Physics through Inquiry

Teacher Guide

PASCO®

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Physics through Inquiry

High School

Teacher Guide
21^{st} 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 standard, such as NGSS. The use of sensors, data analysis and graphing tools, models and simulations, and work with instruments, all support the science and engineering practices as implemented in a STEM-focused curriculum, and are explicitly cited in NGSS. PASCO's lab activities provide students with hands-on and minds-on learning experiences, making it possible for them to master the scientific process and the tools to conduct extended scientific investigations.

About the PASCO 21st Century Science Guides

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

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

The Data Collection System

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

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

Getting Started with Your Data Collection System

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

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

Teacher and Student Guide Contents

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

Lab Activity Components

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

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

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

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

TEACHER INFORMATION	STUDENT INQUIRY WORKSHEET
Objectives	Driving Questions
Procedural Overview	Background
Time Requirement	Pre-Lab Activity
Materials and Equipment	Materials and Equipment
Concepts Students Should Already Know	
Related Labs in This Guide	
Using Your Data Collection System	
Background	
Pre-Lab Activity	
Lab Preparation	
Safety	Safety
Sequencing Challenge	Sequencing Challenge
Procedure With Inquiry	Procedure (+ conceptual questions)
Data Analysis	Data Analysis
Analysis Questions	Analysis Questions
Synthesis Questions	Synthesis Questions
Multiple Choice Questions	Multiple Choice Questions
Extended Inquiry Suggestions	

Electronic Materials

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

The storage device accompanying this manual contains the following:

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

International Baccalaureate Organization (IBO*) Support

IBO Diploma Program

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

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

Using these Labs with the IBO Programs

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

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

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

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

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

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

About Correlations to Science Standards

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

Global Number Formats and Standard Units

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

Reference

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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
		Force and Motion	
1	**Position: Match Graph** Use a motion sensor to introduce the concept of representing motion as a change of position in a graphical form.	Data Collection System PASPORT Motion Sensor Rod stand for motion sensor (optional) *Object to hold (textbook, basket ball) (optional)*	1 1 1 1
2	**Speed and Velocity** Use a motion sensor to test predictions of how the speed and velocity of a cart will differ.	Data Collection System PASPORT Motion Sensor Dynamics track Dynamics track end stop Dynamics cart	1 1 1 1 1
3	**Relative Motion** Use a motion sensor to apply the concepts of relative motion and frames of reference to understanding velocity as a vector quantity in one-dimensional motion.	Data Collection System PASPORT Motion Sensor Dynamics track Cart adapter accessory Variable speed motorized cart *Note card (card stock, 10 cm × 15 cm)*	1 1 1 1 2 1
4	**Acceleration** Use a motion sensor to introduce the concept of representing motion as a change of position in a graphical form.	Data Collection System PASPORT Motion Sensor Dynamics track Dynamics cart Dynamics track pivot clamp Dynamics track end stop Rod stand	1 1 1 1 1 1 1

Lab	Title	Materials and Equipment	Qty
5	**Introduction to Force** Use a force sensor to measure and experience contact forces, and some non-contact forces, in relation to gravity.	Data Collection System PASPORT Force Sensor Balance (optional) Right-angle clamp Rod Stand Short Rod *Masses (at least three different values)* *Objects (textbook, ball, carts, et cetera)*	1 1 1 per class 1 1 1 3 Several
6	**Archimedes' Principle** Use a force sensor to explore the relationship between the volume of fluid displaced by a submerged object and the buoyant force experienced by that submerged object.	Data Collection System PASPORT Force Sensor Balance String Right-angle clamp Rod stand Overflow can Short rod *Cup or beaker to catch water from overflow can* *Graduated cylinder, 25-mL (optional)* *Objects to submerge* *Ruler* *Small cup to add water to the overflow-can* *Water*	1 1 1 per class 25 cm 1 1 1 1 1 1 2 1 1 500 mL
7	**Hooke's Law** Use a force sensor to observe the relationship between the extension of a spring and the resulting force required to extend the spring.	Data Collection System PASPORT Force Sensor Spring Meter stick	1 1 1 1
8	**Newton's First Law** Use a motion sensor to determine the influence of force in the motion of an object, and that an object's motion is unchanged in the absence of an external force.	Data Collection System PASPORT Motion Sensor Dynamics cart Dynamics track Dynamics track end stop Mass and hanger set Super pulley with clamp String	1 1 1 1 1 1 1 ~1 m
9	**Newton's Second Law** Use a force sensor and motion sensor to develop an understanding of the relationship between the net force applied to an object, the acceleration of the object, and the object's mass.	Data Collection System PASPORT Force Sensor PASPORT Motion Sensor Balance Mass Right-angle clamp Rod stand Short Rod Spring	1 1 1 1 per class 1 1 1 1 1

