampling bottle on its side, wrap the aluminum foil around it and cover all sides to prevent light from entering the bottle.

17. ☐ What do you think will happen to the carbon dioxide level in the bottle while the plant is in the dark? Explain your answer.

Answers may vary. Students may predict that the CO_2 level will remain the same because the plant is not photosynthesizing. Some may predict that it will increase because the plant is undergoing cellular respiration.

18. ☐ Keep the light source turned on.

19. ☐ Start data recording. �6.2 Adjust the scale of the graph to show all data. �(7.1.2)

20. ☐ Record data for 8 minutes, and then stop data recording. �(6.2)

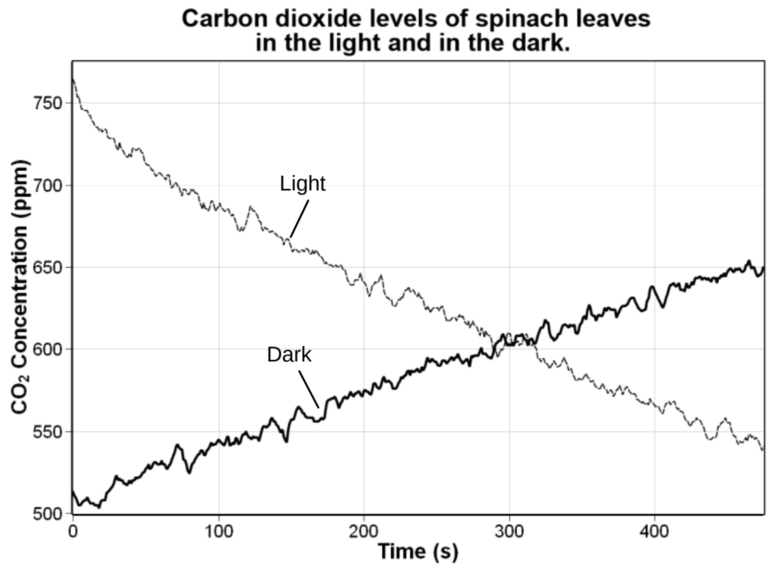
21. ☐ Name the data run "Dark". �(8.2)

22. ☐ Save your experiment. �(11.1)

23. ☐ Clean up your workspace and put away the equipment and materials.

Data Analysis

1. ☐ Graph your data for CO_2 gas concentration (ppm) versus Time (s). Label the overall graph and each axis. Include appropriate units on each axis. Label each line.



2. ☐ Using the available tools on your data collection system, find the change in CO_2 concentration in the sampling bottle during the 8 minutes under bright light and during the 8 minutes in darkness. �(9.2) Record the changes in Table 1.

Note: When filling in Table 1, use a plus sign (+) to indicate a positive change and a minus sign (–) to indicate a negative change.

Table 1: The changes in the CO_2 concentration due to photosynthesis and cellular respiration

Light Condition	**Change in CO_2 Concentration (ppm)**
Light	–253
Dark	+142

Analysis Questions

1. What happens to the concentration of carbon dioxide gas when the spinach leaf is in bright light? Why does this happen?

While light is shining on the leaf, the process of photosynthesis removes carbon dioxide from the air in the sampling bottle. (Although respiration is also occurring, the direct light enables a great deal of photosynthesis, so carbon dioxide absorption due to photosynthesis is greater than the carbon dioxide production due to respiration.)

2. What happens to the concentration of carbon dioxide gas when the spinach leaf is in darkness? Why does this happen?

The level of carbon dioxide increases steadily when the leaf is in the dark. The plant's mitochondria are producing carbon dioxide gas as a byproduct of cellular respiration (which uses glucose to make ATP). Since the plant does not photosynthesize in the dark, the respiration occurring in the leaf is detectable.

Synthesis Questions

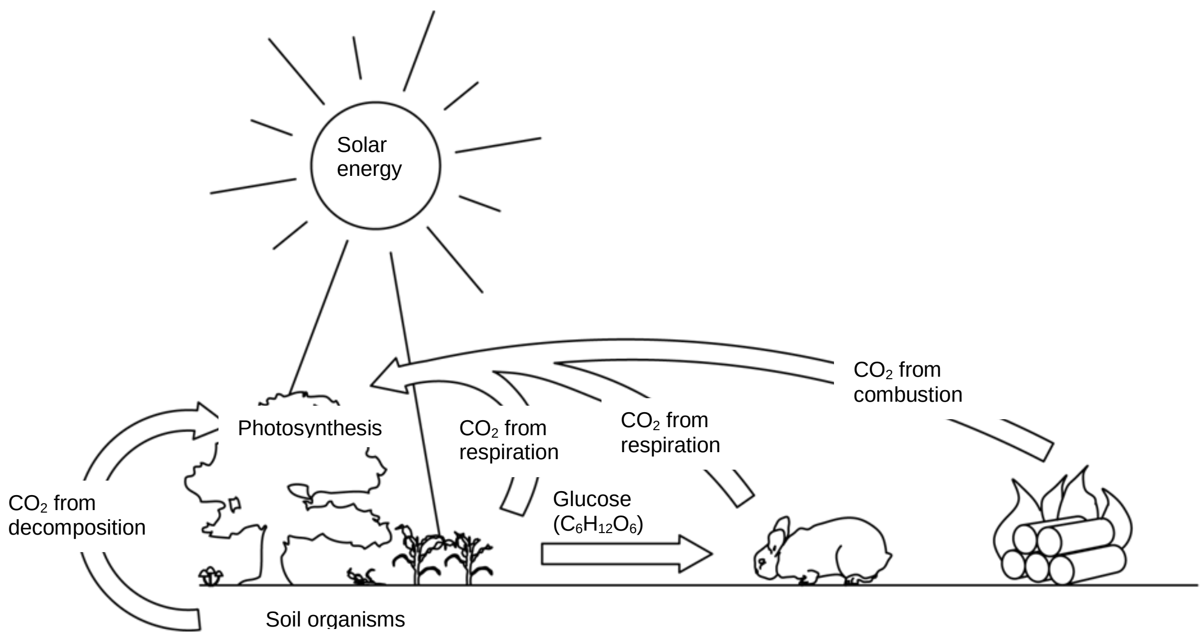
Use available resources to help you answer the following questions.

1. Plants play an important role in the carbon cycle. What is meant by the term "carbon cycle"?

Elements such as carbon move between biotic and abiotic components of an ecosystem. The carbon atoms may be stored short –term or long-term in living things, in the ocean, within rocks, or in other entities. Actions of living things and physical processes cause carbon atoms to move from one location to another. Carbon cycling includes the conversion of CO_2 into carbohydrates as a result of photosynthesis and the release of CO_2 into the atmosphere from the breakdown of carbohydrates during cellular respiration.

2. Draw a diagram to illustrate how plants and animals play a role in the carbon cycle.

Students should draw a flow diagram of the carbon cycle such as the following (or similar to one shown in their textbook):



3. Plant cells contain both chloroplasts and mitochondria. Explain why a plant cell must have both of these organelles to survive.

The chloroplasts are the site of photosynthesis and make the food (sugars) for the cell. Mitochondria are needed in order for the plant to be able to extract the energy from the sugars to make ATP, the usable form of energy for a cell.

4. Oxygen is another gas that relates to photosynthesis. If you were to repeat this investigation using an oxygen gas sensor, would you expect the same results? Explain your answer.

If oxygen gas were measured, there would be an increase in its concentration when the leaf is in the light, since photosynthesis produces oxygen. In the dark, the oxygen gas concentration would decrease as the plant uses oxygen for respiration.

Multiple Choice Questions

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

1. Which of the following are required for photosynthesis to occur?

- **A.** Light
- **B.** Chloroplasts
- **C.** CO_2
- **D. All of the above**

2. Cellular respiration will cause carbon dioxide levels in a sampling bottle to:

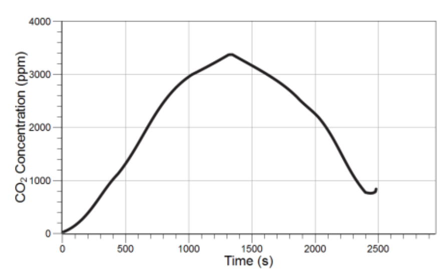
- **A. increase**
- **B.** decrease
- **C.** remain the same
- **D.** fluctuate unpredictably

3. If the light is moved from 15 cm above the leaf to 50 cm above the leaf, what is likely to happen?

- **A.** The carbon dioxide level will increase at a faster rate
- **B.** The carbon dioxide level will decrease at a faster rate
- **C.** The carbon dioxide level will increase at a slower rate
- **D. The carbon dioxide level will decrease at a slower rate**

4. What is shown in the graph of CO_2 concentration versus time for a plant in a closed system?

- **A. Respiration only and then photosynthesis**
- **B.** Photosynthesis and then respiration
- **C.** Light-dependent reactions only
- **D.** Light-independent reactions only



Key Term Challenge

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

1. Plants carry out both photosynthesis and **cellular respiration**. The reactants of photosynthesis are **water** and **carbon dioxide**. The products are **glucose** and **oxygen** gas. **Light** provides the energy required to change inorganic molecules into complex organic molecules. Cellular respiration breaks down complex organic molecules, releasing the **energy** they contain. The reactants of cellular respiration are **glucose** and oxygen gas. The products are carbon dioxide, water, and **ATP**.

2. In a closed system, a **decrease** in carbon dioxide is evidence of photosynthesis, while an **increase** in carbon dioxide is evidence of cellular respiration. A plant in the **dark** will only carry out respiration, but in the light the plant can carry out both respiration and **photosynthesis**. Plants take in carbon dioxide from the **atmosphere**. They also release carbon dioxide into the atmosphere, as well as oxygen gas. Plants and other living things play a role in the cycling of matter, such as the **carbon cycle**.

Extended Inquiry Suggestions

Collect data for longer periods of time (several hours) under each light condition. Based on the data collected, discuss what may be happening after a long time in a lighted condition and then after a long time in a dark condition.

Have students explore plant respiration and photosynthesis using the oxygen gas sensor.

Test factors such as the distance from the light or ambient light. Use a filter to provide a narrow range of light frequencies to the plant.

Use flowers or non-green leaves in the sampling bottle.

Use prepared microscope slides to investigate the tissues in a leaf and the functions of specific cells, such as palisade cells.

6. Respiration of Germinating Seeds

Objectives

Students understand how germinating seeds obtain energy for germination and growth through cellular respiration. In this investigation, students analyze the relationship between

- ♦ Respiration and carbon dioxide production
- ♦ Respiration and the energy requirements of cells
- ♦ Temperature and respiration

Procedural Overview

Students use a carbon dioxide gas sensor with a sampling bottle to measure and compare the carbon dioxide production of

- ♦ Non-germinating seeds
- ♦ Germinating seeds at room temperature
- ♦ Germinating seeds near 0 °C

Time Requirement

♦ Preparation time	24 hours before lab: 10 minutes
	Day of lab: 15 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	40 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Carbon dioxide gas sensor
- ♦ Sensor extension cable
- ♦ Sampling bottle[1]
- ♦ Beaker or cup, 250-mL, for ice water bath
- ♦ Dry beans, 25 mL
- ♦ Wet beans, room temperature, 25 mL
- ♦ Wet beans, chilled, 25 mL
- ♦ Ice
- ♦ Water

[1]Included with the gas sensor.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The overall process (reactants and products) of cellular respiration
- Cellular respiration is necessary to provide energy, in the form of ATP, to cells because energy stored in food is not directly available for cellular work. Respiration produces ATP.
- Enzymes play a key role in biochemical pathways, such as cellular respiration. Enzyme activity is dependent on temperature.

Related Labs in This Guide

Labs conceptually related to this one include:

- Plant Respiration and Photosynthesis
- Metabolism of Yeast
- Cellular Respiration in Yeast

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to your data collection system �(2.1)
- Calibrating a carbon dioxide sensor �(3.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Naming a data run �(8.2)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

Germination occurs when a dormant seed begins to sprout and grow into a seedling. Some steps of the germination process are:

- The seed coat softens and allows for absorption of water.
- The seed swells and the coat cracks and opens, allowing oxygen to become available to cells.
- Enzymes break down starch stored within the seed into glucose molecules that move into the cells.
- Cellular respiration begins as glucose molecules react with oxygen and provide energy to the cells for seed growth and development.

Cellular respiration converts glucose ($C_6H_{12}O_6$), and oxygen (O_2), into carbon dioxide (CO_2) and water (H_2O), and releases energy. The equation for cellular respiration, where "energy" refers to ATP and heat, is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Since carbon dioxide is a product of the reaction, carbon dioxide gas can be measured to determine the rate of cellular respiration.

Pre-Lab Discussion and Activity

Engage students in a discussion about the changes that occur in seeds when they are watered and during germination.

Teacher Tip: If time allows, have students place dry beans in a container of water and observe them over two or more days. This will make the germination process more concrete for them.

Have students note the differences between the dry beans and the wet beans that have soaked in water and are germinating. (These can be the beans they've soaked in water themselves, or the beans you've prepared for this investigation.)

1. What changes occur to a seed during germination?

Dry seeds are hard, while germinating seeds are soft. Soaking in water causes the seed to soften and swell. Eventually the coat cracks open and a seedling emerges (technically, the "radicle").

2. Is a dry, dormant seed dead? Explain your thinking.

Dry seeds are not dead, just inactive. Students should be able to conclude this based on the evidence that soaking a seed in water causes the seed to change and grow. Once something has died, it cannot be "activated" to live again.

3. A large part of a seed's volume and mass is its food reserve. Why do you think a seed needs this food reserve?

Seeds need a food source so when germination begins, a seedling can acquire the energy needed for growth and development. It takes a while for the seedling to grow leaves that can photosynthesize; in the meantime it needs food.

4. What cellular process breaks down food and releases energy?

Cellular respiration

5. Why will carbon dioxide be measured in this investigation?

Since cellular respiration produces carbon dioxide, the rate of carbon dioxide production will indicate the rate at which respiration is occurring.

Lab Preparation

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

1. At least twenty-four hours in advance, place a bag of dry beans into a large beaker. Cover the beans with water. Place the beaker in a dark location for 1 or 2 days.

2. Ensure that the data collection system is fully charged. (This is important if it will not be possible to use the power adapter while collecting data.)

Note: The carbon dioxide gas sensor requires more power than other sensors in order to collect accurate measurements. A fully charged data collection system provides thirty minutes of data recording time.

3. Drain any remaining water from the container containing the beans. At least thirty minutes before students arrive, place half of the germinating beans into a clean beaker. Cover the beans with ice water.

Teacher Tip: The colder the ice bath, the better. Keep adding ice to keep the seeds chilled throughout the class period or throughout the day.

3. Set up a station with ice and small beakers or cups. During the investigation, students will use an ice bath to keep seeds chilled.

4. Set up stations where students can acquire each type of seed needed: dry seeds, germinating seeds at room temperature, and chilled germinating seeds.

Teacher Tip: The seeds can be wet when placed into the sampling bottle for the investigation. However, there should NOT be excess water in the bottle. A volume is provided in the procedures as a guide for the amount of beans to place in the bottle. The volume does NOT indicate a liquid volume.

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	5	2	4	1
Measure the CO_2 gas levels for dormant seeds for 3 minutes. Repeat for warm and cold germinating seeds.	Compare your results with your predictions. Clean up all equipment and put everything away.	Set up your data collection system to measure CO_2 gas.	Analyze your data to determine the rate of production of CO_2 gas, and compare rates for the different conditions.	Gather all materials and equipment to perform the activity, including preparing a simple ice water bath.

Procedure with Inquiry

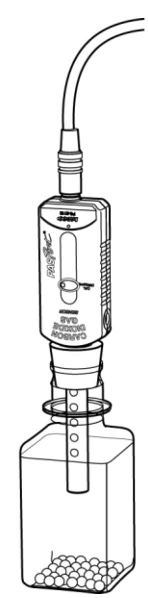
After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Part 1 – Dry, dormant seeds

Set Up

Note: Jarring or bumping the CO_2 gas sensor may cause it to record erratically. Keep the sampling bottle and sensor still while collecting data. Also, be sure that the end of the gas sensor does not come into contact with water.



1. ☐ Place 1 handful of chilled, germinating beans into a small beaker or cup. Cover the beans with water and add ice to create an ice water bath. Set this aside to be used in Part 3 of the investigation.

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

3. ☐ Connect the carbon dioxide sensor to the data collection system using the extension cable. �(2.1)

4. ☐ Calibrate the carbon dioxide gas sensor. �(3.1)

5. ☐ Create a graph display of Carbon dioxide concentration (ppm) versus Time. �(7.1.1)

6. ☐ Place 25 mL of dry seeds into an empty sampling bottle. (The volume is approximate; use the 25-mL line on the side of the sampling bottle as a guide.)

7. ☐ Predict what will happen to the amount of carbon dioxide in the sampling bottle containing dormant seeds. Explain your prediction.

Answers will vary. Based on the pre-lab discussion, students may correctly predict that the seeds are not growing so they won't be using their food source. Therefore, little to no cellular respiration will occur and the carbon dioxide level should remain the same.

Collect Data

8. ☐ Gently push the stopper of the carbon dioxide gas sensor into the sampling bottle.

Note: Do not allow the sampling bottle and sensor to fall over during the experiment.

9. ☐ Start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

10. ☐ After 3 minutes (180 seconds) stop data recording. �(6.2)

11. ☐ Name the data run "dormant seeds". �(8.2)

12. ☐ Remove the carbon dioxide gas sensor from the sampling bottle.

13. ☐ Remove the dry seeds from the sampling bottle. Dispose of them according to your teacher's directions.

14. ☐ Fill the empty sampling bottle with water and then pour the water out. (This will flush excess carbon dioxide from the bottle.)

Part 2 – Germinating seeds, room temperature

Set Up

15. ☐ Predict what will happen to the amount of carbon dioxide in the sampling bottle containing germinating seeds at room temperature. Explain your prediction.

Answers will vary. From the pre-lab discussion, students may correctly predict that since a germinating seed is growing, it will be carrying out cellular respiration as it consumes its food source. Therefore, the amount of carbon dioxide in the bottle should increase.

16. ☐ Place 25 mL of room temperature seeds into the empty sampling bottle. (The volume is approximate; use the 25-mL line on the side of the sampling bottle as a guide.)

Collect Data

17. ☐ Gently push the stopper of the carbon dioxide gas sensor into the sampling bottle.

Note: Do not allow the sampling bottle and sensor to fall over during the experiment.

18. ☐ Wait 10 seconds and then start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

19. ☐ After 3 minutes (180 seconds) stop data recording. �(6.2)

20. ☐ Name the data run "germinating seeds". �(8.2)

21. ☐ Remove the carbon dioxide gas sensor from the sampling bottle.

22. ☐ Remove the germinating seeds from the sampling bottle. Dispose of them according to your teacher's directions.

23. ☐ Fill the empty sampling bottle with water and then pour the water out. (This will flush excess carbon dioxide from the bottle.)

Part 3 – Germinating seeds, cold

Set Up

24. ☐ Predict what will happen to the amount of carbon dioxide in the sampling bottle containing cold germinating seeds. Explain your prediction.

Answers will vary. From previous experience, students may correctly predict that colder temperatures slow down chemical reactions, so the seeds will have a slower cellular respiration rate. Therefore, there should be a slow increase in the amount of carbon dioxide in the bottle.

25. ☐ Remove and transfer 25 mL of chilled seeds from the ice water bath into the empty sampling bottle. (The volume is approximate; use the 25-mL line on the side of the sampling bottle as a guide.)

Collect Data

26. ☐ Gently push the stopper of the carbon dioxide gas sensor into the sampling bottle.

Note: Do not allow the sampling bottle and sensor to fall over during the experiment.

27. ☐ Wait 10 seconds and then start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

28. ☐ After 3 minutes (180 seconds) stop data recording. �(6.2)

29. ☐ Name the data run "cold germinating seeds". �(8.2)

30. ☐ Save your experiment. �(11.1)

31. ☐ Remove the carbon dioxide gas sensor from the sampling bottle.

32. ☐ Remove the cold germinating seeds from the sampling bottle. Dispose of them according to your teacher's directions.

33. ☐ Fill the empty sampling bottle with water and then pour the water out.

34. ☐ Clean up your workspace and put away equipment and materials according to your teacher's directions.

Data Analysis

1. ☐ Use available tools on your data collection system to find the values for Initial and Final CO_2 concentrations (ppm). Record these in Table 1. �(9.1) Then calculate the change in CO_2 concentrations.

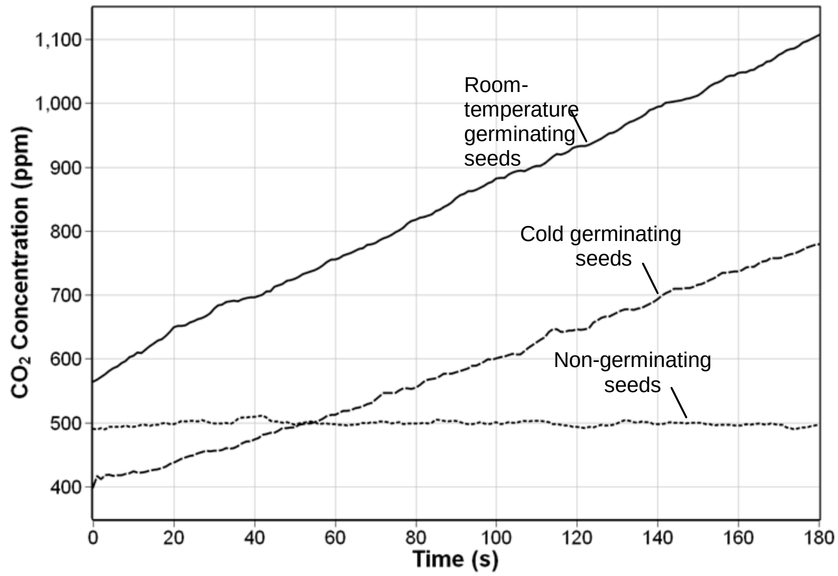
2. ☐ Divide the CO_2 concentration (in ppm) by Time (in seconds) to calculate the rate of change for each run of data or use graph tools on your data collection system to calculate the slope of the line. Record these values in Table 1

Table 1: Comparison of the rate of carbon dioxide production in germinating and non-germinating seeds

Sample	Initial CO_2 Concentration (ppm)	Final CO_2 Concentration (ppm)	Change in CO_2 Concentration (ppm)	Time (s)	Rate of CO_2 Production (ppm/s)
Dry, dormant seeds	490	492	2[1]	180	0.01
Room-temperature germinating seeds	564	1108	544	180	3.02
Cold germinating seeds	418	780	362	180	2.01

[1] The sensor is accurate to ±40 ppm. Changes that occur within this range are insignificant.

3. ☐ Graph your data for CO_2 concentration (in ppm) versus Time. Label the overall graph and the x-axis and y-axis. Label each axis with appropriate units.



Analysis Questions

1. How does the rate of CO_2 production for germinating seeds compare with the rate of CO_2 production for the dry, dormant seeds?

From this example, the rate of gas production for germinating seeds was 3.02 ppm/s versus virtually no change for the non-germinating seeds.

2. How does the rate of CO_2 production for cold, germinating seeds compare with the rate of CO_2 production for the room-temperature, germinating seeds?

In this example, the rate of gas production for cold germinating seeds was significantly less than the rate for the room-temperature germinating seeds.

3. Keeping in mind the visual differences between non-germinating and germinating seeds, what difference would these seed types have in their energy requirements? Explain.

The dormant seeds have very little cellular activity. They are not growing, so they do not need much energy (ATP). Germinating seeds are growing and developing and need a large amount of energy (ATP) for these activities.

4. Use your understanding of energy requirements and cellular respiration to explain the difference in CO_2 production rates between the non-germinating seeds and the germinating seeds.

The dormant seeds are not growing and need very little ATP, so they have a very low respiration rate and do not produce a noticeable amount of carbon dioxide. The germinating seeds are growing and need ATP. Therefore, they are carrying out cellular respiration and producing CO_2.

5. Use your understanding of enzymes and cellular respiration to explain the difference in CO_2 production rates between the room temperature germinating seeds and the cold germinating seeds.

At cold temperatures, the rates of chemical reactions involving enzymes are slower due to reduced enzyme activity. Cellular respiration consists of many reactions within glycolysis, the Krebs cycle, and the electron transport chain. These reactions are dependent on enzymes. With the reactions of the cellular respiration pathways occurring more slowly, less CO_2 is produced per second.

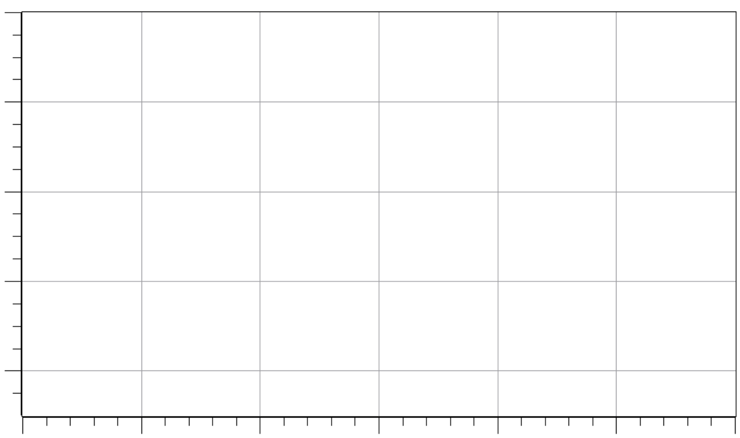
6. There can be a small change in the amount of CO_2 present in the sampling bottle containing dormant seeds. Is this change significant? Explain.

The change is not significant. It is expected that CO_2 concentrations fluctuate in a closed container. In contrast to the differences obtained for the room-temperature and chilled seeds, the change for dormant seeds is due to sampling fluctuation, not respiration rate.

Synthesis Questions

Use available resources to help you answer the following questions.

1. On Day 1 of a 3-day experiment, 50 dry seeds are placed in a sampling bottle and a small amount of water is added to the bottle. A carbon dioxide gas sensor is used to seal the bottle and record carbon dioxide levels once every hour, for three days. Predict what will happen to the carbon dioxide level over the 3 days and sketch a graph to show your prediction. Explain your graph.



Students should draw a graph showing a line with a positive slope; carbon dioxide levels will increase in the bottle over the three days. Students should explain that the seeds will begin to germinate and as they start using their food source, respiration will occur, producing CO_2. Students may or may not show a change in the slope (rate) over the 3 days. If they do, it would be expected that the rate of gas production would be less on Day 1 compared to Day 3.

2. The pH level of soils can vary significantly. Some soils are acidic, some are neutral, and some are alkaline (basic). Describe an experiment you could carry out to test whether the pH of water affects the rate of carbon dioxide production of germinating seeds.

Students should describe an experiment in which they soak seeds (of the same type, such as black beans) in water solutions of different pH. Students should indicate that they would change only the pH (the independent variable) and would hold other variables constant (such as the number of beans and the length of time the beans are soaked).

3. What other factors might affect the rate of production of carbon dioxide gas by germinating seeds?

Other factors that might affect the rate of production of CO_2 gas by the germinating seeds include the size and type of the seeds, the number of days soaked in water, and the age of the seeds. (See the Extended Inquiry Suggestions section.)

Multiple Choice Questions

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

1. Which of the following best describes cellular respiration?

- **A.** Digestion of complex food molecules into smaller molecules
- **B. Release of energy from simple sugars to make ATP**
- **C.** Conversion of simple sugars into complex sugars
- **D.** Synthesis of sugars from carbon dioxide

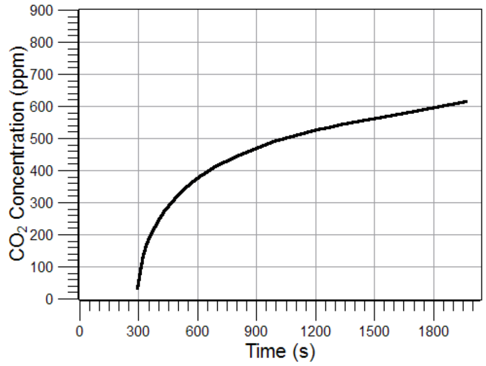
2. Which of the following statements is correct?

- **A.** As seeds germinate, they use up carbon dioxide rapidly.
- **B.** Dormant seeds are dead.
- **C. Cold temperatures reduce enzyme activity involved in cellular respiration pathways.**
- **D.** Chilled seeds become dormant and do not undergo cellular respiration.

3. In cells, the energy stored in glucose is used to make what energy-rich compound?

- **A.** Water
- **B. ATP**
- **C.** ADP
- **D.** DNA

4. According to the following graph, the rate of CO_2 production was highest at what time?



A. 10 to 20 seconds

B. 180 to 240 seconds

C. **300 to 600 seconds**

D. 1200 to 1800 seconds

Key Term Challenge

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

1. The process by which cells obtain energy from glucose is called **respiration**. During this process, cells break down **simple food** molecules and release the energy they contain. The rate of cellular respiration can be determined by the rate of **carbon dioxide** production, which can be monitored in a closed system.

2. Because living things need a continuous supply of energy, the cells of all living things carry out respiration continuously. The term "respiration" also is used to mean **breathing**, as in moving air in and out of your lungs. To avoid confusion, the respiration process that takes place inside mitochondria is referred to as **cellular** respiration. The two kinds of respiration are related. Breathing brings **oxygen** into your lungs, a molecule cells depend on to carry out cellular respiration

3. The overall process of respiration can be summarized in a simple chemical equation. However, respiration is a complex, two-stage process. The first stage, called glycolysis, takes place in the **cytoplasm** of the organism's cells. There, **glucose** molecules are broken down into smaller molecules. Oxygen is not involved in this stage of respiration, and only a small amount of energy is released. The second stage of respiration takes place in the **mitochondria**. There, the small organic molecules are broken down into even simpler inorganic molecules. These chemical reactions require **oxygen**, and a great deal of **energy** is released producing a large quantity of ATP. Two other products of respiration are **carbon dioxide** and water.

Extended Inquiry Suggestions

Collect the data for the rate of CO_2 production for the dormant seeds, the room-temperature germinating seeds, and the cold germinating seeds from all the groups in the class. Calculate the mean value and range for each condition. Facilitate a discussion regarding the possible sources of variation in the data.

Continue the CO_2 data collection and visual observations of the seeds for 1 or 2 more days. After observing the seeds each day, add fresh water. Compare the appearance of the seeds and the rates of CO_2 gas production on each observation day.

Repeat the activity with different kinds of beans or with other seeds, such as sunflower seeds.

Consider the effect of the number of days of germination on the rate of carbon dioxide gas production, or of the pH of the water used to moisten the seeds.

Students should be able to design experiments modeled after this investigation. Challenge the students to work out the details of the procedures to reinforce good experimental design. Different students can carry out different experiments and present their results to the class to facilitate discussion.

7. Role of Buffers in Biological Systems

Objectives

In this activity, students examine the role that buffer solutions have on the ability to balance the pH homeostasis. Students:

- Determine the pH change when they mix an acid with water.
- Determine the pH change when they mix an acid with club soda, which is a buffered salt solution.
- Determine which solution is the best buffer.

Procedural Overview

Students will gain experience conducting the following procedures:

- Use the pH Sensor to measure the change in pH in water and in club soda when they add an acid to them
- Compare the change in pH of water and club soda

Time requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Graduated cylinder, 10-mL
- Beakers (3), 250-mL
- Club soda, 200 mL
- Vinegar, 5% acetic acid, 20 mL
- Large base and support rod
- Utility clamp
- Magnetic stirrer and spin bar
- Wash bottle
- Distilled water, 1 L

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Homeostasis is the property of a living organism that regulates its internal environment to maintain a stable, constant condition.

- Blood cells and the body cells with which they come in contact must maintain a nearly constant pH; therefore, a buffering system is always present in any circulatory system.

- Acidic solutions contain hydrogen ions, and they have a pH less than 7.0.

- Basic solutions contain an excess of hydroxide ions, and they have a pH greater than 7.0.

- We call a solution that resists change in pH when we add an acid or a base a buffer.

Related Labs in this Manual

Labs conceptually related to this one include:

- Organisms and pH

- Soil pH

- 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)

- Starting and stopping data recording �(6.2)

- Displaying pH on the y-axis of a graph with Time on the x-axis �(7.1.1)

- Adjusting the scale of a graph �(7.1.2)

- Naming data runs �(8.2)

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

- Saving your experiment �(11.1)

Background

All living creatures, even single-celled organisms, must maintain very stable internal conditions in order to survive. As the metabolic environment changes, an organism must sustain physiological conditions (such as temperature, pH, water content, and food intake) at healthy levels. This stable level of metabolic conditions is called homeostasis. Organisms maintain homeostasis in a variety of ways. In multicellular organisms, complex buffer systems allow the organism to maintain internal pH, avoiding excessive acidity or excessive alkalinity. Scientists describe how acidic or alkaline a substance is using the pH scale. Substances with a pH of 7 are neutral; substances with a pH lower than 7 are acidic; substances with a pH greater than 7 are alkaline (basic). Because the pH scale is logarithmic, each change of 1 pH unit on the scale corresponds to a ten-fold difference in acidity. Therefore, a solution with a pH of 2 is ten times more acidic than a solution with a pH of 3.

Organisms must respond to changes in the environment and reach a state of stability. Those able to adapt, strengthen the diversity of life. Environmental fluctuations continually bombard living organisms, whether they are single-celled or multi-celled. Physiological homeostasis enables an organism to self-regulate internal processes, in spite of these challenging fluctuations. For single-celled organisms, this is a straightforward process. They exchange oxygen, nutrients, and waste products on a continual basis with the surrounding environment. For multi-celled organisms, this process can be an intricate physiological chain of events, involving tissues, organs, and organ systems. Homeostasis must accommodate changes in external conditions, including variations in oxygen, carbon dioxide, nutrients, temperature, and pH.

A buffer solution resists changes in pH. Buffers are usually mixtures of a weak acid and their salts. Buffering capacity describes its ability to withstand changes in pH. In the human body, physiological buffers, the respiratory system, and the renal (kidney) system accomplish pH homeostasis. Physiological buffers include proteins, phosphate buffer, and carbonic acid–bicarbonate buffer. The carbonic acid–bicarbonate buffer system is important in maintaining blood plasma pH. It is not a great buffering system because its pKa is 6.1 at 37 °C, and the pH of arterial blood plasma is 7.4. If the pH drops below this value, a condition called acidosis occurs.

Pre-Lab Discussion and Activity

Engage students by asking them to define the word "buffer."

Students may come up with many ideas that are not related to biology, like "a space between objects".

Explain to students that cells need to maintain constant conditions for enzymes to function properly.

Both temperature and pH need to remain stable, yet many factors can affect them. Carbon dioxide can dissolve in blood to form carbonic acid, thus reducing the overall pH of the blood. Blood contains components that act as buffers to help prevent drastic changes in blood pH.

Club soda is a buffered salt solution similar to the liquid component of blood. We will add acid to regular water and to club soda, and measure how well the club soda buffers the change.

1. Compared to water, how well do you think club soda will 'buffer' when we add an acid?

Student answers will vary. They may predict that the club soda 'buffer' will be more effective at maintaining pH than the water in both cases.

Teacher Tip: You use club soda for this laboratory because club soda contains sodium bicarbonate and carbonic acid, also found in human blood. The carbonate buffering system allows the pH of blood to be slightly alkaline (pH = 7.2). Even a slight change in blood pH (plus or minus 0.1 units) would have a large-scale effect on the health of body cells and general physiology.

Teacher Tip: Students may notice gas generation when adding the dilute vinegar (acetic acid) to the club soda. This results from the acid decomposition of carbonate and bicarbonate to carbon dioxide gas and water. The carbonate reacts with the acid to effectively neutralize the hydrogen ions being added to the soda. In addition, the added acetate ion acts to neutralize more hydrogen ions.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Dispose of chemicals and solutions as instructed by your teacher.

Sequencing Challenge

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

3	2	5	1	4
Repeat the procedure using club soda instead of distilled water in the beaker.	Put distilled water into a beaker. Add vinegar to the water while measuring the pH.	Clean up all materials according to your teachers instructions.	Gather all necessary materials together. Set up your data collection system.	Analyze your results.

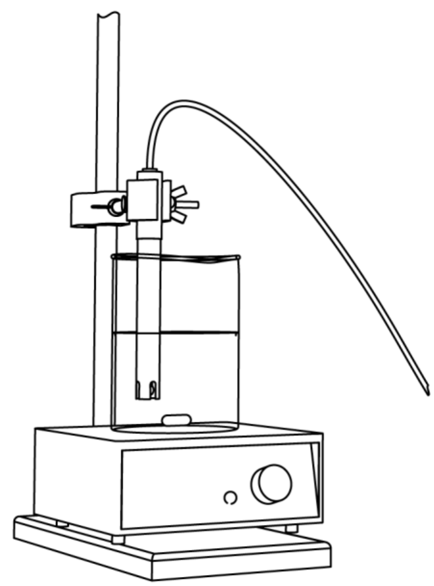
Procedure with Inquiry

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 – Acid and Water

Set Up



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

2. ☐ Connect a pH Sensor to your data collection system. �(2.1)

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

4. ☐ Put a spin bar into a 250-mL beaker.

5. ☐ Place the beaker on the magnetic stirrer.

6. ☐ Use a clamp with a base and support rod to position the pH sensor near the edge of the beaker without it touching the spin bar.

7. ☐ Pour 100 mL of distilled water into the beaker on top of the magnetic stirrer.

8. ☐ Turn on the magnetic stirrer.

9. ☐ What should happen to the pH of your solution?

The pH should decrease sharply.

10. ☐ Pour 10 mL of vinegar into a graduated cylinder.

Collect Data

11. ☐ Start data recording. �(6.2)

Note: The pH of the water should be between 6 and 7.

12. ☐ Record the pH of the water for 30 seconds, and then slowly pour the vinegar from the graduated cylinder into the beaker.

13. ☐ Continue to record the pH data for an additional 10 seconds after adding the vinegar and then stop recording. �(6.2)

14. ☐ Record the total time that you recorded this data run.

Total time should be 45 to 60 seconds for each run.

15. ☐ Name the Data Run "water". �(8.2)

16. ☐ Dispose of the contents of the beaker as directed by your teacher.

17. ☐ Thoroughly rinse the beaker and graduated cylinder.

18. ☐ Rinse the pH sensor with distilled water.

Part 2 – Acid and Club Soda

Set Up

19. ☐ Pour 100 mL of club soda into the beaker on top of the magnetic stirrer.

20. ☐ Turn on the magnetic stirrer.

21. ☐ What should happen to the pH of your solution?

The pH should decrease sharply. However, it will most likely not go as low as the acid + water trial.

22. ☐ Pour 10 mL of vinegar into a graduated cylinder.

Collect Data

23. ☐ Start data recording. �(6.2)

The pH of the club soda should be between 5 and 6.

24. ☐ Record the pH of the club soda for 30 seconds, and then slowly pour the vinegar from the graduated cylinder into the beaker.

25. ☐ Continue to record the pH data for an additional 10 seconds after adding the vinegar, and then stop recording. �(6.2)

26. ☐ Record the total time that you recorded this data run.

Total time should be 45 to 60 seconds for each run.

27. ☐ Name the Data Run "club soda". �(8.2)

28. ☐ Dispose of the contents of the beaker as directed by your teacher

29. ☐ Thoroughly rinse the beaker and graduated cylinder.

30. ☐ Rinse the pH sensor with distilled water.

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

Data Analysis

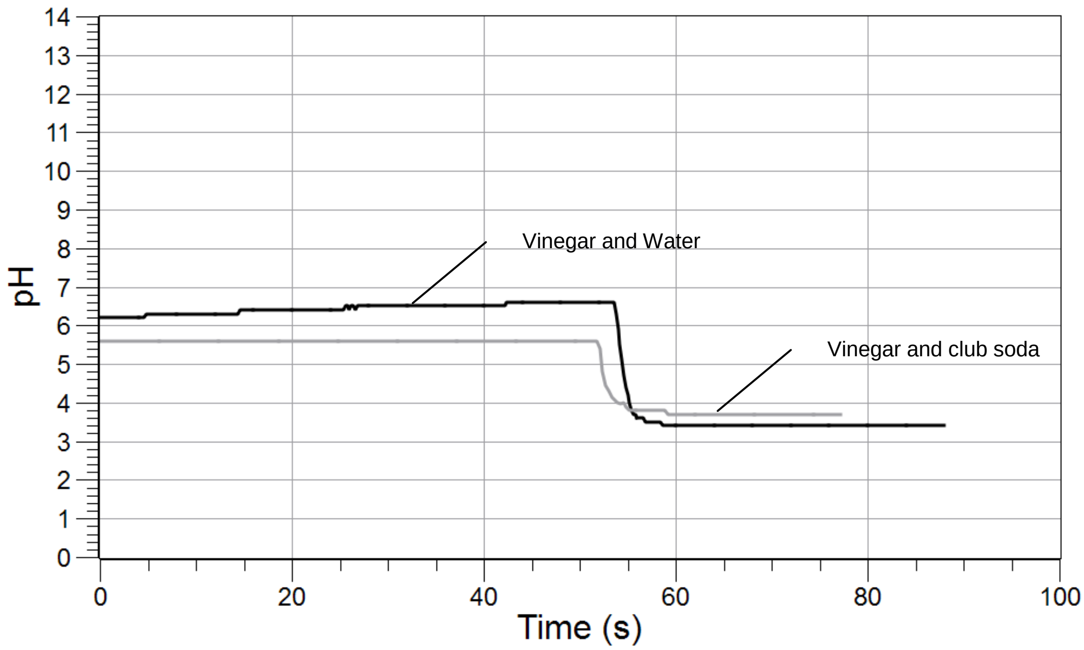
1. ☐ Determine the beginning and ending pH for both the water and club soda trials. �(9.1)

2. ☐ Calculate the change in pH and complete the table.

Table 1: Comparison of pH changes

Description	Beginning pH	Ending pH	Change in pH
Vinegar and water	6.6	3.3	3.3
Vinegar and club soda	5.6	3.7	1.9

3. ☐ Sketch a graph of the changes in pH versus time for each of the tests.



Analysis Questions

1. How do the results of what happened to the pH when you added the vinegar to water match your predictions?

The predictions and results should show a large and sudden decrease in pH of the water when the acid was added.

2. How do the results of what happened to the pH when you added the vinegar to club soda match your predictions?

The predictions and results should show that the pH of the club soda also decreased but to a lesser extent.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Consider the definition of a buffer. Which starting liquid made a better buffer: distilled water (pure water with no dissolved minerals) or club soda (containing sodium bicarbonate and carbonic acid)? How does your experiment show this?

The club soda makes a better buffer than the water. The club soda shows a much smaller pH change when adding acid as compared to water. This activity shows that the pH of the club soda changes by only 1.9 when adding vinegar, yet the water changed by 3.3 pH units. The buffering action of the club soda, along with the low ionization of acetic acid, allowed a small decrease in pH. Students are often surprised at the effectiveness of buffering.

2. Tap water contains minerals. What results would you get if you repeated this experiment using tap water instead of distilled water?

Likely, tap water will have a better buffering effect than that of distilled water. However, the minerals in tap water typically are not the right kind of mineral or in a strong enough concentration to serve as a buffer.

3. Explain how the club soda in this experiment is representative of the buffering ability of blood?

Human blood has bicarbonate ions similar to that of the club soda. Blood is not effective at preventing large scale pH swings, but is very useful in maintaining homeostasis where conditions cause minor fluctuations in pH.

4. Why are buffers important in biological systems?

The enzymes necessary for the catalysis of chemical reactions in cells have a narrow range of pH in which they can function. Some enzymes are so sensitive that even a minor pH fluctuation of .1 can cause the enzyme to become denatured and no longer function. Buffers help prevent these changes in pH and give the system more time to find and remedy the source of the problem.

Multiple Choice Questions

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

1. What property of a living organism regulates its internal environment?

- **A.** Metabolism
- **B. Homeostasis**
- **C.** Buffer system
- **D.** Respiration

2. Which of the following would be the best buffer?

- **A.** Strong acid
- **B.** Strong base
- **C.** Salt with pH of 7.0
- **D. Weak acid and salt combination**

3. Which of the following would indicate a strong acid?

- **A.** pH 7.0
- **B.** pH 14.0
- **C. pH 1.5**
- **D.** pH 7.5

4. Which of the following is most acidic?

- **A. Vinegar**
- **B.** Club Soda
- **C.** Water
- **D.** Human blood

Key Term Challenge

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

1. A stable level of metabolic conditions is called **homeostasis**. Organisms maintain this in a variety of ways. In multicellular organisms, complex **buffer** systems allow the organism to maintain internal pH, avoiding excessive acidity or excessive alkalinity. Scientists describe how acidic or alkaline a substance is using the **pH** scale. Substances with a pH of 7 are **neutral (salts**), while substances with a pH lower than 7 are **acids** and those with a pH greater than 7 are **bases**.