Lab	Title	Materials and Equipment	Qty
10	**Newton's Third Law** Use two force sensors to observe the relationship between an action force and the resulting reaction force.	Data Collection System PASPORT Force Sensors Balance Dynamics carts Dynamics track Compact cart mass, 250 g Discover friction accessory Spring force sensor bumper Collision cup force sensor bumper *Rubber band*	1 2 1 per class 2 1 1 1 1 1 1
11	**Static and Kinetic Friction** Use a force sensor to investigate static friction and kinetic (sliding) friction.	Data Collection System PASPORT Force Sensor Balance Dynamics track Dynamics cart Dynamics cart masses[2] Discover friction accessory String (optional)	1 1 1 per class 1 1 at least 2 1 10 cm
12	**Conservation of Energy** Use a motion sensor to detect how energy is transformed in a cart and track system and to observe that the total energy of the system is conserved.	Data Collection System PASPORT Motion Sensor Balance Dynamics track Dynamics track end stop Dynamics cart with plunger Dynamics track angle indicator Dynamics Track Pivot clamp Rod stand (to elevate track)	1 1 1 per class 1 1 1 1 1 1
13	**Conservation of Momentum** Use two motion sensors to explore the concept of momentum and its conservation during common types of collisions.	Data Collection System PASPORT Motion Sensors Balance Dynamics track Dynamics carts with magnet bumpers, Velcro® bumpers, and plungers	1 2 1 per class 1 2
14	**Impulse Momentum** Use a motion sensor and force sensor to explore the change in momentum that occurs in a collision, and how that change is related to the impulse associated with the collision.	Data Collection System PASPORT Motion Sensor PASPORT Force Sensor Balance Dynamics cart Dynamics track Force accessory bracket	1 1 1 1 per class 1 1 1
15	**Work and Energy** Use a motion sensor and force sensor to develop an understanding of the work-energy theorem that relates the work done on an object by a net force to the change in the object's kinetic energy.	Data Collection System PASPORT Motion Sensor PASPORT Force Sensor with hook Dynamics track Dynamics cart Dynamics track end stop Super pulley with clamp Mass and hanger set Balance String	1 1 1 1 1 1 1 1 1 per class 1.5 m

Lab	Title	Materials and Equipment	Qty
16	**Simple Harmonic Motion** Use a force sensor and motion sensor to determine the spring constant by measuring the spring extension due to each of three different masses suspended from the spring.	Data Collection System PASPORT Force Sensor PASPORT Motion Sensor Balance Assorted masses Meter stick Right-angle clamp Rod stand Short rod Spring	1 1 1 1 per class At least 3 1 1 1 1 1
17	**Pendulum** Use a motion sensor to determine how the mass and length of a simple pendulum affect its period of oscillation.	Data Collection System PASPORT Motion Sensor Balance Large table clamp Metric tape measure Pendulum bobs of the same size (but made of different materials) Pendulum clamp Rod stand Short Rod String	1 1 1 per class 1 1 3 1 1 1 4 m
18	**Circular Motion** Use a force sensor to develop a kinesthetic understanding of circular motion by measuring the period of rotation of a mass in uniform circular motion	Data Collection System PASPORT Force Sensor Balance Meter stick Plastic Tie Plastic tube Rubber stopper, #10, one-hole Short rod String Table clamp Timer *Marker* *Scissors*	1 1 1 per class 1 1 1 1 1 3 m 1 1 1 1
19	**Centripetal Force** Use a force sensor to understand the factors that affect the centripetal force experienced by an object in uniform circular motion.	Data Collection System PASPORT Force Sensor Balance Meter stick Plastic tube Rubber stopper Short rod String Table clamp Timer *Marker* *Scissors*	1 1 1 per class 1 1 1 1 3 m 1 1 1 1