2. Acidic solutions are those that contain an excess of **hydrogen** ions. The greater the concentration of these ions, the more acidic the solution and the lower the **pH** of the solution. Basic solutions contain an excess of **hydroxide** ions. The greater the concentration of these ions, the more basic the solution and the **higher** the pH of the solution.

3. The acidity of the solution affects many chemical reactions. In order for a particular reaction to occur, or to occur at an appropriate rate, the **pH** of the reaction medium must be controlled. **Buffer** solutions, which are solutions that maintain a particular pH, provide such control.

Extended Inquiry Suggestions

Have students test the effect of temperature on the buffer's activity.

Have students prepare several different concentrations of vinegar (concentrated acid and diluted acid), and determine the effects on pH from these different concentrations.

Investigate different soil types on their ability to buffer acid (acid rain).

Ecology

8. Acid Rain

Objectives

Students investigate the reactions that occur between gases in the atmosphere (CO_2 and SO_2) and water droplets, and relate this to the production of acid rain. Students create "acid rain" samples and observe the effect of acid rain on plant growth over the course of one week.

Procedural Overview

Students gain experience conducting the following procedures:

- Using a pH sensor to measure and compare the change in pH due to bubbling carbon dioxide and sulfur dioxide gases into water.
- Using a pH sensor to prepare two "acid rain" samples.
- Observing plant growth and recording observations over several days.

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	45 minutes (Day 1)
	10 minutes (Days 2–5)

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor[1]
- Graduated cylinder, 25-mL
- Small beaker or disposable cup with $NaHCO_3$[2]
- Small beaker or disposable cup with $NaHSO_3$[2]
- Small beaker or cup, 100-mL
- Beaker, 500-mL
- Storage containers for "acid rain"3 (2)
- 1-mL Plastic pipets (2)
- 1-mL Plastic pipet, cut
- 0.025 M Sulfuric acid (H_2SO_4), 100 mL
- Distilled water (50 mL)
- Vinegar (10 mL)
- Small plants[4] (2)

[1] The pH probe may be connected to a pH sensor, a water quality, or chemistry sensor.

[2] The containers of solid chemical substances can be shared by the class.

[3] Wash bottles make good storage containers.

[4] Daises, petunias, philodendrons, bean plants, and similar small plants are good choices.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The pH scale ranges from 1–14; below pH 7 is acidic and above pH 7 is basic.
- The lower the pH value, the greater the number of hydrogen ions (H^+) in the solution.
- The atmosphere consists of a mixture of gases, mostly nitrogen (N_2), and oxygen (O_2). Other gases, such as carbon dioxide (CO_2) are present in trace amounts.
- Burning of fossil fuels releases pollutants into the air.

Related Labs in This Guide

Labs conceptually related to this one include:

- Organisms and pH
- Soil pH
- Water and pH

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 carbon dioxide gas sensor �(3.1)
- Calibrating a pH sensor �(3.6)
- Starting 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)
- Manually entering data into a table � (7.2.3)
- Saving your experiment � (11.1)

Background

Acid rain is a form of precipitation with a pH that is lower than the pH of typical rainfall. Normal rainfall is not neutral (pH 7); a pH of 5.6 is typical for normal rain. Rain with a pH less than 5.6 is considered to be "acid rain". In a number of geographical regions, acid rain has been detected to have a pH below 3.

The pH scale is logarithmic. This means that a change of 1, pH 5 to pH 4 for example, is caused by a 10x increase in the concentration of hydrogen ions [H^+]. A decrease from pH 5 to pH 3 means that the solution now has 100 times (10^2) more H^+ ions.

Acidity can cause harm to the environment and ecological systems. Gases produced during the burning of fossil fuels (particularly coal) are the primary cause of acid rain. Fossil fuels are the main source of energy for power generation. Gases emitted from power generation include SO_2 and NO_2, which react with water in the air forming acidic water droplets that fall as precipitation.

When acid rain falls into lakes or streams, the pH of these bodies of water is lowered, harming some of the organisms in these environments. Acid rain can also harm plants and terrestrial organisms by lowering the pH of the soil. Acidic soils release metal ions, such as aluminum ions, that can be harmful to organisms, especially plants.

Pre-Lab Discussion and Activity

Review the pH scale

Show students 3 beakers of clear liquids: Beaker A (dilute HCl), Beaker B (distilled water), and Beaker C (very dilute HCl). Do not tell the students the names or formulas of the liquids; refer to them only by letter. Test the pH of each solution using a pH sensor. Ask students:

1. What can you conclude about these three liquids?

Two of the liquids are acids, since the pH of these liquids is less than 7. One of the liquids is water (or another neutral substance) because it has a pH of 7.

Tell students that Beaker A and Beaker C both contain hydrochloric acid (HCl). Ask students:

2. Why is the pH of the HCl not the same in both beakers?

One of the beakers (Beaker A) contains more concentrated HCl; it has more H^+ ions and has a lower pH compared to the other beaker.

Discuss what it means for the pH scale to be "logarithmic". For example, a solution of pH of 3 has ten times more hydrogen ions [H+] than a solution of pH 4.

If you collect samples from local bodies of water, describe to the students the sources of your samples and test the pH of each sample with a pH sensor.

Lab Preparation

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

1. Prepare the containers to be used in the Pre-lab activity and discussion.

  a. Add 5–10 mL of dilute (0.1 M or less) hydrochloric acid (HCl) to 300 mL of water. Label the beaker, "A".

  b. Pour approximately 150 mL of the diluted HCl (from the previous step) in a new beaker and fill to 300 mL. Label the beaker, "C".

  c. Add 300 mL of distilled water to a beaker and label the beaker, "B".

2. If you plan to show students the pH of water samples taken from local bodies of water, collect these samples and bring them to class.

Teacher Tip: The solid chemical substances ($NaHCO_3$ and $NaHSO_3$) used in Part 1 of the investigation can be placed in small cups or beakers and shared by the class, rather than each group obtaining their own small sample of the solids.

3. Pour a small amount of sodium bicarbonate into a small cup or beaker. Label the container "$NaHCO_3$".

4. Pour a small amount of sodium bicarbonate into a small cup or beaker. Label the container "$NaHCO_3$".

5. Prepare the "stock" solution of dilute 0.025 M sulfuric acid (H2SO4) from 1.0 M sulfuric acid.

  a. Add 487.5 mL distilled water to a 1000-mL beaker.

  b. Measure 12.5 mL of 1.0 M H_2SO_4 and add the acid to the water in the beaker.

  c. Label a few smaller beakers, "H_2SO_4 for acid rain" and distribute the sulfuric acid into these beakers for student use during the lab.

6. Prepare the pipets to be used by students in the lab.

  a. For each student group, cut a 1-mL plastic pipet approximately 1 cm above the bulb and use a permanent marker to label the pipet "1A".

  b. For each student group, label an uncut 1-mL plastic pipet "1B".

  c. For each student group, label an uncut 1-mL plastic pipet "1C".

  d. Repeat steps a–c, but label the pipets "2A", "2B", and "2C".

7. Purchase small potted plants. If all student groups will observe the plants under all three conditions (control, pH 2–3, and pH 3–4) you will need to purchase 3 plants per group.

  Teacher Tip: Different student groups can be assigned different parts of the procedure. Some groups can observe the control plants while others can observe plants under the acid rain conditions.

8. Make space available in your classroom for the plants to be observed for at least one week. Place the plants under a grow-light or near windows providing adequate light.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Wear protective eye glasses when working with chemicals.
- ♦ Be sure that the solid substances and vinegar are mixed in small volumes, producing only a small volume of gas. If larger amounts are used, the gases created, such as NO_2 can be harmful and the reaction should only be performed in a fume 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.

5	1	4	2	3
Prepare two "acid rain" solutions and monitor plant growth. Determine if acid rain affects plants.	Assemble the "gas generator" and produce carbon dioxide gas.	Analyze the results. Determine the relative impact of the two gases on the pH of water.	Bubble CO_2 into the sample of distilled water while measuring pH.	Repeat the gas generation and pH measurement for SO_2 gas.

Procedure with Guided Inquiry

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

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Part 1 – Create Gases

The following procedure creates carbon dioxide (CO_2) and sulfur dioxide (SO_2), gases that are produced from burning fossil fuels and are emitted into the air. These gases are found naturally in trace amounts but human activities have increased the amount of these gases in the atmosphere.

Set Up

1. ☐ Obtain the plastic pipets needed for the activity.
    a. Two pipets cut just above the bulb, labeled "1A" and "2A".
    b. Four standard 1-mL plastic pipets, labeled "1B", "1C", "2B, "2C".

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

3. ☐ Connect the pH sensor to the data collection system. �(2.1) Rinse the end of the pH sensor with water after removing it from the storage container.

4. ☐ Create a graph display of pH versus Time. �(7.1.1)

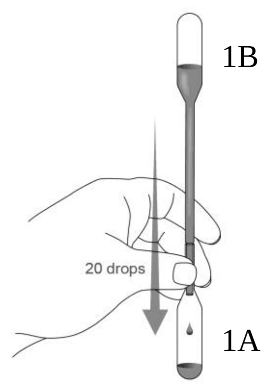
Collect Data

Produce carbon dioxide gas (CO_2) and determine its effect on the pH of water.

$NaHCO_3(s)$ + vinegar → $NaCl(aq)$ + $H_20(l)$ + $CO_2(g)$

5. ☐ Squeeze the bulb of pipet 1A, place the open end of the pipet into the container of $NaHCO_3$, and release the bulb. The pipet should now have a small amount of the solid substance inside of it.

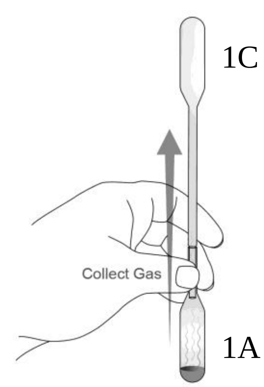
6. ☐ Squeeze the bulb of pipet 1B and place the pipet into a container of vinegar. Release the bulb to draw vinegar into the pipet.



7. ☐ Insert pipet 1B into the opening of pipet 1A. Slowly add 20 drops of vinegar into the bulb of pipet 1A. You should observe a chemical reaction occurring between the vinegar and the $NaHCO_3$.

8. ☐ Set aside pipet 1B.

9. ☐ Squeeze the bulb of pipet 1C and insert the pipet into the opening of pipet 1A. Release the bulb to collect some of the gas created in the reaction into pipet 1C. (This gas is carbon dioxide.)



10. ☐ Set aside pipet 1A.

11. ☐ Add 25 mL of distilled water to a small beaker or cup. Place the pH sensor into the water. Take care to prevent the cup from tipping over when the sensor is placed in it.

12. ☐ Start data recording. �(6.2)

13. ☐ Place pipet 1C into the distilled water and slowly squeeze the bulb of the pipet to bubble the collected gas into the water.

Note: Gently swirl the water as the gas is bubbled into it. Continue swirling during data recording.

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

15. ☐ Stop data recording when the pH of the water is no longer changing. �(6.2)

16. ☐ Name the data run "CO_2". �(8.2)

17. ☐ Normal rainfall is slightly acidic, with a pH below 7. Based on the results of data collection, does the presence of carbon dioxide (CO_2) in the atmosphere contribute to the acidity of rainfall?

Yes, carbon dioxide contributes to the acidic pH of rainfall. Adding CO_2 to the water caused the pH to decrease below pH 7.

18. ☐ Remove the pH sensor from the solution and rinse it with water. Dispose of the solution in the beaker or cup.

Collect Data

Produce sulfur dioxide gas (SO_2) and determine its effect on the pH of water

$NaHSO_3(s)$ + vinegar → $NaCl(aq) + H_20(l) + SO_2(g)$

19. ☐ Set aside the pipets from the first part (1A–1C) and use the pipets labeled "2A", "2B", and "2C" for this part of the investigation.

20. ☐ Squeeze the bulb of pipet 2A, place the open end of the pipet into the container of $NaHSO_3$, and release the bulb. The pipet should now have a small amount of the solid substance inside of it.

21. ☐ As you did before, add 20 drops of vinegar to the solid substance, using pipet 2B.

Note: A chemical reaction may not be apparent, but it is occurring.

22. ☐ Set aside pipet 2B.

23. ☐ Squeeze the bulb of pipet 2C and insert the pipet into the opening of pipet 2A. Release the bulb to collect some of the gas created in the reaction into pipet 2C. (This gas is sulfur dioxide.)

24. ☐ Set aside pipet 2A.

25. ☐ Add 25 mL of distilled water to a small beaker or cup. Place the pH sensor into the water. Take care to prevent the cup from tipping over when the sensor is placed in it.

26. ☐ Start data recording. � (6.2)

27. ☐ Place pipet 2C into the distilled water and slowly squeeze the bulb of the pipet to bubble the collected gas into the water.

Note: Gently swirl the water as the gas is bubbled into it. Continue swirling during data recording.

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

29. ☐ Stop data recording when the pH of the water is no longer changing. � (6.2)

30. ☐ Name the data run "SO_2". � (8.2)

31. ☐ Save your experiment. � (11.1)

32. ☐ Complete Table 1 in the Data Analysis section.

33. ☐ Remove the pH sensor from the solution and rinse it with water. Dispose of the solution in the beaker or cup.

Part 2 – Create "Acid Rain"

Rainfall in the United States measures between pH 5.7–4.1. The lowest pH values are observed in the Northeast. For the plant growth portion of this investigation, we will use two acidic solutions. The acid will be sulfuric acid (H2SO4). When sulfur dioxide (SO2) emitted into the air reacts with water, sulfuric acid is produced.

34. ☐ Obtain a 500-mL beaker and add 250 mL of water and 5 mL of the "stock" sulfuric acid solution to the beaker. Place the pH sensor into the beaker.

35. ☐ Start data recording. �(6.2)

36. ☐ Slowly add distilled water to the beaker until the pH of the solution measures between pH 3–4.

Note: If the pH measures above 4, add a very small amount of stock solution to decrease the pH to below 4.

37. ☐ Stop data recording. �(6.2)

38. ☐ Pour the "acid rain" solution you just created into the storage container provided by your teacher. Label the storage bottle with the formula and pH of the solution. Also, record the pH of the solution in Table 2 of the Data Analysis section.

Note: If you have additional "acid rain" solution that does not fit in the storage bottle, give your teacher the excess solution.

Teacher Tip: Save the excess of the students' solutions so that more "acid rain" can be provided to students during the week if they run out of their initial solutions when watering the plants.

39. ☐ In the empty beaker, repeat the procedures above to create an "acid rain" solution, but this solution should have a pH value of 4.5–5.3.

40. ☐ Pour the "acid rain" solution you just created into a storage container. Label the storage bottle with the formula and pH of the solution. Record the pH value in Table 2.

41. ☐ Measure and record the pH of tap water. This water will be the "control", representing rainfall that is not acid rain.

Part 3 – Monitor Plant Growth

42. ☐ In your group, or as a class, determine a method and procedure for watering the plants for one week (or more).

Students are likely to suggest that water from each "acid rain" storage bottle be added to the soil surrounding the plant. Some students may suggest putting the "acid rain" in spray bottles and simulating rainfall by misting the leaves and soil. Either method is valid. Facilitate a discussion with students about controlled variables, especially controlling for the volume of water added or number of sprays applied. Students can also decide whether to water plants every day or every other day.

43. ☐ Based on your teacher's instructions, obtain one or more small plants. Label the pot of each plant with the names of students in your group. Also, label the pot of the plant with the type of rain it will receive (pH 3–4, pH 4.5–5.3, or tap water).

44. ☐ Record in Table 2 of the Data Analysis section your initial observations of the plants.

45. ☐ If the acid rain affects plant growth, what changes to the plant do you predict will occur?

Answers will vary, but students might predict changes in leaf color, wilting, etc.

46. ☐ Place the plants in a location where they will receive adequate sunlight.

47. ☐ For at least one week, water the plants with the various solutions (pH 3–4, pH 4.5–5.3, and tap water). Record detailed observations in Table 2.

Data Analysis

1. ☐ Record data from Part 1 of the investigation into Table 1.

Table 1: pH measurements for acid rain samples

Gas	Maximum pH	Minimum pH	Change in pH
Carbon dioxide (CO_2)	7.5	6.9	–0.6
Sulfur dioxide (SO_2)	8.7	5.2	–3.5

2. ☐ On the following page, record observations of plant growth over the course of 5 or more days.

Table 2: Observations of Plant Growth

Day of Experiment	Appearance of the Plants		
	Control (pH 6.8)	Acid Rain #1 (pH 3.2)	Acid Rain #2 (pH 4.9)
1	Plant appears healthy	Plant appears healthy	Plant appears healthy
2	No Change	No Change	No Change
3	No Change	Foliage is looking wilted	No Change
4	No Change	Foliage wilted, some leaves are brown, stems wilting	Foliage appears wilted
5	No Change	Plant appears dead	Foliage wilted, some leaves are turning brown

Analysis Questions

1. What effect did the gases (CO_2 and SO_2) have on the pH of water? Why did this occur?

Both gases decreased the pH of the water. The water became acidic due to reactions between the gas molecules and water molecules. The reactions produce hydrogen ions (H+) that cause the pH to decrease.

$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO3^-(aq)$

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq) \rightarrow H^+ + HSO_3^-(aq)$

2. Comparing the two gases, which gas could potentially cause the most damage to an ecosystem? Support your answer with evidence.

Sulfur dioxide would likely cause more damage than carbon dioxide. The sulfur dioxide caused a much greater decrease in the pH of the water and would contribute more significantly to the production of acid rain.

3. When did you first notice a change in the plants that were treated with acid rain? Describe the change you noticed first.

The first change was noticed on Day 3 of the experiment. The leaves looked a little wilted.

4. Summarize the changes that were observed in the plants over the course of the experiment. How did the actual changes compare to what you predicted?

The leaves wilted and some of the leaves turned brown. Eventually, the entire plant wilted and looked dead. Answers will vary when students compare actual results to their predictions.

5. Did the "acid rain" samples of different pH affect the plants differently?

Yes, the pH of the "acid rain" sample affected the rate of decline in plant growth. The lowest pH acid rain caused changes that were first observed on Day 3. The more dilute (higher pH) acid rain didn't cause noticeable changes until Day 4.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Which gas, CO_2 or SO_2, is present in the atmosphere primarily due to man-made pollution? Explain.

Sulfur dioxide comes primarily from human activities, such as burning fossil fuels. While the burning of fossil fuels also produces carbon dioxide, carbon dioxide is also produced naturally by living things during cellular respiration.

2. Coal from the western United States has a lower percentage of sulfur impurities than coal found in the eastern United States. Which region would you expect to experience more problems related to acid rain? Explain.

The eastern United States suffers more effects from acid rain than other regions. The power production in this region uses coal that is higher in sulfur impurities and the power production releases sulfur dioxide into the air. This pollution causes formation of acid rain, typically the lowest pH precipitation measured in the country.

3. Acid rain can cause metal ions, such as aluminum ions, to be released into the soil. Why does this happen?

Acids can react with metal-containing compounds. This releases the metal ions from the compound.

4. In addition to affecting plant growth on land, acid rain can also affect plant and animal life in lakes, ponds, and other bodies of water. Identify at least two ways that acid rain would make its way into these bodies of water.

Acid rain can fall directly into the water as precipitation. In addition to this, acid rain may enter the water due to runoff. Acid rain may be trapped in snow and released into rivers when the snow melts.

Multiple Choice Questions

1. Which of the following is true about acid rain?

- **A. Acid rain is linked to CO2 and SO2 molecules in the atmosphere.**
- **B.** Acid rain only affects aquatic organisms.
- **C.** The higher the pH the more acidic the rain.
- **D.** All of the above are true.

2. Which of the following play important roles in the formation of acid rain?

- **A.** Gases in the atmosphere.
- **B.** Buffers in soils and water.
- **C.** Water in the atmosphere.
- **D. 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.

4. Acid rain has been linked to

- **A.** Damage to fish through reactions that create high aluminum concentrations in the water.
- **B.** Reduced nutrient uptake by tree roots.
- **C.** Weakening trees, so they become more susceptible to other types of damage.
- **D. 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. Acid rain affects a variety of plants and animals. Acid rain is a form of precipitation with a pH that is **lower** than the pH of typical rainfall. The severity of the effects of acid rain depends on many factors. It can even affect bodies of water in locations away from where the rain falls, due to movement of water through the **water cycle**. Some types of **organisms**, such as plankton, certain insects, crustaceans, and trout eggs are especially susceptible to damage due to the **low** pH of the water. Acid rain does not just affect terrestrial organisms. **Plants** are harmed when soil contains acidic water, due to the dissolving of **metal ions**, such as aluminum. Some soils have chemicals that **buffer** (neutralize) the effect of acid rain, whereas other soils do not. Crops may have decreased **productivity** due to acidic soils.

2. pH is a measurement of the **concentration** of hydrogen ions [H^+] in water. pH values normally range from 0 through 14: the lower the value, the **higher** the concentration of hydrogen ions. Solutions with pH values below 7 are increasingly **acidic** as the value approaches zero. A pH of 7 is **neutral**—neither acidic nor basic. pH values greater than 7 are considered **basic**. The pH scale is said to be logarithmic, so a solution of pH 3 has **ten** times more hydrogen ions than a solution of pH 4.

3. Gases produced from **fossil fuels** include carbon dioxide (CO_2) and sulfur dioxide (SO_2). These gases are emitted from **power plants** when coal, or other fuels, are burned for power generation. When the gases combine with **water**, acid rain is formed. Sulfur dioxide is a man-made pollutant, but **carbon dioxide** is a natural component of the atmosphere. However, human activities have dramatically increased the concentration of this gas in the atmosphere over the past 100 years.

Extended Inquiry Suggestions

Use different types of plants and compare the sensitivity of the plants to the acid rain treatment. Also, an antacid tablet containing aluminum can be added to the acid rain sample to determine the effect of metal ions on plant growth.

9. Cellular Respiration in Yeast

Objectives

Guide students to investigate how to measure the dissolved oxygen concentration in yeast solutions in the presence and absence of sugar at different temperatures.

Procedural Overview

Students will gain experience conducting the following procedures:

- Use a dissolved oxygen sensor to measure the concentration of dissolved oxygen in a dilute sugar solution
- Measure the dissolved oxygen concentration of a sugar solution before and after adding an activated yeast solution
- Measuring the dissolved oxygen concentration of dilute sugar solutions at varying temperatures, using the temperature sensor, before and after adding activated yeast solution

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dissolved oxygen sensor
- Fast response temperature probe
- Beaker, 250 mL (3)
- Graduated cylinder
- Sugar, 30 g
- Activated yeast solution, 45 mL[1]
- Distilled water, 1 L
- Ice bath (1-L beaker filled with ice)
- Weighing papers (3)
- Balance
- Hot plate
- Stirring rod
- Labeling tape
- Marker

[1] To formulate an activated yeast solution, refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Prokaryotic versus eukaryotic cells
- Enzyme structure and function
- Basics of aerobic and anaerobic cellular respiration

Related Labs in This Guide

Labs conceptually related to this one include:

- Metabolism of Yeast
- Plant Respiration and Photosynthesis
- Respiration of Germinating Seeds

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)
- Calibrating a DO sensor �(3.3) *
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Viewing statistics of data (9.4)
- Saving your experiment �(11.1)

*Calibrating the dissolved O_2 sensor is an optional task.

Background

Are yeast aerobic or anaerobic organisms? Yeasts are actually single-celled organisms that are facultative anaerobes, organisms that have the ability to undergo aerobic respiration in the presence of oxygen and anaerobic respiration in its absence. With oxygen present, yeast will preferentially undergo aerobic respiration because they can make 36 ATP molecules per glucose molecule through aerobic respiration, compared to the 2 ATP molecules produced through anaerobic respiration.

In this activity, yeast will use the dissolved oxygen and the sugar in the water solution as the reactants in the equation:

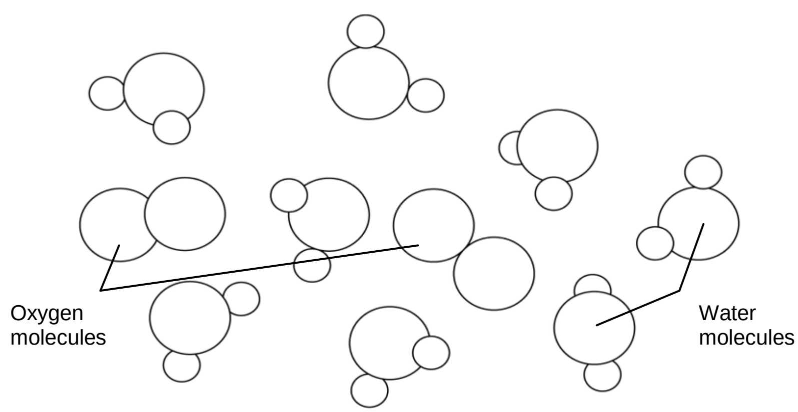
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + 6H_2O + \text{energy (primarily stored in ATP molecules)}$$

As time progresses, you should see a decrease of the concentration of dissolved oxygen level in the water solution, because the yeast cells use it to create ATP. Enzymes drive the overall reaction. Enzymes function best within a specific temperature range, in this case 32 to 38 °C. You should expect to see less oxygen consumed at lower temperatures, because even though aerobic respiration can occur, the enzyme functions at maximum capacity in warmer temperatures. If you were to heat the solution too high, the enzymes would become denatured and not function at all.

Pre-Lab Discussion and Activity

1. What is dissolved oxygen?

Many students do not understand the concept of dissolved oxygen. They know that aquatic organisms, like fish, require oxygen for survival, and that the oxygen is in the water. However, when pressed for more information about the process, students think that the oxygen fish use comes from the water molecule itself (the oxygen from the H_2O, as in the water molecule is being split). First, students need to understand that oxygen is dissolved between the water molecules. This is a hard concept for them to understand. Using the analogy of CO_2 being dissolved in soda, is helpful for them to begin to understand that a gas can dissolve in a liquid. Then, explaining that oxygen can dissolve in water (it just doesn't make it "fizzy" or "bubbly" when you drink it) becomes easier for students to understand



Schematic model of oxygen gas dissolved in water.

2. What is the basic formula for aerobic cellular respiration?

Glucose + O_2 → CO_2 + H_2O + ATP molecules

Be sure to discuss and point out the reactants that are necessary to start the reaction and the end products. Explain that in the activity you will use a dissolved oxygen sensor. The yeast will use the dissolved oxygen, like the fish discussed in Question 1, as their oxygen source for aerobic respiration.

3. Are yeast aerobic or anaerobic organisms?

Yeasts are actually facultative anaerobes, organisms that have the ability to undergo aerobic respiration in the presence of oxygen and anaerobic respiration in its absence. If oxygen is present, yeast will preferentially undergo aerobic respiration because they can make 36 ATP per glucose molecule through aerobic respiration compared to the 2 ATP produced through anaerobic respiration.

4. How can the rate of aerobic cellular respiration be measured in organisms like yeast?

Students can measure the amount of carbon dioxide produced as a byproduct of cell respiration, or they could measure the amount of oxygen consumed by the organism during respiration.

Cell respiration rates can be easily measure in a dilute sugar solution containing yeast. Aerobic respiration rates can be explored by measuring the amount of dissolved oxygen present in the yeast solution. Ask students to predict what they will observe when they combine the yeast solution with sugar. Students should indicate that the dissolved oxygen in the yeast solution will decrease as the yeast use the oxygen for aerobic cellular respiration.

5. Does temperature affect respiration rates in yeast?

This is an excellent opportunity to review enzymes with your students. Because all three steps of aerobic cellular respiration depend on the activity of enzymes, respiration rates would certainly be affected by changes in enzymatic activity. Take this opportunity to review with your students that enzymes are catalytic proteins. Proteins are organic molecules that have specific 3-D configurations. The specificity of an enzyme depends on the shape of its active site, the location on the protein where the enzyme will bind to its substrate. Enzymes have an optimal pH and temperature at which they work most efficiently. When pH and temperature deviate too far past optimal, the enzyme will denature and shape to the active site will change, no longer specifically fitting the substrate. Ask your students to make a connection between these concepts and the effects of temperature on respiration activity in yeast.

Lab Preparation

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

1. Start a culture of active yeast approximately 30 minutes before class begins. To do this for a class of eight groups, add approximately 450 mL of warm water (30 to 35 °C) to 3 packages of dry yeast. Baker's yeast from the grocery store works very well, but make sure that the package is not expired. Add 5 g of sucrose (table sugar), and mix well to assure that the yeast is thoroughly wetted. You will know that you have living, active yeast if the solution has a foamy head after 10 to 15 minutes.

2. The yeast will become active in 5 to 10 minutes and will begin to metabolize the sugar you have added. The suspension will be suitable for use for the remainder of the day, but you should not store it overnight. It might not be active after 24 hours.

3. If you need to make yeast solutions for more than one class, make a larger batch by adjusting the recipe accordingly. To ensure maximum yeast activity for the class, mix the yeast and water at the start of the day, but initially only add 1 g of sugar. Add 1 g more of sugar 10 to 15 minutes before each class. This will ensure that each class uses yeast with the same level of activity.

4. Once you have made the initial solution, there is no need to maintain the yeast at 30 to 35 °C. Make sure that the temperature of the yeast stays between 20 °C or above 45 °C.

5. If you are using a dissolved oxygen probe with a dissolved oxygen sensor, you cannot use the stainless steel temperature probe to gather your data. Electrical interference will occur and your data will not be accurate. Use a fast-response temperature probe. However, if you are using a dissolved oxygen probe with a Water Quality Sensor, you may use either temperature probe.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Handle the hot plate and hot glassware with care.

♦ 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	1	5	3	4
Measure the dissolved oxygen (DO) concentration of yeast-sugar solution at room temperature	Make sugar-yeast solutions of varying temperatures.	Compare and analyze DO concentrations at various temps in yeast-sugar solutions.	Next, measure the DO concentration of yeast-sugar solution at increased temperature.	Finally, measure the DO concentration of yeast-sugar solution at decreased temperature.

Procedure with Inquiry

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

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

Set Up

1. ☐ Start a new experiment on the data collection system, �(1.2) and connect the dissolved oxygen (DO) and temperature sensors to the system. �(2.2)

Note: You can calibrate the sensor, but it is not necessary for this activity. You are looking only at relative changes in DO concentration.

2. ☐ Display Dissolved Oxygen (mg/L) on the y-axis of a graph with Time on the x-axis. �(7.1.1)

3. ☐ Label the 250 ml beakers, 1 through 3, using the labeling tape and marker.

4. ☐ Add 200 mL of room temperature distilled water to each of the three beakers.

5. ☐ Leave beaker #1 at room temperature.

6. ☐ Place beaker #2 in the ice bath to cool until ready for use.

7. ☐ Place beaker #3 on the hot plate on a low setting, and allow it to warm to approximately 35 °C.

Part 1 – Room temperature solution

Collect Data

8. ☐ Place the end of the Temperature Sensor into the water in beaker #1.

9. ☐ Start recording data, �(6.2) adjust the scale of a graph to view all data, �(7.1.2) and write the temperature in Table 1.

10. ☐ Remove and rinse the temperature probe.

11. ☐ How do you think the dissolved oxygen concentration will change after adding yeast at room temperature, to a cold solution, and to a warm solution? Explain your answer.

Answers will vary. However, students that are familiar with the cellular respiration equation will know that oxygen is required for cellular respiration to occur. Most will predict that the dissolved oxygen concentration should decrease after the addition of the yeast at room temperature. The yeast will begin to use the sugar and oxygen as a reactant in aerobic cellular respiration. They should expect to see less oxygen consumed at lower temperatures, and the rate of oxygen consumption should be greatest in the warm solution.

12. ☐ Place the DO sensor carefully into the water, and gently stir the solution with the sensor.

The silver ring on the DO sensor should be immersed in water, but the sensor should not be touching the bottom of the beaker.

13. ☐ Stir the water gently and continuously with the DO sensor for 30 seconds, and then pour 15 mL of the activated yeast solution into the beaker. Continue to stir while you add the yeast.

14. ☐ Record data for 300 seconds, and then stop data recording. �(6.2)

15. ☐ Rinse the DO sensor with the wash bottle or small beaker of clean water, and return it to the storage bottle.

16. ☐ Why do you have to measure the dissolved oxygen concentration of the water for 30 seconds before you add the yeast solution?

Measuring the dissolved oxygen before the addition of yeast allows you to observe conditions in the solution prior to manipulation. It would be difficult to understand the change in dissolved oxygen without knowing the initial concentration.

Part 2 – Cold solution

Collect Data

17. ☐ Place the end of the temperature sensor into the water in beaker #2.

The beaker should remain on ice throughout this part of the lab.

18. ☐ Start data recording, �(6.2) adjust the scale of a graph to view all data, �(7.1.2) and write the temperature in Table 1.

19. ☐ Remove and rinse the temperature probe.

20. ☐ Place the DO sensor carefully into the cold water, and gently stir with the sensor.

The silver ring on the DO sensor should be immersed in water, but the sensor should not be touching the bottom of the beaker.

21. ☐ Stir the water gently and continuously with the DO sensor for 30 seconds, and then pour 15 mL of the activated yeast solution into the sugar solution. Continue to stir while you add the yeast.

22. ☐ Record data for 300 seconds, and then stop recording data. �(6.2)

23. ☐ Rinse the DO sensor with the wash bottle or small beaker of clean water, and return it to the storage bottle.

Part 3 – Warm solution

Collect Data

24. ☐ Place the end of the temperature sensor into the water in beaker #3.

The beaker should remain on the hotplate on "Low" throughout this part of the lab.

25. ☐ Start data recording, �(6.2) adjust the scale of a graph to view all data, �(7.1.2) and write the temperature in Table 1.

If the temperature rises above 40 °C, it is possible to cause damage to the DO sensor.

26. ☐ Remove the temperature probe.

27. ☐ Place the DO sensor carefully into the warm water (not above 40 °C), and gently stir with the sensor.

The silver ring on the DO sensor should be immersed in water, but the sensor should not be touching the bottom of the beaker.

28. ☐ Stir the water gently and continuously with the DO sensor for 30 seconds, and then pour 15 mL of the activated yeast solution into the sugar solution. Continue to stir while you add the yeast.

29. ☐ Collect data for 300 seconds, and then stop collecting data. �(6.2)

30. ☐ Rinse the DO sensor with the wash bottle or small beaker of clean water, and return it to the storage bottle.

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

Data Analysis

1. ☐ Use the Statistics tool �(9.4) to find the minimum and maximum DO concentration on all three data runs, and record in Table 1.

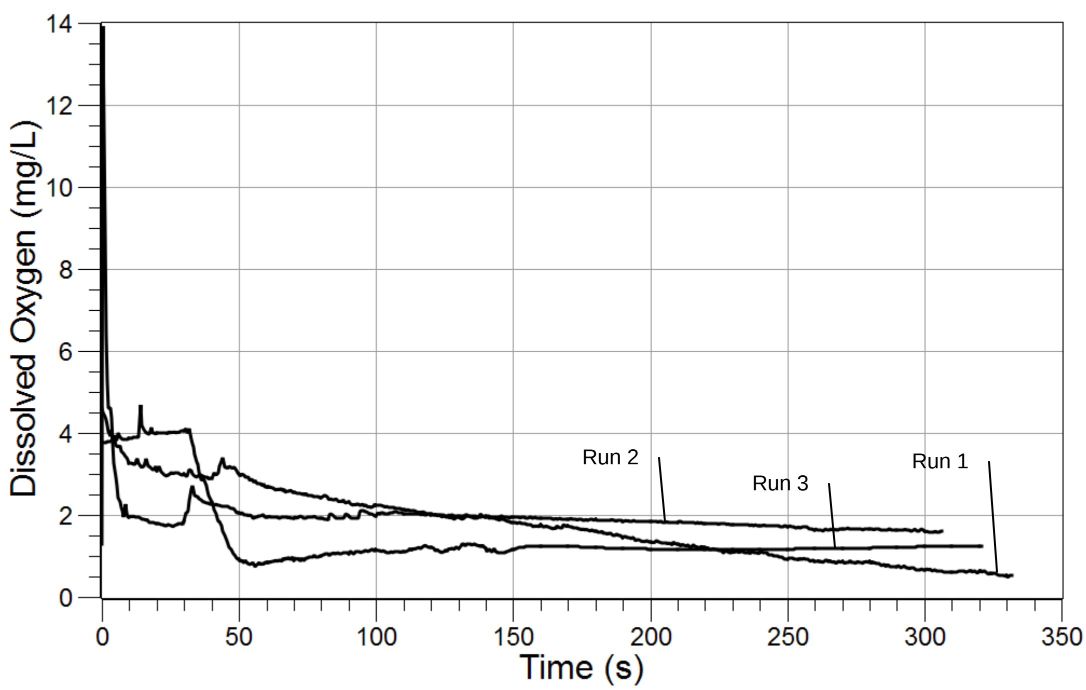
2. ☐ Use this information to calculate the rate of oxygen consumption by the yeast during all three data runs.

Rate of DO Consumption = (Maximum [DO] – Minimum [DO]) / Time (s)

Table 1: Dissolved oxygen and temperature

Run	Condition	Temperature (°C)	Maximum DO (mg/L)	Minimum DO (mg/L)	Rate of DO Consumption ($mg \cdot L^{-1} \cdot s^{-1}$)
#1	Room Temperature	21.0	3.0	0.6	0.008
#2	Cold Temperature	10.0	2.7	1.6	0.0037
#3	Warm Temperature	43.9	4.1	1.2	0.010

3. ☐ Draw a graph of all three data runs. Be sure to label the overall graph, the x-axis and y-axis, and include units on the axes.



Analysis Questions

1. Compare your results for each part of the lab (room temperature, cold, and warm solutions) with your initial predictions. Were your predictions similar to your results? If not, can you think of a reason why they may not have been similar?

Answers will vary. For the room temperature solution, the concentration of dissolved oxygen should have decreased rapidly for a short time and then plateaued. In the cold solution, the decreased temperatures should have a negative effect on the rate of respiration in the yeast, thereby decreasing oxygen consumption. In the warm solution, the increased temperature should accelerate the effect on the rate of respiration in the yeast.

2. In which temperature did the DO level decrease most rapidly? What does this indicate?

The rate of oxygen consumption was the greatest in the warm beaker. The optimal temperature for the environment of yeast is 32 to 38 °C. Yeasts begin to die when the temperature exceeds approximately 48 to 50 °C.

3. Why is oxygen consumption a good measure of respiration rate in yeast?

Oxygen consumption is used to measure respiration rates in yeast because oxygen is a reactant in the reactions of aerobic cellular respiration. Specifically, oxygen is the final electron acceptor in the electron transport chain. A decrease in dissolved oxygen concentration in the solution is an indirect way to measure cell respiration rates in yeast. If the yeast are using the sugar in the solution to make ATP through aerobic cellular respiration, then the dissolved oxygen concentration of the solution will decrease.

Synthesis Questions

1. What is the equation for aerobic cellular respiration?

Glucose + $O_2 \rightarrow CO_2 + H_2O$ + ATP

2. If oxygen is not present, respiration can still occur. What is that process called? What additional end products are produced?

Without oxygen present, anaerobic respiration occurs. There are two types of anaerobic respiration: lactic acid fermentation, which produces lactic acid, and alcoholic fermentation, which produces ethyl alcohol.

3. Explain the difference in the amount of energy produced in aerobic versus anaerobic respiration.

In aerobic respiration, 1 glucose molecule is broken down to produce about 36 ATP molecules. In anaerobic respiration, 1 glucose molecule is broken down to produce about 2 ATP molecules.

4. Name some food and beverage products that are made through fermentation.

Yogurt, bread, kimchi, wine, and beer are examples of common products made through fermentation.

Multiple Choice Questions

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

1. Cellular respiration takes place in

- **A.** Plants only.
- **B.** Animals only.
- **C.** Plants and animals only.
- **D.** **All eukaryotic organisms.**

2. Cellular respiration is the process by which organisms

- **A.** **Release energy from sugar for metabolic use.**
- **B.** Create complex organic molecules from simple ones.
- **C.** Covert heat to chemical energy for metabolic work.
- **D.** Do more than one of the above.

3. Oxygen consumption can be used as a measure of metabolic rate because oxygen is:

- **A.** **Necessary for maximum ATP production**
- **B.** Necessary to replenish glycogen levels.
- **C.** Necessary for fermentation to take place.
- **D.** Required for all living things.

4. By the process of cellular respiration, what is/are released into the environment?

- **A.** Oxygen
- **B.** Carbon dioxide
- **C.** Water
- **D.** **Both B and C**

Key Term Challenge

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

1. The process by which cells "withdraw" energy from glucose with oxygen present is called **aerobic respiration**. **36** ATP molecules are produced during an aerobic respiration cycle. If oxygen is not available, cells can also perform **anaerobic respiration**. Much fewer ATP molecules are produced during this process. There are two types of anaerobic respiration: alcoholic and **lactic acid** fermentation.

2. Cellular respiration is regulated by **enzymes**. Enzymes have a specific **temperature** and pH at which they function most effectively.

3. The overall process of respiration can be summarized in a simple chemical equation. However, respiration is a complex, two-stage process. The first stage takes place in the **cytoplasm** of the organism's cells. There, **glucose** molecules are broken down into smaller molecules. Oxygen is not involved in this stage of respiration, and only a small amount of energy is released. The second stage of respiration takes place in the **mitochondria**. There, the small molecules are broken down into even smaller molecules. These chemical reactions require **oxygen**, and a great deal of **energy** is released. Two other products of respiration are **carbon dioxide** and water.

Extended Inquiry Suggestions

How much oxygen do other organisms consume in a solution? Use pond water, or add algae to water and measure the biological oxygen demand (BOD).

10. Energy Content of Food

Objectives

Guide students to measure the change in temperature of water that is heated by burning samples of food and to compare the energy content of those samples.

Procedural Overview

Students gain experience conducting the following procedures:

- Construct a calorimeter to help measure temperature changes
- Burn different food samples

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor
- Extension cable
- Large base support and rod
- Food holder (10 x 10 cm cardboard, aluminum foil, paper clips)[2]
- Balance
- Graduated cylinder, 100-mL
- Food sample (2) [1]
- Aluminum can, 354-mL (12 ounce)
- Distilled water, 50 mL (per sample)
- Matches (one book)
- Wood splint (4)

[1] To formulate the food samples refer to the Lab Preparation section.

[2] To formulate the food holder refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Structure and function of macromolecules
- The law of conservation of mass
- The law of conservation of energy
- Specific heat
- Heat capacity of water and other substances

Related Labs in This Guide

Labs conceptually related to this one include:

- Enzyme Action
- Respiration of Germinating Seeds
- Metabolism of 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 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)
- Naming a data run �(8.2)
- Finding the values of a point on a graph �(9.1)
- Saving your experiment �(11.1)

Background

When burning food warms a known quantity of water, the amount of thermal energy given off by the food is theoretically equal to the amount of thermal energy gained by the water. The following equation describes this idea:

$$Q = m \times c \times \Delta T$$

The value for Q is the amount of thermal energy; m is the mass of the water; c is the specific heat of water; and ΔT is the change in temperature of the water.

The specific heat of water (c) equals 4.186 joules. People may be more familiar with saying that the specific heat of water equals one calorie. However, this familiarity is tricky. When people think about how many "calories" are listed on packages of food, the technically correct reference is "Calorie" with an upper case "C". Also called a kilocalorie or kcal, one Calorie equals 1000 calories. The metric equivalent of a Calorie is 4186 joules.

A calorie (lower case "c") equals 4.186 joules. A calorie (lower case "c") is the amount of energy it takes to raise the temperature of 1 gram of water by 1 degree Celsius. This is the "*c*" in the equation. Although it may add to confusion, "kilojoule" (1000 joules) is another common term.

Pre-Lab Discussion and Activity

Engage students with questions leading up to the activity of literally burning food, by setting it on fire, to determine which food source has the most stored energy in it. Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity.

1. What does it mean to say, "All human activity requires burning food for energy"?

Some students may state that exercising is burning energy. Explain that in the body, cells need to extract the energy stored in food sources. This process occurs in the mitochondria through the process of cellular respiration.

2. Which food sample will produce the most energy: a cashew or a marshmallow?

Some students may state that the sweet marshmallow will produce the most energy. Some may state cashews contain fat and that fat will produce more energy. Cellular respiration begins with glucose, but energy can be stored in many forms, such as fat, protein, and complex carbohydrates. Glucose is the most easily accessible form of energy. However, fat stores more than twice as much energy.

3. How can you compare the energy content of one food sample with another?

Some students may say that it involves weighing the sample. Others may pick up on the idea that burning food involves temperature. A calorie (lower case "c") is the amount of energy it takes to raise the temperature of 1 gram of water by 1 degree Celsius. Burning a sample of food under a container of water will heat the water. Measuring the change in temperature of the water offers a way of comparing the energy content of the burned foods.

4. Does the mass of a food sample make a difference in the energy content of the sample?

Some students may understand that more massive foods contain more energy content.

5. Will the time that the food takes to burn make a difference in the energy content of the sample?

Some students may state that slower burning food has less energy content because it is harder to access it. Others may understand that food that takes longer to burn must have more energy in it.

Lab Preparation

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

1. Provide two food samples: one with high fat content (cashew) and one with high carbohydrate content (marshmallow). You can substitute other high fat and high carbohydrate samples.

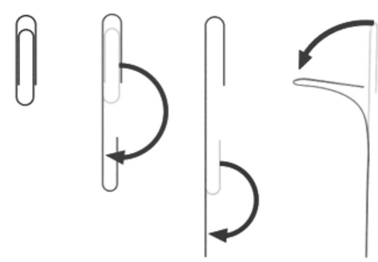
2. Consider the following instructions and the images below so that you can explain to students how to build a food holder. Each food sample will be placed on this little platform to be safely burned.

   a. Cover the 10 by 10 cm cardboard square with aluminum foil.

   b. Straighten a large paper clip, leaving one hooked end.

   c. Bend the hooked end to a 90-degree angle.

   d. Along the diagonal, 2 cm off-center, poke the straightened end of the paper clip through the foil-covered cardboard.



   e. Bend the paper clip at a 90-degree angle, and tape it to the bottom side of the cardboard.

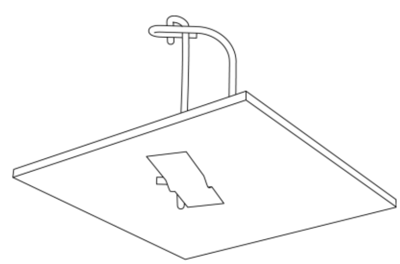
   f. Straighten the second large paper clip, leaving one hooked end.

   g. Bend the hooked end of the second paper clip to a 90-degree angle.

   h. Along the same diagonal, 2 cm off-center (4 cm from the other clip), poke the straightened end of the second clip through the cardboard.

   i. Bend the second clip to a 90 degree angle and tape it to the bottom side of the cardboard.

   j. Link the tops of the hooked ends of the paper clips to form a platform for placing food samples.



Teacher Tip: Be aware of students with food allergies to be sure any student who is allergic to one of the food samples does not handle the food.

Teacher Tip: Properly vent the lab or use a ventilating hood because smoke is produced from the burning of the food samples.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ If you have a food allergy to one of the foods used in this lab, let another lab partner handle the food.
- ♦ Take care when using matches and wooden splints.

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
Obtain or construct something that will hold the burning food.	Measure the mass of an aluminum can with 50 mL of distilled water.	Measure the final mass of the burned food sample.	Place the food sample on the food holder and light with a wood splint.	Keep the sensor in the water at least 45 seconds after the sample stops burning.

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

Note: Use the balance through this procedure to measure mass.

Note: Referenced throughout this procedure, Table 1 is in the Data Analysis section.

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

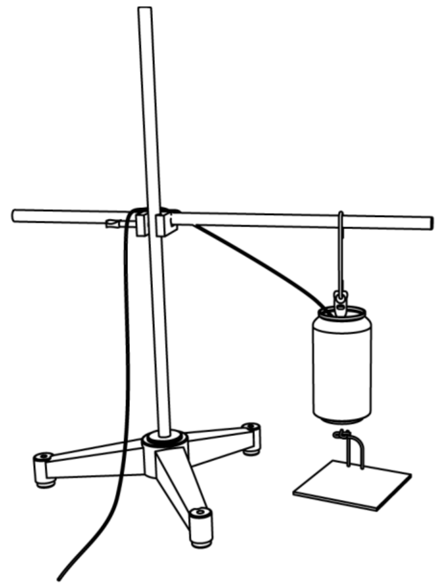
2. ☐ Connect an extension cable into a port on the data collection system. Connect the other end of the extension cable to the temperature sensor. � (2.1)

3. ☐ Display the Temperature (°C) on the y-axis versus Time in seconds (s) on the x-axis of a graph. � (7.1.1)

4. ☐ Measure the mass of the aluminum can and record it in Table 1.

5. ☐ Add 50 mL of distilled water to the aluminum can. Measure the total mass of the can plus the water and record it in Table 1.

6. ☐ Bend a large paper clip and hang one hooked end to the support rod that is attached to the large base. (See the illustration.)



7. ☐ Using the other hooked end of the bent paper clip, hang the aluminum can filled with water by the pop-top tab. (See the illustration.)

8. ☐ Build a food holder as directed by your teacher.

Note: Building a food holder involves covering a 10 by 10 cm cardboard with foil, poking bent paper clips through the cardboard and taping them, then linking them together.

9. ☐ Place a cashew, the first food sample, on the linked paper clips of the food holder.

10. ☐ Adjust the support rod as needed so that the food sample on the paper clips will be 2 to 3 centimeters below the aluminum can.

11. ☐ Measure the total mass of the food sample and food holder and record it in Table 1.

12. ☐ Insert the temperature sensor into the water, taking care not to let the end of the sensor rest on the bottom of the can.

Note: Depending on the type of can, you might need to use a utility clamp to support the sensor

Collect Data

13. ☐ Start data recording. � (6.2)

Note: Prepare to quickly place the burning food sample directly under the aluminum can and to leave it there until it stops burning.

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

15. ☐ Light a wooden splint with a match, and use the splint to light the food sample on the food holder.

Note: Remain still while the food is burning. Any breeze may divert the flames from the food sample making contact with the bottom of the aluminum can.

16. ☐ Immediately after the food sample stops burning, gently twirl the can to stir the water with the sensor still in it.

17. ☐ Stop recording data when the temperature stops rising, which may be 45 seconds or more after the food sample stops burning. � (6.2)

18. ☐ Name data run 1, to a name appropriate for the type of food that was burned. � (8.2)

19. ☐ Measure the mass of the burned food sample and holder and record it in Table 1.

20. ☐ Why do you need to measure the final mass of the burned food sample?

To determine the actual amount of the food sample that was burned during the procedure.

21. ☐ Remove the temperature sensor from the can.

22. ☐ Empty the water from the can.

23. ☐ Add 50 mL of fresh distilled water to the can, and hang it from the support rod as before.

24. ☐ Make sure all food is removed from the food holder before testing the next sample.

25. ☐ Refer to the previous steps to capture data for the other food sample, starting with placing a food sample on the linked paper clips of the food holder. Name data run 2, to a name appropriate for the type of food that was burned.� (8.2)

Note: Make sure, as with the first run, that each food sample is placed two to three centimeters from the aluminum can.

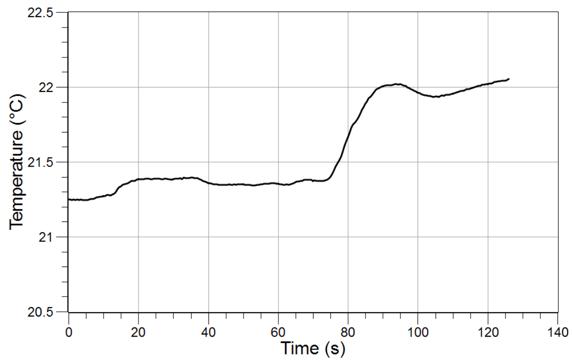
26. ☐ Save your experiment � (11.1) and clean up according to your teacher's instructions.

Data Analysis

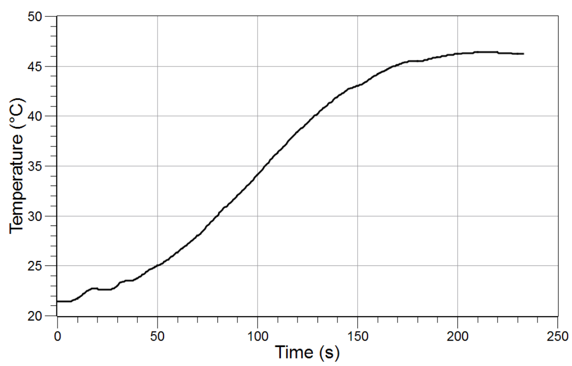
For each food sample many of the rows are filled in directly based on steps in the Procedure section. The following instructions help you calculate the remaining rows.

1. ☐ Make a sketch of your data for Temperature versus Time. Identify which food was used in each sample. Label the overall graph, the x-axis, the y-axis, and include units on the axes.

Marshmallow data:



Cashew data:



1. ☐ Using available tools on your data collection system find Temperature values for Table 1 in the Data Analysis section. �(9.1)

2. ☐ For the mass of water subtract the mass of the container from the mass of the container plus the water.

3. ☐ For the change in mass of the food sample subtract the mass of the sample + holder after burning from the mass of the sample + holder before burning.

4. ☐ For the change in temperature of the water (ΔT) subtract the temperature after burning from the temperature before burning.

5. ☐ For the generated heat in the water used (Q) multiply the mass (m) of the water times the change in temperature (ΔT) of the water times the specific heat of water (c). Since the unit of measure in the table is kilojoules instead of joules, divide the result by 1000.

$$Q = m \times c \times \Delta T$$

Note: The value "c" is the specific heat of water. The number of joules, 4.186, is expressed in grams per degree Celsius.

6. ☐ For the energy content of the food sample divide the generated heat in the water (Q) by the change of mass of the sample.

7. ☐ For the average energy content of the food sample, add the energy content number of every student in the class and divide by the number of energy content results that were obtained in the activity.

Table 1: Energy content of a cashew and a marshmallow

Item	Cashew	Marshmallow
Mass of empty container (grams)	48.5	48.5
Mass of container + water (grams)	99.1	98.4
Mass of water (grams)	50.6	50.0
Mass of sample + holder before burning (grams)	9.06	7.69
Mass of sample + holder after burning (grams)	8.63	7.30
Change in mass of food sample (grams)	0.43	0.39
Water temperature before burning (°C)	21.4	21.2
Water temperature after burning (°C)	46.2	22.1
Change in temperature, ΔT (°C)	24.8	0.80
Generated heat, Q (kilojoules)	5.25	0.17
Energy content or heat per gram of sample (kilojoules per gram)	12.2	0.43
Average energy content of all samples tested in the class (kilojoules per gram)		

Analysis Questions

1. Which food had the highest energy content?

Answers will vary. In the sample data provided the cashew had the highest energy content at 12.2 kilojoules per gram.

2. Which food had the lowest energy content?

Answers will vary. In the sample data provided the marshmallow had the lowest energy content at 0.44 kilojoules per gram.

3. Do you think that all of the energy released by the burning food sample was absorbed by the water? Why or Why not?

Not all the energy released by the burning food is absorbed by the water. Some of the energy released by the burning food is transferred to the air, the aluminum can, and the food holder instead of water.

4. What are some things you would do to change the procedure in this activity?

Suggestions might include insulating the setup so less energy is transferred to the air, or measuring the temperature change of the aluminum can and the food holder in order to determine how much of the energy they absorb. This suggestion can lead to exploration of specific heat and heat capacity for different substances.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Based on your the samples you tested what can you conclude about the relative energy content of fats and carbohydrates?

The results should demonstrate that the food sample that contains fat has the higher energy content.

2. What advice would you give to a sports team about the energy content of these foods?

Answers will vary. Although fatty food contains more energy per gram, they are often harder to digest and are not the source of energy that will be metabolized first. Carbohydrates are more readily accessed by cells for instant energy boosts.

3. For each of the sample foods how many minutes of reading could you manage from a 50-gram serving. (A light activity such as reading consumes about 7 kilojoules per minute.)

Answers will vary depending on food samples used. Based on the sample data, on 50 grams one could read for about 87 minutes on cashews and 3 minutes on marshmallows.

Multiple Choice Questions

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

1. In what form do animals store glucose (carbohydrates)?

- **A.** amylose
- **B.** **glycogen**
- **C.** glycerol
- **D.** guanine

2. Which of the following will yield the most energy per gram, when burned?

- **A.** carbohydrates
- **B.** sugars
- **C.** **fats**
- **D.** proteins

3. Which of the following is the most accessible for cells to use to convert into ATP? Hint: It is used first during cellular respiration.

- **A.** **carbohydrates**
- **B.** protein
- **C.** fat
- **D.** DNA

Key Term Challenge

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

1. A **fat** is a large lipid made from two kinds of smaller molecules: glycerol and fatty acids. The main function of fats is **energy storage**. A gram of fat stores more than **twice** as much energy as **carbohydrates**. This compact energy storage enables mobile animals to get around much better than if the animal had to carry its stored energy in the bulkier form of carbohydrates. In addition to storing energy, fat tissue cushions vital organs and insulates the body.

2. Water can absorb or release relatively large amounts of **energy** in the form of heat with only a slight change in its own temperature. This property of water is called **specific heat** and is used to capture the energy released from the burning food samples in the experiment.

3. **Nutrients** in your diet provide energy for powering cellular processes. The energy available in food is measured in kilocalories, which are equal to 1,000 **calories**. A calorie is the amount of heat energy required to **raise** the temperature of 1 gram of water 1 degree Celsius. The greater the number of calories in a quantity of food, the **more** energy the food contains.

Extended Inquiry Suggestions

Using the same procedure, measure the energy content of other kinds of foods and compare results to published values for the foods.

Have students keep a food diary for the amount of food they eat in one day. Using the food labels and various books on nutrition, have the students calculate their total energy intake for one day.

11. Exploring Microclimates

Objectives

In this activity, students explore local microclimates by measuring weather data around the school. Students:

- Measure weather conditions at different locations using a weather sensor, and compare with current weather conditions in the area
- Determine the impact that a location's environmental conditions have on the microclimate of a given area

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the temperature, barometric pressure, relative humidity, and dew point of various microclimates around their school ground
- Comparing weather data and drawing conclusions concerning factors that may affect microclimates

Time Requirement

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

Materials and Equipment

For each student or group:

- Mobile data collection system
- Weather/anemometer sensor (or weather sensor)
- Sensor extension cable
- Cardboard box (or other covering)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- A microclimate is the climate of a small, localized area in which the climate differs from the general climate due to the unique amounts of sunlight, wind, and moisture in this localized area.
- Temperature describes a degree of hotness or coldness as measured using a thermometer. Temperature is also a measure of how fast the atoms and molecules of a substance move.
- Three kinds of heat transfer are radiation, conduction, and convection.
- Climate describes all weather occurring over a period of years in a given place.
- Weather is the state of the atmosphere, with variables such as temperature, cloudiness, precipitation, and radiation. Weather also takes into account conditions such as relative humidity, barometric pressure, temperature, and dew point.

Related Labs in This Guide

Labs conceptually related to this one include:

- Weather in a Terrarium
- Acid Rain

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data acquisition device �(2.1)
- Starting and stopping recording �(6.2)
- Displaying data in a graph�(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Changing the variable on the x- or y-axis of a graph �(7.1.9)
- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

A microclimate is the climate of a small area that differs from the area around it. It may be warmer or colder, wetter or drier, or more or less prone to frosts.

A number of factors impact the conditions in a microclimate. The slope of land; the direction in which the slope faces; and the amount of shade, wind, exposure, and drainage will also all impact the conditions in a microclimate. Other things like a nearby body of water or the presence of an urban area also influence microclimates. Urban areas are notoriously much warmer than the surrounding open land because the buildings, sidewalks, and pavements absorb and reflect or radiate heat.

Your house, school, and other buildings create microclimates. Just like urban areas, your house absorbs heat during the day and radiates that heat back at night.

Paved surfaces such as patios, driveways and sidewalks can absorb heat and radiate it at night, moderating nighttime temperatures. These impervious areas cannot absorb water and may create wet spots if water flowing off of them concentrates into one area. Similar wet areas may occur where water flows off roofs or out of downspouts.

Wind can create a microclimate. For example, a prevailing northwest wind at your house can create a warmer, more sheltered microclimate on the south and east sides of your house. While the north side of your house or school may receive harsh winds and no sun during the winter, in summer (when the sun rises north of east and sets north of west), these same areas can bake in heat and dry out from the same prevailing winds. Also, wind hitting your house or school creates turbulence and higher wind speeds along the wall as the wind goes around the corners of the building.

Buildings can also create "rain shadows" on the lee side of a house during windy rains. Trees can also prevent rain from hitting the ground and offer shade that keeps the temperature cooler than an area with a lot of sun.

The difference between weather and climate is a matter of time. Weather is the atmospheric conditions at a given point in time, whereas climate is the prevailing atmospheric conditions over a relatively long period of time (years).

Pre-Lab Discussion and Activity

Engage your students in a formal class discussion, brainstorming session, or with individual written responses by asking them to discuss the following questions:

1. What is the difference between weather and climate?

Weather is the state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity, and barometric pressure.

Climate includes the weather conditions, including temperature, precipitation, and wind, that prevail in a particular region.

2. What is a microclimate?

A microclimate is the climate of a specific place within an area as contrasted with the climate of the entire area.

3. What conditions affect microclimates?

The amount of shade, wind, exposure, and drainage will all impact the conditions in a microclimate, as can things like a nearby body of water or the presence of an urban area.

4. Name several good locations on the school grounds with varying microclimates.

Answers will vary. Areas such as those in the Lab Preparation section may be suggested.

Lab Preparation

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

1. Use the internet, radio, or TV for local weather conditions to help you choose a "good weather" day for doing this lab. A sunny day works best.
2. You may want to walk school grounds to determine the best locations for studying microclimates.
3. Try to choose several locations with different microclimates. Try to avoid overcast days. Suggestions include:
   - Shaded grass area
   - Shaded concrete or asphalt areas
   - Sunny grass area
   - Sunny concrete or asphalt areas
   - Area near the North side of school building
   - Area near the South side of school building
   - Areas that are very moist or very dry
   - Areas with a lot of vegetation

Teacher Tip: It is easier to compare results if your units for weather data measurements on your data collection device are the same as those for local weather data.

Teacher Tip: Cover the weather/anemometer sensor to protect it from direct sunlight. A cardboard box works well.

Teacher Tip: Instruct students to keep their voices quiet when they are outside collecting data so they do not disrupt other classes.

Teacher Tip: Plan to watch students carefully while collecting temperature and weather data outside.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Do not go into restricted areas or near moving vehicles.
- ♦ Do not touch or approach animals, because they may bite.

Sequencing Challenge

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

2	3	4	1	5
Set up your equipment to measure temp-erature, baro-metric pressure, relative humidity, dew point, and wind speed.	Choose locations to take measurements Collect data at the different locations.	View your data and record your measurements in the data table. Save your data.	Obtain your current local weather. Record these in the data table.	Determine the average temperature for each location.

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. ☐ Obtain your current local weather conditions from your teacher, radio, TV, or the internet. This is your control data.

2. ☐ Record your control data in Table 1.

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

4. ☐ Connect a weather/anemometer sensor to your data collection system using a sensor extension cable. �(2.1)

5. ☐ Create a data display in a graph. �(7.1.1)

Note: You may choose any of the weather options (temperature, humidity, etc.) to display on the y-axis of the graph with Time on the x-axis. All weather measurements will be recorded simultaneously, regardless of what is displayed.

6. ☐ Make a list of the locations near your school at which you plan to take weather measurements. You should have at least 4.

There are several location characteristics that you should consider for data recording:

- Shaded grass area
- Shaded concrete or asphalt areas
- Sunny grass area
- Sunny concrete or asphalt areas
- Area near the North side of school building
- Area near the South side of school building
- Areas that are very moist, or very dry
- Areas with a lot of vegetation

Location 1: Shaded grass area near the football field

Location 2: Sunny area near the South side of school building

Location 3: Sunny area in the parking lot

Location 4: Shady area near the North side of school building

7. ☐ Which weather data measurement will have the greatest change while investigating microclimates: temperature, barometric pressure, relative humidity or dew point?

The greatest variation may occur with temperature, due to the influence of wind, sun, and structures on a changing temperature. Alternatively, humidity might vary the most if some areas are irrigated or near a body of water, while other areas are in paved or rocky or are sunny and dry.

Collect Data

8. ☐ Perform the following steps at each of your four locations:

a. ☐ Go to the location.

b. ☐ Write a description of the physical conditions of this location (shade, sun, asphalt, moist, etc.) in Table 1 in the Data Analysis section.

c. ☐ Hold your sensor approximately 1 meter above the ground, and start data recording. �(6.2)

Note: Your weather/anemometer sensor will record all possible measurements, even though they are not displayed on the graph screen.

d. ☐ Collect data for 60 seconds. You can monitor the time using the graph screen. Remember to cover the sensor to shield it from direct sun.

e. ☐ Stop recording data after 60 seconds. �(6.2)

f. ☐ Name the data run �(8.2) with a location description, such as "Football Field" and write the name in Table 1.

g. ☐ What differences in measurements do you expect to see in the next location?

Answers will vary, but students should specifically relate changes they expect in weather parameters to differing features of the two locations.

9. ☐ Why did you need to collect data for 60 seconds?

This allows time for the sensor to stabilize.

10. ☐ Why was holding the sensor 1 meter above the ground important?

Weather conditions have a standard monitor elevation so that you gather consistent measurements from one area to the next. Reflective radiation from the ground, soil moisture, and low-growing plants can all affect the measurements such as temperature and humidity. We want to minimize as many variables as possible. However, if students want to investigate the effects of elevation and biotic conditions on weather, you should encourage them to do it as an extension to this activity.

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

Data Analysis

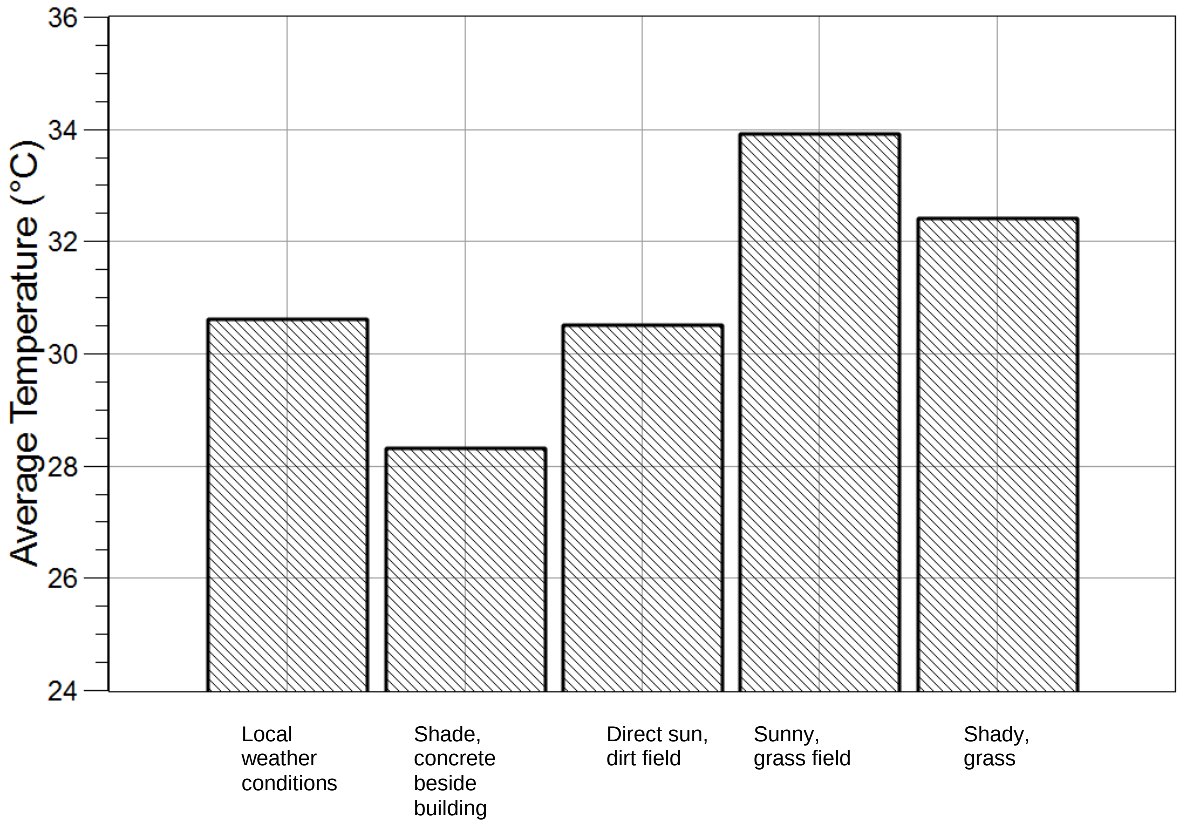
1. ☐ View your statistics of data to complete Table 1. �(9.4)

2. ☐ Toggle through the different data measurements by changing the variable on the y-axis �(7.1.9) and view the statistics of each measurement �(9.4) and record the information in Table 1.

Table 1: Data table

	Description of Location (shade, sun, asphalt, concrete)	Average Temp. (°C)	Average Relative Humidity (%)	Average Barometric Pressure (in Hg)	Dew Point (°C)	Wind Speed or Conditions
Local Weather Conditions (control data)	partly cloudy	30.6	60	29.9	22.2	5 mph
Run 1	shade, concrete beside building	28.3	66	29.9	20.6	light
Run 2	direct sun, dirt field	30.6	67	30	22.9	light
Run 3	sunny grass field	33.9	71	29.9	27.1	0
Run 4	shady grass	32.4	61	30	23.2	0

3. ☐ Draw a bar graph that represents the average temperature recorded at each location. Label the overall graph, as well as the x-axis and y-axis, including units and scale of measurement on the y-axis and location labels on the x-axis.



Analysis Questions

1. What happened to the temperature at each location? Did it stay the same or change?

Answers will vary. Students should see some temperature changes depending on the amount of sunlight, radiant heat, and reflected heat.

2. What happened to the dew point at each location? Did it stay the same or change?

Answers will vary. Students may see small changes in the dew point as the temperature changes. Wind conditions may also affect this.

3. What happened to the barometric pressure at each location? Did it stay the same or change?

Answers will vary. The barometric pressure should change very little.

4. What happened to the relative humidity at each location? Did it stay the same or change?

Answers will vary depending on absolute humidity and temperature changes in the different locations.

5. What measurement in your data changed the most? What can account for this?

Answers will vary. Most students should see a greater change with temperature, especially in sunny areas with asphalt or concrete surfaces; however, local conditions might yield greater variation in humidity.

6. Compare your predictions to your results. Were your predictions accurate, or did your results show something other than what you expect? Explain any differences.

Answers will vary, but to support their answers, students should include specific reference to the data they collected as it relates to different features of the different locations.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If your temperature data showed a change from location to location, what environmental factors do you think influenced these changes?

The amount of shade, wind, exposure, and drainage all impact the conditions in a microclimate, as can things like a nearby body of water or the presence of an urban area.

2. Why would your barometric pressure remain the same (or similar) while some of your other measurements showed a change?

Barometric pressure is not influenced by the same environmental conditions as the other data readings. Since all measurements are taken at about the same time and altitude, the barometric pressure would not be expected to vary much.

3. What physical structures in your school yard, identified in your locations, might influence the data changes that you observed?

The school building (or other physical structure), trees, hedges, walls, stadiums and seating, bodies of water, and ground material may all affect the measurement readings.

4. What effect do plants have on the microclimate?

Plants provide shade and increase humidity and cooling through transpiration, and they also may block air flow.

Multiple Choice Questions

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

1. **Which of the following do not affect microclimates?**

- **A.** Sunlight
- **B.** Wind
- **C.** **Animals**
- **D**. Plants

2. **All of the weather conditions that prevail in a particular region are called:**

- **A.** Weather
- **B.** **Climate**
- **C.** Microclimate
- **D.** Abiotic factors

3. **In what way can buildings affect a microclimate?**

- **A.** Increase temperature
- **B.** Decrease temperature
- **C.** Change in wind speed
- **D.** **All of the above**

4. **Which of the following is NOT one of the three main constituents of weather?**

- **A.** Temperature
- **B.** Humidity
- **C.** Air pressure
- **D.** **Altitude**

Key Term Challenge

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

1. Microclimate is the suite of climatic conditions of a small, specific place within a larger area measured in localized areas near the earth's surface. Environmental variables including **temperature**, **sunlight**, **wind speed**, and **moisture** influence microclimates.

2. Weather is the day-to-day conditions of the atmosphere at a specific place and time. Four main constituents of weather include **temperature**, **wind**, moisture, and **air pressure**. All weather systems have well-defined cycles and structural features, and they are governed by the laws of heat and motion. These conditions are studied in **meteorology**, the science of weather and weather forecasting.

3. Weather differs from **climate**, which is the weather that a particular region experiences over a long period of time. Climate includes the **averages** and variations of all weather elements. Climate is the long-term effect of the sun's radiation on the rotating earth's varied surface and **atmosphere**. It can be understood most easily in terms of **annual** or seasonal averages of temperature and precipitation. Climate has profound effects on vegetation and animal life, including **humans**.

Extended Inquiry Suggestions

Have students conduct this investigation at different times of the year. Then, compare data collected during a warm month and data collected during a cold month. Are the changes in microclimates greater in warm or cold conditions?

Students can collect data at different distances from the ground. Does elevation affect the microclimate?

12. Exploring Microclimates through Temperature

Objectives

In this activity, students explore local microclimates by measuring weather data around the school. Students:

- Measure weather conditions at different locations using a weather sensor, and compare with current weather conditions in the area
- Determine the impact that a location's environmental conditions have on the microclimate of a given area

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the temperature of various microclimates around their school ground
- Comparing weather data and drawing conclusions concerning factors that may affect microclimates

Time Requirement

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

Materials and Equipment

For each student or group:

- Mobile data collection system
- Temperature sensor

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ A microclimate is the climate of a small, localized area in which the climate differs from the general climate due to the unique amounts of sunlight, wind, and moisture in this localized area.
- ♦ Temperature describes a degree of hotness or coldness as measured using a thermometer. Temperature is also a measure of how fast the atoms and molecules of a substance move.
- ♦ Three kinds of heat transfer are radiation, conduction, and convection.
- ♦ Climate describes all weather occurring over a period of years in a given place.
- ♦ Weather is the state of the atmosphere, with variables such as temperature, cloudiness, precipitation, and radiation. Weather also takes into account conditions such as relative humidity, barometric pressure, temperature, and dew point.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Weather in a Terrarium
- ♦ Acid Rain
- ♦ Exploring Microclimates with a GPS
- ♦ Exploring 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 a sensor to your data collection system �(2.1)
- ♦ Starting and stopping recording data �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Viewing statistics of data �(9.4)
- ♦ Saving your experiment �(11.1)

Background

A microclimate is the climate of a small area that differs from the area around it. It may be warmer or colder, wetter or drier, or more or less prone to frosts.

A number of factors impact the conditions in a microclimate. The slope of land; the direction in which the slope faces; and the amount of shade, wind, exposure, and drainage will also all impact the conditions in a microclimate. Other things like a nearby body of water or the presence of an urban area also influence microclimates. Urban areas are much warmer than the surrounding open land because the buildings, sidewalks, and pavements absorb and reflect or radiate heat.

Your house, school, and other buildings create microclimates. Just like urban areas, your house absorbs heat during the day and radiates that heat back at night.

Paved surfaces, such as patios, driveways and sidewalks can absorb heat and radiate it at night, moderating nighttime temperatures. These impervious areas cannot absorb water and may create wet spots if watering flowing off of them concentrates into one area. Similar wet areas may occur where water flows off roofs or out of downspouts.

Wind can create a microclimate. For example, a prevailing northwest wind at your house can create a warmer, more sheltered microclimate on the south and east sides of your house. While the north side of your house or school may receive harsh winds and no sun during the winter, in summer (when the sun rises north of east and sets north of west), these same areas can bake in heat and dry out from the same prevailing winds. Also, wind hitting your house or school creates turbulence and higher wind speeds along the wall as the wind goes around the corners of the building.

Buildings can also create "rain shadows" on the lee side of a house during windy rains. Trees can also prevent rain from hitting the ground and offer shade that keeps the temperature cooler than an area with a lot of sun.

The difference between weather and climate is a matter of time. Weather is the atmospheric conditions at a given point in time, whereas climate is the prevailing atmospheric conditions over a relatively long period of time (years).

Pre-Lab Discussion and Activity

Engage your students in a formal class discussion, brainstorming session, or with individual written responses by asking them to discuss the following questions:

1. What is the difference between weather and climate?

Weather is the state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity, and barometric pressure.

Climate includes the weather conditions, including temperature, precipitation, and wind, that prevail in a particular region.

2. What is a microclimate?

A microclimate is the climate of a specific place within an area as contrasted with the climate of the entire area.

3. What conditions affect microclimates?

The amount of shade, wind, exposure, and drainage will all impact the conditions in a microclimate, as can things like a nearby body of water or the presence of an urban area.

4. Name several good locations on the school grounds with varying microclimates.

Answers will vary. Areas such as those in the Lab Preparation section may be suggested.

Lab Preparation

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

1. Use the internet, radio, or TV for local weather conditions to help you choose a "good weather" day for doing this lab. A sunny day works best.
2. You may want to walk school grounds to determine the best locations for studying microclimates.
3. Try to choose several locations with different microclimates. Try to avoid overcast days. Suggestions include:
   - Shaded grass area
   - Shaded concrete or asphalt areas
   - Sunny grass area
   - Sunny concrete or asphalt areas
   - Area near the North side of school building
   - Area near the South side of school building
   - Areas that are very moist or very dry
   - Areas with a lot of vegetation

Teacher Tip: Instruct students to keep their voices quiet when they are outside collecting data so they do not disrupt other classes.

Teacher Tip: Plan to watch students carefully while collecting temperature and weather data outside.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not go into restricted areas or near moving vehicles.
- Do not touch or approach animals, because they may bite.

Sequencing Challenge

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

2	3	4	1	5
Set up your equipment.	Choose locations to take measurements Collect data at the different locations.	View your data and record your measurements in the data table. Save your data.	Obtain your current local weather. Record these in the data table.	Determine the average temperature for each location.

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. ☐ Obtain your current local weather conditions from your teacher, radio, TV, or the internet. This is your control data.

2. ☐ Record your control data in Table 1.

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

4. ☐ Connect a temperature sensor to your data collection system.

5. ☐ Create a data display in a graph showing Temperature on the y-axis and Time on the x-axis. �(7.1.1)

6. ☐ Make a list of the locations near your school at which you plan to take temperature measurements. You should have at least 4.

There are several location characteristics that you should consider for data recording:

- ♦ Shaded grass area
- ♦ Shaded concrete or asphalt areas
- ♦ Sunny grass area
- ♦ Sunny concrete or asphalt areas
- ♦ Area near the North side of school building
- ♦ Area near the South side of school building
- ♦ Areas that are very moist, or very dry
- ♦ Areas with a lot of vegetation

Location 1: Shaded grass area near the football field________________________________

Location 2: Sunny area near the South side of school building________________________

Location 3: Sunny area in the parking lot____

Location 4: Shady area near the North side of school building________________________

Collect Data

7. ☐ Perform the following steps at each of your four locations:

a. ☐ Go to the location.

b. ☐ Write a description of the physical conditions of this location (shade, sun, asphalt, moist, etc.) in Table 1 in the Data Analysis section.

c. ☐ Hold your sensor approximately 1 meter above the ground, and start data recording. �(6.2)

d. ☐ Collect data for 60 seconds. You can monitor the time using the graph screen. Remember to cover the sensor to shield it from direct sun.

e. ☐ Stop recording data after 60 seconds. �(6.2)

f. ☐ Name the data run �(8.2) with a location description, such as "Football Field", and write the name in Table 1.

g. ☐ What differences in temperature do you expect to see in the next location?

Answers will vary, but students should specifically relate changes they expect in weather parameters to differing features of the two locations.

8. ☐ Why did you need to collect data for 60 seconds?

This allows time for the sensor to stabilize.

9. ☐ Why was holding the sensor 1 meter above the ground important?

Weather conditions have a standard monitor elevation so that you gather consistent measurements from one area to the next. Reflective radiation from the ground, soil moisture, and low-growing plants can all affect the measurements such as temperature and humidity. We want to minimize as many variables as possible. However, if students want to investigate the effects of elevation and biotic conditions on weather, you should encourage them to do it as an extension to this activity.

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

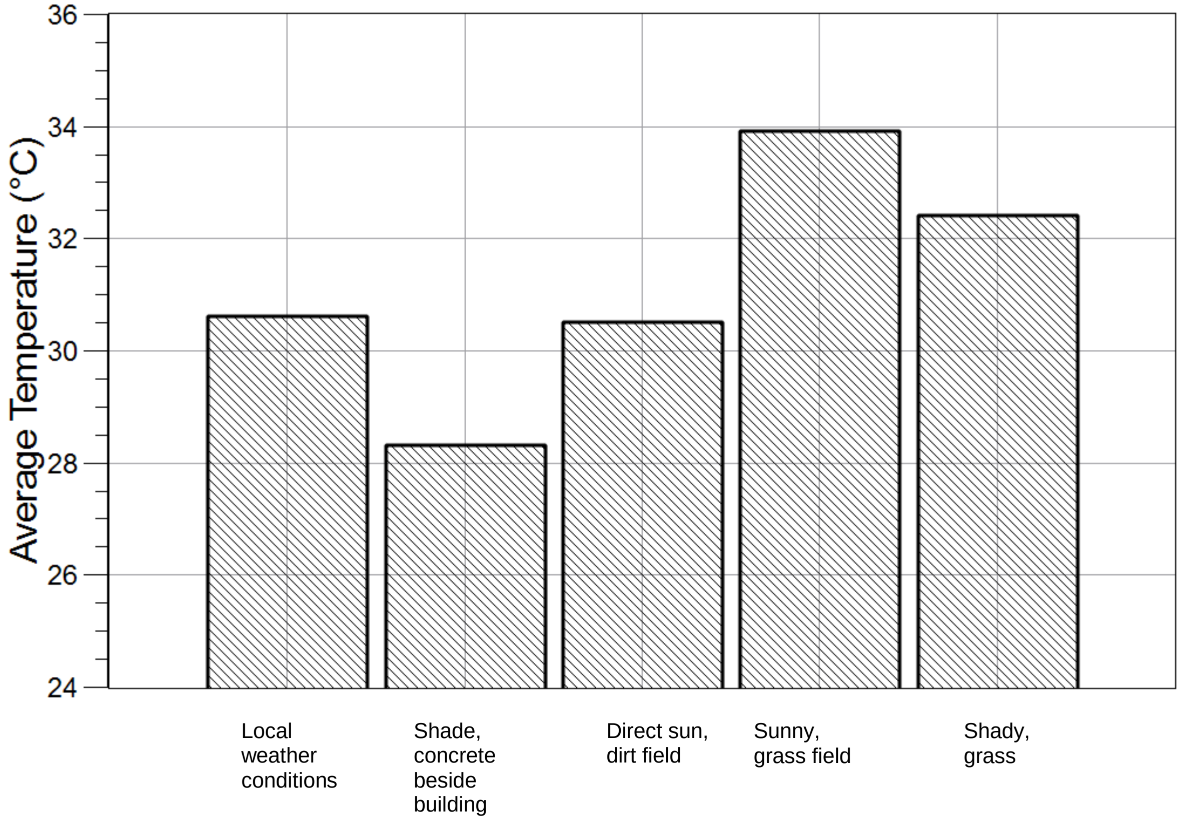
Data Analysis

1. ☐ View the statistics to complete Table 1. �(9.4)

Table 1: Microclimate measurements

Location (label)	Description of Location (shade, sun, asphalt, concrete)	Average Temperature (°C)
Local Weather Conditions (control data)	partly cloudy	30.5
Run 1	shade, concrete beside building	28.3
Run 2	direct sun, dirt field	30.5
Run 3	sunny, grass field	33.9
Run 4	shady, grass	32.4

2. ☐ Plot a graph that represents the average temperature recorded at each location. Label the overall graph.



Analysis Questions

1. What happened to the temperature at each location? Did it stay the same or change?

Answers will vary. Students should see some temperature changes depending on the amount of sunlight, radiant heat, and reflected heat.

2. Compare your predictions to your results. Were your predictions accurate, or did your results show something other than what you expect? Explain any differences.

Answers will vary, but to support their answers, students should include specific reference to the data they collected as it relates to different features of the different locations.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If your temperature data showed a change from location to location, what environmental factors do you think influenced these changes?

The amount of shade, wind, exposure, and drainage all impact the conditions in a microclimate, as can things like a nearby body of water or the presence of an urban area.

2. What physical structures in your school yard, identified in your locations, might influence the data changes that you observed?

The school building (or other physical structure), trees, hedges, walls, stadiums and seating, bodies of water, and ground material may all affect the measurement readings.

3. What effect do plants have on the microclimate?

Plants provide shade and increase humidity and cooling through transpiration and they also may block air flow.

Multiple Choice Questions

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

1. Which of the following do not affect microclimates?

- **A.** Sunlight
- **B.** Wind
- **C.** **Animals**
- **D.** Plants

2. All of the weather conditions that prevail in a particular region are called:

- **A.** Weather
- **B.** **Climate**
- **C.** Microclimate
- **D.** Abiotic factors

3. In what way can buildings affect a microclimate?

- **A.** Increase temperature
- **B.** Decrease temperature
- **C.** Change in wind speed
- **D.** **All of the above**

4. Which of the following is NOT one of the three main constituents of weather?

- **A.** Temperature
- **B.** Humidity
- **C.** Air pressure
- **D.** **Altitude**

Key Term Challenge

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

1. Microclimate is the suite of climatic conditions of a small, specific place within a larger area measured in localized areas near the earth's surface. Environmental variables including **temperature**, **sunlight**, **wind speed**, and **moisture** influence microclimates.

2. Weather is the day-to-day conditions of the atmosphere at a specific place and time. Four main constituents of weather include **temperature, wind**, moisture, and **air pressure**. All weather systems have well-defined cycles and structural features, and they are governed by the laws of heat and motion. These conditions are studied in **meteorology**, the science of weather and weather forecasting.

3. Weather differs from **climate**, which is the weather that a particular region experiences over a long period of time. Climate includes the **averages** and variations of all weather elements. Climate is the long-term effect of the sun's radiation on the rotating earth's varied surface and **atmosphere**. It can be understood most easily in terms of **annual** or seasonal averages of temperature and precipitation. Climate has profound effects on vegetation and animal life, including **humans**.

Extended Inquiry Suggestions

Have students conduct this investigation at different times of the year. Then, compare data collected during a warm month and data collected during a cold month. Are the changes in microclimates greater in warm or cold conditions?

Students can collect data at different distances from the ground. Does elevation affect the microclimate?

13. Metabolism of Yeast

Objectives

Students will explore the production of carbon dioxide gas by yeast in aerobic and anaerobic conditions and determine if high temperatures effect the respiration of yeast.

Procedural Overview

Students will gain experience conducting the following procedures:

- Use a carbon dioxide gas sensor to measure the change in CO_2 concentration versus time for grape juice and yeast in various temperature conditions.
- Calculate and compare the rate of CO_2 gas production for each trial

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10-15 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each student or group:

- Data collection system
- carbon dioxide gas sensor and extension cable
- Sampling bottle (included with sensor)
- Beaker (2), 250-mL
- Graduated cylinder, 100-mL
- Graduated cylinder, 10-mL
- Hot plate
- Stirring rod
- Yeast, dry (1 package)
- Grape juice
- Water, 1 L

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Optimal conditions for enzyme functionality.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Enzyme Action
- ♦ Plant Respiration and Photosynthesis
- ♦ Respiration of Germinating Seeds
- ♦ Cellular Respiration in 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 a sensor to your data collection system �(2.1)
- ♦ Calibrating a carbon dioxide gas sensor �(3.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Saving your experiment �(11.1)

Background

All organisms require a source of energy to maintain cell physiology and growth. Cellular respiration is the process utilized to oxidize food molecules and release the energy to fuel life processes.

There are two types of cellular respiration, aerobic and anaerobic. Both begin with glycolysis. Glycolysis is a biochemical process utilized by most organisms, including yeasts, to convert glucose to pyruvate and adenosine triphosphate (ATP). Prior to glycolysis, enzymes break down starch into complex sugars (such as sucrose) and then into simple sugars (such as fructose and glucose).