Lab	Title	Materials and Equipment	Qty
20	**Projectile Motion** Use two photogates to learn how two independent motions, horizontal and vertical, are descriptions of the motion of a projectile.	Data Collection System	1
		PASPORT Photogates	2
		Digital adapter	1
		Digital extension cable (optional)	1
		Time of flight Pad	1
		Projectile launcher	1
		Projectile	1
		Photogate mounting bracket	1
		Carbon Paper (optional)	1
		Large table clamp	1
		Plumb bob	1
		Ram rod	1
		Short rod	1
		Metric tape measure	
		Tape	1 roll
		Pencil or pen	1
		Sheet of white paper	10
	Thermodynamics		
21	**Temperature versus Heat** Use a temperature sensor to explore the relationship between heat transfer and temperature change in various substances.	Data Collection System	1
		PASPORT Temperature Sensor[1]	2
		Balance	1 per class
		Aluminum mass, 200-g	2
		Calorimetry cup	2
		Copper mass, 200-g	2
		Hot plate	1
		String, 15-cm	4
		Paper clip	2
		Beaker, 600-mL	1
		Vegetable oil	500 g
		Water	500 g
22	**Phase Change** Use a stainless steel temperature sensor to observe physical changes in a system undergoing a phase change.	Data Collection System	1
		PASPORT Stainless Steel Temperature Sensor	2
		Hotplate	1
		Rod stand	1
		Utility clamp	2
		Beaker, 150-mL	2
		Test tube, 20-mm × 150-mm	1
		Ice cube	1
		Ice, crushed	~120 g
		Lauric acid	8 g
		Stirring rod	1
		Water	200 mL

Lab	Title	Materials and Equipment	Qty
23	**Specific Heat of a Metal** Use a stainless steel temperature sensor to compare the heat transferred by different metals to water.	Data Collection System PASPORT Stainless Steel Temperature Sensor Balance Calorimetry cup Hot plate Metal sample String, 15-cm *Beaker, 600-mL* *Tongs* *Water*	1 1 1 per class 3 1 3 3 1 1 1 L
24	**Heat of Fusion** Use a temperature sensor to understand heat as energy and the transfer of heat during the phase change from solid to liquid.	Data Collection System PASPORT Temperature Sensor[1] Balance Hot plate Calorimetry cup Stir station (optional) *Beaker, 600-mL* *Ice cubes* *Paper towel* *Stirring rod* *Water*	1 1 1 per class 1 1 1 1 3 or 4 1 sheet 1 300 mL
25	**Heat of Vaporization** Use a temperature sensor to develop a better understanding of the phase change from gas to liquid.	Data Collection System PASPORT Temperature Sensor[1] Balance Calorimetry cup Water trap Steam generator Stir station (optional) Tubing, 1/4 inch inner diameter[2] *Clip or rigid U-shaped tube* *Scissors* *Stirring rod (optional)* *Tape (optional)* *Water*	1 1 1 per class 1 1 1 1 0.5 m 1 1 1 1 roll 1 L
26	**Boyle's Law** Use an absolute pressure sensor to observe the relationship between volume and pressure of an enclosed gas at constant temperature.	Data Collection System PASPORT Absolute Pressure Sensor Quick release connector[2] Syringe, 20 mL[2] Tubing[2]	1 1 1 1 1