Animal cells and some unicellular organisms convert the pyruvate to lactic acid (lactic acid fermentation). Some plant cells and unicellular organisms convert the pyruvate to ethanol and carbon dioxide gas (alcoholic fermentation).

Yeasts are versatile organisms. Unlike most other organisms that obtain their cellular energy either through aerobic respiration (requiring gaseous oxygen) or through anaerobic respiration (requiring the absence of oxygen), yeast cells respire in either condition, depending upon the availability of gaseous oxygen..

When oxygen is available, yeast cells respire using aerobic respiration. Aerobic respiration produces molecules of carbon dioxide gas and water along with ATP molecules. The yeast cells then use these ATP molecules, which act like tiny chemical batteries, to fuel their life processes. During aerobic respiration, yeast cells grow and reproduce by asexual budding.

Under anaerobic conditions, yeast metabolism shifts to alcoholic fermentation, a type of anaerobic cellular respiration. During fermentation, enzymes break down complex carbohydrates into simpler ones

In this activity, yeast cells will use the dissolved oxygen and the sugar in the juice solution as the reactants in the equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy (primarily stored in ATP molecules)}$$

As time progresses, you should see an increase in the carbon dioxide levels in the air above the solution as carbon dioxide is being created as an end product of cellular respiration. The carbon dioxide will outgas from the liquid solution and be detectable by the carbon dioxide sensor in the air above the liquid. Enzymes drive the overall reaction. Enzymes function best within a specific temperature range, in this case 32 to 38 °C. You would expect to see less carbon dioxide generated at lower temperatures, because even though aerobic respiration can occur, the enzyme functions at maximum capacity in warmer temperatures. If you were to heat the solution too high, the enzymes would become denatured and not function at all.

Pre-lab Discussion and Activity

Engage your students by asking them how much they know about the foods they eat. Ask, "Can you name any foods that are made by microorganisms like yeast and bacteria?"

Allow students time to respond while you make a list of all their ideas on the board. Try to categorize food items made by bacteria in the first column (such as, yogurt), things made by yeast in a second column (such as bread, beer), and things *not* made by microorganisms in a third column. After all students have had a chance to contribute their ideas, indicate what the "columns" are. If they have not listed any items made by yeast (such as bread, beer, wine), be sure to put those in the list yourself.

Explain that in today's activity you will be working with yeast.

Yeasts, like all living organisms, go through the process of cellular respiration. Yeasts are special in that they can use aerobic cellular respiration if oxygen is present (like we can) or they can use a type of anaerobic cellular respiration, alcoholic fermentation, if oxygen is not present. Large amounts of carbon dioxide gas are an end product of aerobic cellular respiration, whereas very little is produced during alcoholic fermentation. The carbon dioxide that is produced during aerobic cellular respiration, as well as during fermentation can be visible in foods such as dough rising or bubbles found in beer.

In this lab, students will measure carbon dioxide gas production during the yeast metabolism of grape juice. Have them answer the following questions before beginning the lab.

1. How would a change in temperature (either very cold or very hot) affect the carbon dioxide gas production?

Typically cold conditions have less of an effect on biological systems than heat does. Heat will denature enzymes that catalyze key reactions in respiration, thus drastically reducing the amount of CO_2 produced by the yeast.

2. How will the gas production change over time?

Student answers will vary depending on their experience. They may accurately predict that the amount of carbon dioxide gas given off by the yeast suspension will drop when the yeast is boiled.

Gas production should continue to increase over time as the yeast population grows by asexual budding.

Teacher Tip: Do not expose the end of the CO_2 gas sensor to moisture or let the end get wet.

Teacher Tip: Remind your students to NOT bump or jar the CO_2 gas sensor during data collection.

Lab Preparation

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

♦ You may choose to pre-boil the yeast to save time.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Use proper care around hot plates and boiling liquids.

♦ 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	1	5	3	4
Heat 25 mL of yeast solution to a boil.	Activate dry yeast by adding to 100 mL of warm (< 40 °C) tap water and allow to sit for 15 to 20 minutes.	Analyze your results.	First, using the CO_2 sensor, measure changes in CO_2 production for a sample of yeast mixed with grape juice.	Then, using the CO_2 sensor, measure changes in CO_2 production for a sample of boiled yeast sample mixed with grape juice.

Procedure with Inquiry

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

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

Part 1 – Room temperature grape juice and yeast (aerobic)

Set Up

1. ☐ Start a new experiment �(1.2)

2. ☐ Place 100 mL of warm tap water in a beaker (be sure that the temperature is below 40 °C), add a package of dry yeast to the beaker, and stir well.

The yeast will become active in 15 to 20 minutes.

3. ☐ Transfer 25 mL of the yeast solution to a different beaker.

4. ☐ Place the beaker on a hot plate, and boil the 25 mL yeast solution.

5. ☐ Connect a carbon dioxide gas sensor to the data collection system. �(2.1)

6. ☐ Display CO_2 on the y-axis of a graph with Time on the y-axis of a graph. �(7.1.1)

7. ☐ Calibrate the carbon dioxide gas sensor. �(3.1)

8. ☐ Add 75 mL of room temperature grape juice to the sampling bottle.

9. ☐ Mix the yeast suspension well, and add 5 mL to the juice.

10. ☐ Put the end of the carbon dioxide gas sensor loosely into the sampling bottle. (You do not want gas pressure to build up too high in the sampling bottle.)

Collect Data

11. ☐ Start data recording. �(6.2) Adjust the scale of the graph to view all data. �(7.1.2)

12. ☐ What do you expect to happen to the carbon dioxide level during data collection?

Carbon dioxide levels will increase as cellular respiration occurs.

13. ☐ Collect data for 5 minutes, and then stop data recording. �(6.2)

14. ☐ Carefully remove the carbon dioxide gas sensor from the sampling bottle.

15. ☐ Dispose of the contents as directed, and rinse the inside of the bottle.

Part 2 – Room temperature grape juice and boiled yeast

Set Up

16. ☐ Add 75 mL of room temperature grape juice to the sampling bottle.

17. ☐ Transfer 5 mL of the boiled yeast to the sampling bottle.

18. ☐ Put the end of the carbon dioxide sensor loosely into the sampling bottle. (You do not want gas pressure to build up too high in the sampling bottle.)

Collect Data

19. ☐ Start data recording. �(6.2) Adjust the scale of the graph to view all data. �(7.1.2)

20. ☐ What do you expect to happen to the carbon dioxide level during data collection?

Carbon dioxide levels will rise slightly, if at all, because heating denatured the enzymes in the yeast when they were heated.

21. ☐ Collect data for 5 minutes, and then stop data recording. �(6.2)

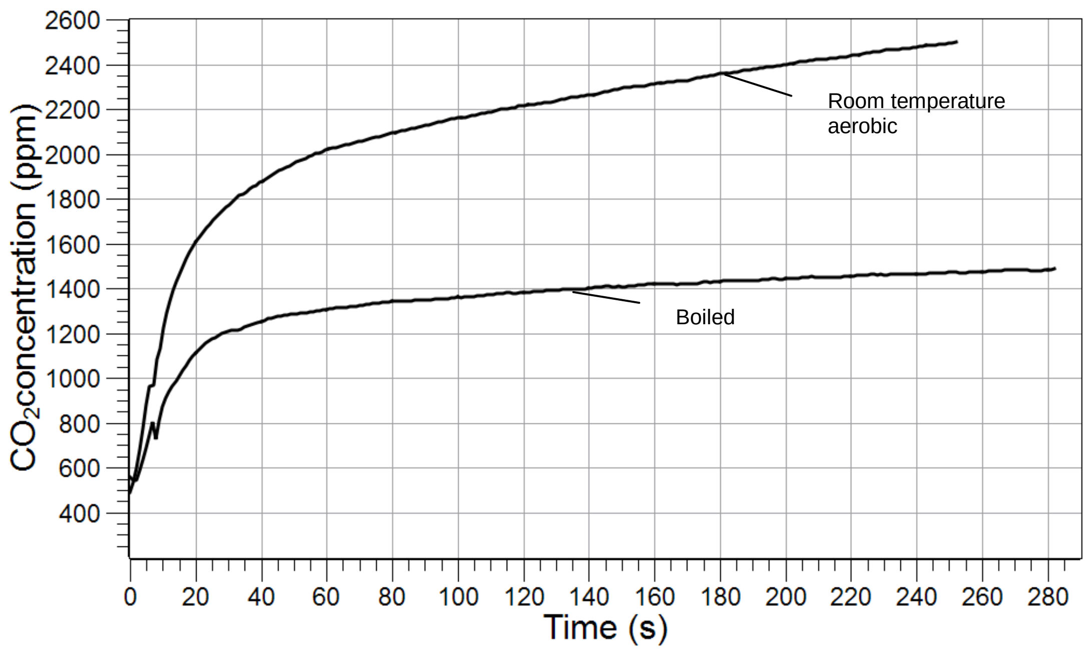
22. ☐ Carefully remove the carbon dioxide gas sensor from the sampling bottle.

23 ☐ Dispose of the contents as directed, and rinse the inside of the bottle.

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

Data Analysis

1. ☐ Graph your data for CO_2 concentration versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes. Label the data for each trial: room temperature and boiled yeast.



2. ☐ Use available analysis tools to find the initial and final CO_2 concentrations (ppm) as well as the total time (s) of the data run, and record these in Table 1. �(9.1)

3. ☐ Find the rate of production of CO_2 for each data run using the following formula, and record these values in Table 1:

CO_2 Production Rate = (Final CO_2 Concentration – Initial CO_2 Concentration) ÷ Total Time

Table 1: Data table

Data Run	Initial CO_2 (ppm)	Final CO_2 (ppm)	Total Time (s)	CO_2 Production Rate (ppm/s)
Room temperature grape juice and yeast	492	2499	252	7.96
Grape juice and boiled yeast	558	1487	282	3.29

Analysis Questions

1. What is the overall rate of CO_2 production for grape juice and yeast at room temperature conditions, and how does the rate change over time?

In this example, the rate of gas production for grape juice and yeast was 7.96 ppm/s. The rate increases rapidly at first and then more slowly toward the end of the experiment.

2. How does the rate of CO_2 production for the grape juice and boiled yeast compare to the rate for the room temperature grape juice and yeast?

Answers will vary. The rate of CO_2 production in boiled yeast sample is very low. The heat kills the yeast, and they are unable to perform cellular respiration.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What can you conclude about the affect of the high temperatures on the yeast suspension?

The heat causes the death of many yeast cells and reduces the metabolism of the yeast so that almost no carbon dioxide gas is produced.

2. Based on this information, do you think you have living yeast in bread after it has been cooked?

No. Once the bread is cooked, the yeast is dead. This is why you must wait for the bread to rise to the appropriate size before baking.

3. If yeast are facultative anaerobes and are crucial in the making of products like beer and wine, are there still yeast living in those products when you consume them?

In products made through alcoholic fermentation, once the alcohol level reaches a certain percentage, it becomes toxic for the organism living in it, and they will die. Different species have different tolerance levels. Some die at a 3% alcohol concentration, and some can survive at higher levels. Often times the dead yeast and other byproducts are filtered out of the finished product to produce a clear liquid.

Multiple Choice Questions

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

1. Which one of the metabolic pathways listed below is found in all organisms?

- **A.** Cellular respiration
- **B.** Citric acid cycle
- **C.** The electron transport chain
- **D.** **Glycolysis**
- **E.** Fermentation

Key Term Challenge

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

1. **Cellular respiration** is a series of complex chemical reactions that involve releasing stored energy in food to fuel life processes. There are two types of cellular respiration, **aerobic** (which utilizes oxygen) and **anaerobic** (which does not utilize oxygen). Both begin with **glycolysis**. During glycolysis, the glucose breaks down into **pyruvate**. Some organisms convert the pyruvate to ethanol and carbon dioxide gas (**alcoholic fermentation**).

2. Yeasts are able to undergo either aerobic respiration or alcoholic fermentation. When oxygen is available, yeast cells respire using aerobic respiration. During aerobic respiration, molecules of **carbon dioxide** gas and **water** along with **ATP** molecules are produced. When oxygen is not available, yeast cells respire using alcoholic fermentation. During these reactions, only **two** molecules of CO_2 and **two** ATP are formed from each glucose molecule. Instead of water, two molecules of **ethanol** are also formed. Therefore, this series of reactions is much less efficient in producing ATP molecules that can be used by the cell for its life processes. Most of the energy of the sugar molecule remains in the ethanol molecules.

Extended Inquiry Suggestions

Have students bring in recipes and the materials needed to make fermented products, such as kimchi or bread dough.

14. Rate of Photosynthesis for an Aquatic Plant

Objectives

Guide students to understand the amount of oxygen produced through photosynthesis in an aquatic plant exposed to ambient light, bright light, and darkness.

Procedural Overview

Students gain experience conducting the following procedures using an aquatic plant in a closed system:

- Collecting data in ambient light
- Collecting data in bright light
- Collecting data in darkness

Time Requirement

♦ Preparation time	20 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	60 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dissolved oxygen sensor
- Fast-response temperature probe
- Photosynthesis tank or similar setup[1]
- Rubber stopper, #3[2]
- Magnetic stirrer and stir bar
- Lamp, 100 W (or equivalent)
- Cloth, heavy, about 50-cm by 50-cm
- *Elodea* plant (several)[3]
- Water

[1]For an alternative to a photosynthesis tank, see the Lab Preparation section.

[2]Stopper comes with the photosynthesis tank.

[3]*Elodea* plants work best (Test ahead of time to ensure that any substituted plant works sufficiently well.)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The significance of and relationship between photosynthesis and respiration
- The cell theory
- Form and function of cell organelles
- Plants are able to use light from the sun to produce food
- Photosynthesis uses light energy to convert water and carbon dioxide into sugar and oxygen
- The process of photosynthesis includes light-dependent reactions and light-independent reactions

Related Labs in This Guide

Labs conceptually related to this one include:

- Plant Respiration and Photosynthesis
- Respiration of Germinating Seeds

Using Your Data Collection System

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- 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)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

All plants and certain microorganisms make food from carbon dioxide, water, and sunlight. It is a complex series of steps called photosynthesis that take place in chloroplasts. The generalized equation for this process is given below:

$$6CO_2 + 6H_2O \xrightarrow{\text{light/chlorophyll}} C_6H_{12}O_6 + 6O_2$$

Aquatic plants and photosynthetic microorganisms release the oxygen gas (O_2) into the water where it dissolves. This dissolved oxygen is mixed into, but not chemically combined with, the water. There is a limited amount of O_2 gas that water can hold, so when the concentration reaches a certain level (saturation), the O_2 diffuses (or out-gases) into the air.

The series of biochemical events that comprise photosynthesis have been classified into two main sets: the light-dependent reactions and the light-independent reactions. The set classified as the light-dependent reactions, at its most basic level, involves capturing light energy into energized molecules that are then used in the set of light-independent reactions to fuel the synthesis of sugars from carbon dioxide and water. The light-dependent reactions are so named because light energy is required. The light-independent reactions do not require light; however, they can and do occur under lighted conditions.

During the "light reactions" (or light-dependent) cycle of the photosynthesis process, chloroplasts use sunlight energy to split water molecules into hydrogen ions and oxygen (photolysis). The reactions produce ATP and NADPH and release oxygen. Scientists have shown, using isotopes as tracers, that the released oxygen comes from the splitting of the water molecule rather than the oxygen bound in the carbon dioxide molecule. The light-dependent reaction takes place within the membrane of thylakoids that make up the grana of the chloroplast.

The light-independent reaction reduces carbon dioxide, using the ATP and NADPH supplied during the light-dependent cycle. In plants, the light-independent reactions takes place in the stroma of the chloroplast.

When a plant is exposed to light, it undergoes photosynthesis and aerobic cellular respiration at the same time. When the plant is not exposed to light, it undergoes aerobic cellular respiration, but it does not undergo photosynthesis. (Aerobic respiration uses oxygen; anaerobic respiration does not.)

Since Earth's surface is predominantly covered by water, the majority of the gaseous oxygen on Earth comes from aquatic plants and photosynthetic microorganisms, such as algae and diatoms. Almost all land-dwelling and water-dwelling creatures depend on the biochemical reactions of photosynthesis for life: for the O_2 produced in the light-dependent reactions and the sugars produced in light-independent reactions.

Pre-Lab Discussion and Activity

Introduce students to measuring the dissolved oxygen concentration in water that contains an aquatic plant.

1. What will happen to the concentration of dissolved oxygen in the water if the plant is exposed to bright light?

Student answers will vary depending on their experience. They may predict that the amount of dissolved oxygen in the tank will increase while the plant is exposed to bright light.

2. What will happen to the concentration of dissolved oxygen in the water if the plant is put into a dark environment?

Student answers will vary depending on their experience. They may predict that the amount of dissolved oxygen in the tank will decrease while the plant in darkness.

Discuss, or draw on the board, a generalized food chain or food web. Then ask:

3. What role do photosynthetic organisms play in the energy flow of an ecosystem?

Photosynthetic organisms are the base of all food webs. Without photosynthetic organisms, the energy from sunlight could not be captured and converted into stored energy that other organisms use as a food source.

Lab Preparation

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

Note: Sensor calibration is good laboratory practice. However, this activity deals only with relative changes in measurements. It is not necessary to calibrate the dissolved oxygen sensor.

Note: Consider having your more advanced class (or one that has more lab time scheduled) set up the activity. This setup could be used by other classes. Once a good setup is achieved, you can use it all day or for two or more consecutive days.

Note: Consider connecting a fast-response temperature probe to the data collection device to monitor the temperature of the water, which could be heated by the light source.

Note: The set up for the photosynthesis tank, including the intensity of light, is extremely important for good results in this lab.

1. A day or two in advance, make sure you acquire the correct aquatic plant, including the amount of plant material.

   - *Elodea* plants work best. (Test well ahead to ensure that any substituted plant works sufficiently well.)
   - Use fresh, healthy plants, such as those from stores specializing in aquaria or plants from a classroom aquarium
   - Plants with evidence of new growth on the top

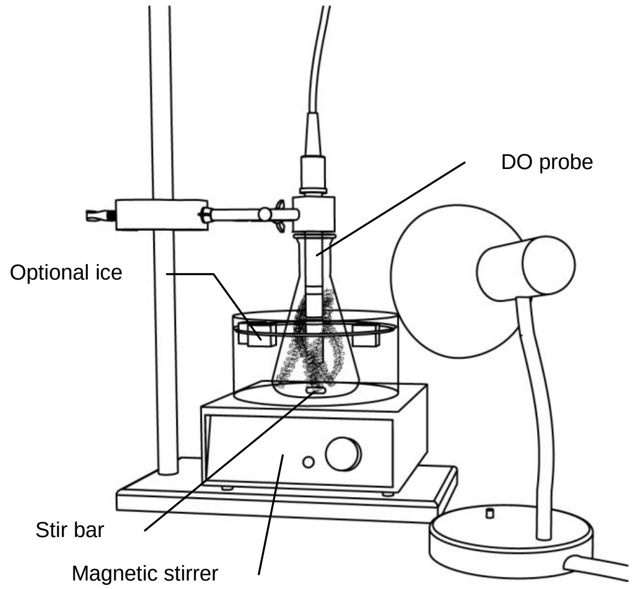
   Note: Check local regulations if you collect field samples of *Elodea* plants, which are often abundant and healthy "in the wild."

2. A day in advance, prepare dechlorinated water by letting tap water sit in an open container overnight. (Alternatively, treat water with chlorine remover.)

3. Store the plants near a sunny window or fluorescent light in de-chlorinated water.

4. If you do not have a photosynthesis tank, use a flask and a dish or beaker instead. To prevent out-gassing, put a thin layer of mineral oil on top of the water.

5. Use a 100-watt fluorescent bulb, or equivalent light, that can screw into a standard light socket. Do not shade the light. (Two high-intensity halogen or incandescent lights will work.)



Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Wear protective equipment such as safety goggles, gloves, and an apron.

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	1	4	5
Turn on the magnetic stirrer to its highest setting. Collect dissolved oxygen data for ambient light.	Make sure the end of the dissolved oxygen sensor is situated about 1 cm above the stir bar.	Add *Elodea* plants into a photosynthesis tank and fill the tank with de-chlorinated water.	Next, turn on the lamp to its brightest setting.	Finally, record the data with the plant in darkness.

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 to the data collection system. �(2.1)

3. ☐ Display Dissolved Oxygen in milligrams per liter (mg/L) on the y-axis versus Time in seconds (s) on the x-axis of a graph. �(7.1.1)

4. ☐ Adjust the scale of the graph to view all data. �(7.1.2)

5. ☐ Fill the inner chamber of the tank with water.

6. ☐ Add several large, healthy sprigs of the *Elodea* plant into the inner chamber.

7. ☐ Add a stir bar into the inner chamber.

8. ☐ Put the large two-hole stopper into the top of the tank.

Note: Water from the inner chamber should overflow when the stopper is placed on the tank.

9. ☐ Place the photosynthesis tank on the magnetic stirrer.

10. ☐ What is the reason for using the stirrer?

The nature of the dissolved oxygen sensor is that it consumes oxygen in its immediate environment, which can lead to a localized drop in the dissolve oxygen level. Stirring the sample helps to assure reliable readings.

11. ☐ Put cold water into the outer chamber of the tank.

12. ☐ Why are you adding cold water to the outer chamber of the tank?

The light that shines on the tank can potentially increase the temperature of the system. Potentially, enzymes needed during photosynthesis can become denatured if the temperature of the water is allowed to increase too high. Additionally, high temperatures accelerate the growth of bacteria and other microorganisms in the water, which can obscure the results. The cold water in the outer tank keeps the temperature in the inner tank lower to avoid these problems.

13. ☐ Remove the storage bottle from the end of the dissolved oxygen sensor.

14. ☐ Carefully insert the end of the sensor through the larger opening in the two-hole stopper.

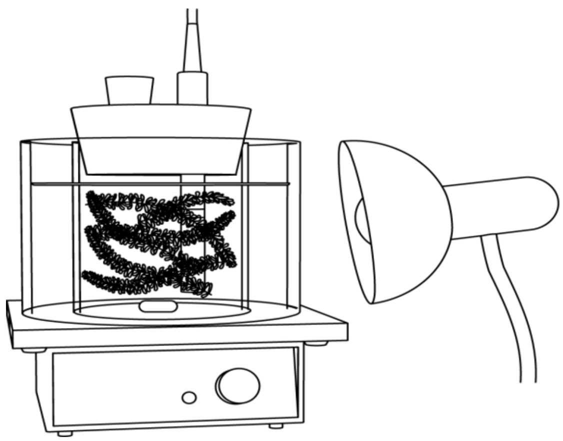
15. ☐ Make sure that the metal band on the dissolved oxygen sensor is below the surface of the water in the tank, the end of the sensor is situated about 1 cm above the stir bar, that no plant material is touching the end of the sensor, and that no air bubbles are trapped on the end of the end of the sensor.

16. ☐ Place a #3 rubber stopper into the other hole in the two-hole stopper.

17. ☐ What would happen if you did not use the stopper to seal your system?

You will not have a sealed, closed system and your dissolved oxygen readings will be incorrect. The stir bar would create a small amount of turbulence that may cause more oxygen to be introduced into the system.

18. ☐ Without turning on the lamp, place the lamp very near the photosynthesis tank so the light will shine on the *Elodea* plant.



Collect Data

19. ☐ Turn on the magnetic stirrer to a moderate speed so the water circulates in the tank.

20. ☐ Start data recording using ambient room light (normal light) only. �(6.2) Adjust the scale of a graph to show all data �(7.1.2)

21. ☐ Describe what happens to the level of dissolved oxygen.

The level may dip and then begin to increase slowly. During this time, the sensor is reaching equilibrium.

22. ☐ After 5 minutes, turn on the lamp.

23. ☐ Do you see a difference in the level for dissolved oxygen for bright light? Describe what happens.

The rise in dissolved oxygen for the bright light is greater (higher rate) than for ambient light.

24. ☐ Continue to record data for an additional 20 minutes with the lamp on.

25. ☐ Turn the lamp off. Do not stop recording data.

26. ☐ Carefully cover the setup with a heavy cloth so the plant is in total darkness.

27. ☐ What do you expect to happen to the DO level when the plant is covered with a cloth?

Most students will predict that the DO level will decrease.

28. ☐ Continue recording data for 15 additional minutes with the plant in darkness.

29. ☐ Stop data recording. �(6.2)

30. ☐ What happens to the level of dissolved oxygen in darkness?

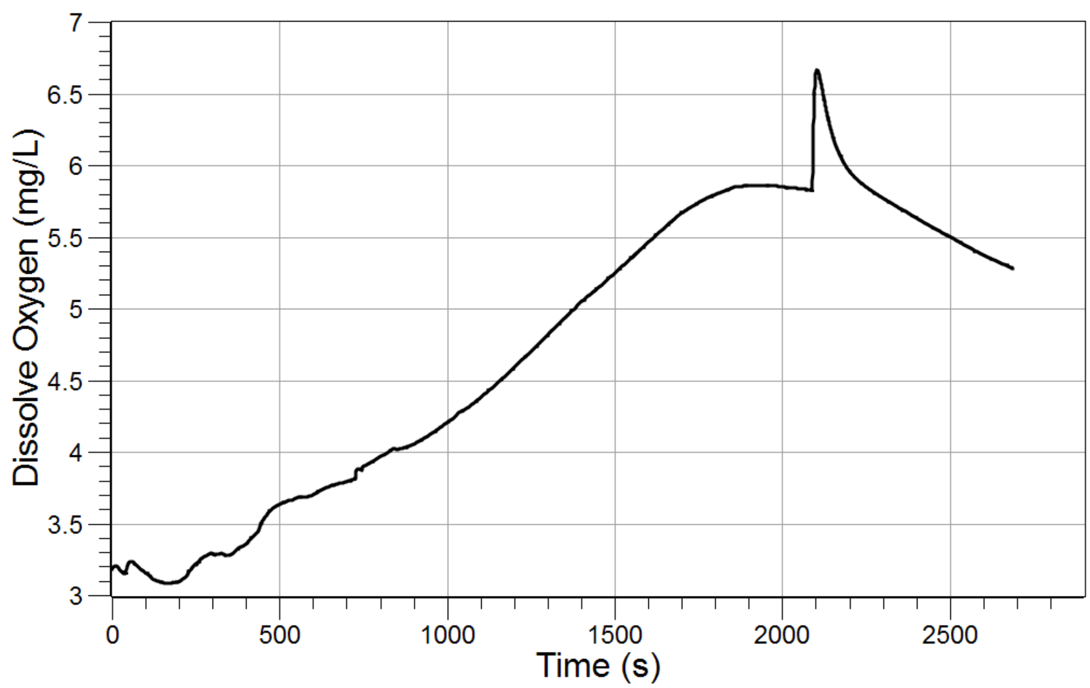
The level of dissolved oxygen goes down.

31. ☐ Turn off the magnetic stirrer.

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

Data Analysis

1. ☐ Make a sketch of your data for Dissolved Oxygen versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes. Also, label the times when the light was turned on, and when the plant was in darkness.



2. ☐ Using available tools, find the maximum values for ambient light and bright light, and the minimum value for darkness. �(9.1) Record your findings in Table 1 in the Data Analysis section.

Table 1: Dissolved oxygen (DO) concentration in ambient light, bright light, and darkness

Light Condition	**DO Concentration (mg/L)**
Ambient light (maximum value)	3.3
Bright light (maximum value)	6.6
Darkness (minimum value)	5.3

Analysis Questions

1. What happens to the level of dissolved oxygen when the plant is in bright light? Why does this happen?

For this example, the level of dissolved oxygen increased slowly from 3.3 to 6.6 mg/L. The plant's chlorophyll captures the light energy and produces carbohydrate. A byproduct of the light-dependent reactions is gaseous oxygen that dissolves into the water.

2. What happens to the level of dissolved oxygen when the plant is in darkness? Why does this happen?

The level of dissolved oxygen reaches a peak shortly after the plant is put in darkness, and then it slowly decreases. The plant undergoes cellular respiration all the time. Cellular respiration consumes oxygen. When light is shining on the plant, the production of oxygen is greater than the consumption of oxygen. In darkness, the production of oxygen stops, but the consumption of oxygen continues. As a result, the dissolved oxygen level in the water goes down.

3. What happens to the level of dissolved oxygen when the plant is in ambient light and then bright light?

The level of dissolved oxygen increases when the light is turned on.

4. How is the amount of oxygen produced through photosynthesis in an aquatic plant affected by different light conditions?

The amount of dissolved oxygen produced by an aquatic plant increases as the light intensity increases. For this example, in ambient light, the maximum amount of dissolved oxygen was 3.3 mg/L. It rose to 6.6 mg/L in bright light and decreased to 5.3 mg/L in darkness.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What is meant by a "closed system"? Explain how your setup represented a closed system.

A closed system is an experimental setup that removes exterior influences and reduces the number of variables that can change in the system. The tank containing the aquatic plant and water is sealed so that the dissolved oxygen being measured cannot escape from the test environment."

2. Why does the concentration of dissolved oxygen increase under high intensity light?

During the light-dependent reactions, the plant's chlorophyll captures the light energy in a chemical form. The plant uses this captured energy to produce sugars during the light-independent reactions. A byproduct of these light-dependent reactions is gaseous oxygen (O_2), which diffuses out of the plant cells into the water, thus increasing the concentration of O_2 dissolved in the water.

3. Why does the concentration of dissolved oxygen decrease in darkness?

Cellular respiration consumes oxygen. Cellular respiration, by plants and by microorganisms in the water, goes on all the time. When light is shining on a plant, the rate of production of oxygen is greater than the rate oxygen is used by cellular respiration. However, in the dark, cellular respiration continues to use up oxygen, and no oxygen is being produced by the plant. The net result is a decrease in dissolved oxygen.

4. What role do photosynthetic organisms play in the energy flow in an ecosystem?

Photosynthetic organisms are called producers and are the base of all food chains and food webs. Producers are able to capture the energy from the sun and convert it into chemical energy in the form of sugars. All life ultimately depends on photosynthetic organisms for energy stored in the food sources.

5. What would happen to all consumers if the producer population was inhibited? Give an example of an event that may cause producers to be unable to photosynthesize.

If producers were isolated from light, they would not be able to photosynthesize. A large volcanic eruption, fire, or comet impact event might produce enough airborne debris to block sunlight from reaching photosynthetic organisms. In that case, both producers and consumers would die from lack of food.

Multiple Choice Questions

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

1. Photosynthesis is a process of chemical reactions that converts ______________ energy to _____________ energy.

- **A. Light, chemical**
- **B.** Chemical, light.
- **C.** Chemical, heat
- **D.** Sunlight, light

2. An end result of photosynthesis is energy stored in what form?

- **A.** Carbon dioxide
- **B.** Oxygen.
- **C.** Water
- **D. Glucose**

3. Which of the following is *not* used in the overall reactions of photosynthesis?

- **A.** Light
- **B. Oxygen**
- **C.** Water
- **D.** Carbon dioxide

4. In a typical plant, which of the following factors are *not* necessary for photosynthesis?

- **A.** Chlorophyll
- **B. Sugar (glucose)**
- **C.** Water
- **D.** Carbon dioxide

5. What are photosynthetic organisms called?

- **A.** Consumers
- **B.** Heterotrophs
- **C. Producers**
- **D.** Dinoflagelletes

Key Term Challenge

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

1. In the process of **photosynthesis**, plants use the energy of sunlight to convert water and carbon dioxide into high-energy carbohydrates including **glucose. Oxygen** is a byproduct of the process.

2. In plants, photosynthesis takes place inside the **chloroplast**. The reactions of photosynthesis occur in two parts: the **light-dependent** reactions and the **light-independent** reactions. The light-dependent reactions take place within the **thylakoid** membranes of the chloroplasts. The light-dependent reactions use energy from **light** to convert ADP and NADP+ into the energy carriers ATP and NADPH and produce oxygen. The oxygen gas produced by **photosynthesis** is the source of nearly all the oxygen in Earth's atmosphere.

3. In plants, the light-independent process takes place in the **stroma** of chloroplasts and does not require light. During this process, plants use the energy of ATP and NADPH to produce glucose (sugar)**.** The light-independent process uses carbon dioxide in its series of reactions. As photosynthesis proceeds, this process steadily removes **carbon dioxide** from the atmosphere and produces **energy-rich sugars**.

Extended Inquiry Suggestions

The rate of photosynthesis depends on several conditions, including which colors of light are available to be absorbed by the pigments in a plant leaf. The principal pigment in advanced plants is chlorophyll. Carotenes and xanthophylls play a secondary role. They transfer the energy they absorb to chlorophyll for use in photosynthesis. The different pigments absorb different colors of light.

Explore what happens to the rate of photosynthesis when different colors of light shine on the plant. Use sheets of colored plastic between the lamp and the photosynthesis tank, or put food coloring into the water in the outer chamber of the tank.

15. Soil pH

Objectives

Guide students to understand what soils, in their local community, would support agricultural crops, based on pH level.

- Record detailed observations about the environment where the soil samples were taken.
- Determine and compare the acidity or alkalinity of each soil sample.

Procedural Overview

Students gain experience conducting the following procedures:

- Gather soil samples from different locations in the area and record detailed observations.
- Measure the acidity or alkalinity of three different soil samples using a pH sensor.

Time Requirement

♦ Preparation time	5 minutes (day before); 10 minutes (day of)
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Extension cable
- Beaker, 250-mL (3)
- Graduated cylinder, 100-mL
- Measuring spoons (1 set)
- Stirring rod
- Wash bottle
- Digging device
- Sealable plastic bag (3)
- Soil sample, 60 mL (3)
- Distilled water, 400 mL
- Paper towels
- Marking pen

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ pH scale
- ♦ Soil types
- ♦ Ecosystems

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Water and pH
- ♦ Water purification

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 the pH sensor �(3.6)
- ♦ Monitoring live data without recording �(6.1)

Background

Soil pH is an important chemical indicator of the acidity or alkalinity of agricultural land. Modifications in pH can alter the chemical composition of rock and compromise soil robustness, thus leading to a decline in plant health. Because a change in pH can alter the fate of an agricultural crop by interfering with soil chemistry, pH has become an invaluable tool to measure soil fitness.

Soil pH depends upon the chemical nature of the parent material, the indigenous plants, the agricultural history, and management practices (fertilizing and liming). Such essential information helps in the selection of crops that will be economically productive.

The human population continues to increase, creating an unrelenting demand for agriculturally productive land. All life depends on soil. Soil is a dynamic habitat composed of living and dead organic matter, minerals, and nutrients, which provide an ideal medium to sustain plant and animal life. Agricultural land is important for human survival, considering that three-quarters of the Earth's surface is covered with water. Half of all land is either desert, mountainous, or polar. It is either too hot or too cold to be considered arable agricultural soil.

The pH scale measures the acidity or alkalinity of a solution. This scale ranges from 0 (highly acidic) to 14 (highly alkaline). Distilled water, with a pH of 7, is a neutral solution. The pH scale is a negative logarithm of the concentration of hydrogen ions. A change of one unit of pH represents a ten-fold change in acidity or alkalinity. A solution with a pH of 5.0 is 10 times more acidic than a solution with a pH of 6.0 and 100 times more acidic than a solution with a pH of 7.0.

The availability of nutrients is directly affected by soil pH. If the soil pH is too high or too low, nutrients may become insoluble and unavailable to the root system of plants. As a result, plants will exhibit symptoms of nutrient deficiencies regardless of what is added to the soil. Nitrogen (N), phosphorous (P), and potassium (K) are vital nutrients to plant vigor, yet they differ in their availability to plants depending upon the soil pH. Nitrogen (nitrate) is more available at a pH above 5.5, whereas phosphorous is more soluble at a pH between 6.0 and 7.0.

Soil organisms are equally affected by the surrounding pH. Some nitrogen-fixing bacteria in the root nodules of legume plants such as alfalfa, soybeans, and peanuts, thrive in a pH range of 5.5 to 7.5 but may not tolerate a soil pH beyond that range. Strongly acidic soils interfere with other beneficial microorganisms. Extreme pH can alter the decomposition of organic matter by these microorganisms and prevent the release of nitrogen and other essential plant nutrients that would normally be recycled into the soil. The death of microorganisms present in the soil can cause a rapid decline in soil health and ultimately decrease crop yield.

Pre-lab Discussion and Activity

Engage your students by having them answer the following questions, and then compare their answers with the student seated next to them. Proceeding from that interaction, guide a class discussion about the different soil samples in your community.

1. What kind of soil is common in your community? Is it mostly clay? Is it sandy? Is it rich, dark, and full of organic material? Is it rocky?

Answers will vary depending on region.

2. What kind of pH values do you predict the soil in your community will have: very acidic, slightly acidic, neutral, slightly alkaline, or very alkaline?

Answers will vary depending on region and student understanding of possible pollution sources or naturally occurring phenomenon. Guide student discussion by pointing out areas such as salt flats, agricultural areas, industrial areas, and areas where runoff pools.

3. What role do you think pH plays in the health of the soil?

Students should be able to draw on prior knowledge that all living things have a tolerable pH range in which they can survive. Most students will only consider plants when discussing evidence of healthy soil, but be sure to point out invertebrates, microscopic organisms, and other living things that live in and participate in the health of the soil.

Lab Preparation

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

Note: Students need to obtain permission before collecting soil samples from private property.

1. Prepare students to take detailed notes about the sites where they collect soil samples. Observations such as the following will be recorded in Table 1 in the Data Analysis section:

- The appearance of the soil and soil composition, including conditions such as arid or humid
- The appearance and types of plants and other organisms
- Animal tracks and the appearance of animals
- The terrain, holes in the ground, and the geological features of rocks
- Nearby buildings and whether nearby roads are asphalt, cement, gravel, or dirt
- Anything unusual about the area

Note: If 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. Instruct students regarding the procedure for bagging, sealing in the moisture, and labeling the source for each soil sample.

3. To test the pH of soil, students can collect soil samples from their yards and neighborhoods. They should consider novel locations such as vacant lots, areas next to buildings, gardens, roadsides, and hiking trails.

4. The pH sensor should be calibrated as part of the procedure. However, if standardized buffer solutions are not available for calibration, inform students that results may not be as precise if the sensors are not calibrated. Explain that when pH data is compared with a standard or norm or with pH data from another pH sensor, small differences in electronics and probes could literally mean the difference between life and death as it relates to an organism. A half point difference in a pH measurement means a five times difference in acidity or alkalinity, because pH applies a logarithmic scale.

5. For best results, perform the tests in the lab at room temperature (25°C).

Note: Changes in temperature alter hydrogen ion activity in the solution, consequently changing the pH result.

Teacher Tip: Have a copy of the user manual for the pH sensor available to students.

Teacher Tip: Instruct students *not* to collect soil samples in areas high in animal wastes.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ To avoid health risks, do *not* collect soil samples in areas high in animal wastes.
- ♦ Wear protective equipment such as safety goggles, gloves, and an apron, when handling chemicals.
- ♦ Dispose of chemicals and solutions as instructed.

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
Describe with detail the environment for each soil sample.	Obtain three different soil samples using the same techniques.	For each sample, rinse the pH sensor with distilled water, and place it into the beaker. Record the pH in the data table.	For each sample, add 60 mL of distilled water into a beaker with 60 mL (4 tablespoons) of sample soil and mix thoroughly.	Let the soil-water mixture stand for several minutes prior to recording data to promote hydrogen ion (H^+) dissociation.

Procedure with Inquiry

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

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

Part 1: Obtaining Samples plus Initial Observations (Day before Lab)

1. ☐ Collect a soil sample using the following technique:

- **a.** Clean the digging device.
- **b.** Clear leaves and any other contaminating debris.
- **c.** With the digging device loosen the soil as deep as eight centimeters.
- **d.** Place at least 60 mL (4 tablespoons) 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 at least two more soil samples using the same technique.

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

This technique keeps variables from affecting the experiment control.

4. ☐ Record observations following the instructions above Table 1 in the Data Analysis section.

5. ☐ Why did you choose the collection sites you chose?

Ideally, students will select sites that will exhibit a wide variety of pH readings and be from a wide variety of soil types.

Part 2: Working with Gathered Samples and Observations

Set Up

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

7. ☐ Connect a pH sensor into a port on the data collection system. �(2.1)

8. ☐ Label a beaker for each soil sample as you did with the sample bags.

9. ☐ Remove any rocks, sticks, or foreign objects from the sample bags.

10. ☐ Leaving the soil sample inside the bag, crush the soil with a digging tool and mix the crushed particulates thoroughly.

Note: Soil moisture content should be uniform throughout the samples to facilitate equivalence between the samples.

11. ☐ Why do you need to crush the soil?

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

12. ☐ Place 60 mL (4 tablespoons) of the first soil sample in the beaker labeled for that sample.

13. ☐ Add 60 mL of distilled water to the beaker and mix thoroughly with a stirring rod.

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

Measuring pH cannot be done with solids. Generally, water must be added to liberate the ions for measurement.

15. ☐ Let the soil-water mixture stand for several minutes prior to data collection to promote hydrogen ion (H^+) dissociation.

16. ☐ Repeat the steps to prepare the other two soil samples.

Collect Data

17. ☐ Calibrate the pH sensor. �(3.6)

18. ☐ Rinse the sensor with distilled water.

19. ☐ Why is the sensor rinsed with distilled water before testing each sample?

Distilled water is used to keep the sensor from having cross contamination from the other samples. Distilled water does not contain any chemicals that might alter the pH sensor. Regular tap water would.

20. ☐ Place the sensor into the first beaker.

21. ☐ Monitor live data without recording. �(6.1)

22. ☐ Stir the mixture gently with the sensor until the reading stabilizes (as much as 60 seconds).

23. ☐ Record the pH in Table 2 in the Data Analysis section.

24. ☐ Remove the pH sensor from the beaker and wash it thoroughly with tap water.

25. ☐ Rinse the sensor with distilled water, monitor and record a stabilized pH reading for the other two water samples, as you did for the first sample.

26. ☐ Clean up the equipment and work area.

Sample Data

In this activity, data was monitored to record a single stabilized point of data for each data run. No sample graphical data was collected. See Table 2 in the Data Analysis section for sample amounts.

Data Analysis

1. ☐ Record detailed observations for each soil sample in Table 1, replacing the location number with the label you gave it.

- The appearance of the soil and soil composition, including conditions such as arid or humid
- The appearance and types of plants and other organisms
- Animal tracks and the appearance of animals
- The terrain, holes in the ground, and the geological features of rocks
- Nearby buildings and whether nearby roads are asphalt, cement, gravel, or dirt
- Anything unusual about the area

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.

Table 1: Detailed observations of soil sample locations

Soil sample location	Observations
1	
2	
3	

Table 2: Stabilized pH readings for soil samples

	Soil sample location	pH
1	Potting soil	5.3
2	High school	7.1
3	Farm	6.4

Analysis Questions

1. Which soil sample was the most acidic? Considering the observations recorded in Table 1, explain the reason for the lower pH compared with the other samples.

Answers will vary. In the sample data provided, the potting soil was more acidic due to the organic material mixed in.

2. Which soil sample was the most alkaline? Considering the observations recorded in Table 1, explain the reason for the higher pH compared with the other samples.

Answers will vary. In the sample data provided, the local soil was more alkaline due to being closer to a 'neutral' pH than the potting soil.

3. Which of the soil samples might be able to effectively neutralize acid rain? Explain why?

Answers will vary. Buffering ability depends on organic and mineral content in addition to physical properties such as particle density and size. Alkaline soils containing limestone or calcium carbonate are better buffers than soils that contain granite.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Based on your pH results only, would any of the soil samples from your three collection sites be capable of supporting a healthy agricultural crop?

Answers will vary. Soil samples with a pH level between 5.5 and 7.5 are likely to indicate soil that can support a healthy agricultural crop. However, it is important to research the specific ranges of pH tolerance for different crops.

2. How could you safely alter your soil in order to improve its ability to support agricultural crops?

To raise the pH of soil (neutralize soil acidity), the best way is to add lime (sold as dolomite, hydrated lime, ground limestone, and mixed lime) to the soil.

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

3. What did you notice about the different types and number of living organisms in your soil samples? What might this indicate about the health of soil in your area?

Typically, students will see more living things in rich organic soil, where more nutrients are available to support "mini ecosystems." As organisms die and decompose, the nutrients stored in the cellular material are recycled into the soil and make it better able to sustain plant life. Dead organisms provide a rich nutrient source for bacteria, fungi, and small invertebrates. Such soil is better able to support more life. This provides evidence that life is interdependent.

4. What evidence of human interaction or interference could you identify when collecting your samples? How do you think that this interaction has altered the original condition of the soil?

Answers will vary, but may include references to lawns and gardens, agricultural areas, garbage or pollution. Most students will recognize that there are very few places in their community where the land has *not* been altered by humans. Many students will indicate that humans have improved the soil condition to suit their own needs, but some may indicate that human activity has negatively impacted the area.

Multiple Choice Questions

1. How much more or less H^+ does a solution at pH 6 contain than the same amount of a solution at pH 8?

- **A.** 2 times more
- **B.** 4 times more
- **C.** **100 times more**
- **D.** 4 times less

2. Which of the pH levels listed below represents the strongest base?

- **A.** 5
- **B.** 7
- **C.** 10
- **D.** **13**

3. Cranberries grow best in a slightly acidic soil. In which of the following locations would cranberries grow the best?

- **A.** Soft loamy soil
- **B.** **Soil with high organic content**
- **C.** Soil with a pH of 8.2
- **D.** Clay-type soil

Key Term Challenge

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

1. Soil pH is based on the measurement of **hydrogen ions** in a solution. There are different factors affecting soil pH. The pH of soil is influenced by the kinds of materials from which the soil was first formed. If soil was developed from acidic rocks, then the soil will generally have a **lower** pH. High rainfall amounts affect soil pH by removing basic nutrients from the soil with those elements being replaced by elements such as aluminum, which can create an **acidic** environment. Humans also play a role in soil pH by pollution and application of fertilizers.

2. Acid precipitation, or **acid rain**, describes rain, snow, sleet, or fog that contains high levels of sulfuric and nitric acids. These acids form when sulfur dioxide gas and nitrogen oxide gas react with water in the atmosphere. Acid precipitation makes soil and bodies of water, such as lakes, **more** acidic than normal. These high acid levels can harm plant and animal life directly.

Extended Inquiry Suggestions

Investigate the differences in the buffering ability of sandy soils and clay-loam soils. Measure pH values for each soil type in 50 mL samples of distilled water, diluted hydrochloric acid, and dilute sodium hydroxide.

Design an experiment exploring the effect of soil pH on seedling growth.

16. Transpiration

Objectives

In this exploration, students use a barometer as a potometer to measure the rate of water uptake in plants due to transpiration.

- This activity demonstrates the concept of "transpiration pull."
- Students explore the effects of environmental factors, such as air movement, on the rate of transpiration.

Procedural Overview

Students use a barometer/low pressure sensor to measure the change in pressure in a tube connecting the sensor to the stem of a plant as the plant undergoes transpiration in still air and then in moving air.

- Students use the analysis tools of the data collection system to determine the change in pressure per unit of time for each condition.
- Students compare the changes in pressure per unit of time (rate of transpiration) for each condition and propose reasons for the changes.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	60 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Barometer/low pressure sensor
- Sensor extension cable
- Large base and support rod
- Clamp, utility
- Clamp, three-finger
- Pipet
- Knife
- Fan
- Bowl
- Glycerin, 1 mL
- Petroleum jelly, 2 to 3 g
- Plant seedling, 12 to 15 cm tall
- Water, 1 L

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Cellular transport: osmosis and diffusion
- ♦ The significance of and relationship between photosynthesis and respiration
- ♦ How cell functions are regulated
- ♦ How root pressure, capillary action, and transpiration work together to transport water through a plant
- ♦ The structure of a leaf is optimized for absorbing light to allow photosynthesis to take place
- ♦ Plants keep their stomata open to allow transpiration to take place

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Osmosis
- ♦ Membrane Permeability
- ♦ Plant Respiration and Photosynthesis
- ♦ Rate of Photosynthesis for an Aquatic Plant

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 the barometer/low pressure sensor to the data collection system using an extension cable �(2.1)
- ♦ Starting data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the graph to show all data �(7.1.2)
- ♦ Naming a data run �(8.2)
- ♦ Finding the value of a point on a graph �(9.2)
- ♦ Saving your experiment �(11.1)

Background

Transpiration is the evaporation of water from a plant surface. Guttation is the loss of water from the ends of vascular tissues at the margins of leaves. The amount of water needed by plants for growth and maintenance of tissue is small compared to the amount that is lost through transpiration and guttation. If water lost from leaves is not replaced by water transported from the plant roots, the plant wilts and dies.

The transport of water up the xylem tissue in plants is controlled by differences in the concentration of water molecules (water potential or pressure difference). In a root, minerals transported from the soil accumulate in the xylem vessels of the vascular tissues of the stem. This, along with the negative pressure (tension) in the xylem tissues, lowers the water potential of the xylem. Because of this difference, water moves into the xylem by osmosis, forcing fluid up the xylem vessels. This upward movement results in root pressure, but this pressure only moves water a short distance up the xylem. Transpiration pulls the water and dissolved minerals (xylem sap) further up the xylem.

Transpiration involves a linked chain of processes as follows:

1. The concentration of water molecules in the air surrounding the leaf is lower than the concentration of water molecules in the moist air surrounding the leaf's mesophyll cells, resulting in the movement of water vapor through the leaf's stomatal openings into the surrounding air.

2. The concentration of water molecules in the moist air spaces surrounding the mesophyll cells is now decreased, resulting in evaporation of water from the outside of the mesophyll cells.

3. Evaporation of water from the outside of the mesophyll cells causes water to be drawn from the inside of the mesophyll cell to its outer surface.

4. The mesophyll cells now have a lower water potential than the xylem, resulting in water moving from the xylem to the mesophyll cells.

5. The water potential in the xylem at the top of the plant becomes less than the water potential in the xylem in the lower part of the plant.

6. Through the combined forces of the differences in water potential, cohesion of water molecules due to hydrogen bonds, adhesion of the water molecules to the walls of the xylem cells, and root pressure, the upward force on the water molecules becomes greater than the force of gravity, and the water moves upward in the plant.

7. As water moves up the xylem, the water potential in the roots' xylem tissue decreases.

8. When water potential in the roots becomes less than that of the surrounding soil, water moves into the roots, allowing the transpiration process to continue.

The environmental factors that affect the rate of transpiration include atmospheric humidity, air movement (wind), air temperature, light intensity, and soil conditions.

Humidity surrounding the plant is the most important environmental factor that influences transpiration rate. Transpiration is increased when the air above the plant is dry (less saturated with water vapor) because the diffusion gradient is steep. Conversely, when the relative humidity is high, the diffusion gradient is low and the transpiration rate slows down.

Although most of the water is transpired though stomata, some is lost through cuticular transpiration. Plants located in arid environments often have a thickened cuticle. The increase in the cutin (wax-like material) on the surface of leaves can reduce transpiration and protect plants from water loss.

Stomata open when guard cells become turgid and close when the water is lost from the guard cells and they become flaccid. After an episode of rapid transpiration, stomata close to prevent further desiccation. The distribution of stomata is variable in plant species. Many species have stomata on the bottom surface of the leaf only, or with a small number also on the upper leaf surface. These plants are better adapted to prevent water loss via transpiration than plants with stomata equally located on both upper and lower leaf surfaces.

Pre-Lab Discussion and Activity

Note: The barometer/ low pressure sensor used for this lab is designed to be used with noncorrosive gases such as air, helium, and nitrogen This barometer comes with a length of plastic (polyurethane) tubing and several “quick-release” style connectors.

You will model the procedure that students will use to conduct the lab activity. Choose a different plant for your demonstration than the one students will use, and challenge students to compare your results with theirs.

Connect the seedling to the barometer/low pressure sensor (refer to the Procedure section for details). As the plant’s leaves transpire—that is, as water evaporates from their surface—use the sensor to measure the change in pressure at the end of the plant stem. Use a fan to blow air across the plant’s leaves and again measure the change in pressure.

Ask students to predict the following:

1. How much will the pressure change in 10 minutes?

Answers will vary depending on the student’s experience. In general, many students predict that the pressure will drop as the plant’s leaves transpire.

2. How will the rate of transpiration under normal conditions compare to the rate of transpiration when air blows across the leaves?

Students might predict that the rate of transpiration will be greater when the air blows across the leaves than when the leaves are in still air.

3. How might other factors such as light intensity, humidity, and ambient temperature change the rate of transpiration?

Students might predict that high humidity would reduce the rate of transpiration, and high temperature or light intensity would increase the rate of transpiration.

Teacher Tip: To reduce the number of air bubbles in the tubing, let the water sit at room temperature overnight, allowing excess dissolved gases to escape.

Teacher Tip: Honeysuckle plants, bush bean seedlings, and tomato plant seedlings work well.

Teacher Tip: It is important to assemble the apparatus precisely as shown in the Procedure with Guided Inquiry section.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Be careful as you use a knife or razor blade to trim the plant stem.

♦ Do not let the barometer/low pressure sensor get wet.

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
First, record data in still air.	Mount the sensor to the support rod. Connect the seedling to the sensor using a water-filled tube. Set up a graph display.	Analyze the data to find the change in barometric pressure and time. Determine the relative rates of transpiration.	Next, record data in moving air.	Adjust the scale of the graphs to show all data. Sketch the graphs of the collected data.

Procedure with Inquiry

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

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

Part 1 – Transpiration in Still Air

This portion of the lab looks at transpiration of a plant located in still air.

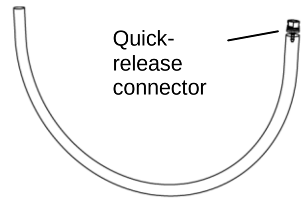
Set Up

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

2. ☐ Connect a barometer/low pressure sensor to the data collection system using a sensor extension cable. �(2.1)

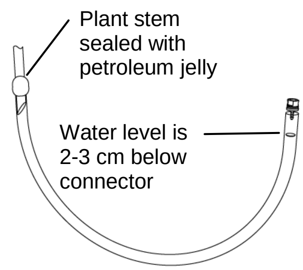
3. ☐ Display a graph on the data collection system showing Barometric Pressure (hPa) on the y-axis and Time (s) on the x-axis. �(7.1.1)

4. ☐ Put a drop of glycerin on the barbed end of the quick-release connector, and insert the barb into one end of the plastic tubing. The barb will not go completely into the tubing. However, be sure that it is in far enough so it does not easily fall out.



5. ☐ Use a knife or single-edge razor blade to cut the stem of a plant seedling 2 to 3 cm above the soil. Immediately immerse the cut end of the seedling in a bowl of water.

6. ☐ Trim the freshly cut end of the stem to a 45-degree angle, keeping the cut end submerged.



7. ☐ Why do you think it is important to keep the plant stem under water after you cut it?

Air bubbles will cause a disruption of the cohesion of water molecules in the xylem. When the water molecules are no longer "stuck together" when air is introduced into the xylem, the results might be affected.

8. ☐ Bend the piece of plastic tubing into a "U-shape." Use a pipet or an eyedropper to fill the tubing with water.

9. ☐ Place the tubing into the bowl of water. While holding the tubing underneath the water, insert the plant stem, cut-end first, into the tubing.

Note: Avoid creating air bubbles in the tubing.

10. ☐ Raise the tubing and plant out of the water, keeping the tube in a "U" shape. Adjust the level of the tubing so there is a 2- or 3-cm air gap beneath the connector end. Water will spill out of the tubing. Be sure that water in the tubing *always* stays in contact with the plant.

Note: Don't allow the connector-end of the tubing to be lower than the plant-end of the tubing.

11. ☐ Spread petroleum jelly around the end of the tube to create an airtight seal between the edge of the plastic tubing and the plant stem. If you see water leaking from the end of the tubing around the plant, add more petroleum jelly.

Note: Be sure that the petroleum jelly does not come in contact with the cut end of the plant stem.

12. ☐ Why do you think that petroleum jelly is needed?

Petroleum jelly prevents gas from escaping and causing a false pressure reading.

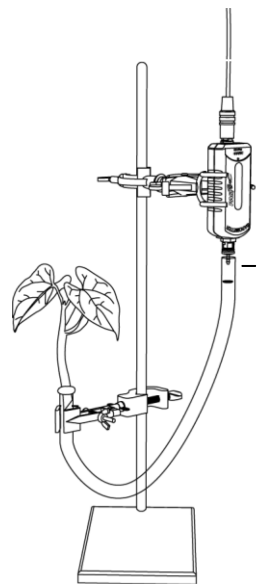
13. ☐ What would happen if the petroleum jelly came in contact with the cut end of the stem?

The petroleum jelly would block water from entering the xylem. If water was blocked from entering the system, transpiration could only be measured until all the existing water in the xylem passed through the leaf.

Note: If air bubbles form around the cut end of the stem, pull the tubing away from the stem. Use the eyedropper to refill the open end of the tubing with water. Put the stem back into the water in the tubing.

14. ☐ Secure the tubing with the plant seedling in an upright position using a clamp and the base-and-support rod.

15. ☐ Mount the barometer/low pressure sensor to the support rod with the three-finger clamp. The pressure port should be above the cut end of the stem, preventing water from entering the sensor.



16. ☐ Align the quick-release connector on the tubing with the connector on the pressure port of the sensor. Push the connector onto the port, and then turn the connector clockwise until it clicks (about one-eighth turn).

Note: Make sure that no water enters the sensor. There should be a 2- to 3-cm air pocket between the water level and the pressure port.

Note: Do not move the sensor up or down on the support rod while recording data.

17. ☐ Do you expect to see an increase or decrease in pressure if transpiration is occurring? Explain your answer.

Answers may vary depending on students' knowledge of pressure and volume relationships. If the plant is transpiring, there should be a drop in pressure. Water is moving out of the tubing, into the plant, and then out of the leaf. The trapped air pocket will expand to fill the space vacated by the water. With the same number of air molecules in a larger space, the pressure of the air will decrease.

Collect Data

18. ☐ Start recording data. �(6.2)

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

20. ☐ Record data for 600 seconds (10 minutes), and then stop recording. �(6.2)

21. ☐ To restore the pressure in the tubing to the original value, carefully disconnect and then reconnect the tubing to the sensor.

Analyze Data

22. ☐ Why is it necessary to restore the pressure?

To compare runs, they must have the same starting point, which in this case is normal atmospheric pressure.

23. ☐ Describe your graph. What happened to the pressure?

The pressure is decreasing over time.

24. ☐ Name Run 1 "Still Air". �(8.2)

25. ☐ What are some of the controlled variables in this experiment?

A controlled variable is the starting air pressure—using standard atmospheric pressure as a reference point. Other controlled variables include the temperature, humidity, and movement of the surrounding air.

Part 2 – Transpiration in Moving Air

Set Up

26. ☐ Place the fan at about 1 meter from the plant seedling.

27. ☐ Put the fan on a low setting so it blows a light breeze over the seedling.

28. ☐ What do you expect to happen to the rate of pressure change when you add wind? Explain your answer.

Answers may vary. Students may expect that more transpiration or less transpiration will occur when the wind is blowing. Some students may mention adaptations such as closing stomata to conserve water. Others may assume that water will transpire through the plant at a faster rate because the fan is blowing the humid air away from the leaf and creating a water potential differential.

Collect Data

29. ☐ Start recording data. �(6.2)

Note: A new graph page will automatically open with a new data run.

30. ☐ Adjust the graph to show all data. �(7.1.2)

31. ☐ Record data for 600 seconds (10 minutes, then stop recording data. �(6.2)

32. ☐ Describe your graph. What happened to the pressure?

The pressure will have decreased over time. Depending on the species of plant being used, the rate of change might be more or less than the first trial.

33. ☐ Name Run 2 "Wind". �(8.2)

Analyze Data

34. ☐ What is your independent variable (the variable you are changing) in this experiment?

Air movement is the independent variable in this experiment.

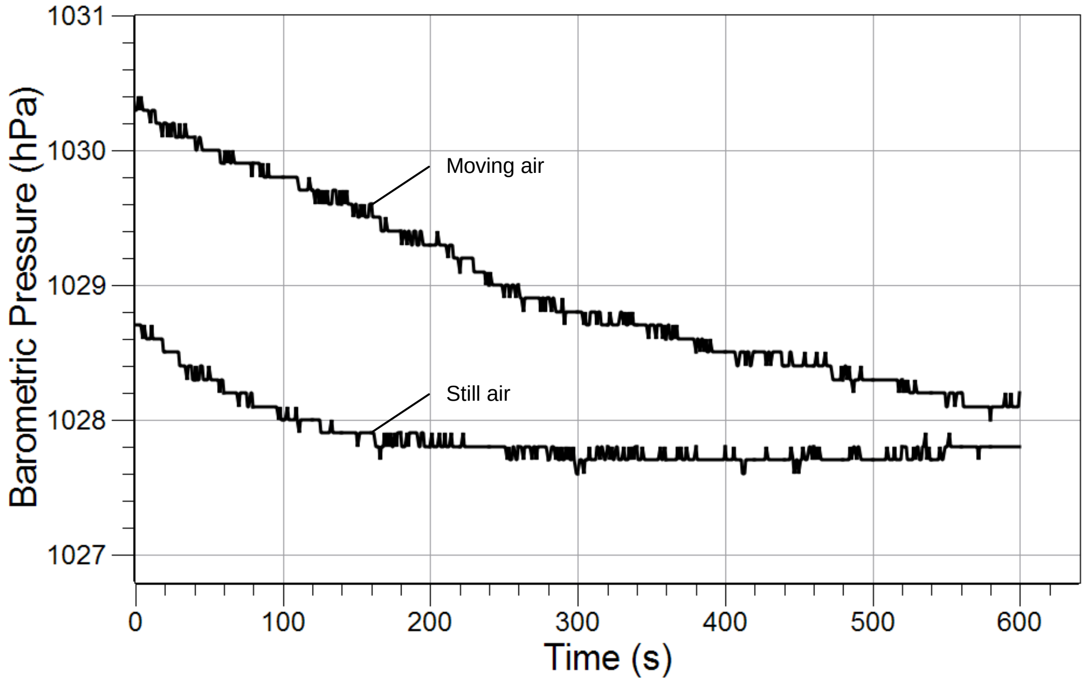
35. ☐ What is the dependent variable (the variable that responds to the changes of the independent variable)?

Air pressure is the dependent variable. It depends on the air movement.

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

Data Analysis

1. ☐ Draw a sketch of your Barometric Pressure versus Time graph for each data run, including scaling for the y-axis and x-axis. (You will have 2 sketches of data on one graph.) Be sure you correctly scale your sketches so you can compare one with the other.



2. ☐ Use the graph tools of your data collection system �(9.2) to find the data from your graph to complete the first two columns in the Table 1. Then, calculate the rate of transpiration.

Table 1: Calculate the rate of transpiration of leaves in still air and in moving air

Transpiration Run	**Δ*P* (hPa)**	**Δ*t* (s)**	**Rate of Transpiration (hPa/min)**
Without Fan	–0.9	600	–0.09
With Fan	–2.2	598	–0.22

Analysis Questions

1. What was the rate of pressure change in the plastic tubing? Does a decrease in pressure in the tubing correspond to an increase or to a decrease in water loss through the seedling's stomata? Explain.

The pressure decreases and the rate of pressure change varies with each student setup. A decrease in pressure inside the tubing corresponds to an increase in water loss through the stomata. As water is lost through the stomata, more water is drawn out of the tubing and into the plant's xylem by transpiration, causing the volume of water in the tubing to decrease. The trapped air pocket expands to fill the space vacated by the water, so the pressure of the air decreases because volume is inversely proportional to pressure.

2. Did the fan affect the rate of pressure change? Explain how the fan affects transpiration. What natural phenomena does the fan mimic?

The fan increases the flow of air across the leaves, mimicking wind. An increase in air flow around the seedling increases the rate of pressure change, because wind decreases the boundary layer of still air at the surface of a leaf. (The still air layer slows the rate of leaf water loss.) Increased wind speed causes the rapid removal of evaporating water molecules from the leaf surface, thus decreasing the water potential in the air surrounding the leaf. Decreased water potential leads to increased rates of water loss from the leaf.

Note, however, that certain species of plants can close their stomata in windy conditions. The results might show a decrease in the rate of transpiration if you chose a plant with this type of adaptation.

3. Describe some adaptations that enable plants to minimize water loss from their leaves.

Adaptations include reduced number of stomata, a decrease in leaf surface area, an increase in the thickness of the leaf cuticle, and other adaptations such as dense hairs or sunken stomata that decrease air movement around stomata.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Would you expect all plant species to have the same transpiration rate under similar environmental conditions? Why or why not?

No. Plants have different physiological adaptations to various environmental conditions.

2. Do you think that leaves or stems are more important in the process of evaporation through transpiration?

Leaves have the most stomata and, therefore, are the site of the most transpiration.

3. Would exposing a cut stem to air affect the rate of transpiration as measured in this experiment? Explain your answer.

Yes. Exposing a cut stem to air would allow air to enter the vascular tissue. This would interfere with the uptake of water.

4. How would covering the lower side of the leaves with petroleum jelly affect transpiration?

Covering the lower side of the leaves with petroleum jelly would block the stomata and prevent the evaporation of water from the leaf.

5. Would the transpiration rate in a conifer leaf (needle) be higher or lower than a deciduous (broad) leaf? Explain your answer.

The conifer leaf has a smaller surface area and would therefore have a lower rate of transpiration than a leaf of a deciduous plant.

6. What would the data look like if the leaves were removed from the plant prior to collecting data? How does this relate to what you know about transpiration?

Removing the leaves would reduce the area for transpiration, and the data would show a reduced or zero transpiration rate. This should relate to what students know about the function of the leaves in transpiration.

7. Describe the data you might obtain if the experiment was performed without a plant. Why are controls necessary in scientific investigations?

If the experiment was performed without the plant, the data would not show any significant change in pressure. Controls are necessary to provide a basis for comparison of the experimental data.

Multiple Choice Questions

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

1. Which of the following describes the fate of most of the water taken up by a plant?

- **A.** It is used as a solvent.
- **B.** It is used as a hydrogen source in photosynthesis.
- **C.** **It is lost during transpiration.**
- **D.** It makes cell elongation possible.

2. In a plant, where does transpiration take place?

- **A.** All parts of the plant
- **B.** **Leaves**
- **C.** Stem
- **D.** Only the aerial parts

3. Most transpiration takes place through the:

- **A.** **Stomata**
- **B.** Epidermis
- **C.** Stem
- **D.** Cuticle

4. All of the following can affect transpiration except:

- **A.** Humidity
- **B.** Temperature
- **C.** Air movement
- **D.** **Leaf color**

Key Term Challenge

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

1. **Transpiration** is the evaporation of water from a plant surface. The amount of water needed by plants for growth and maintenance of tissue is **small** compared to the amount that is lost through the transpiration. If water lost from leaves is not replaced by water transported up from the plant **roots**, the plant wilts and dies.

2. The transport of water up the **xylem** tissue in plants is controlled by differences in the concentration of water molecules. Because of this difference, water moves into the xylem by **osmosis**, forcing fluid up the xylem vessels. This upward movement results in root pressure, but this pressure only moves water a short distance up the xylem. Transpiration pulls the water and dissolved minerals further up the xylem.

3. There are hundreds of **stomata** in the epidermis of a leaf. Most are located in the lower epidermis. This reduces water loss because the lower surface receives less solar radiation than the upper surface. Each stoma allows the carbon dioxide necessary for **photosynthesis** to enter, while water evaporates through each stoma in transpiration.

4. Studies have revealed that about 10 percent of the moisture found in the atmosphere is released by plants through transpiration. The remaining 90 percent is supplied mainly by evaporation from oceans, seas, and other bodies of water. Some factors affecting transpiration are **humidity**, **air movement**, and **air temperature**.

Extended Inquiry Suggestions

Calculate the rate of transpiration per unit of leaf surface area. Determine the surface area of the leaves on the plant as follows:

- Cut the leaves (but not the stems) from the plant and weigh the leaves.
- Cut a 5 cm by 5 cm section of a leaf and weigh the section.

Note: For plants with small leaves, cut sections from several leaves to equal about 5 cm by 5 cm of leaf area.

- Divide the weight of the 5 by 5 cm section of leaf by 25 to find the approximate weight of a 1-cm square section.
- Divide the total weight of the leaves by the weight of a 1-cm square section to find the approximate leaf surface area.
- Divide the rate of transpiration (hPa/min) by the surface area.

Use different species of plants to compare transpiration rates.

Determine the effect of the following environmental factors on the rate of transpiration:

- Light intensity
- Humidity
- Temperature

17. Water and pH

Objectives

Students analyze the differences in how water pH changes when "acid rain" is added.

- ♦ Analyze water from different sources for pH and conductivity.
- ♦ Determine that water with more dissolved solids, for instance from a pond, lake, river, well, or swimming pool, is relatively resistant to changes in pH, after adding a small amount of acid.
- ♦ Identify why mountain water sources and ecosystems are more susceptible to damage by acid rain or other forms of acidic or basic pollution than are water sources and ecosystems located at lower elevations in valleys.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Students measure the pH and conductivity of water from various sources and analyze the effect of "acid rain" on each of them.

Time Requirement

♦ Preparation time	10 minutes (day before); 10 minutes (day of)
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ pH sensor
- ♦ Conductivity sensor
- ♦ Beaker, 250-mL (4)
- ♦ Graduated cylinder, 100-mL
- ♦ Small container (for diluted vinegar solution)
- ♦ Pipet
- ♦ Stirring rod
- ♦ White vinegar, 250 mL[1]
- ♦ Water sample, 250 mL (3)[2]
- ♦ Distilled water, 250 mL
- ♦ Labels
- ♦ Marking pens

[1]To formulate the diluted vinegar solution refer to the Lab Preparation section.

[2]Collect at least three water samples in separate screw-topped containers.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Conductivity
- ♦ Buffers
- ♦ pH
- ♦ Total Dissolved Solids
- ♦ Ions

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Soil pH
- ♦ Water Purification
- ♦ Acid Rain

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)
- ♦ Connecting multiple sensors to your data collection system �(2.2)
- ♦ Calibrating the pH sensor �(3.6)
- ♦ Setting up a conductivity sensor for a particular sensitivity �(4.2)
- ♦ Monitoring live data without recording �(6.1)
- ♦ Adding a variable to a digits display �(7.3.2)
- ♦ Saving your experiment �(11.1)

Background

The pH (acidity or concentration of hydronium—H_3O^+—ions) of water is an important attribute, because pH influences the behavior of cellular enzymes that are necessary for life processes. Water that has a pH that is too low or too high will not support the growth of many organisms (the lower the pH, the higher the acidity). For example, at a pH of 5 or lower, most fish eggs will not hatch. A pH of 6.5 to 8.2 is optimal for most organisms.

Freshwater acidification due to acid rain can lead to a decline or loss of fish populations. Below pH 4.5, no fish are likely to survive. A decrease in pH is often associated with an increase in toxic metal availability, particularly for aluminum and mercury. Decreased pH and elevated aluminum have been shown to increase fish mortality, decrease fish growth, decrease egg production and embryo survival, and result in physiological impairment of adult fish. In general, embryos, fry, and juveniles are less acid-tolerant than adult fish. Aluminum can precipitate onto fish gills, inhibiting diffusion and resulting in respiratory stress.

Acid deposition is a possible cause of declines in amphibian populations. The larval stages of aquatic amphibian species are most affected by acidic water. Many frog species use temporary ponds, but these tend to be small and shallow and are easily affected by acid rain because their only sources of water are rainfall and snow melt. Frogs that use large, permanent bodies of water for breeding generally lay their eggs in the summer, so they do not experience the acid pulses from snow melt. However, the eggs and larvae of these species are even more sensitive to subtle changes in pH levels than those of species that breed in temporary ponds. As with fish, the toxic effect of decreased pH levels on amphibians is complicated when concentrations of metals, such as aluminum, increase. As a general rule, embryos of sensitive amphibian species are killed by water with a pH of 4.5 or lower, while embryos of tolerant species can survive a pH as low as 3.7.

Although birds and mammals are not directly affected by water acidification, they are indirectly affected by changes in the quantity and quality of their food resources. Some birds, such as the osprey, have difficulty living around an acidified lake because there are far fewer fish to be found. In Scotland, otters are quite rare around acidic streams and rivers, since their main food supply, fish, is reduced.

On the other hand, rapidly growing algae or submerged aquatic vegetation remove CO_2 from the water during photosynthesis, significantly increasing pH levels. When pH exceeds 9.0, it begins to be harmful to salmonids and perch.

The pH of water that has a low level of dissolved solids, such as the nearly pure water of high mountain lakes and streams, is easily changed by adding acid or base to the water because it lacks minerals that act as buffers against change in pH. Thus, acid rain or rapid algae growth will have a large impact on pH in these bodies of water.

In contrast, consider the pH of water that has a higher level of dissolved solids or alkalinity, such as lakes, ponds, and rivers that exist in valleys; ground water; and ocean water. Dissolved solids can buffer them from rapid changes in pH as a result of the addition from the environment of acidic or basic substances. Therefore, acid rain or rapid algae growth will have relatively less effect on the pH of these bodies of water.

Pre-Lab Discussion and Questions

To prepare students this lab, engage them in a discussion of the following:

1. What are factors that can influence pH levels in water?

The pH of water that has a low level of dissolved solids, such as the nearly pure water of high mountain lakes and streams, is easily changed by adding acid or base to the water. Thus, acid rain or rapid algae growth will have a large impact on pH in these bodies of water.

The pH of water that has a high level of dissolved solids or alkalinity, such as lakes, ponds, and rivers that exist in valleys, ground water, and ocean water, are buffered by dissolved solids from rapid changes in pH as a result of the addition from the environment of acidic or basic substances. Therefore, acid rain or rapid algae growth will have relatively less effect on the pH of these bodies of water.

2. Describe the pH scale.

The pH scale measures the acidity or alkalinity of a solution. This scale ranges from 0 (highly acidic) to 14 (highly alkaline). Distilled water, with a pH of 7, is a neutral solution. The pH scale is a negative logarithm of the concentration of hydrogen ions. Therefore, a change of one unit of pH represents a ten-fold change in acidity or alkalinity. A solution with a pH of 5.0 is 10 times more acidic than a solution with a pH of 6.0 and 100 times more acidic than a solution of pH 7.0.

3. How is the pH of water affected by acid rain?

Acid rain, to the extent that it is lower in pH than the water it mixes with, will lower the pH of that water. However, different water sources have different types, and amounts of dissolved solids. Dissolved solids can often act as a buffering system, preventing large scale changes in the pH of those water systems. Typically, water that has a high conductivity has a large amount of dissolved solids in it and will resist pH changes.

4. What is conductivity?

Salt dissociates into anions and cations in water, producing an electrolyte solution capable of conducting electricity. By passing an electric current between two electrodes on a probe, the measured conductivity is proportional to the salt concentration in the sample; thus, a high level of salinity will result in a high electrical conductivity output. The standard unit of electrical conductivity is microsiemens per centimeter (µS/cm).

Lab Preparation

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

Note: Students need to obtain permission before collecting soil samples from private property.

1. Prepare students to take detailed notes about the sites where they collect water samples. Observations such as the following will be recorded in Table 1 in the Data Analysis section:
    - The appearance of the water source, including water clarity and water movement
    - The appearance and types of plants and other organisms
    - Animal tracks and the appearance of animals
    - The terrain, holes in the ground, and the geological features of rocks
    - Nearby buildings and whether nearby roads are asphalt, cement, gravel, or dirt
    - Anything unusual about the area

2. To test the pH of water, students can collect water samples from their homes and neighborhoods. They should consider novel types of water, for instance, from ponds, rivers, wells, and swimming pools, as well as samples like tap water or a favorite brand of bottled water.

3. The pH sensor should be calibrated as part of the procedure. However, if standardized buffer solutions are not available to accomplish this, inform students that results may not be as precise if the sensors are not calculated. Explain that when pH data is compared with a standard or norm or with pH data from another pH sensor, small differences in electronics and sensors could literally mean the difference between life and death as it relates to an organism. A half point difference in a pH measurement means a five times difference in acidity or alkalinity, because pH applies a logarithmic scale.

4. To dilute the vinegar solution, mix 50 mL of vinegar with 50 mL of distilled water in a 250-mL beaker.

5. For best results, perform the tests in the lab at room temperature (25 °C).

> **Note:** Changes in temperature alter hydrogen ion activity in the solution, consequently changing the pH result.

Teacher Tip: Have a copy of the user manual for the pH sensor and for the conductivity sensor available to students.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Avoid any water that might contain bacteria or sewage.
- ♦ Wear protective equipment, such as safety goggles, gloves, and an apron, when handling chemicals.
- ♦ Dispose of chemicals and solutions as instructed.

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
Rinse the pH sensor with distilled water.	Collect water samples from three different sites.	Collect and record data for a water sample containing diluted vinegar.	Place the pH sensor into a water sample, wait for the reading to stabilize, and record data.	Add 1 mL of diluted vinegar into a water sample.

Procedure with Inquiry

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

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

Part 1 – Obtaining samples and initial observations (day before lab)

1. ☐ Rinse three screw-topped containers thoroughly with distilled water.

2. ☐ Collect three water samples from your home or neighborhood, for instance, from ponds, rivers, wells, swimming pools, tap water, or your favorite brand of bottled water.

Note: Avoid any water that might contain bacteria or sewage.

Note: Label each water sample, for instance “Swimming pool” or the name of the lake.

3. ☐ Why do you need to avoid water containing bacteria or sewage?

Water containing bacteria or sewage adds nutrients into the water that could alter results. In addition, it could make you ill.

4. ☐ Record observations following the instructions above Table 1 in the Data Analysis section.

5. ☐ Why did you choose the collection sites you chose?

Ideally, students will select sites that will exhibit a wide variety of pH readings and be from a wide variety of soil types.

Part 2 – Establishing control benchmarks

Set Up

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

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

8. ☐ Calibrate the pH sensor unless the teacher guides you otherwise. �(3.6)

9. ☐ Connect a conductivity sensor to the data collection system. �(2.2)

Note: The conductivity sensor does not need to be calibrated because the inherent error in conductivity sensors is miniscule compared to the range of conductivity involved here.

10. ☐ Monitor live data without recording �(6.1) and be sure that both pH and conductivity measurements are visible. �(7.3.2)

11. ☐ Measure and pour 200 mL of distilled water and 200mL of vinegar into separate 250-mL beakers

Collect Data: Distilled Water and Vinegar (controls)

12. ☐ Rinse the sensor with distilled water.

13. ☐ Why is the sensor rinsed with distilled water before testing each sample?

Distilled water is used to keep the sensor from cross-contaminating the other samples. Distilled water does not contain any chemicals that might alter the pH sensor, but regular tap water would.

14. ☐ Place the pH sensor into the beaker of distilled water.

15. ☐ Wait until the pH reading stabilizes (up to 60 seconds).

16. ☐ Record the pH of the distilled water in the control section of Table 2 in the Data Analysis section.

17. ☐ Remove the pH sensor from the distilled water and place into the beaker filled with vinegar.

18. ☐ Wait until the pH reading stabilizes (up to 60 seconds).

19. ☐ Record the pH of the vinegar in the control section of Table 2 in the Data Analysis section.

20. ☐ Remove the pH sensor from the solution.

21. ☐ Rinse the conductivity sensor with distilled water.

22. ☐ Place the conductivity sensor into the beaker containing only distilled water.

23. ☐ Wait until the conductivity reading stabilizes (up to 60 seconds).

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

25. ☐ Record the conductivity of the distilled water in the control section of Table 2 in the Data Analysis section.

Part 3 – Working with gathered water samples

Set Up

26. ☐ Label a beaker for each water sample as you did with the screw-topped containers.

27. ☐ Measure 200 mL of the each water sample into its own 250-mL beaker.

Collect Data: pH of water samples before adding vinegar

28. ☐ Monitor and record a stabilized pH for the three water samples, as you did for the distilled water.

Note: Rinse the sensor with distilled water before proceeding to the next water sample.

Collect Data: Conductivity of water samples before adding vinegar

29. ☐ Rinse the sensor with distilled water, and monitor and record a stabilized conductivity for the three water samples as you did for the distilled water.

30. ☐ What is the purpose of measuring change in conductivity as well as change in pH?

Initial conductivity is a good indicator of total dissolved solids in a solution. Dissolved solids can often act as a buffer and help minimize changes in pH when an acid or base is added.

Collect Data: pH of water samples after adding vinegar

31. ☐ Rinse the stirring rod and pipet with distilled water.

32. ☐ Using the pipet, add 1 mL of diluted vinegar to each water sample.

33. ☐ What is the purpose of adding the diluted vinegar to each water sample? What could the vinegar represent in nature?

The diluted vinegar is an acid that will be added to determine its affect on the samples collected. It could represent acid rain running off into a body of water.

34. ☐ Stir gently with a stirring rod.

35. ☐ Rinse the pH sensor with distilled water, and monitor and record a stabilized pH for the each of the three water samples with vinegar added

Collect Data: Conductivity of water samples after adding vinegar

36. ☐ Rinse the conductivity sensor with distilled water, and monitor and record a stabilized conductivity for each of the three water samples with vinegar added.

37. ☐ Clean up the equipment and work area.

Data Analysis

1. ☐ Record detailed observations for each water sample in Table 1, replacing the sample number with the label you gave it.

- The appearance of the water source, including water clarity and water movement
- The appearance and types of plants and other organisms
- Animal tracks and the appearance of animals
- The terrain, holes in the ground, and the geological features of rocks
- Nearby buildings and whether nearby roads are asphalt, cement, gravel, or dirt
- Anything unusual about the area

Table 1: Detailed observations of water sample locations

Water sample type	**Observations**
1	
2	
3	

2. ☐ Record the pH and conductivity for each water sample in Table 2, replacing the number with the water sample label you gave it.

Table 2: Stabilized pH and conductivity readings for water samples before and after applying “acid rain”

Water Sample Type	Before Adding Acid		After Adding Acid		Change in pH	Change in Conductivity
	pH	Conductivity	pH	Conductivity		
Spring Water	7.3	119	5.2	167	–2.1	48
Tap Water	6.5	205	4.8	233	–1.7	28
Pond Water	6.8	236	4.3	285	–2.5	49
Control Readings	**Conductivity of Distilled Water** 45 µS/cm		**pH of Distilled Water** 6.7		**pH of Diluted Vinegar (“Acid Rain”)** 3.4	

Analysis Questions

1. List your water samples in order of increasing conductivity level. Make a second list of your samples in order of increasing pH level.

Answers will vary according to the samples collected.

2. Which water samples seemed to show the least amount of pH change when the acid was added? Why do you think these samples were resistant?

The samples that showed the least amount of change should be samples that have high amounts of dissolved solids in them. The dissolved solids act as a buffer. For this example, the water samples had similar amounts of dissolved solids that were 2 to 4 times greater than that for the distilled water. The pH of all samples was less affected by the addition of the acid than the pH of the distilled water, which changed by –3.3 pH units.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In some high mountains regions, polluted air results in snow with a low (acidic) pH. What might be the consequences of the snow melt into high mountain creeks and lakes in the springtime in such area? Explain using data from the lab.

The water at these locations has low levels of dissolved solids and pH can easily be changed by adding acid to the water. Thus pollution greatly impacts the water.

2. In rivers that run through agricultural areas, the runoff from the fields often contains soil and dissolved fertilizers. What might be the consequences of this runoff to the river water? Would you expect such river water to be as sensitive as the rivers in high mountain areas to acid pollution? Explain using data from the lab.

The water at lower elevations has a higher level of dissolved solids and is buffered by dissolved solids from rapid changes in pH, so it would not be as sensitive as the rivers in high mountain areas to acid pollution. In this example, we saw that the pH of water samples that contained more dissolved solids as revealed with the conductivity sensor was changed less than the pH of distilled water, which contained lower levels of dissolved solids.

3. Since most aquatic organisms live in the neutral range of pH, what could make the pH of aquatic locations differ from normal?

Acid rain, human pollution, and rapid algae bloom could alter pH.

4. If you were testing the pH of an actual aquatic site and the pH registered outside of the normal range, what could you hypothesize about the cause of this?

Answers will vary but some reasons could be acid rain, runoff from nearby farm land, human pollution, rapid algae bloom, etc.

5. What natural bodies of water would be the most resistant to acidification from acid rain? Which would be affected the most? Explain your answer.

Oceans would be very resistant to change in pH due to their high volume of water and high levels of dissolved solids, which have a buffering effect. High mountain streams that have very little dissolved solids in them would be the most susceptible to drastic pH changes.

Multiple Choice Questions

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

1. What is the pH value for a solution that is neutral?

- **A.** 3
- **B.** 5
- **C.** **7**
- **D.** 9

2. Which of the following could result in changes in the pH of water in a lake?

- **A.** Mining
- **B.** Agricultural activity
- **C.** Air pollution
- **D.** **All of the above**

3. Below which pH level are many fish species unable to live?

- **A.** 9
- **B.** 7
- **C.** 6
- **D.** 4

Key Term Challenge

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

1. The pH level indicates how **acidic** or how **basic** (alkaline) a solution is. When a substance is dissolved in water, it produces charged molecules called ions. Acidic water contains extra **hydrogen** ions (H^+) while basic water contains extra **hydroxyl** ions (OH^-). Rainwater is expected to be **neutral**, but it is actually somewhat acidic. This is caused by the rain dropping through the atmosphere and dissolving gaseous carbon dioxide, which causes a weak acid to form. Thus pure rainfall tends to have a pH of about 5.6.

2. Fish originate in ponds, rivers, streams, lakes, and oceans. Since each of these locations has different **pH** levels, there is not a "normal" pH that applies to all fish. Saltwater fish prefer an **alkaline** pH of 8.0 or above. Freshwater fish thrive in an **acidic** environment with a range lower than that, somewhere between 5.5 and 7.5, depending on the specific species.

Extended Inquiry Suggestions

Lead a discussion of the impact of pH levels on aquatic organisms. Include in this discussion groundwater and eutrophication (nutrient pollution).

Have students research the mechanisms of action of pH buffers.

Test the reaction of the various samples to the addition of a basic solution, such as diluted ammonia.

18. Water Purification

Objectives

Guide students to understand the effectiveness of various treatments for improving the quality of water.

Procedural Overview

Using a pH sensor and a conductivity sensor, students gain experience conducting and comparing the following procedures:

- Measure a sample of polluted water to establish a controlled reference.
- Measure the water sample after applying sedimentation only.
- Measure the water sample after applying sedimentation and filtration.
- Measure the water sample after applying coagulation, sedimentation, and filtration.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 to 15 minutes
♦ Lab activity	80 minutes

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Conductivity sensor
- Erlenmeyer flask, 250-mL
- Beaker, 250-mL (2)
- Funnel
- Stirring rod
- Wash bottle and waste container
- Lens tissue
- Coffee filter (2)
- Egg whites, 5 mL
- Polluted water[1]
- Distilled water, 500 mL

[1]To formulate polluted water (using soil and water) refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Conductivity
- ♦ pH

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Soil pH
- ♦ Water and pH

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)
- ♦ Monitoring live data without recording �((6.1)
- ♦ Displaying data in a digits display �(7.3.1)

Background

Water purification involves several types of processes, with a goal of obtaining water that is safe for a particular use, such as human consumption. It is necessary to remove mineral particles, organic matter, toxic chemicals, and disease-causing microorganisms.

The three primary treatments for municipal wastewater are screening, coagulation (also known as flocculation), and sedimentation, plus there are secondary and tertiary treatments.

First, water is passed through a coarse screening process to remove sticks, leaves, and other large objects. Sand and grit settle out as well. Next, flocculation aggregates particles into a mass. This typically involves adding a chemical that attaches to small particles, such as bacteria or other impurities, and helps the floc come together. Then, aided by gravity, the floc and other solid material accumulate at the bottom in a process called sedimentation.

Various kinds of filtration can be applied during primary, secondary, or tertiary stages of treatment.

Secondary treatment uses microorganisms and sometimes natural degradation over time to remove dissolved organic matter. In a tertiary process, the water may be treated with disinfectants. Furthermore, the pH may be adjusted to prevent corrosion of water pipes and harm to organisms in the body of water that receives the treated water.

In this experiment, two sensors monitor the process of water purification: a pH sensor and a conductivity sensor. The pH sensor measures the acidity or alkalinity of the water. The conductivity sensor measures the level of dissolved salts in the water. Although not part of this lab activity, a turbidity sensor is another tool for measuring water quality. A turbidity sensor measures the concentration of solids suspended in the water.

Pre-Lab Discussion and Activity

Engage your students with the following questions:

1. What happens to all of the water that goes down the drains in your kitchens and bathrooms?

Many will respond that it goes into the sewer. (It is likely that many students have never considered what happens beyond this.) Before wastewater can be released into natural waterways, it must go through a water treatment plant.

Note: Overview the process of water purification and relate it to the procedure in this lab, including the three types of sensors students will be using and the measurements they will be taking.

2. Which of the following water treatment processes will result in the purest water, and why:

- ♦ Sedimentation
- ♦ Sedimentation and filtration
- ♦ Coagulation, sedimentation, and filtration

Note: Student may tend to think that the most processing leads to the purest water. Depending on the method used for coagulation, this may or may not be true.

For the purposes of this lab, the terms coagulation and flocculation are synonymous. To the extent that they can be distinguished, coagulated particles are irreversibly clustered, whereas flocculated particles can be disaggregated.

Lab Preparation

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

1. To prepare "polluted water," mix 1 cup of soil with 2 gallons of water.

2. Although separating egg whites is part of the procedure, consider doing it for students ahead of time.

> **Note:** Store-bought egg whites may alter the conductivity results due to the presence of added sodium.

3. To assure sufficient time to complete each of the trials, assign each group one of the trials and compile class data at the end of the period, or take two days to complete the activity.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Wash hands thoroughly after handling raw eggs.

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
Allow the sample of polluted water to settle for 20 minutes. Determine the pH and conductivity of the sedimented sample.	Calibrate the pH sensor. Determine the pH, and conductivity of a sample of polluted water.	Analyze your data, and clean up your workstation.	Then, measure the pH and conductivity of the polluted sample of water after sedimentation and filtration treatment.	Finally, measure the pH and conductivity of the polluted sample of water after coagulation, sedimentation, and filtration treatment.

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 pH sensor to the data collection system. �(2.1)

3. ☐ Calibrate the pH sensor. �(3.6)

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

Note: The conductivity sensor does not need to be calibrated because the inherent error in conductivity sensors is miniscule compared to the range of conductivity involved here.

5. ☐ Display the pH and conductivity measurements in a digits display. �(7.3.1)

6. ☐ Rinse the pH and conductivity sensors with distilled water.

Part 1 – Before sedimentation (control)

Collect Data

Note: When handling the sensors, take care not to disturb the water sample.

7. ☐ Stir the polluted water thoroughly.

8. ☐ Pour 200 mL of the polluted water into a 250-mL beaker.

9. ☐ Insert the pH and conductivity sensors into the beaker and record the initial values in Table 1 in the Data Analysis section.

10. ☐ Remove the pH and conductivity sensors and carefully rinse each with distilled water.

Part 2 – After sedimentation only

Collect Data

Note: When handling the sensors, take care not to disturb the water sample.

11. ☐ Allow the beaker to sit undisturbed for 20 minutes.

12. ☐ Predict how the pH and conductivity of the sample may change after settling.

Student predictions may vary. Students may accurately predict that the pH and conductivity will remain the same. They may reason that little change will happen in what is ionized and dissolved in the water, when the large particles settle out.

13. ☐ Insert the pH and conductivity sensors into the beaker.

14. ☐ Monitor the values for pH and conductivity on your data collection system. �(6.1) When the values are stable, record them in Table 1 in the Data Analysis section.

15. ☐ Remove the pH and conductivity sensors and carefully rinse each with distilled water.

16. ☐ How did the pH and conductivity levels change after sedimentation?

The pH and conductivity levels should have remained constant or decreased only slightly. This data is a reference point for the effectiveness of the additional treatments.

Part 3 – After sedimentation and filtration

Collect Data

Note: When handling the sensors, take care not to disturb the water sample.

17. ☐ As before, stir the polluted water; pour 200 mL into a beaker; insert the two sensors; then monitor the data, �(6.1) and record the two stabilized measurements in the table.

18. ☐ Allow the beaker to sit undisturbed for 20 minutes.

19. ☐ Place a coffee filter into a funnel, and put the funnel in an Erlenmeyer flask.

20. ☐ Without disturbing the sediment at the bottom of the beaker, carefully pour 100 mL of the settled water from the beaker into the coffee filter.

21. ☐ Predict how the pH and conductivity of the sample may change after treatment.

Student predictions may vary. Students may accurately predict that the pH and conductivity will remain the same or decrease slightly more than the previous sample.

22. ☐ Insert the two sensors into the treated water; then monitor the data �(6.1) and record the two stabilized measurements in the table.

23. ☐ How did the pH and conductivity levels change after sedimentation and filtration?

The pH remains fairly constant and conductivity levels decreased more significantly than the first trial.

Part 4 – After coagulation, sedimentation, and filtration

Collect Data -

Note: When handling the sensors, take care not to disturb the water sample.

24. ☐ As before, stir the polluted water; pour 200 mL into a beaker; insert the two sensors; then monitor the data, �(6.1) and record the two stabilized measurements in the table.

25. ☐ Place 5 mL of egg white into the beaker of polluted water.

26. ☐ With a stirring rod, vigorously mix the egg white in the water.

27. ☐ What is the purpose of adding the egg white?

The egg white is a coagulating agent.

28. ☐ Allow the beaker to sit undisturbed for 20 minutes.

29. ☐ Rinse the Erlenmeyer flask thoroughly with distilled water.

30. ☐ Place a coffee filter into a funnel, and put the funnel in an Erlenmeyer flask.

31. ☐ Without disturbing the sediment at the bottom of the beaker, carefully pour 100 mL of the settled water from the beaker into the coffee filter.

32. ☐ Predict how the pH and conductivity will change after mixing the sample with egg white, allowing the sample to settle and then filtering.

The addition of the coagulating agent, the egg white, results in water that is less cloudy but the water will also have a higher conductivity and pH.

33. ☐ Insert the two sensors into the treated water; then monitor the data �(6.1) and record the two stabilized measurements in the table.

34. ☐ How did the pH and conductivity levels change after coagulation, sedimentation, and filtration?

The addition of the coagulating agent, the egg white, results in water that is less cloudy but the water also has a higher conductivity and pH.

35. ☐ Clean up according to your teacher's instructions.

Data Analysis

Table1: pH and conductivity for the polluted water sample before and after purification.

Treatment	**pH (7.0 is neutral)**		**Conductivity (µS/cm*)**	
	Before	**After**	**Before**	**After**
Sedimentation	7.0	6.5	610	439
Sedimentation and filtration	7.0	6.7	610	146
Coagulation, sedimentation, and filtration	7.0	8.1	610	1190

*µS/cm is microsiemens per centimeter

Analysis Questions

1. Which treatment resulted in the lowest conductivity?

Sedimentation and filtration resulted in the lowest conductivity.

2. Which treatment resulted in the most neutral pH?

Sedimentation and filtration resulted in the most neutral pH.

3. Which treatment results in the best water quality? Explain your answer.

Sedimentation and filtration resulted in the best water quality because it had the lowest conductivity and most neutral pH. Coagulation, sedimentation and filtration resulted in conductivity and pH readings that are too high for the water to be potable.

4. Why do you think that the water treated with the egg white had the highest conductivity?

The high salt content in the egg raises the conductivity level of the water.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Does the conductivity of any of the tests exceed the limits for potable water?

Only the treatment using coagulation, sedimentation, and filtration had conductivity levels that exceeded the limits for potable water.

2. Are the dissolved solids safe to consume?

Given that none of the techniques in this lab involved disinfection, it is not safe to assume that the dissolved solids are safe for consumption.

3. Is the pH of the water acceptable?

The pH of the water is acceptable for either treatment involving sedimentation or sedimentation and filtration.

4. Are the treatments economically feasible?

All of the treatments are economically feasible because they are simple and inexpensive. However, the coagulation treatment with egg whites is not practically feasible for a large quantity of water.

Multiple Choice Questions

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

1. **Which word best describes a pH of 7?**

- **A.** Acidic
- **B.** Basic
- **C.** **Neutral**

2. **How many microsiemens per centimeter (µS/cm) approximate the upper range of the conductivity of drinking water?**

- **A.** 1 µS/cm
- **B.** **800 µS/cm**
- **C.** 2055 µS/cm
- **D.** 5000 µS/cm

Key Term Challenge

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

1. Purifying contaminated water into **potable** water, or into water that is safe to release back into the environment, involves a variety of treatments. First, grit and other large substances are removed through screening and grinding. Adding a **coagulating agent** to the water forms sticky globs that attach to small particles. This phase of purification is also known as **flocculation**. During the **sedimentation** phase, the floc and other particles settle to the bottom of the water. Finally, the water is filtered.

2. Three measurements are used to monitor the process of water purification: turbidity, conductivity, and pH. **Turbidity** represents the concentration of solids suspended in the water. The unit of measurement is the **NTU**. When the water is turbid, it is harder to sanitize. **Conductivity** refers to the level of dissolved salts in the water. When water has too many dissolved solids, it is "hard," tastes bitter, and leaves deposits on clothes and water pipes. The **pH** level represents the acidity or alkalinity of the water. Water must be adjusted to certain pH levels for treatments such as coagulation to work properly. After treatment, the pH must be adjusted to neutral.

Extended Inquiry Suggestions

Investigate other types of filters and coagulating agents on the effectiveness of water treatment.

Conduct an Internet search on water treatment and water quality standards. Write a report on some aspect of interest.

19. Weather in a Terrarium

Objectives

Using a weather sensor in the microclimate of a terrarium, understand changes in temperature, absolute and relative humidity, dew point, and barometric pressure.

- Determine the minimum, maximum, and average values for each of the weather-related measurements.
- Compare the changes in each of the weather-related measurements.
- Determine relationships between the weather-related measurements.

Procedural Overview

Students gain experience conducting the following procedures:

- Use a weather sensor for a 24-hour period in a terrarium or equivalent microclimate.
- Collect data about temperature, absolute and relative humidity, dew point, and barometric pressure.
- Analyze the relative changes in different factors of weather.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	24 hours

Materials and Equipment

For each student or group:

- Data collection system
- Weather anemometer sensor
- Extension cable
- Small box or other support
- Terrarium (or suitable alternative)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The difference between weather and climate
- The causes of low and high pressure air masses
- The difference between absolute and relative humidity
- The definition of dew point

Related Labs in This Guide

- Exploring Microclimates
- Transpiration

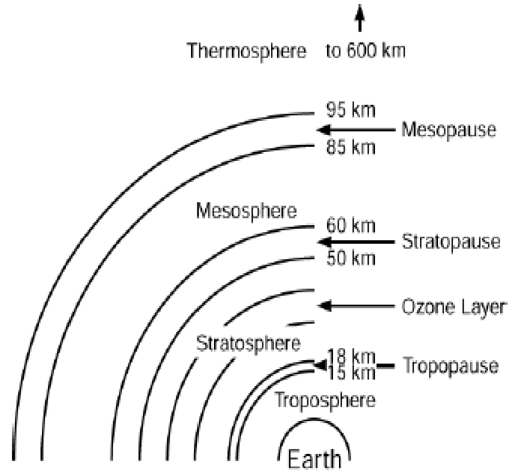
Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to your data collection system �(2.1)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Displaying two graphs simultaneously �(7.1.11)
- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

Weather is a daily "snapshot" of the atmosphere at a specific place and time. Earth's atmosphere can be divided into six layers: the troposphere, stratosphere, mesosphere, ionosphere, thermosphere, and exosphere. Of these layers, the troposphere (6 to 10 miles thick) is closest to the earth's surface and is home to the factors that contribute to the complex system known as weather. In the troposphere, the sun warms the air, increasing the kinetic energy of the gas molecules. These consequently rise and are replaced by colder air molecules. This process of convection creates winds and transports clouds.



Three main constituents of weather include temperature, moisture (humidity), and air pressure.

Temperature, measured in units of degrees Celsius (°C) or Fahrenheit (°F), is related to the average kinetic energy of molecules. Dew point is the temperature at which water vapor starts to condense in air at the existing atmospheric pressure and water vapor content.

Humidity is a measure of the amount of water vapor in the air. Meteorologists describe humidity using several terms, including absolute humidity, relative humidity, and specific humidity. Relative humidity is the amount of water vapor in the air compared to the amount the air could hold if it was totally saturated at that temperature.

Atmospheric pressure is the force of air molecules upon the earth's surface. Differences in pressures between air masses cause the air mass to move, resulting in a change of weather.

A terrarium can serve as a model of a microclimate—a small region that has its own weather patterns.

Pre-Lab Discussion and Activity

Engage students by asking the following questions. Besides temperature, which is a fairly straightforward topic, this should include the less familiar factors of humidity, pressure, and dew point.

1. What is the weather like outside today, including predicted high temperature and such things as rain, snow, fog, or wind.

Answers will vary based on location and time of year.

2. How do you know what today's weather is?

Many students will respond that they saw a weather forecast on the news, or heard a report on the radio.

3. How do professional weather people formulate a forecast?

They interpret radar and other technological observations. Students may also refer to what it is usually like at this time of year. However, this sort of thing refers more to the idea of climate.

4. How do you distinguish between a daily weather forecast and a description of climate in your geographic area?

Weather is defined as the day to day environmental conditions in an area. Climate refers to a more stable set of conditions and trends seen in an area year after year.

5. What is the difference between relative humidity and absolute humidity?

Absolute humidity is the total amount of water vapor in the atmosphere at that place and time, usually measured in grams of water per cubic meter of air. Relative humidity is the amount of moisture in the air compared to what the air can hold at that temperature, recorded as a percentage.

To calculate relative humidity, divide the actual water vapor density by the possible water vapor density at a particular temperature. Then multiply by 100.

6. What is "dew point"? How is it related to temperature?

Dew point is the temperature at which the water vapor in the air condenses and leaves the air as dew, fog, or if a surface is cold enough, frost. At this temperature the air is 100 percent saturated with water vapor. Colder air (having less thermal energy) cannot supply as much energy to the water molecules to keep them apart, and so the water molecules tend to "stick together" and condense out of the air.

7. How is barometric pressure related to weather patterns?

A barometric "high" occurs when an air mass has higher pressure than the pressure of the surrounding air mass. A barometric "low" occurs when an air mass has a lower pressure than the surrounding air mass. There is no set value to distinguish between high and low pressure areas. Meteorologists look at the difference between two regions.

In a high pressure system, the air is slowly descending. As air descends closer to the surface of the earth, it begins to warm. This typically prevents the formation of clouds and is usually associated with good weather.

The air that descends in high pressure areas flows to regions of low pressure. (Most things in science move from areas of high pressure to areas of low pressure.) As warming high pressure air moves to areas where the surface pressure is low, it begins to rise. As air rises it begins to cool. If a relatively warm air mass flows near bodies of water, it often captures water vapor. Rising air cools to a point where water vapor can condense and generate clouds and precipitation. This is why low pressure is typically associated with bad weather.

Lab Preparation

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

Note: The weather anemometer sensor is a multisensor that measures temperature, absolute and relative humidity, dew point, barometric pressure, as well as wind speed

1. Consider searching the web for a description of how to build a simple terrarium.
2. Keeping the following in mind, place your terrarium and the plants in it so that it optimizes the gathering of data that is different from the ambient room conditions.
   - Isolate the terrarium from the room environment.
   - The terrarium does not have to be sealed.
   - Unless purposely positioned there, do not place the terrarium in direct sunlight (outdoors or in a window). Too high of an internal temperature may develop.

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.

5	4	2	1	3
Clean up all equipment and put everything away.	Analyze your data and compare your results with your predictions.	Set up the weather sensor in the terrarium.	Gather all materials and equipment to perform the activity.	Collect temperature, humidity and pressure 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. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect the weather sensor to the extension cable. Connect the extension cable to the data collection system. �(2.1)

3. ☐ Change the sample rate so that the sensor records 1 data point every 2 minutes. �(5.1)

4. ☐ Choose two variables to display on your data collection system (for example: one graph of Temperature versus Time and another of Barometric pressure versus Time. �(7.1.11)

Note: The weather sensor records many different measurements simultaneously. If needed, your teacher can guide you in displaying other variables.

5. ☐ Place the terrarium in a well-lit area (near a window), but not in direct sunlight.

6. ☐ Place a small box or other support in the terrarium.

7. ☐ Place the weather sensor on a small box or support.

   Note: Make sure that the end of the sensor extends beyond the edge of the support so that air can flow past the sensor.

8. ☐ Of temperature, absolute humidity and barometric pressure, which do you predict will have the greatest percentage change in a 24-hour period?

Answers will vary, but many students may predict that temperature will fluctuate more than humidity and barometric pressure.

9. ☐ Of temperature, absolute humidity and barometric pressure, which do you predict will have the least percentage change in a 24-hour period?

Answers will vary, but many students may predict that pressure will have the least amount of fluctuation.

Collect Data

10. ☐ Start recording data. �(6.2)

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

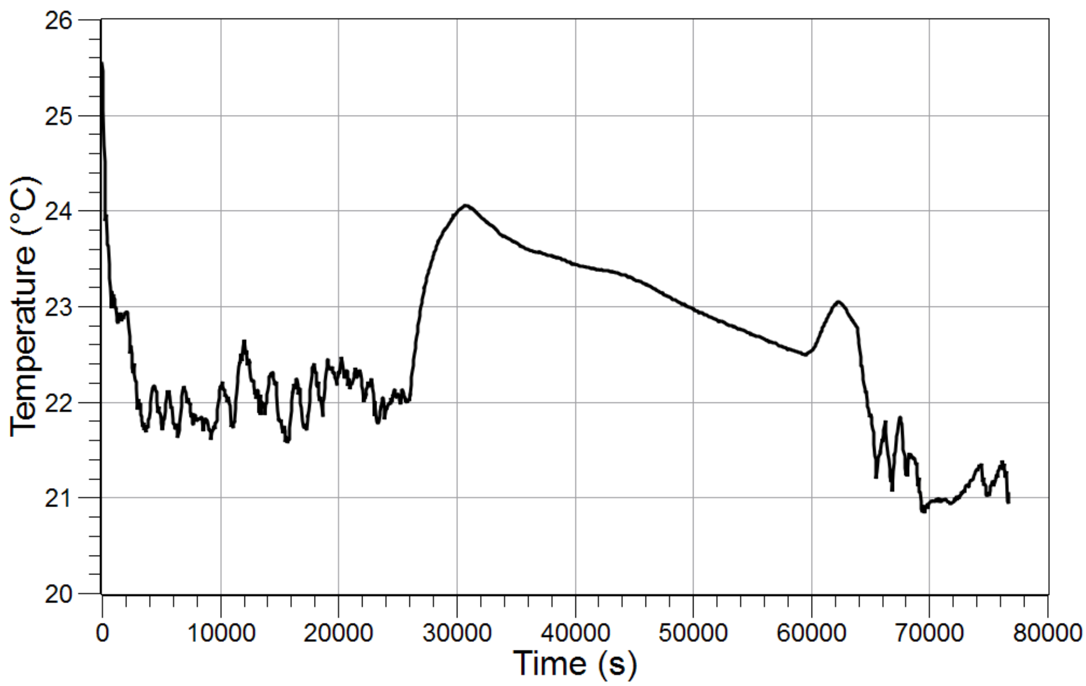
12. ☐ Record data for 24 hours.

13. ☐ At the end of 24 hours, stop recording data. �(6.2)

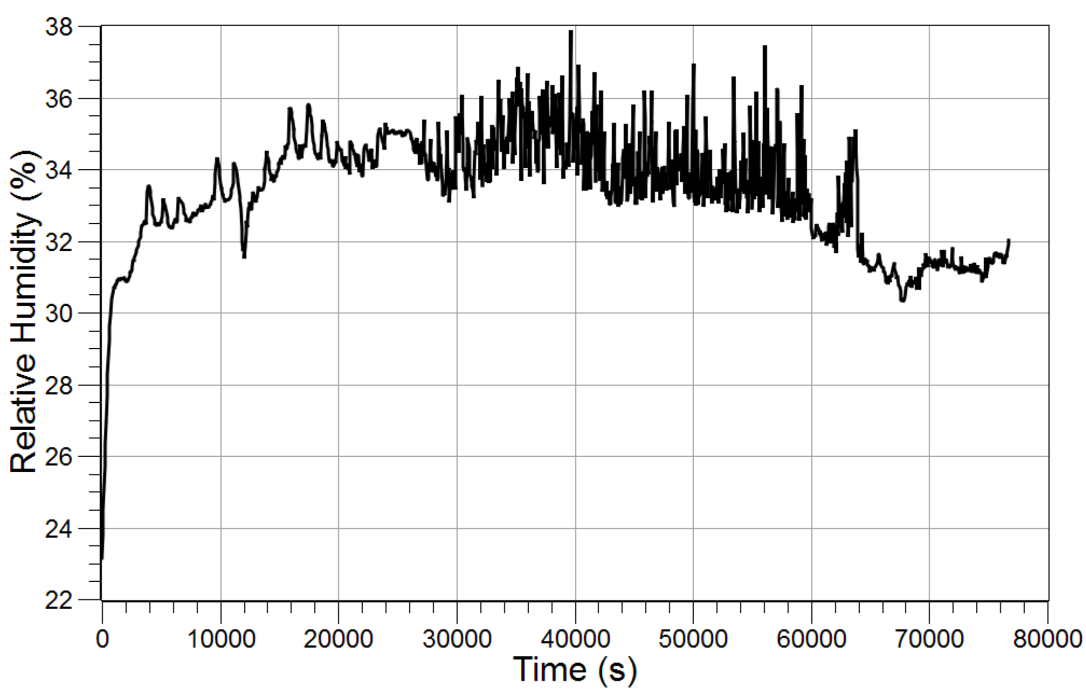
14. ☐ Save your experiment, �(11.1) and clean up according to your teacher's instructions.

Data Analysis

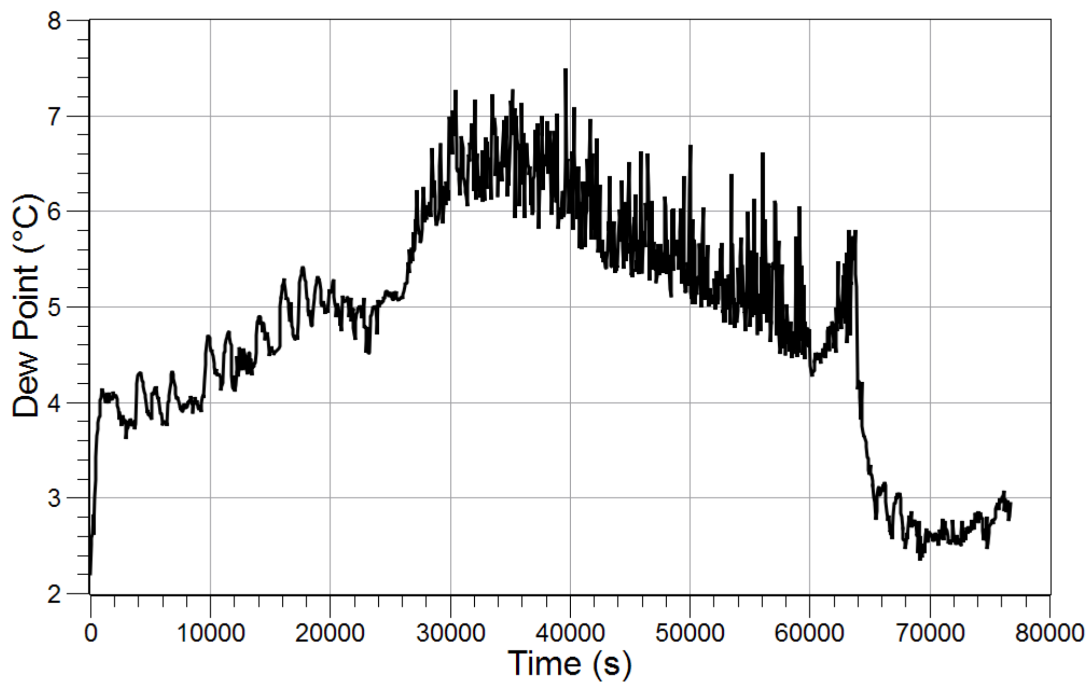
1. ☐ Make a sketch of your data for Temperature versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



2. ☐ Make a sketch of your data for Relative Humidity versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



3. ☐ Make a sketch of your data for Dew Point versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



4. ☐ Use available tools to find the minimum, maximum and average � (9.4) temperature, relative humidity, dew point, absolute humidity and barometric pressure. Record your data in Table 1 below. Then calculate the percent change over time.

Table 1: Measurements for temperature, humidity, dew point, and barometric pressure

Measurement	Minimum	Maximum	Average	% Change
Temperature (°C)	26.8 °C	47.6 °C	29.5 °C	43.7%
Relative Humidity	19%	60%	47%	68%
Dew Point (°C)	13.6 °C	19.9 °C	15.8 °C	31.6%
Absolute Humidity (grams per cubic meter)	11.8 g/m^3	16.8 g/m^3	13.6 g/m^3	29.8%
Barometric Pressure (inches of mercury)	29.59 in Hg	29.68 in Hg	29.62 in Hg	0.3%

Analysis Questions

1. Which factor changed the most over 24 hours?

Most likely temperature will change most.

2. Which factor changed the least?

Most likely barometric pressure will change least.

3. Did your predictions in the activity section match the data collected? Explain.

Answers will vary according to student data.

4. What connections can you make between the outside weather and the weather inside the terrarium during the 24-hour period? Why might they be different?

There will probably be little connection between the two, other than barometric pressure, depending on local weather conditions. Answers should include the presence of plants and any standing water in the terrarium as sources for higher absolute and relative humidity, as well as the "greenhouse effect" due to the transparent terrarium materials causing higher than ambient air temperature readings. The term "microclimate" applies well to this affect on ambient temperature.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What happens to the relative humidity when the temperature drops?

As the temperature drops, the relative humidity percentage rises.

2. Why does relative humidity change when temperature changes?

As the temperature changes, the amount of water that can be kept in the vapor state changes due to an increase or decrease in the thermal energy of the air molecules, and therefore the amount of energy transferred to the water molecules in the air also changes. The greater the thermal energy, the higher the percentage of water molecules that can stay in the vapor state.

3. Why would the presence of plants in the terrarium lead to higher humidity readings in the terrarium?

Plants lose water through their leaves in a process called transpiration. This enables the plant to bring more water up into the plant through the roots. Transpiration therefore leads to more water vapor in the terrarium.

4. Why does the approach of a low pressure air mass into an area tend to bring precipitation?

Where there is a low pressure air mass, there is warmer (less dense) air than the air next to it. Warm air rises. At higher elevations, this air cools. The water vapor in it condenses and falls from its high elevation as precipitation.

5. Discuss some adaptations that organisms have that allow them to survive in changing weather conditions. Give some specific examples of adaptations that may allow organisms to survive any significant global climate shifts.

Organisms have different behavioral and physiological adaptations that allow them to adjust to changing weather conditions. Examples include sweating, shivering, moving into the shade, moving into the sun, shedding, and the closing or opening of apertures called stomates.

For larger scale climate shifts, new environmental conditions may trigger a natural selection where species evolve to be better fit for the new climate. Desert organisms that can better conserve water, such as cacti and small mammals, may be one example of how organisms adapt to survive climate changes that result in more arid conditions.

Multiple Choice Questions

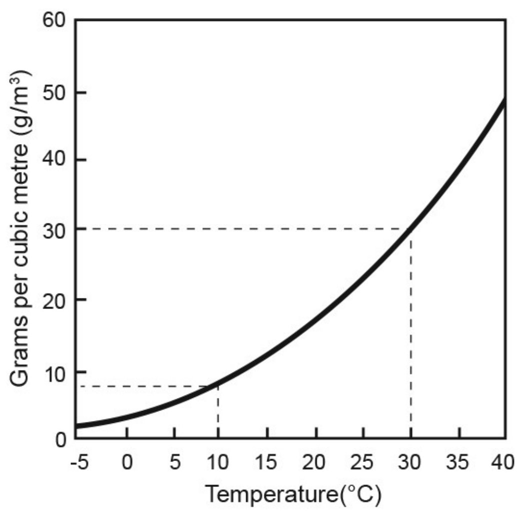
Select the best answer or completion to each of the questions or incomplete statements below.

1. Which type of air mass has a relative humidity of 100 percent?

- **A.** Humid
- **B.** Temperate
- **C.** Dry
- **D. Saturated**

2. Based on the accompanying graph of an air mass, which can hold more water vapor: warmer air or cooler air?

- **A. The warmer air**
- **B.** The cooler air
- **C.** Neither one significantly more than the other
- **D.** Sometimes the warmer air; sometimes the cooler air



3. Which term refers to the actual amount of water vapor in the air?

- **A.** Precipitation
- **B.** Dew point
- **C. Absolute humidity**
- **D.** Relative humidity

4. When is relative humidity highest?

- **A. When air temperature is near the dew point**
- **B.** When air temperature is rising
- **C.** When the wind blows
- **D.** When air temperature is falling

Key Term Challenge

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

1. The state of the atmosphere at a specific time and place is **weather**. **Temperature** refers to the kinetic energy of the air molecules. The **barometric pressure** refers to the weight of the air. **Humidity** refers to the amount of water vapor in the air. These and other factors influence the state of the atmosphere. Weather depends on the type of **air mass** over an area. An air mass is a large body of air that has nearly the same temperature and humidity throughout.

2. Humidity is typically expressed in two ways. Absolute humidity is the actual amount of **water vapor** the air contains at that time. **Relative** humidity is the amount of water vapor in the air compared with the maximum amount of water vapor the air could hold at that temperature and pressure. When the atmosphere reaches a low enough temperature that the relative humidity reaches 100 percent **saturation**, the water vapor **condenses** from the atmosphere and forms dew, fog, or frost. This temperature is known as the **dew point**.

3. The long term average weather conditions in a given area is called **climate**. A **microclimate** is the set of atmospheric conditions measured in a smaller, somewhat isolated study area.

Extended Inquiry Suggestions

Have the students use wet-dry bulb thermometers (sling psychrometer) and a relative humidity chart to find relative humidity. Have students research to find why a dry bulb and a wet bulb thermometer are both needed to find relative humidity.

Have students find out how dew point relates to the comfort level at a given temperature (heat index).

Have students find the dew point using a beaker of ice and water, a temperature sensor attached to the outside of the beaker, and observing at what temperature moisture first begins to condense on the outside of the beaker. Relate this information to why moisture condenses on a cold glass or drink can on a warm day.

Physiology

20. EKG: Factors That Affect the Heart

Objectives

Students measure and observe the electrical activity of the heart muscle using an electrocardiogram (EKG) sensor:

- ♦ Determine the duration of three intervals of Voltage versus Time for the EKG before and after exercise.
- ♦ Compare the time intervals for the EKG before and after exercise for males and females.
- ♦ Propose other factors in addition to activity level that may affect the EKG time intervals.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Use the EKG sensor to measure the electrical current associated with heart contractions.
- ♦ Record and display heart voltage signals from the EKG.
- ♦ Determine the PR interval duration at rest and after exercise.
- ♦ Determine the QRS complex duration at rest and after exercise.
- ♦ Determine the QT interval duration at rest and after exercise.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	40 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ EKG sensor
- ♦ Electrode patches (included with sensor)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The human circulatory system consists of the heart, blood vessels, and the blood that flows through them.
- Cardiovascular diseases can usually be avoided and controlled by exercise, proper diet, and the avoidance smoking.
- When you exercise, your heart beats faster to meet the demand for more blood and oxygen by the muscles of the body. The more intense the activity, the faster your heart will beat. Therefore, monitoring your heart rate during exercise can be an excellent way to monitor exercise intensity.
- An EKG shows how fast the heart is beating. It shows the heart's rhythm (steady or irregular).

Related Labs in This Guide

Labs conceptually related to this one include:

- Exercise and Respiration Rate
- Exercise and Heart Rate

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)
- Naming a data run �(8.2)
- Measuring the distance between two points in a graph �(9.2)
- Saving your experiment �(11.1)

Background

Activity stimulates the heart to contract more vigorously than it does when the body is at rest. The EKG sensor measures cardiac electrical potential waveforms (voltages) produced by the heart's myocytes, causing its chambers to contract. The EKG is not a direct measure of heart muscle activity. However, a comparison of the EKG measured during rest and the EKG measured after mild exercise may indicate the changes that take place in the cycle of heart contractions due to activity.

An electrocardiogram, also called an EKG or ECG, is a simple test that detects and records the electrical activity of the heart. It helps to detect and locate the source of heart problems. Electrical signals in the heart trigger heartbeats. These signals start at the top of the heart in an area called the right atrium. The electrical signals travel from the top of the heart to the bottom. They cause the heart muscle to contract as they travel through the heart. As the heart contracts, it pumps blood to the rest of the body.

An EKG shows how fast the heart is beating. It shows the heart’s rhythm (steady or irregular).

With each heart beat, the pacemaker of the heart (called the SA node) conducts electricity. The electrical current travels from the SA node in the right upper chamber of the heart down to the two lower chambers, the ventricles, of the heart. The electrical activity always precedes each contraction. Electrodes placed throughout the body record the signal generated from the heart. A normal EKG signal typically has five waves:

- P wave—represents the electrical signal in the upper chambers (depolarization of the atria) of the heart and occurs before the atria contract to squeeze blood into the lower chambers (the ventricles). Repolarization of the atria is hidden by the QRS wave.

- Q, R, and S waves (QRS complex)—represent the electrical signal that occurs before the ventricles squeeze blood out through the aorta and to the body (depolarization of the ventricles).

- T wave—represents the electrical signal that occurs just before the upper chambers of the heart expand and refill with blood (repolarization of the ventricles).

One part of a typical EKG is a "flat line" or trace indicating no detectable electrical activity. This line is called the isoelectric line. Deviation from this line indicates electrical activity of the heart muscles.

In a typical EKG, the first deviation from the isoelectric line is an upward pulse following by a return to the isoelectric line. This is the P wave, and it lasts about 0.04 seconds.

After a return to the isoelectric line, there is a short delay. The heart's upper chambers depolarize and send a signal along the atrioventricular bundle of conducting fibers to the Purkinje fibers, which bring depolarization to all parts of the ventricles almost simultaneously. (That bundle is known as the Bundle of His, named after German cardiologist, Wilhelm His.)

After the atrioventricular node depolarizes, there is a downward pulse called the Q wave. Shortly after the Q wave, there is a rapid upswing of the line called the R wave followed by a strong downswing of the line called the S wave and then a return to the isoelectric line. These three waves together are the QRS complex. This complex is caused by the depolarization of the ventricles and is associated with the contraction of the ventricles.

After a short period of time the chemical ions that have been involved in the contraction migrate back to their original locations. The movement of these ions generates an upward wave that then returns to the isoelectric line. This upward pulse is called the T wave and indicates repolarization of the ventricles.

The sequence from P wave to T wave represents one heart cycle. The number of such cycles in a minute is called the heart rate and is typically 70 to 80 cycles (beats) per minute at rest.

Pre-Lab Discussion and Activity

Encourage students to make some practice runs after talking about connecting the EKG sensor and projecting possible results.

Draw a "typical" EKG trace on the board and label the 5 waves (P, Q, R, S, and T).

Define the PR interval: The PR interval is the period that extends from the onset of atrial depolarization (beginning of the P wave) until the onset of ventricular depolarization (beginning of the QRS complex).

Define the QRS complex: The QRS complex extends from the beginning of the Q wave to the end of the S wave, representing the period of ventricular depolarization.

Define the QT interval: QT interval is measured from the onset of the Q wave (or the onset of the R wave if there is no Q) until the termination of the T wave. It is is the period that extends from the beginning of ventricular depolarization until the end of ventricular repolarization.

1. How will the PR, QRS, and QT intervals for the EKG after exercise compare with the same intervals for the same person's EKG at rest?

Heart rate tends to increase during exercise and remain at an elevated level for a period of time after exercise. Students may predict that the three intervals will be shorter after exercise than they were before exercise.

2. How will the EKG intervals before and after exercise for females compare with the EKG intervals before and after exercise for males?

Answers will vary depending on the student's experience. In general, many students may predict that the heart rate after exercise will be greater for females than they are for males, and that the three intervals will be shorter for females both before and after exercise.

3. In addition to exercise, what other factors do you think might affect the EKG?

Physical fitness, emotional stimulus, caffeine, tobacco, meditation, body temperature, and fatigue are all factors that may affect the EKG.

4. Discuss how the EKG electrode attaches and the voltage signals.

The EKG sensor has three cables with small metal clips at the end. The clips attach to small electrode patches that stick to the skin. The sensor is designed to produce a signal between 0 and 5 volts, with 1 volt being the isoelectric line. Deviation from the isoelectric line indicates electrical activity.

5. Why is it important to scrub the areas of skin where the electrode patches will be attached?

The electrical signal produced by the heart and detected at the body's surface is very small, so it is important that the electrode patch makes good contact with the skin. Scrubbing the areas of skin with a paper towel removes dead skin and oil. If the EKG trace is very irregular, apply rubbing alcohol to clean the skin more thoroughly. After the alcohol evaporates, put new electrode patches on the cleaned areas of skin.

Teacher Tip: Pre-calibrated at the factory, the EKG sensor is designed to provide accurate and reliable data for educational purposes. It is *not* intended for use as a medical instrument.

Teacher Tip: This activity is easier to do if one person is in charge of recording data and keeping track of time while another person is being measured.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ This activity requires the person whose EKG is being measured to perform exercise such as jogging in place for 2 minutes. Do not perform this activity if vigorous exercise will cause discomfort.
- ♦ Watch students carefully. If the exercise causes discomfort or pain, ask the student to stop data collection.

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
Record data for 20 seconds after the person has exercised for 3 minutes.	Use analysis tools to determine the PR, QRS, and QT intervals.	Connect the alligator clips to the sensor patches.	First, record data for 20 seconds while the person is at rest.	Prepare the skin area and attach the patches.

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

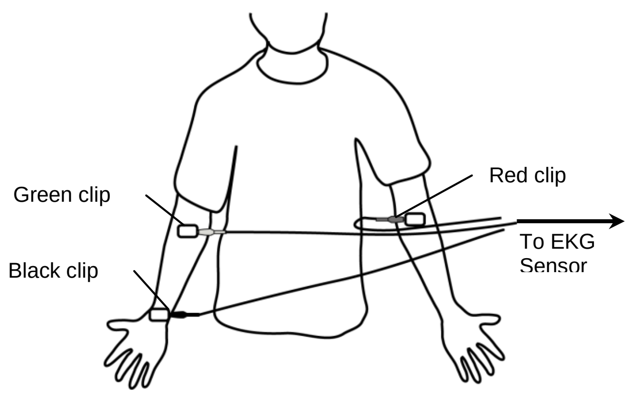
1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect the EKG sensor to the top of the data collection system. �(2.1)

3. ☐ Display Voltage in millivolts (mV) on the y-axis versus Time in seconds (s) on the x-axis of a graph. �(7.1.1)

4. ☐ Peel three electrode patches from the backing paper. Firmly place the first electrode on the right wrist. Place a second electrode on the right elbow pit. Place the third electrode on the left elbow pit.

5. ☐ Place each electrode so it is on the inside part of the arm (closer to the body) and so the tab on the edge of the electrode patch points down. This way, the wire of the electrode can hang freely, without twisting the edge of the electrode patch.



6. ☐ Connect the *black* (or "reference") alligator clip to the *right wrist* electrode patch.

7. ☐ Connect the *green* (or negative) alligator clip to the *right elbow* electrode patch.

8. ☐ Connect the *red* (or positive) alligator clip to the *left elbow* electrode patch.

9. ☐ Remind the person whose EKG is being measured to relax, to remain as still as possible, and not to look at the data as it is recorded.

Collect Data

Before Exercise

10. ☐ Start data recording. �(6.2)

11. ☐ Why do you think that subject needs to remain relaxed and still?

Muscle activity in the arms causes electrical signals that may overwhelm the cardiac signals recorded in the EKG.

12. ☐ After 20 seconds, stop data recording. �(6.2)

13. ☐ Name data run 1 "Before Exercise". �(8.2)

14. ☐ Save this part of your experiment. �(11.1)

15. ☐ Remove the clips from all three electrode patches. Leave the electrode patches attached to the person whose EKG is being measured.

16. ☐ Why are the clips removed before exercise?

There is no need for the clips to remain connected. Students will have difficulty exercising with the clips connected.

After Exercise

17. ☐ Have the test subject exercise for 3 minutes by jogging in place (or an equivalent activity such as stepping in place or jumping jacks).

18. ☐ What kind of exercise did you perform?

Answers may vary but could include running in place, jumping, jumping jacks.

19. ☐ At the end of 3 minutes of exercise, have the test subject sit down in a chair or lie down on a couch. Reattach the metal clips to the electrode patches in the same arrangement as before.

20. ☐ Remind the person whose EKG is being measured to relax, to remain as still as possible, and not to look at the data as it is recorded.

21. ☐ Start data recording. �(6.2)

22. ☐ After 20 seconds, stop data recording. �(6.2) Remove the metal clips and carefully remove the electrode patches.

23. ☐ Describe how you feel after exercising for three minutes.

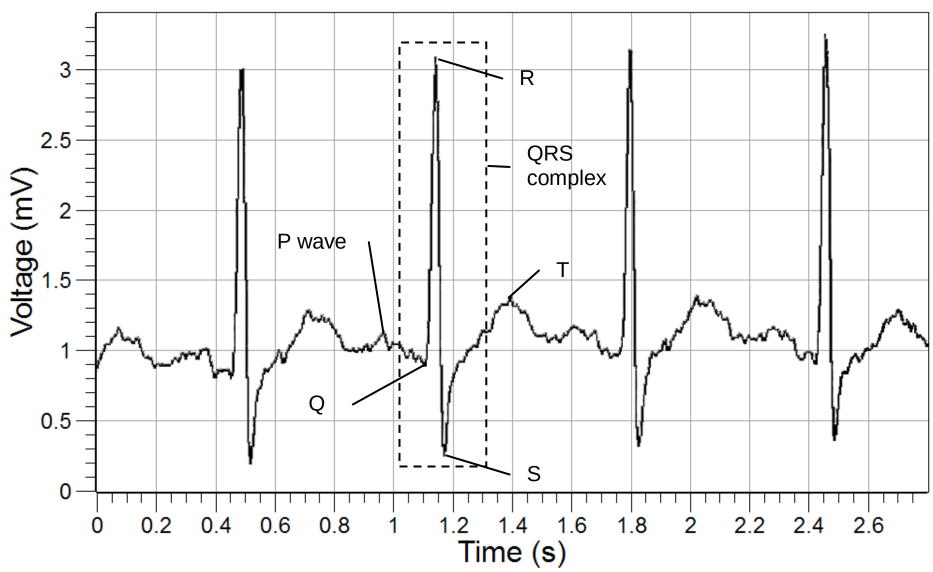
Students should feel a somewhat elevated heart rate. Some students may be winded.

24. ☐ Name data run 2 "After Exercise".

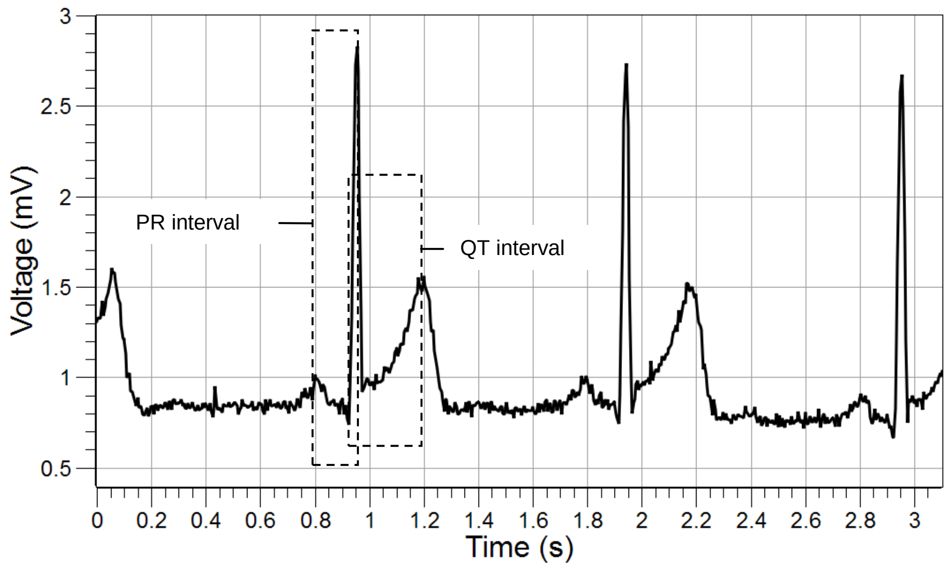
25. ☐ Save your experiment, �(11.1) and clean up according to your teacher's instructions.

Data Analysis

1. ☐ Use the following illustration to identify the waves in your EKG data. Then follow the directions for analyzing your data.



2. ☐ Make a sketch of your data for Voltage versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes. Label the data P, QRS, and T areas of the graph.



3. ☐ Adjust the scale of the graph so you can view the first 3 seconds of data and are able to see the P wave, QRS complex, and the T wave of the EKG pattern for "Before Exercise." �(7.1.2)

4. ☐ In the graph of the EKG "Before Exercise," use available tools �(9.2) to find the duration (seconds) of the PR interval, the QRS complex, and the QT interval. Record each value in Table 1.

5. ☐ Repeat the analysis process for the graph of EKG "After Exercise". Record each value in Table 1.

Note: The table below includes a column with typical average ranges. Healthy hearts often have data outside these ranges. *Do not be alarmed* if an EKG in this activity falls outside these ranges. Also, reading an EKG effectively takes considerable training and skill, and the sensor in this activity is *not* intended for medical purposes.

Table 1: EKG parameters before and after exercise compared with the typical range

EKG Parameter	Time before Exercise (seconds)	Time after Exercise (seconds)	Typical Range (seconds)
PR interval	0.185	0.170	0.120 to 0.200
QRS complex	0.105	0.95	Under 0.100
QT interval	0.305	0.275	Under 0.380

Analysis Questions

1. Compare your values for the PR interval duration for the EKG at rest with the values for the PR interval duration for the EKG after exercise.

The duration of intervals for the EKG after exercise should be shorter than the duration of intervals for the EKG at rest. One explanation is that during activity, the heart muscle must pump more blood and accomplishes this task by pumping more quickly.

2. Compare your values for the QRS interval duration for the EKG at rest with the values for the QRS interval duration for the EKG after exercise.

The duration of intervals for the EKG after exercise should be shorter than the duration of intervals for the EKG at rest. One explanation is that during activity, the heart muscle must pump more blood and accomplishes this task by pumping more quickly.

3. Compare your values for the QT interval duration for the EKG at rest with the values for the QT interval duration for the EKG after exercise.

The duration of intervals for the EKG after exercise should be shorter than the duration of intervals for the EKG at rest. One explanation is that, during activity, the heart muscle must pump more blood and accomplishes this task by pumping more quickly.

4. Are there more peaks (R waves) in the resting or exercising graph? What does the number of peaks represent?

Students should indicate that their exercising tracings have more peaks (R waves). The R waves represent contraction of the heart ventricles, pumping blood to the body. You could count the number of peaks per minute to determine heart rate.

Synthesis Questions

Use available resources to help you answer the following questions.

1. The electrocardiogram is a tool used to diagnose certain types of heart problems. Name some heart conditions that could be identified with the EKG.

The EKG can be used to find the cause of unexplained chest pain, such as a heart attack, inflammation of the sac surrounding the heart (pericarditis), or reduced blood flow to the heart muscle (ischemia).

It can also be used to find the cause of symptoms of heart disease, such as unexplained chest pain, shortness of breath, dizziness, fainting, or rapid irregular heartbeats (palpitations).

2. How can an EKG recording help doctors diagnose a heart attack that is happening now or has happened in the past?

A cardiologist can look at a patient's EKG and determine the presence of damaged cardiac muscle based on the time interval between electrical waves.

3. How do the durations of the intervals for the EKG after exercise compare with the typical durations of intervals? What does this indicate about your physical condition?

After exercise, the duration of intervals should be shorter. The fitter you are, the more likely you are to have longer intervals. They might be longer than the typical range or in the top of the range if you are physically fit. Falling outside the range does NOT automatically indicate that you are unhealthy. Drawing conclusions from an EKG is complicated and requires training and additional information.

4. How do the durations of EKG intervals before and after exercise compare for females and males?

Answers will vary.

Multiple Choice Questions

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

1. Which of the following *cannot* affect an EKG test?

- **A**. Physical fitness
- **B**. Caffeine
- **C.** Tobacco
- **D**. **Ice cream**

2. Compared with the duration of the QRS complex in an EKG of a person at rest, what happens to the duration of the QRS complex after exercise?

- **A.** Remain the same
- **B**. Longer duration
- **C**. **Shorter duration**
- **D**. Increases and then decreases

3. What is the number of P wave–to–T wave cycles in a minute called?

- **A**. Maximum heart rate
- **B**. **Heart rate**
- **C.** QRS complex
- **D**. Electrocardiogram

4. What is the electrical activity through the upper chambers of the heart (atria) called?

- **A**. QRS complex
- **B**. **P wave**
- **C.** T wave
- **D.** ST wave complex

Key Term Challenge

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

1. **EKG** is a test that checks for problems with the electrical activity of your heart. An EKG translates the heart's **electrical** activity into line tracings on paper. The spikes and dips in the line tracings are called **waves**.

2. The heart is a muscular pump made up of **four** chambers. The two upper chambers are called **atria**, and the two lower chambers are called **ventricles**. A natural electrical system causes the heart muscle to contract and pump blood through the heart to the **lungs** and the rest of the body.

3. The **P** wave is a record of the electrical activity through the upper heart chambers. The **QRS** complex is a record of the movement of electrical impulses through the lower heart chambers. The **ST** segment corresponds to the time when the ventricle is contracting but no electricity is flowing through it. The ST segment usually appears as a straight, level line between the QRS complex and the T wave. The **T** wave corresponds to the period when the lower heart chambers are relaxing electrically and preparing for their next muscle contraction.

Extended Inquiry Suggestions

There are many variations possible with this activity. The variables to test are limited only by people's imaginations. Some possible questions to explore include the following:

- Does drinking an “electrolyte-replacement sports drink” during exercise cause a measurable change in the EKG trace?
- Does eating a banana or other potassium-rich food, immediately after mild exercise, cause a measurable change in the EKG trace?
- Through controlled breathing or relaxation techniques, can students cause a measurable change in the EKG trace?
- Does a mild stimulant such as the caffeine in coffee or some carbonated drinks cause a measurable change in the EKG trace?

21. Exercise and Heart Rate

Objectives

Using a heart rate sensor, students monitor the effect of physical exertion in relation to their level of fitness. Students will:

- ♦ Determine their average heart rate before, during, and after exercise
- ♦ Determine exercise levels based on heart rate that produce the maximum health benefit

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Prepare the exercise heart rate sensor
- ♦ Determine heart rate before exercise
- ♦ Determine heart rate during exercise
- ♦ Determine heart rate after exercise
- ♦ Determine target exercise heart rate range

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Hand Grip Heart Rate Sensor

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ The human circulatory system consists of the heart, blood vessels, and the blood that flows through them.
- ♦ Exercise causes the heart to beat faster to meet the demand for more blood and oxygen by the muscles of the body. The more intense the activity, the faster your heart will beat. Monitoring heart rate during exercise can be an excellent way to monitor exercise intensity.
- ♦ Exercise; proper diet; and avoidance of smoking, alcohol, and other drug abuse helps prevent cardiovascular disease and other detrimental health consequences.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Exercise and Respiration Rate
- ♦ EKG: Factors that Affect the Heart

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)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Viewing statistics of data �(9.4)
- ♦ Saving your experiment �(11.1)

Background

Heart rate is a term used to describe the frequency of the cardiac cycle. Usually, heart rate is calculated as the number of contractions (beats) of the heart in one minute. Therefore, heart rate is usually expressed as beats per minute (bpm). When resting, the typical adult human heart beats at about 70 bpm in males and 75 bpm in females, although this rate varies among people. The pulse is one way of measuring heart rate.

The body increases heart rate in response to a wide variety of conditions in order to increase the cardiac output (the amount of blood ejected by the heart per unit time). Exercise causes a person's heart rate to increase above the resting heart rate. As the physical activity becomes more vigorous, the heart rate continues to increase. With sufficiently vigorous exercise, the heart rate reaches its maximum rate.

The reference range for resting heart rate is between 60 bpm and 100 bpm. Less than 60 bpm is termed bradycardia. Greater than 100 bpm is termed tachycardia.

Estimated Maximum Heart Rate

You can apply a mathematical formula, based on your age, to estimate your maximum heart rate, as follows:

220 – age = estimated maximum heart rate.

Target Heart Rate Range

Target heart rate range (also known as training heart rate range or exercise heart rate range) is the range of heart rates reached during aerobic exercise that enables one's heart and lungs to receive the most benefit from a workout. The most common method for calculating the target heart rate range is by multiplying the estimated maximum heart rate times the percent intensity that produces maximum cardiovascular benefits, generally considered to be a range of 50% to 85% intensity.

The following example assumes a maximum heart rate of 180:

- 50% intensity: 180 x 0.50 = 90 beats per minute
- 85% intensity: 180 x 0.85 = 153 beats per minute

Pre-Lab Discussion and Activity

Engage your students with the following questions:

1. How will heart rate change with exercise?

Heart rate tends to increase during exercise and remain at an elevated level for a period of time after exercise.

2. How close will your recovery heart rate be to your resting heart rate (rate before exercise)?

Answers will vary. Heart rate returns to the resting rate in about 7 to 10 minutes, and the recovery heart rate depends on many factors, such as overall fitness and age.

3. How will the heart rate for females compare with the heart rate for males before, during, and after exercise,?

Answers will vary depending on the student's experience.

Inform students that they will be exercising by running in place, so they will need to find a space in the classroom to do this without bumping into anything, while still maintaining a position close to the data collection system. Point out any precautions that students might need to be aware of in your particular classroom environment.

Lab Preparation

Note: The hand grip heart rate sensor is designed to provide accurate and reliable data for educational purposes. It is not intended for use as a medical instrument.

1. Encourage students to make some practice runs.
2. Normal grip force is adequate for this activity. Squeezing the handles too hard can lead to inconsistent data.
3. Formulate a classroom management plan for this activity that will minimize potential disruption.
   - ♦ Inquire ahead of time (perhaps with the school nurse) whether any students should be excluded from participation due to medical or health issues.
   - ♦ Communicate behavior expectations clearly to students ahead of time.
   - ♦ Consider asking students to participate as test subjects on a voluntary basis only.

Safety

Add this important safety precaution to your normal laboratory procedures:

- ♦ Watch students carefully. If the exercise causes discomfort or pain, ask the student to stop exercising and data collection.

Sequencing Challenge

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

5	1	3	2	4
Use graphing tools to determine average heart rate and recovery time.	Hold handles comfortably in hands.	Record heart rate during exercise.	Record resting heart rate.	Record heart rate during recovery period.

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 sensor to the port on the data collection system. �(2.1)

3. ☐ Display Heart Rate in beats per minute on the y-axis versus Time in seconds (s) on the x-axis of a graph. �(7.1.1)

Collect Data

There are three parts to data recording.

- ♦ Measure the resting heart rate for 1 minute.
- ♦ Measure heart rate during exercise for 3 minutes.
- ♦ Measure the recovery heart rate after exercise for 2 minutes.

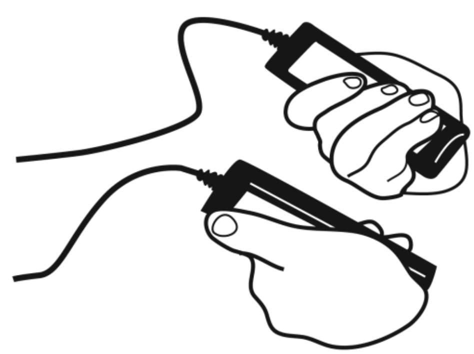
Note: This activity is easier to do if one person is in charge of recording data and keeping track of time while another person is being measured.

Note: Once you begin to collect data, continue to collect data until the end of the experiment. Do not stop collecting data as you change activities.

Note: During data collection, only 1 data point will be recorded every 5 seconds.

4. ☐ What is your control data point in this experiment?

The control is the average heart rate at rest.



5. ☐ Grasp the hand grip sensors with both hands. Remind the person who is being monitored to relax, to remain as still as possible, and not to look at the data as it is recorded.

6. ☐ Start data recording. �(6.2)

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

8. ☐ Describe your graph for the first 60 seconds?

The graph should have fairly steady readings between 60 and 80 bpm.

9. ☐ After 1 minute, the person who is being measured stands up and runs in place for 3 minutes while data collection continues.

10. ☐ Describe your graph for this 180-second interval.

Depending on fitness, answer will vary. A likely increase would be to 110 to 120 bpm.

11. ☐ After exercise, the person who is being measured sits for *2* minutes while data collection continues.

12. ☐ What is the unit of measurement that your data is being recorded in?

Beats per minute (bpm)

13. ☐ Remind the person who is being monitored to relax, to remain as still as possible, and not to look at the data as it is recorded.

14. ☐ Describe your graph for this 120-second interval?

Depending on fitness, answer will vary. A likely decrease would be to 80 or 90 bpm.

15. ☐ Continue collecting data until the test subject's heart rate returns to that person's initial resting heart rate.

16. ☐ If your results are not satisfactory, repeat the procedure for a second trial.

17. ☐ Stop data recording. �(6.2)

18. ☐ If time allows, switch roles and repeat the procedure to allow another person in your group to be monitored.

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

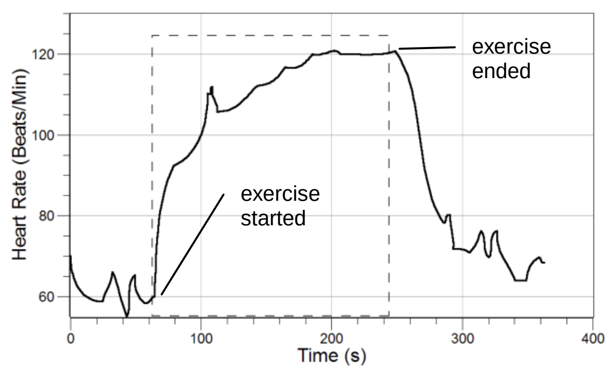
Data Analysis

1. ☐ Using available tools on your data collection system, find your average resting and exercise heart rates �(9.4) and your heart rate recovery time. �(9.2) Record these in Table 1.

Table 1: Resting and exercise heart rates plus recovery time

Item	Value
Resting Heart Rate (average)	67 bpm
Exercise Heart Rate (maximum)	109 bpm
Recovery Time (time from end of exercise to initial resting heart rate)	3.5 minutes

2. ☐ Make a sketch of your data for Heart Rate versus Time. Label the points at which exercise started and stopped.



Use of a graph tool to determine the average exercise heart rate during exercise (109 bpm).

Analysis Questions

1. How does the heart rate for exercise compare with the heart rate at rest?

Answers will vary. The heart rate during this exercise may be about one-third more than the heart rate at rest.

2. How does the heart rate after the designated 2-minute recovery period compare with the heart rate at rest?

Theoretically, the heart rate will begin to return to the resting heart rate within a few minutes during the recovery period. However, the recovery heart rate only 2 minutes after exercise is generally higher than the resting heart rate.

3. Before, during, and after exercise, how did the heart rate for females compare with the heart rate for males?

Answers will vary.

4. How did the heart rate change of people who tend to be physically active compared with the heart rate change of people who have a more sedentary lifestyle?

Physically active people should experience smaller changes in heart rate than less physically active people, when they engage in the same level of activity.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Calculate your own exercise (target) heart rate range.

- ♦ Calculate your estimated maximum heart rate: 220 – (your age) = ______________________
- ♦ Using this estimated maximum heart rate, multiply times 0.5 to determine the lower limit of your target heart rate range: ________
- ♦ Multiply times 0.85 to determine the upper limit: ________

2. How does the data you collected relate to fitness level? Is it within the calculated target heart rate range? Explain.

Answers will vary. Depending on fitness, students may need to exercise more vigorously or up to 20 minutes to achieve this range. Other students may quickly reach their target heart rate range, and a few students might exceed the target heart rate range, indicating that they might need to exercise more moderately.

3. Why must an athlete exercise longer or more vigorously to reach a maximum heart rate compared to a less fit individual?

A conditioned body can respond more efficiently and effectively to greater demands than a less fit one.

4. Using your resting heart rate, calculate the beats within a lifetime of 80 years:

- Beats/minute = _________70__________(cardiac output)
- Beats/hour = _________4200____________
- Beats/day = _________100,800____________
- Beats/year = _______36,792,000__________
- Beats/lifetime = ____2,943,360,000__________

Multiple Choice Questions

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

1. The upper limit of target heart rate, in beats per minute, is 85% of the theoretical maximum heart rate. The maximum heart rate can be estimated by subtracting the person's age, in years, from 220. To the nearest whole number, what is the upper limit of target heart rate of a person who is 26 years old?

- **A.** 134
- **B.** 155
- **C.** **165**
- **D.** 194.

2. Which of the following might cause an increase in average resting heart rate?

- **A.** Age
- **B.** Stress
- **C.** Medication
- **D.** **All of the above**

3. How would you predict the maximum heart rate?

- **A.** **220 minus a person's age**
- **B.** 220 times the percentage intensity
- **C.** 220 minus the reserve heart rate
- **D.** None of the above

4. While resting, the average female human heart rate is about:

- **A.** 120 over 80
- **B.** 120
- **C.** **75**
- **D.** None 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. Maximum heart rate is related to your age. As we grow older, our maximum heart rate tends to be lower. To estimate the maximum heart rate, subtract the person's age from the number **220.**

2. The **target heart rate range** is the number of beats per minute (bpm) that produces the maximum health benefit during aerobic exercise. For most healthy individuals, this range is **50** to **85** percent of maximum heart rate. So, if your estimated maximum heart rate is 180 bpm, the low end of the range would be **90** bpm, and the high end of the range would be **153** bpm

3. **Heart rate** is a term used to describe the frequency of the cardiac cycle. Usually, it is calculated as the number of contractions (beats) of the heart in one minute. Therefore, heart rate is usually expressed as **beats per minute**. When resting, the typical adult human heart beats at about **70** bpm (males) and **75** bpm (females), although this rate varies among people. The reference range for resting heart rate is between 60 and 100 bpm. The **pulse** is one way of measuring the heart rate.

Extended Inquiry Suggestions

Compare the heart rates of different animal species, and determine if there is a relationship between heart rate and animal size.

Research the longevity of different animals, and compare this information to their heart rates. Does a relationship exist between an animal's lifespan and its heart rate?

Design an experiment to test the effects of caffeine on the heart rate (participants who drink coffee, tea, or cola).

Challenge students to establish an exercise/activity program and chart these activities, including type of exercise and duration. Suggest a goal of at least 30 minutes of aerobic activity, three to four times per week. After several weeks, encourage students to reevaluate their target heart rate.

22. Exercise and Respiration Rate

Objectives

Measure the resting respiration rates of individuals and determine whether exercise causes a change in respiration rate.

Procedural Overview

Students gain experience conducting the following procedures:

- Using a breath rate sensor, students measure respiration rate before, during, and after exercise.

- Using analysis tools, students perform calculations on the data.

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Breath rate sensor[1]

[1] For sanitary reasons, each person being monitored needs his or her own mask.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Organs involved in the circulatory and respiratory systems

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Exercise and Heart Rate
- ♦ EKG: Factors that Affect the Heart
- ♦ Volume of Breath

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)
- ♦ Finding the values of a point on a graph �(9.1)
- ♦ Viewing the statistics of a graph �(9.4)
- ♦ Saving your experiment �(11.1)

Background

In humans, oxygen cannot be stored in sufficient quantities for more than a few minutes. At rest, the blood holds about a quart of dissolved oxygen, but it is continually being used by the cells to produce energy. The lungs constantly need to be working to furnish a sufficient supply for various activities. In turn, cells produce carbon dioxide as a metabolic waste product. If carbon dioxide builds up in the bloodstream, blood pH can decrease rapidly and be fatal.

Human respiration rate is controlled by a part of the brain called the medulla oblongata. It sends signals to the body to adjust breathing to provide enough oxygen for every activity, including sleeping, eating, and exercising. The brain measures the level of carbon dioxide (not the level of oxygen) in the blood and adjusts the respiration rate as needed. During exercise, the cells burn oxygen faster to produce more energy for the body, which creates more carbon dioxide as a waste product. This increased carbon dioxide level is detected by the brain, which signals for a higher respiration rate to provide more oxygen for the cells.

Breathing is an involuntary action controlled by the brain, but it can also be controlled voluntarily.

Hyperventilation is abnormally rapid, deep breathing and usually occurs when anxiety or emotional stress stimulates the part of the brain that regulates breathing. Kidney failure and diabetes may also cause hyperventilation. Too much carbon dioxide is exhaled, leaving less in the blood. This causes the vessels to constrict, decreasing the flow of blood. With too little blood reaching the brain, the person may become dizzy and faint.

Attacks of hyperventilation may last a half hour. Trying to slow the breathing rate can control such attacks. Exhaling into a paper bag and breathing the air in the bag can increase the carbon dioxide content in the blood and shorten the attack.

Table 1: Average human rates of breathing, by age

	Average Number of Breaths per Minute		**Average Number of Breaths per Minute**
Newborns	44	Older children	16 to 25
Infants	20 to 40	Adult, at rest	12 to 20
Preschool children	20 to 30	Adults, during exercise	35 to 45

Pre-Lab Discussion and Activity

Engage students asking them to draw on their prior knowledge of how their body changes during exercise, by having them answer the following questions individually, and then by sharing their responses in a class discussion.

1. How does respiration rate change with exercise? How does heart rate change during exercise? How are heart rate and respiration rate related?

Respiration rate and heart rate tend to increase during exercise and remain at an elevated level for a period of time after exercise. Breath rate increases to bring more oxygen into the lungs and then into the blood and remove more carbon dioxide from the body. Heart rate increases to be able to deliver the oxygen-rich blood to cells at a faster rate.

2. How will the respiration rate before and immediately after exercise compare between males and females.

Answers will vary depending on the experience. In general, many students may predict that the respiration rate before, during, and after exercise will be greater for females than they are for males.

Lab Preparation

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

1. For sanitary reasons, each person being monitored will need his or her own mask.

2. It is possible to do this activity using respiration rate belt. However you will not be able to collect data *during* exercise. The mechanics of the belt and sensor produce less reliable results during bodily movement.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ This activity requires the person whose respiration rate is being measured to exercise (jog in place for one minute). Do NOT perform this activity if vigorous exercise will cause discomfort or difficulty in breathing.

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
Gather all equipment and set up your data collection system.	Record breath rate after exercise.	Attach the breath rate sensor to the test subject.	Record resting breath rate for one minute.	Record breath rate during one minute of exercise.

Procedure with Inquiry

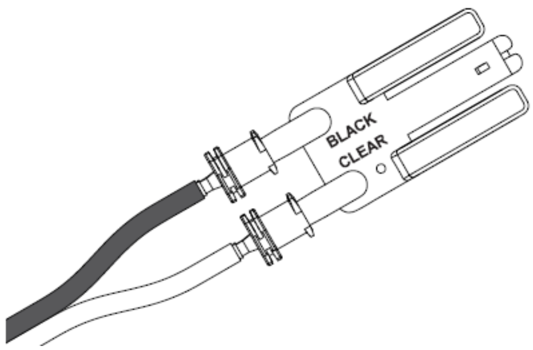
After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

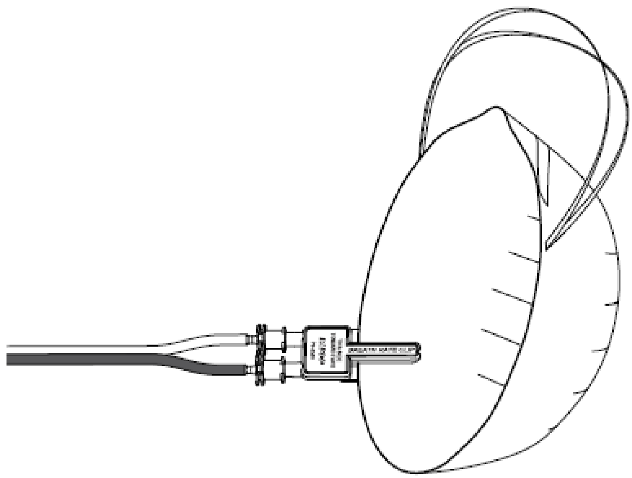
Note: Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these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

Set Up

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

2. ☐ Set up the mask, blue clip, and the black and clear leads according to the instructions that came with the breath rate sensor.

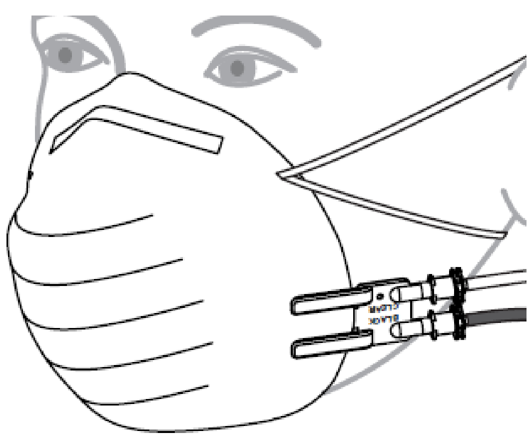




3. ☐ Connect the breath rate sensor to your data collection system. �(2.1)

4. ☐ Display Respiration Rate in breaths per minute on the y-axis versus Time in seconds (s) on the x-axis of a graph. �(7.1.1)

5. ☐ Place the mask on the face of the person who will be monitored.



6. ☐ What do you predict will happen to the rate of breathing before, during, and after exercise?

Answers will vary based on prior experience. Most students will correctly predict that breath rate should increase during exercise and slowly return to normal once exercise is complete.

Collect Data

Note: Once started, record data continuously through 1 minute at rest, 1 minute of exercise, and 1 minute of recovery.

7. ☐ Remind the person who is being monitored to relax, breathe normally, and *not* to look at the data as it is recorded.

8. ☐ Start recording data. �(6.2)

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

10. ☐ After 1 minute at rest, the person being monitored jogs in place.

11. ☐ Remind the person being monitored to inhale and exhale in smooth, even breaths.

Note: Erratic breathing or hyperventilation adversely affects the results.

12. ☐ After 1 minute, the person being monitored sits or stands very still.

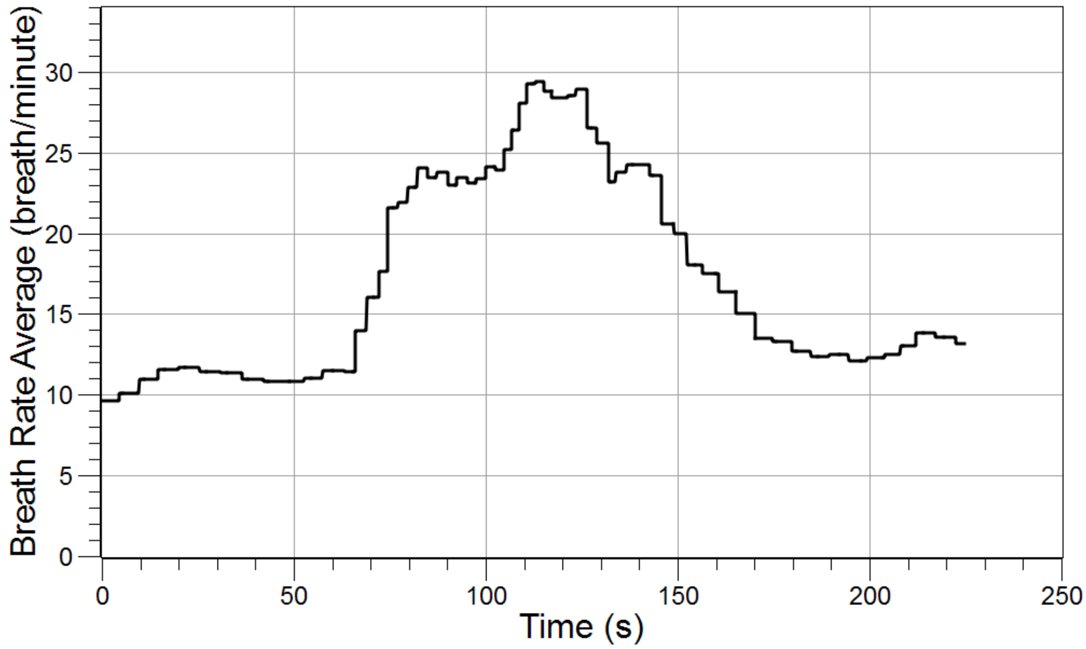
13. ☐ Remind the person being monitored to relax, breathe normally, and *not* to look at the data as it is recorded.

14. ☐ Stop recording data after breathing returns to normal. �(6.2)

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

Data Analysis

1. ☐ Make a sketch of your data for Breath Rate versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



2. ☐ Using the available tools on your data collection system, �(9.1) �(9.4) fill in Table 1.

Table 1: Rate of breathing at rest, during, and after exercise

	Minimum Breath Rate	Maximum Breath Rate	Average Breath Rate
At rest	10	12	11
During exercise	11	29	23
After exercise	12	29	17

Analysis Questions

1. How does the respiration rate immediately after exercise compare with the respiration rate at rest before exercise?

In this example, the breath rate during exercise is almost three times greater than the resting rate.

2. How long did it take after exercise for breath rate to return to normal?

The answer will vary depending on the physical fitness of the individual. Typically, people that are more fit have a shorter recovery period. In this example, the subject took 1 minute to recover.

3. When was the maximum breath rate reached for the person being monitored?

Answers may vary. In the sample data shown, the maximum breath rate achieved was about 50 seconds into the 60-second exercise period.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Why did the rate of respiration increase during exercise?

Because there is a greater demand for oxygen in the cells and a greater amount of carbon dioxide being produced as a waste product, heart rate increases to move the blood through the circulatory system at a more rapid rate. Breath rate increases to help exchange the carbon dioxide and oxygen gas faster.

2. What other physiologic responses change during exercise?

Heart rate, cardiac output, and tidal volume (quantity of air breathed in during each respiratory cycle) all increase during exercise in an attempt to get as much oxygen as possible to muscle cells.

Multiple Choice Questions

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

1. What is the name of the main muscle that helps regulate breathing?

- **A.** Pharynx
- **B. Diaphragm**
- **C.** Alveoli
- **D.** Bronchioles

2. Where does oxygen exchange happen?

- **A.** Pharynx
- **B.** Trachea
- **C.** Bronchi
- **D. Alveoli**

3. What part of the brain regulates involuntary breathing?

- **A.** Thymus
- **B.** Hypothalamus
- **C.** **Medulla oblongata**
- **D.** Cerebrum

Key Term Challenge

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

1. Every cell in your body needs oxygen. When you breathe air in, it contains oxygen. **Oxygen** is essential in the process of cellular respiration. **Carbon dioxide** is a waste product, generated by your cells during **cellular respiration**. If carbon dioxide is not removed from your bloodstream, the pH of your blood will drop and cause a condition called **acidosis.** This can be fatal. Blood flows to the **alveoli** in the lungs**,** where oxygen **enters** the bloodstream and carbon dioxide **exits** the bloodstream. Carbon dioxide is exhaled from the lungs.

2. During exercise, more **oxygen** is required by the cells in your body. Your cells are also producing **carbon dioxide** at a faster rate. A part of the brain called the medulla oblongata recognizes the need for heightened gas exchange and **increases** your breath rate. In addition, your heart rate increases in an effort to move the oxygen-**rich** blood to the cells faster.

Extended Inquiry Suggestions

Compare the respiration rate before, during, and after exercise between females and males.

Compare the respiration rate change for people who are physically active versus people who have a more sedentary lifestyle.

23. Muscle Fatigue

Objectives

Students determine their grip strength and compare muscle fatigue in hand muscles caused by isotonic ("same tension") and isometric ("same length") exercise. As part of this process, they will do the following:

- ♦ Investigate a loss of force as muscle fatigue develops during a sustained isotonic contraction. Isotonic contractions are produced when heavy objects are lifted.
- ♦ Investigate a loss of force as muscle fatigue develops during a sustained isometric contraction. Isometric contractions occur when a muscle is not allowed to shorten.

Procedural Overview

Students exercise their hand muscles two different ways, and after each type of muscular contraction, measure the grip force of the hand with a sensor:

- ♦ Measure the change in force exerted when gripping the sensor before and after timed muscular contractions (both isotonic and isometric).
- ♦ Compare the measured forces to determine if muscles become fatigued differently due to the two types of muscular contraction.
- ♦ Compare the measured forces to determine if there is a difference in the way the dominant and non-dominant hands become fatigued.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	30 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Force Sensor
- ♦ Rubber ball, tennis ball, or equivalent (approximately 7 cm diameter)
- ♦ Timer (stopwatch or equivalent)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Muscles cells, like all cells, require oxygen and energy to function properly.
- ♦ Muscles do various types of work, including isotonic and isometric activity.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Exercise and Respiration Rate
- ♦ Exercise and Heart Rate

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)
- ♦ Naming a data run �(8.2)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Saving your experiment �(11.1)

Background

Everyone is familiar with the sight of a muscular physique with muscles body builders strive to perfect, but there are many muscles we cannot see. Cardiac (heart) muscles, like skeletal muscle fibers, are striated. Cardiac muscles, however, are involuntarily controlled, that is, there is no conscious control by the individual.

Smooth muscles are also involuntary muscles and are regulated by the autonomic nervous system. They are located within the walls of internal organs, including the bronchi of the lungs, the bladder, stomach, walls of blood vessels, the iris, and the uterus.

Like most functions that occur within the human body, muscle contraction requires energy. The energy to move muscles comes from the molecule ATP (adenosine triphosphate). Energy is released when ATP hydrolyzes to form adenosine diphosphate (ADP) and a phosphate ion (Pi): $ATP \rightarrow ADP + Pi^+$

Muscles are arranged in motor units that consist of a nerve and the neuromuscular junctions that connect the nerve to the muscle cells. This organization permits a single nerve cell to fire a signal to all of the muscle cells within that unit, resulting in simultaneous contraction of the unit.

A single nerve impulse results in a muscle twitch; the muscle is stimulated and then relaxes before the maximum tension can develop. If the impulses continue in succession, a stronger twitch develops, because the muscle does not completely rest between twitches. Without a period of rest for muscle cells, a continual muscular contraction develops, called "tetanus." In this situation, ATP levels diminish and muscle fatigue occurs.

An increase in forceful muscular training can cause increased muscle mass by increasing fiber size. Resistance training may also increase the number of fibers. For this reason, isotonic and isometric exercises can significantly influence muscle mass.

Sustained exercise can deplete oxygen levels, resulting in an accumulation of lactic acid. Factors that cause fatigue may be due to elevated lactic acid within muscle fibers. People associate lactic acid with sore muscles, cramps, and fatigue. However, lactic acid contributes to energy production during muscle activity. Lactic acid aids in carbohydrate utilization and is an energy source for production of glucose and glycogen in the liver, especially during periods of stress.

Lactic acid begins to form once a person exceeds his or her anaerobic threshold. Typically, this intensity is 85% to 90% of one's maximum heart rate. When oxygen levels return to normal, the lactic acid is quickly converted to pyruvic acid and finally into carbon dioxide, water, and ATP. The goal during exercise conditioning is to improve lactic acid tolerance by improving oxygen delivery to muscle cells and enhancing one's level of performance.

Isometric Exercise

In isometric exercise, muscles contract but joints do not move, so muscle fibers maintain a constant length. The exercises are typically performed against an immovable surface, for example, pressing the palm of a hand against a wall.

Isometric training is effective for developing the strength of a particular muscle or group of muscles. It is often used for rehabilitation because the exact area of muscle weakness can be isolated, and strengthening exercises can be administered at the proper joint angle. Isometric strength training is not ideal for sports training, which requires dynamic, rather than static, muscle action. However, it requires no special equipment and has little chance of injury.

The isometric exercise in this activity consists of squeezing the sides of the force sensor for 60 seconds.

Isotonic Exercise

In isotonic exercise, a body part is moved and the muscle shortens or lengthens. Although sit-ups, push-ups, and pull-ups are isotonic, lifting free weights, like dumbbells and barbells, is considered the classic form of isotonic exercise.

The isotonic exercise in this activity consists of squeezing a tennis ball at a moderate rate for 60 seconds.

Pre-Lab Discussion and Activity

Engage your students with the following questions:

1. How will your grip strength after 1 minute of isotonic exercise (repetitive squeezing and releasing with the same tension) compare to your grip strength after 1 minute of isometric exercise (continuous squeezing against an immovable object)?

In most cases the decrease in grip strength should be greater with isometric exercises

2. How will the grip strength of your dominant hand after exercise compare to the grip strength of your non-dominant hand after exercise?

In most cases the decrease in grip strength should be greater in the non-dominant hand.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Stop the data collection activity if the squeezing becomes painful or particularly uncomfortable.

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
Determine the grip force measurements after isotonic and isometric exercises.	Analyze the data and compare your results with your classmates.	Determine the grip force measurements before exercise.	Determine the average grip force after isotonic exercise.

Procedure with Inquiry

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

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

Set Up

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

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

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

4. ☐ Screw the rubber bumper into the front of the force sensor.

Part 1 – Before exercise (control)

Collect Data

5. ☐ Which is your dominant hand?

Left or right; answers will vary.

6. ☐ Put the middle and ring fingers of your dominant hand through the finger holes on the back end of the force sensor.

7. ☐ Press the "zero" button on the force sensor.

8. ☐ Place your thumb on the rubber bumper.

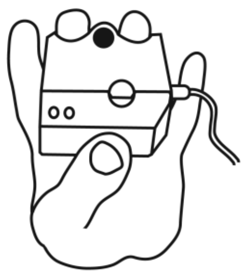
9. ☐ Why is it necessary to zero the force sensor?

This resets the sensor to zero.

10. ☐ Start data recording. �(6.2) Try to maintain a force of 40 N for the entire 60 seconds. If 40 N is too great a force to maintain, apply a lower force (30 N, for example) throughout the experiment.

Note: In this trial allow the subject to look at the screen to try and maintain the 40 N force.

Note: *Do not* squeeze with your index finger or little finger—squeeze only with your thumb on the rubber bumper and the two middle fingers that are in the finger holes of the sensor.



Squeeze the force sensor

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

12. ☐ Stop recording data after 60 seconds. �(6.2)

13. ☐ Name data run 1, "Dominant". �(8.2)

14. ☐ Which is your non-dominant hand?

Left or right; answers will vary.

15. ☐ Switch to your non-dominant hand and repeat the previous steps.

16. ☐ Name data run 2, "Non-dominant". �(8.2)

17. ☐ Save this part of your experiment. �(11.1)

18. ☐ What is the experimental purpose of measuring grip strength before exercising?

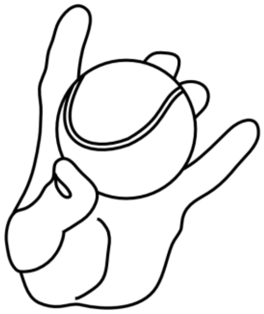
This serves as a control, a standard of comparison.

Part 2 – After isotonic exercise

19. ☐ What is an example of an isotonic exercise?

Lift a barbell or other heavy object.

20. ☐ Grip a tennis ball between the middle and ring fingers and thumb of your dominant hand.



Isotonic exercise

21. ☐ After isotonic exercise, will your grip strength stay the same, decrease, or increase?

Typically, grip strength will decrease.

22. ☐ Squeeze and release every 2 to 4 seconds with your thumb and two middle fingers. Do this for 60 seconds, trying to reapply the same amount of force. Do not squeeze with your index finger or little finger.

Note: No data is collected yet.

23. ☐ At the end of 60 seconds, quickly put the middle two fingers of your dominant hand through the finger holes on the back end of the force sensor. As before press the "zero" button on the force sensor, and then place your thumb on the rubber bumper.

Note: *Do not* look at the graph in this trial. Try to maintain 40 N of force (or the same force used previously) throughout the entire time period.

Note: *Do not* squeeze with your index finger or little finger—squeeze only with your thumb and two middle fingers.

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

25. ☐ While collecting data, *without watching the screen*, squeeze with your thumb and two middle fingers for 60 seconds, trying to maintain a constant force of 40 N.

26. ☐ Stop data recording after 60 seconds.

27. ☐ Name data run 3, "dominant isotonic".

28. ☐ Switch to your non-dominant hand and repeat the same procedure.

29. ☐ Name data run 4, "non-dominant isotonic".

30. ☐ Save this part of your experiment.

31. ☐ Was your prediction correct? What happened to your grip strength after 60 seconds?

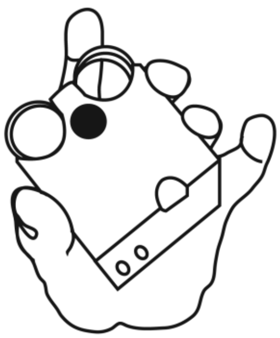
Typically, grip strength will decrease from the control exercise.

Part 3 – After isometric exercise

32. ☐ What is an example of an isometric exercise?

Push against a wall or any other stationary, unmovable object.

33. ☐ Grip the sides of the force sensor between the middle and ring fingers and thumb of your dominant hand. Do not place them through the finger holes and on the rubber bumper as before.



Isometric exercise

34. ☐ How is isometric exercise different from isotonic exercise?

Answers may vary. Isometric exercise means that the contracting muscles do not move. They do not lengthen or shorten.

35. ☐ Will your grip strength, after isometric exercise, stay the same, decrease, or increase?

Typically, grip strength will decrease.

36. ☐ Squeeze with your thumb and two middle fingers for 60 seconds trying to maintain a constant force of 40 N. Do not squeeze with your index finger or little finger to "help" squeeze.

Note: No data is collected yet.

37. ☐ At the end of 60 seconds, quickly put the middle two fingers of your dominant hand through the finger holes on the back end of the force sensor. As before press the "zero" button on the force sensor, and then place your thumb on the rubber bumper.

38. ☐ Start data recording, �(6.2) and adjust the scale of the graph to show all data. �(7.1.2) To collect data, this time *without watching the screen*, squeeze with your thumb and two middle fingers for 60 seconds, trying to maintain a constant force of 40 N. Do not squeeze with your index finger or little finger.

39. ☐ Stop data recording after 60 seconds.

40. ☐ Name data run 5, "dominant isometric".

41. ☐ Switch to your non-dominant hand and repeat the same procedure.

42. ☐ Name data run 6, "non-dominant isometric".

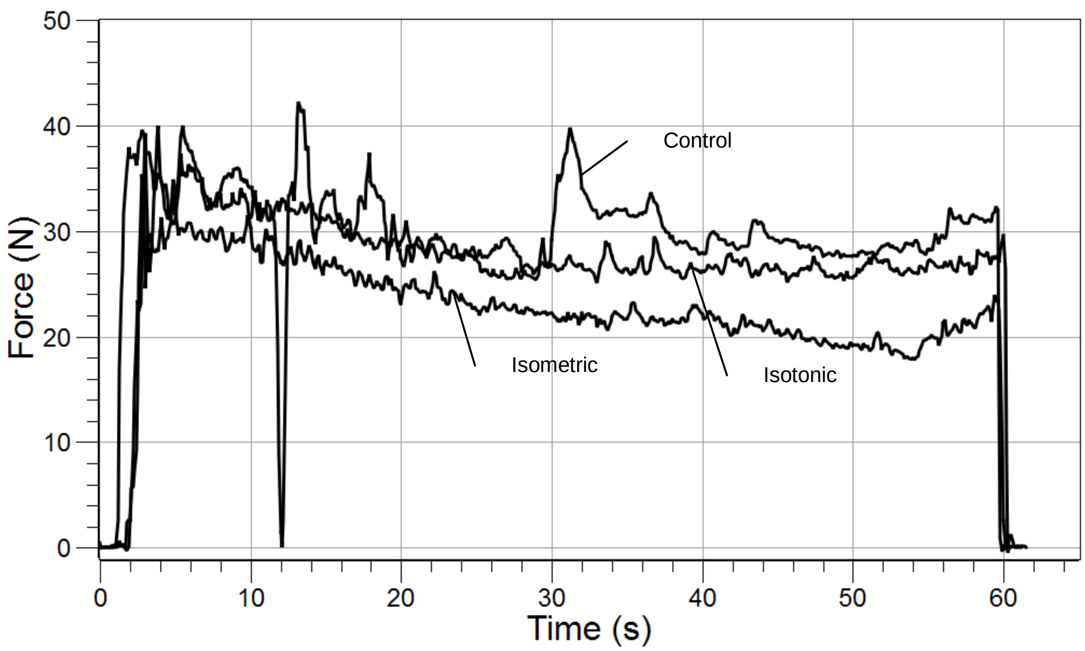
43. ☐ Was your prediction correct? What happened to your grip strength after 60 seconds?

Typically, grip strength will decrease from your control exercise.

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

Data Analysis

1. ☐ Make a sketch of all 3 runs of data for Force versus Time for the *dominant hand*. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



2. ☐ Make a sketch of all 3 runs of data for Force versus Time for the *non-dominant hand*. Label the overall graph, the x-axis, the y-axis, and include units on the axes.

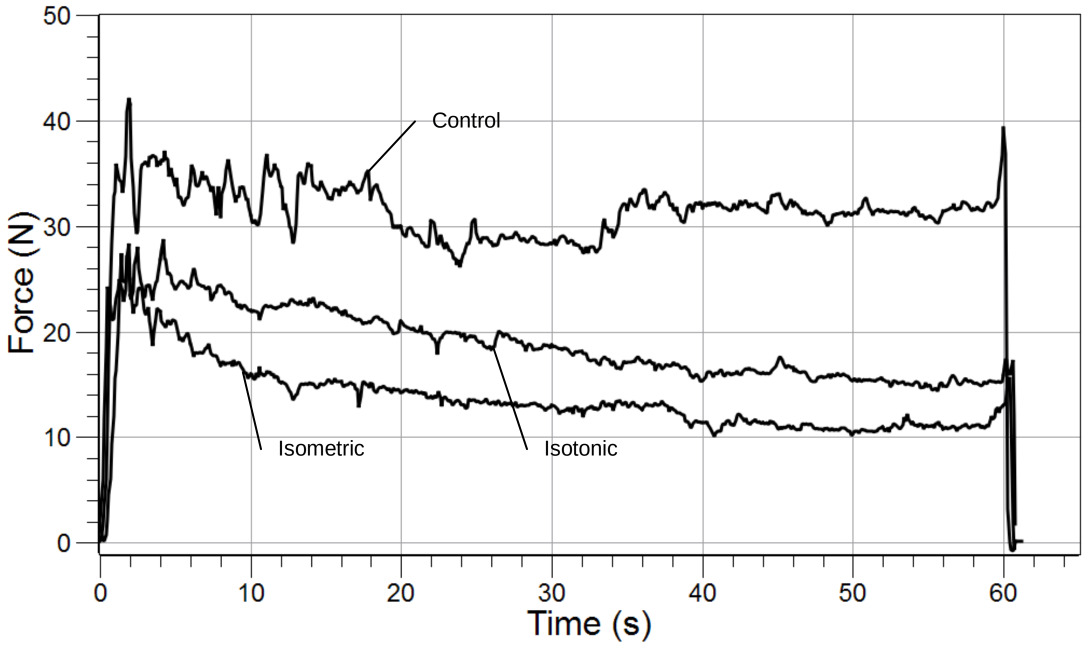


Table 1: Initial, final, and average force with the dominant hand

Run	Grip Force – Dominant Hand	Initial Force (N)	Final Force (N)	Average Force (N)
1	Before exercise, dominant hand	41	38	40.1
3	After isotonic exercise, dominant hand	42	34	39.6
5	After isometric exercise, dominant hand	44	31	40.6

Table 2: Initial, final, and average force with the non-dominant hand

Run	Grip Force – Non-dominant Hand	Initial Force	Final Force	Average Force
2	Before exercise, non-dominant hand	42	37	39.4
4	After isotonic exercise, non-dominant hand	46	30	37.6
6	After isometric exercise, non-dominant hand	55	25	32.5

Analysis Questions

1. What happened to your grip strength after you did the exercise?

Grip force decreased over time after the exercise when compared with the grip force before exercise.

2. How did your grip force change when you did the isotonic exercise compared to when you did the isometric exercise?

Grip force decreased more rapidly during the isometric exercise compared with the isotonic exercise.

3. Were the results different for the dominant and the non-dominant hand after 60 seconds? Explain.

Yes. The non-dominant hand showed a faster decrease in force than the dominant hand.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Describe an activity where your body loses the ability to deliver adequate oxygen to the muscles.

For example, you lose the ability if you run at too fast pace for too long a time.

2. Another word for “without oxygen” is "anaerobic." During this cycle of oxygen debt, what product accumulates in the muscle tissues? What happens to muscles as this product accumulates?

Lactic acid is being produced. Muscles feel as if they are "burning."

3. Do you think that frequently used muscles would tire faster or slower than muscles that are not used as much? Explain.

Frequently used muscles would tire more slowly. Frequently used muscles become larger and have more reserve energy.

Multiple Choice Questions

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

1. What kind of muscle contraction does *not* involve shortening or lengthening the muscle?"

- **A.** Fatigue
- **B.** Isotonic
- **C.** **Isometric**
- **D.** Isometric and isotonic

2. What term refers to the most force that a muscle can achieve and is directly proportional to the muscle size?

- **A.** Power
- **B.** Endurance
- **C.** **Strength**
- **D.** Performance

3. What kind of muscle contraction is involved when heavy objects are lifted?

- **A.** **Isotonic**
- **B.** Isometric
- **C.** Isometric and isotonic
- **D.** Involuntary

4. What common acid forms when muscles exceed an anaerobic threshold?

- **A.** **Lactic acid**
- **B.** Acetic acid
- **C.** Citric acid
- **D.** ATP

Key Term Challenge

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

1. Active muscles require energy and therefore require a continuous supply of **oxygen** and nutrients. For fuel, muscles rely on **glucose** from the bloodstream, glycogen stored in the muscle fibers, or fat molecules during vigorous, prolonged exercise. When energy availability fails to keep pace with the demands being placed on the muscle, the muscle will lose its physiological ability to **contract** in a controlled fashion due to ATP depletion. Even though the muscle may still receive nerve stimulation to move, **muscle fatigue** occurs.

2. **Isometric** contraction is one in which the muscle is activated, but instead of being allowed to lengthen or shorten, it is held at **constant length**. An example of isometric contraction would be carrying an object in front of you.

3. All lifting exercises require **isotonic** contractions. This happens when the muscle **shortens** as it **contracts**. An example of isotonic contraction can be seen when we flex the bicep muscle.

Extended Inquiry Suggestions

Have students repeat the experiment after immersing their hands in ice water for a specified period.

Compile aggregate class data, and compare the results of males versus females.

Design an experiment that incorporates other factors that may alter the rate of muscle fatigue (for instance, speed of movement, range of movement, weight of load, body position, or physical fitness).

24. Regulation of Body Heat

Objectives

Guide students to understand the extent that external conditions, such as ice water, moving air, or wearing gloves, cause changes in skin temperature.

- Use temperature sensors to measure the changes.
- Use graphing analysis tools to record and compare the changes.
- Speculate about the reasons for the changes.

Procedural Overview

Students will gain experience measuring skin temperature on the back of the hand under the following conditions:

- In still air
- In moving air
- Wearing a glove or mitten
- In ice water

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature probe (2)[1]
- Large bowl (or similar container)
- Fan
- Glove or mitten
- Tape or adhesive covers
- Ice, crushed or cube, 1 L
- Water, 1 L
- Towel (several)

[1]Fast-Response or Skin/Surface temperature probes

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Animals that maintain a constant body temperature are endotherms.
- Many mammals have sweat glands that help them regulate body temperature.
- Mammals have a high metabolism which helps them generate body heat.
- Environmental temperature extremes can result in the failure to maintain normal body temperature.
- Temperature is a degree of hotness or coldness the can be measured using a thermometer. It is also a measure of how fast the atoms and molecules of a substance are moving.
- Three kinds of heat transfer are radiation, conduction, and convection.

Related Labs in this Guide

Labs conceptually related to this one include:

- EKG: Factors that Affect the Heart
- Muscle Fatigue
- Exercise and Heart Rate
- Exercise and Respiration Rate

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)
- Connecting multiple sensors to your 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)
- Naming a data run �(8.2)
- Finding the values of points on a graph �(9.1)
- Measuring the distance between two points in a graph �(9.2)
- Saving your experiment �(11.1)

Background

Your body produces metabolic heat as a byproduct of every reaction that occurs inside you. The more active you are, the more heat your body produces. Your body must regulate the heat generated by metabolic reactions to maintain your internal temperature. Your internal (core) temperature must remain relatively constant because your enzymes work best at 37 ˚C. Your body is constantly monitoring and adjusting its processes to maintain relatively stable and constant internal conditions. This state is called homeostasis.

An organism's ability to maintain its body temperature within tolerable limits is known as thermoregulation. Some animals, including most mammals and birds, are endothermic. They regulate body temperatures internally. It is similar to a thermostat regulating the heat that keeps the temperature in a house comfortable. The biological thermostat of endotherms keeps body temperature within a normal range. When body temperature changes, receptors sense the change and trigger an adjustment. To maintain correct body temperature, mammals must be able to produce and conserve body heat in colder temperatures. Also, they must dissipate excess body heat in warmer temperatures.

The mechanisms mammals have for producing heat include shivering, cellular metabolism, and circulatory adaptations. Shivering generates heat as muscles quickly contract and shake. Cellular metabolism releases heat and warms the body from the chemical breakdown process that occurs within cells. Circulatory adaptations, such as countercurrent heat exchange, transfer heat from the core of the animal's body to the periphery by specially designed blood flow paths. From the core, warmer blood flows to colder extremities. This moderates the temperature, for instance, to an exposed arm or leg.

Animals that regulate temperature within a given range are described as endotherms. "Warm-blooded" is the more familiar term. Mammals and birds are endothermic because they maintain a relatively constant inner body temperature. The temperature of cold-blooded animals varies according to the temperature of the environment. The scientific term used to describe "cold-blooded" is ectotherm.

In humans and other mammals, temperature regulation represents the balance between heat production from metabolic sources and heat loss for a variety of reasons. Evaporation (perspiration) as well as radiation, convection, and conduction, all cause heat loss. In a cold environment, body heat is conserved first by constriction of blood vessels near the body surface and later by waves of muscle contractions, or shivering, which serve to increase metabolism. Shivering can result in a maximum five-fold increase in metabolism.

Pre-Lab Discussion and Activity

Engage your students by asking them to share any experiences where they have been excessively hot or cold and brainstorm about the reasons why.

1. What are some of the physiological changes, some of the things your body has done, when it is very hot or very cold?

Various answers may include sweating, shivering, changes in skin color, and goose bumps.

2. Why did such changes occur?

Some may know the terms vasodilation and vasoconstriction. With vasodilation (widening), more blood flows near the surface of the skin, and heat can be lost to the environment this way. Typically, these vessels look larger, and the skin color becomes pink or red. Vasodilation reduces the risk of internal organs overheating. With vasoconstriction (narrowing), less blood flows near the surface of the skin. Less surface transfer of heat occurs, maintaining heat at the body core. The skin can look pale, bluish, or gray.

3. Which will probably change skin temperature more: a hand with moving air blowing across it or a hand held in ice water?

Students will likely predict that ice water will have a greater cooling effect.

4. How much will the skin temperature change while a hand is held in ice water and how much will it change for the first minute after removing the hand from the ice water?

Students will likely predict skin temperature will become substantially colder while the hand is held in ice water. Answers should vary more regarding whether skin temperature rises, falls or stays the same for the first minute after removing the hand from ice water. Some may know that it may take time before the body triggers a new signal that the surrounding environment has become warmer again.

Lab Preparation

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

Teacher Tip: Watch students carefully. If the ice water causes discomfort or pain, ask the student to stop data collection.

GLX users: Connect two fast response temperature probes directly into the built in temperature ports on the left side of your device.

SPARK users: Plug one fast response temperature probe into the built in temperature port on the top of your device. You will need a blue temperature sensor box to plug into one of the PasPort sensor ports on the top of your device. Then, connect the fast response temperature probe into the blue sensor box. The device will now recognize both sensors.

DataStudio and SPARKvue users:You will need to have 2 sensor ports available. PASCO suggests 2 USBLinks, or a PowerLink. You will need TWO blue temperature sensor boxes to plug into the interface device. Then, connect one fast response temperature probe into one of the blue temperature sensor boxes, and the second fast response temperature probe into a second blue temperature sensor box.

Safety

Add this important safety precaution to your normal laboratory procedures:

- If the ice water causes discomfort or pain, stop data collection.

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

5	2	3	4	1
Analyze collected data.	Attach a temperature probe to the back of a hand.	First, measure skin temperature in still air.	Next, record skin temperature in moving air, in a glove, and in ice water.	Display Temperature versus Time on a graph in the data collection system.

sequence.

Procedure with Inquiry

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

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

Set Up

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

2. ☐ Connect a temperature probe into a port on the data collection system. �(2.1)

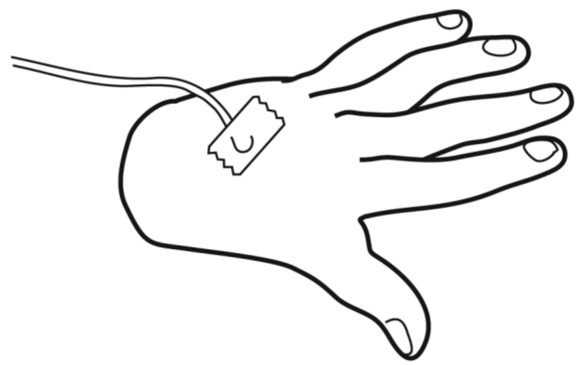
3. ☐ Connect a second temperature probe into a second port. �(2.2)

4. ☐ Display Temperature (°C) on the y-axis versus Time in seconds (s) on the x-axis of a graph. �(7.1.1)

5. ☐ Obtain a large bowl or similar container. It will be used later to hold ice water.

6. ☐ Use tape or adhesive covers to fasten the temperature probe so the tip of the probe is on the back side of your hand.

7. ☐ Fasten the other temperature probe in the same way to the back of the other hand.



Note: Variables will be introduced on one hand. Conditions for the other hand will be kept the same.

Part 1 – In still air

Collect Data

8. ☐ Start data recording. �(6.2)

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

10. ☐ Remind the person being measured to sit, relax, and not look at the data as it is recorded.

11. ☐ Why do you think that it is necessary to sit still?

Any movement may result in faulty readings.

12. ☐ Stop data recording after 6 minutes. �(6.2)

13. ☐ Name data run 1, "Still air". �(8.2)

14. ☐ What is the skin temperature of your hand in still air?

Answers will vary, but should be around 31˚C.

15. ☐ Why is the temperature recorded for still air called the "control"?

The temperature in still air is the normal condition with which the variable factors will be compared.

Part 2 – In moving air

Collect Data

16. ☐ Place a fan so that it will blow air across the right hand and *not* blow across the left hand.

17. ☐ Turn on the fan.

18. ☐ Remind the person being measured to sit, relax, and not look at the data as it is recorded.

19. ☐ Start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

20. ☐ Turn off the fan after 2 minutes.

21. ☐ Continue recording data for 4 more minutes.

22. ☐ Stop data recording. �(6.2)

23. ☐ Name data run 2, "Moving air". �(8.2)

24. ☐ How does the skin temperature in moving air compare with the temperature in still air?

Moving air should have a cooling effect that lowers the skin temperature.

25. ☐ Allow 5 minutes for the hand to return to normal temperature.

Part 3 – In a glove or mitten

Collect Data

26. ☐ Place a glove or mitten on the right hand.

27. ☐ Why is a glove or mitten used?

This tests the use of an insulator that traps body heat.

28. ☐ Remind the person being measured to sit, relax, and not look at the data as it is recorded.

29. ☐ Start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

30. ☐ Remove the glove or mitten after 2 minutes.

31. ☐ Continue recording data for 4 more minutes.

32. ☐ Stop data recording. �(6.2)

33. ☐ Name data run 3, "Glove" or "Mitten". �(8.2)

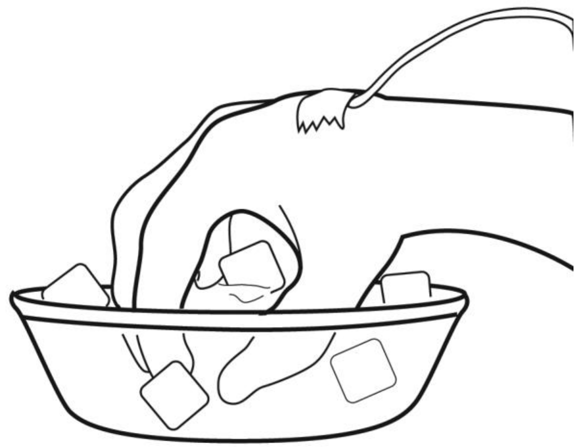
34. ☐ How does the skin temperature in the glove or mitten compare with the temperature in still air?

The glove or mitten should have a warming effect that raises the skin temperature.

35. ☐ Allow 5 minutes for the hand to return to normal temperature.

Part 4 – In ice water

Collect Data



36. ☐ Put ice and water into a large bowl or similar container. Leave enough room in the container so that you can put your hand into the ice water, as instructed, without causing any to spill.

37. ☐ Place the right hand so that the palm and fingers are completely in the ice water, *leaving the back of hand and the probe above water.*

38. ☐ Start data recording. �(6.2) Adjust the scale of the graph to show all data. �(7.1.2)

39. ☐ Remind the person being measured to sit, relax, and not look at the data as it is recorded.

40. ☐ Remove the hand from the ice water after 2 minutes.

Note: Tell the subject that it is OK to remove the hand from the ice water before two minutes if it is too uncomfortable.

41. ☐ Continue recording data for 4 more minutes.

42. ☐ Stop data recording. �(6.2)

43. ☐ Name data run 4, "Ice water". �(8.2)

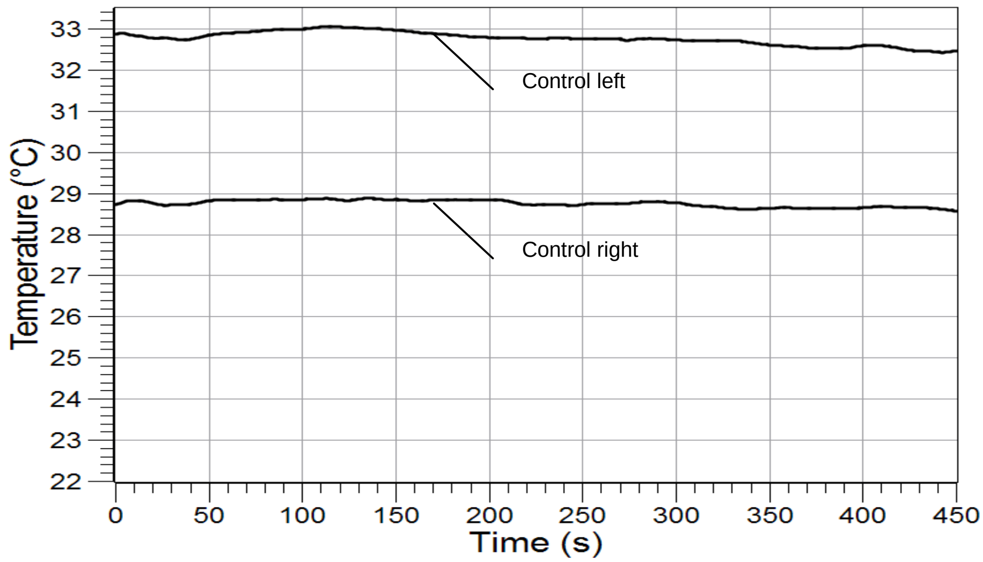
44. ☐ How does the skin temperature in the ice water compare with the temperature in still air?

Skin temperature decreases significantly in ice water compared with still air. Typically, the temperature decreases for the first minute and starts to rise after the hand is removed from the ice water. However, in some individuals, the physiological trigger for vasoconstriction takes longer, causing a continued drop in surface temperature for several minutes.

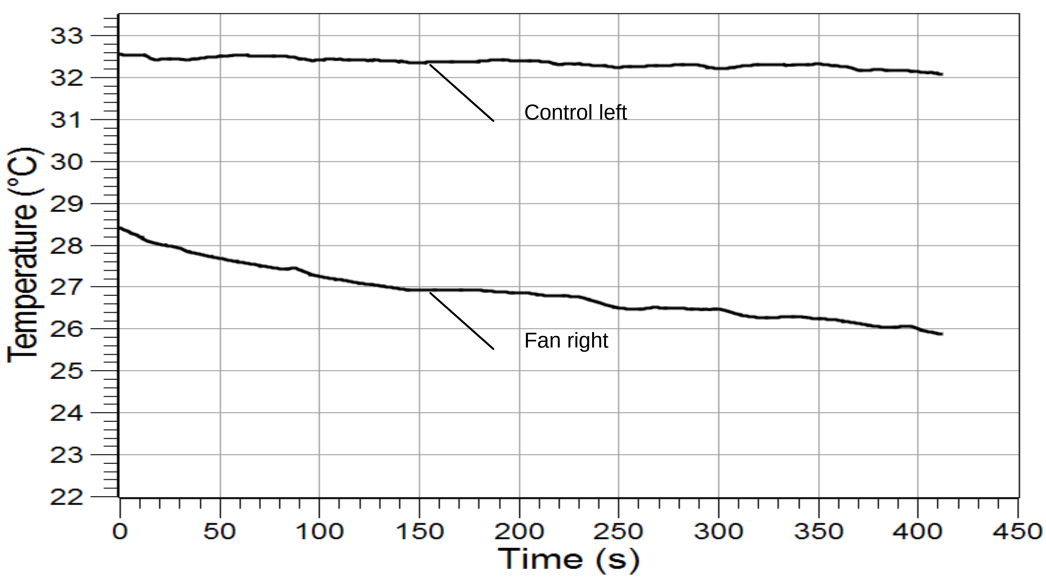
45. ☐ Save your experiment � (11.1) and clean up according to your teacher's instructions.

Data Analysis

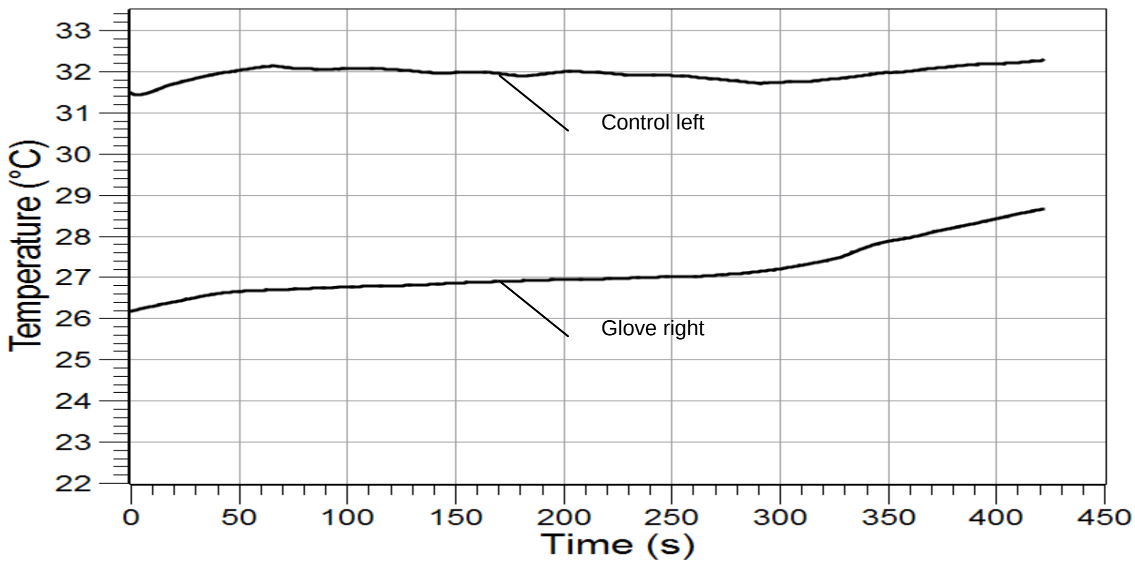
1. ☐ Make a sketch of your data for Temperature versus Time for the CONTROL. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



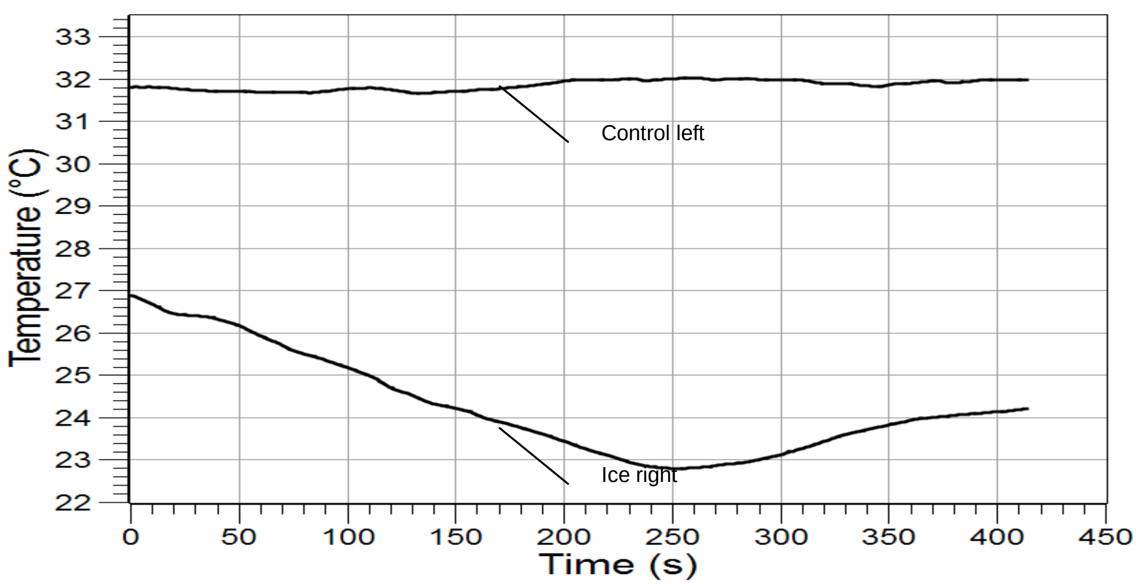
2. ☐ Make a sketch of your data for Temperature versus Time for the FAN. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



3. ☐ Make a sketch of your data for Temperature versus Time for the GLOVE. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



4. ☐ Make a sketch of your data for Temperature versus Time for the ICE WATER. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



5. ☐ Use available tools on your data collection system �[(9.1)] �[(9.2)] to complete the following table.

Table 1: Temperature changes for hand in still air, moving air, glove, and ice water

Trial	Starting Temperature (°C)	Temperature at Time of Greatest Change (°C)	Greatest Change in Temperature (°C)
Hand (left) in still air (control)	32.9	32.5	–0.4
Hand (right) in still air	28.7	28.9	0.2
Hand (left) in still air (control)	32.5	32.1	–0.4
Hand (right) in moving air	28.4	25.9	–2.5
Hand (left) in still air (control)	31.4	32.2	0.8
Hand (right) in glove or mitten	26.2	28.6	2.4
Hand (left) in still air (control)	31.8	31.6	0.2
Hand (right) in ice water	26.9	22.8	–4.1

Analysis Questions

1. What is the reason for any difference between skin temperature in moving air and skin temperature in still air?

Answers will vary. While there was nothing to cause the temperature of the hand in still air to change, moving air removed the thin layer of warm air next to the skin that acts as insulation. Without its protective layer of warm air, the skin cooled.

2. How does the skin temperature change during the first minute after the hand is removed from the ice water?

Answers will vary. In some examples, the skin temperature will rise the first minute after the hand was removed from the ice water. In most examples, it will continue to fall even after the hand is removed from the water. The brain has caused the vessels near the skin surface to constrict, forcing blood toward the core to help preserve heat energy and maintain core body temperature.

3. How did the change in skin temperature during the first minute after the hand is removed from the ice water compare to your prediction?

Answers will vary. Students should specifically mention their prediction and compare it with the data they collected.

4. How can you explain any differences in the starting temperatures of each hand? How could you reduce this problem?

It is possible that the sensors were not precisely calibrated to the same temperature. To reduce discrepancies, students could calibrate each of the temperature sensors before beginning the experiment. It is also possible that each hand IS a slightly different temperature to begin. This could be due to vascular and circulatory differences within the individual.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Why is it important to have a one hand remain at room temperature in still air during every trial in this experiment?

An experimental control is a test in which the independent variable is kept constant in order to measure changes in the dependent variable.

2. How do the results in this experiment help explain homeostasis?

Homeostasis involves regulating the internal environment or the body, so as to maintain a stable, constant condition. In this experiment, the body is constantly trying to maintain its normal level (typically 37 ˚C). It is adjusting to external influences on the skin temperature of the affected hand.

3. Explain how a person may get frostbite on their fingers and toes, but their core body temperature may remain relatively constant.

In an effort to maintain heat energy in very cold temperatures, vasoconstriction of the vessels in the extremities occurs and forces blood toward the body core. While this may protect the core, the loss of heat through the skin in the extremities can damage them.

Multiple Choice Questions

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

1. Animals capable of maintaining a constant body temperature are called:

- **A.** Poikilothermic
- **B. Endothermic**
- **C.** Cold-blooded
- **D.** Ectothermic

2. How does your body produce heat?

- **A. Metabolism**
- **B.** Cell division
- **C.** Metamorphosis
- **D.** Conduction

3. During perspiration how does the body lose heat?

- **A.** Conduction
- **B.** Radiation
- **C. Convection**
- **D.** Metabolism

4. How is temperature regulated in the human body?

- **A.** Perspiration
- **B.** Shivering
- **C.** Fever
- **D. 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. Humans and other mammals are **endothermic**. That is, they maintain a relatively constant body temperature despite widely ranging environmental temperatures. Although the average human body temperature is **36.7** degrees Celsius (**98.6** degrees Fahrenheit), this temperature varies depending on individual differences, time of day, the stage of sleep, and the ovulatory cycle in women. Your body is constantly monitoring and adjusting its processes to maintain relatively stable and constant internal conditions. This state is called **homeostasis**.

2. Heat flows from **higher** temperature to **lower** temperature. **Conduction** is the transfer of heat between objects that are in direct contact with each other. For instance, if a person sits on the cold ground, heat moves from the body to the cold ground. **Convection** is the transfer of heat by the movement of air or liquid moving past the body. This explains why a breeze across the skin may cool one down, whereas trapping air inside clothing keeps the body warm.

3. When the body is too hot, it decreases heat production and increases **heat loss**. One way of increasing heat loss is through the dilation of blood vessels in the skin. When these vessels dilate, large quantities of warm blood from the core of the body are carried to the skin, where heat loss may occur via **radiation**, convection, and conduction. **Evaporation** of fluids from the body also causes heat loss.

Extended Inquiry Suggestions

Determine the change of skin temperature when applying the following for a period of time:

- ♦ A hot pack and a warm pack and a cold pack
- ♦ Water at room temperature, warm water, and cold water

25. Volume of Breath

Objectives

Guide students to explore the pulmonary function test and the volume of breath and to understand the distinction between tidal volume and forced expiratory volume percentage.

Procedural Overview

Students use a spirometer in an activity that is much like the pulmonary function test:

- ♦ Determine the volume of one normal breath (tidal volume).
- ♦ Determine the forced expiratory volume for 1 second.
- ♦ Determine the maximum amount of air in the lungs (vital capacity).
- ♦ Compare the tidal volume and forced expiratory before and after aerobic exercise.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Spirometer
- ♦ Spirometer mouthpiece (1 per student)
- ♦ Stopwatch

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Respiration
- ♦ Structure and function of the human respiratory system

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Exercise and Respiration Rate

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)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Measuring the distance between two points in a graph �(9.2)
- ♦ Saving your experiment �(11.1)

Background

Breathing in and out (inhaling and exhaling) is as natural as anything we do. Our respiratory system manages the complex task of exchanging gases in the air–oxygen for carbon dioxide–with the circulatory system. The lungs are spongy organs filled with countless small sacks called alveoli that are surrounded by networks of the smallest blood vessels called capillaries. The alveoli and capillaries exchange gas molecules as the blood in the capillaries moves along near the alveoli.

A spirometer is often used as part of the pulmonary function test. The spirometer measures the amount of air moved during breathing. During this test, a person breathes through the spirometer for several quiet breathing cycles and one forced breathing cycle (one large inhalation followed by one large exhalation).

The pulmonary function test can record important measurements of volume exchanged over time. Significantly, the forced expiratory volume in 1 second ($FEV_{1.0}$) provides an indication of how well a person can exhale during maximum effort. This volume tends to be reduced in people with obstructive lung diseases such as asthma, chronic bronchitis, and emphysema. It tends to be increased in people with restrictive lung diseases such as pulmonary fibrosis. The forced expiratory volume percentage ($FEV_{1.0}$%) is typically 75% to 85% in a healthy subject.

Pulmonary function testing also considers tidal volume (TV). This volume of a single breath is the amount of air moved into and out of the lungs during quiet breathing (breathing without effort). Additionally, pulmonary function testing considers vital capacity (VC), which is the maximum volume of movable air in the lungs.

Spirometry is usually reported in both absolute values and as a predicted percentage of normal. Normal values vary depending on gender, race, age, and height. It is not possible to interpret pulmonary function tests without such information. There is no single set of standard reference values. So, “normal” varies with the reference value used in each laboratory.

Pre-Lab Discussion and Activity

Engage your students by having a brainstorming or discussion session based around the following questions. Accept all answers and write ideas on the board or overhead projector to remain displayed during the activity. At the end of the activity, go back and see if the data you collected support any of the ideas that were listed.

1. Discuss some lung diseases, such as asthma and emphysema. Ask students if they know anyone that has these problems and their causes. Ask students to think about how the quality of life is affected, for people with lung disease.

2. How much air do you think your lungs hold?

Answers will vary especially because many factors affect lung capacity. Six liters is a fair example of total lung capacity for an average-sized adult male.

3. Each time you exhale, do you fully remove all the air from your lungs?

Students may say that the answer is “no.” A residual volume of air remains in the lungs even after a forced exhalation.

4. How will the volume of air inhaled and exhaled change after you exercise? Explain why you think that.

Answers will vary, but students should suggest that after exercise they will need to breathe faster or deeper to satisfy the bodies increased demand for oxygen and removal of carbon dioxide.

5. How will the forced expiratory volume percentage for females compare with this percentage for males?

Students may say that this is a ratio, not a measure of absolute volume and capacity. Other factors aside, it should be about the same.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Students with known respiratory problems should not participate in the forced exhalation portion of this activity. It could cause breathing difficulties.

- ♦ Mouthpieces should *not* be shared among individuals and should be disposed of after use. There is no method to sterilize the mouthpiece or clean the membrane within the device.

> **Note:** The membrane within the spirometer collects saliva, bacteria, and other exhaled particles. This produces health concerns as well as data irregularity after more than several uses. The mouthpieces are intended for a single test occasion, which may include more than one test with the same individual.

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
Have the subject sit or stand at ease with the mouthpiece inserted and the nose pinched closed.	Connect the spirometer to the data collection system.	Compare TV and $FEV_{1.0}$, values between males and females.	Have the subject follow the breathing pattern outlined for measuring lung volume.	Determine TV, $FEV_{1.0}$, and VC based on the collected 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.

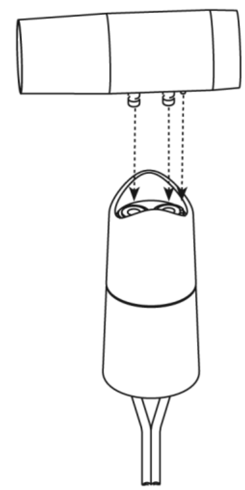
Set Up

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

2. ☐ Connect the spirometer to the data collection system. �(2.1)

3. ☐ Connect the mouthpiece to the handle noting the small pin on the mouthpiece and the aligning notch on the handle.

4. ☐ Program the data collection system to calculate lung volume based on an assumed value for functional residual capacity (2.5 liters) and the measured flow rate from the sensor. �(2.3)



Connect mouthpiece to handle

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

Collect Data

6. ☐ Predict how the measured lung volume will change through the process of breathing normally, breathing deeply, and breathing normally again.

Students should predict that the lung volume for the normal breaths will be less than that for the deep breath.

7. ☐ Start data recording. �(6.2)

Note: *Wait* until the red indicator on the sensor stops flashing. Wait until the green *ready* indicator is lit before you move the mouthpiece and handle.

Note: The person who is being measured should sit or stand comfortably and *not* look at the data as it is recorded.

8. ☐ Why should the person being measured *not* look at the data as it is being recorded?

The person being measured may alter his or her breathing patterns in order to achieve the desired result.

9. ☐ Ensure that all breath flows through the mouthpiece:

- Place the tapered end of the mouthpiece between the front teeth with the lips creating a seal around the mouthpiece.
- Hold the nose closed.
- Breathe only through the mouth during the measurements.

10. ☐ After the green *ready* indicator on the spirometer is lit, breathe using the following sequence:

Note: The person who keeps track of the breaths should count aloud to guide the breathing: "4 normal breaths, 1 … 2 … 3 … 4 … inhale deeply … exhale deeply, maximum effort … and 2 normal breaths, 1 … 2 …."

a. Take 4 normal, quiet breaths.

b. Inhale deeply, followed immediately by exhaling deeply with maximum effort.

c. Take 2 normal, quiet breaths.

11. ☐ Stop data recording. �(6.2)

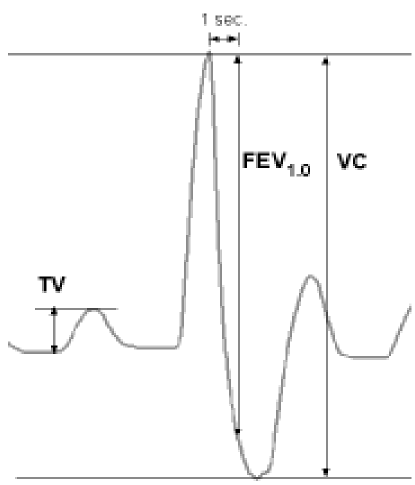
12. ☐ Using the stopwatch, the person being tested should exercise aerobically for 3 minutes. *(Exercise examples: jumping jacks and running in place)*

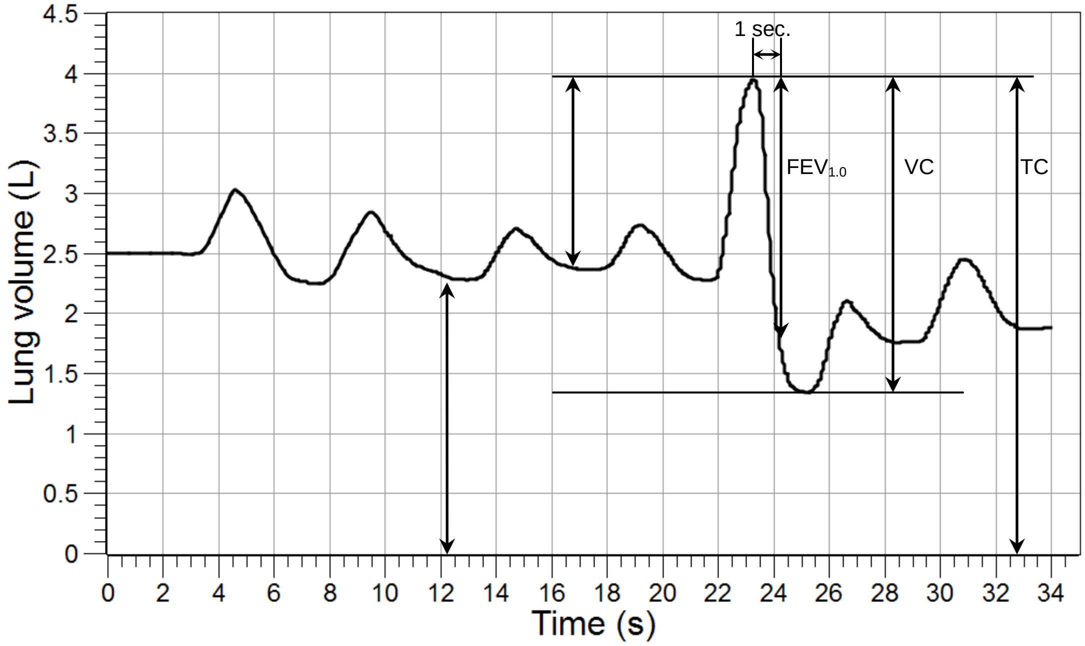
13. ☐ Immediately after stopping, stand comfortably and repeat the pulmonary test (steps 7-11).

14. ☐ Save your experiment. �(11.1)

Data Analysis

1. ☐ Graph your data for Lung Volume versus Time. Label the overall graph, the x-axis, the y-axis, and include units on the axes. Label the tidal volume (TV), the forced expiratory volume in 1 second ($FEV_{1.0}$), and the vital capacity (VC). Use the diagram as a reference for these measurements.





2. ☐ From your data, measure the distance (time in seconds) that determines the tidal volume (TV), the forced expiratory volume in 1 second ($FEV_{1.0}$), and the vital capacity (VC). �(9.2) Record these measurements in Table 1 for each run of data.

3. ☐ Calculate the forced expiratory volume percentage as follows:
Divide the forced expiratory volume in 1 second by the vital capacity and multiply by 100:

$$FEV_{1.0}\% = FEV_{1.0} \div VC \times 100$$

Record the value in Table 1.

Table 1: Volume and vital capacity measurements from a pulmonary function test

Measurement	**Value before exercise**	**Value after exercise**
Tidal volume (TV): volume of 1 breath	0.37 L	0.59 L
Forced expiratory volume in one second ($FEV_{1.0}$)	2.20 L	2.00 L
Vital capacity (VC): maximum movable air in the lungs	2.59 L	2.55 L
Forced expiratory volume percentage ($FEV_{1.0}\%$)	85%	78%

Analysis Questions

1. How did the tidal volume change after exercise? Why is that?

The tidal volume will increase after exercise because the bodies increased demand for oxygen continues for a while even after exercise has stopped. Additionally excess carbon dioxide produced during exercise needs to be expelled.

2. How did the $FEV_{1.0}$ change after exercise?

The person has just stretched the rib muscles and the diaphragm to reach the maximum capacity. The ability to forcefully exhale may be slightly diminished after exercise and/or performing a pulmonary test.

3. How did the vital capacity change after exercise?

The vital capacity should remain unchanged.

4. Describe how the person's breathing rate and tidal volume changed to meet the increased oxygen demand during and after exercise. Support your answer with evidence.

During exercise the mitochondria in the muscles have to produce more ATP to power muscles. This requires more oxygen. As sugars are broken down to produce ATP carbon dioxide is produce and begins to build up in the tissues. This combination of increased oxygen demand and excess carbon dioxide signals the brain to increase heart rate and respiration rates. This is visible in the data with faster breathing.

5. You may have noticed a slight variation in the lung volume measured for each of the first four breaths. Why is that?

The lung volume measurements will vary as the person adjusts to the mouthpiece and to breathing only through the mouth.

Synthesis Questions

Use available resources to help you answer the following questions.

1. How does the tidal volume for females compare with the tidal volume for males?

The tidal volume for males is generally greater than it is for females because of the larger body size and associated larger lung size.

2. How did the results compare with your answers to the pre-lab questions?

Answers will vary. The results should shed some light on the value of using a ratio rather than raw values to compare people who have different body sizes.

3. How would tidal volume change in an individual with a respiratory disorder such as asthma?

Individuals with respiratory disorders have reduced tidal volume because these disorders typically cause restrictions or blockages in airways.

Multiple Choice Questions

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

1. What happens when you exhale?

- **A. Both the diaphragm and rib muscles contract.**
- **B.** Both the diaphragm and the rib muscles relax.
- **C.** The rib muscles contract, and the air pressure in the alveoli becomes lower than the atmospheric pressure.
- **D.** The volume of the chest cavity increases.

2. After maximum inhalation, what is the maximum amount of air a person can exhale called?

- **A. Vital capacity**
- **B.** Tidal volume
- **C.** Residual capacity
- **D.** Ventilation volume

3. What process exchanges carbon dioxide and oxygen gas in the alveoli and lung capillaries?

- **A.** Osmosis
- **B. Diffusion**
- **C.** Phagocytosis
- **D.** Endocytosis

Key Term Challenge

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

1. When you inhale, air moves sequentially through your nose or mouth to the **pharynx**, **larynx**, **trachea**, **bronchi,** and **bronchioles**. Within the bronchioles are small sacks called **alveoli** that are surrounded by networks of the smallest blood vessels called **capillaries**. It is at this site that gas exchange occurs in the lungs.

2. A **spirometer** is often used as part of the **pulmonary function test**. The spirometer measures the amount of air moved during breathing. One of the more significant measurements is **forced expiratory volume in 1 second** ($FEV_{1.0}$), which provides an indication of how well a person can exhale during maximum effort. Another useful measurement from the pulmonary function test is **tidal volume**. This is the volume of one breath or the amount of air moved into and out of the lungs during quiet breathing (breathing without effort). The ratio of $FEV_{1.0}$/VC (vital capacity), also referred to as the **forced expiratory volume percentage,** ($FEV_{1.0}$%) can help to detect abnormalities in respiratory function. The primary abnormality detected by spirometry is airways obstruction, which results in a $FEV_{1.0}$/VC ratio of less than 70 to 80%.

Extended Inquiry Suggestions

Students could use the same experimental design to determine inspiratory capacity, functional residual capacity, and total lung capacity.

Students could research typical values for pulmonary function tests and forced expiratory volumes in 1 second for people with asthma or other types of lung disease.