Lab	Title	Materials and Equipment	Qty
27	**Absolute Zero** Use an absolute pressure sensor and a temperature sensor to experimentally determine a numerical value for absolute zero in degrees Celsius.	Data Collection System PASPORT Absolute Pressure Sensor PASPORT Temperature Sensor[1] PASPORT Sensor Extension Cable Barbed quick-release connector[2] Barbed tubing-to-rubber stopper[2] connector Hot Plate Rod Stand Three-finger clamp Tubing[2] Utility clamp *Beaker, 600 mL* *Disposable pipet* *Glycerin* *Oven Mitt* *Rubber stopper, 1-hole #2* *Tape* *Test tube, 20 mm X 150 mm*	1 1 1 1 1 1 1 1 1 ~ 15 cm 1 1 1 1 1 1 ~ 6 cm 1
	Electricity and Magnetism		
28	**Charge and Electric Field** Use a charge sensor to observe the nature of charging different objects by contact and to explore the electric field produced by a variety of charged objects.	Data Collection System PASPORT Charge Sensor Charge producers Faraday ice pail Proof planes *Aluminum rod* *Fur cloth* *Glass rod* *Plastic rod* *Silk cloth*	1 1 1 pair 1 2 1 1 1 1 1
29	**Voltage: Fruit Battery/Generator** Use a voltage sensor to explore both the chemical and physical production of a potential difference.	Data Collection System PASPORT Voltage Sensor Alligator clips (one red, one black) Series/Parallel battery holders *Copper* *Zinc* *Batteries, "D" cell* *Variety of fruit*	1 1 2 3 1 piece 1 piece 3 Minimum 1 piece per student group
30	**Ohm's Law** Use a voltage sensor and current sensor to investigate the relationship between current, voltage, and resistance in a circuit.	Data Collection System PASPORT Current Sensor PASPORT Voltage Sensor Charge/Discharge circuit board Patch cord, 4 mm banana plug *AA cell battery*	1 1 1 1 5 2

Lab	Title	Materials and Equipment	Qty
31	**Series and Parallel Circuits** Use a voltage sensor and current sensor to explore the properties of both series and parallel circuits.	Data Collection System PASPORT Current Sensor PASPORT Voltage Sensor Alligator clip adapters (optional) DC power supply, 10 V, 1 A minimum Patch cord, 4 mm banana plug Resistors, at least 3 different known values Switch, single-pole single-throw	1 1 1 10 1 10 3 to 6 1
32	**RC Circuit** Use a voltage sensor and current sensor to explore the behavior of a simple circuit of a resistor and capacitor in series.	Data Collection System PASPORT Voltage Sensor PASPORT Current Sensor Charge/discharge circuit board Banana plug patch cord, 4mm *AA cell batteries*	1 1 1 1 5 2
33	**Magnetic Field: Permanent Magnet** Use a magnetic field sensor to investigate the magnetic field strength of a permanent magnet as a function of distance from the magnet.	Data Collection System PASPORT Magnetic Field Sensor PASPORT Sensor Extension Cable (optional) Meter stick (non-metallic) Neodymium magnet (1/2 or 3/4")	1 1 1 1 1
34	**Magnetic Field: Coil** Use a current sensor and magnetic field sensor to understand some of the factors affecting the electromagnetic field strength within a solenoid.	Data Collection System PASPORT Current Sensor PASPORT Magnetic Field Sensor PASPORT Sensor Extension Cable (optional) Coils of varying turns but the same radius DC power supply, 10 V, 1 A minimum Meter stick Patch cord, 4 mm banana plug	1 1 1 1 3 1 1 3
35	**Faraday's Law of Induction** Use a voltage sensor to observe the electromotive force generated by passing a magnet through a coil.	Data Collection System PASPORT Voltage Sensor No-Bounce pad (optional) 200, 400, and 800 turn coils Magnets, different strengths Three-finger clamp Rod stand *Paper* *Pen or pencil* *Tape*	1 1 1 1 each 3 1 1 1 sheet 1 1 roll
		Light	
36	**Inverse Square Law** Use a light sensor to experience the concept of light intensity varying inversely as the square of the distance from a point source of light.	Data Collection System PASPORT Light Sensor PASPORT Sensor Extension Cable Basic optics bench Basic optics light source Basic optics Aperture bracket	1 1 1 1 1 1

Lab	Title	Materials and Equipment	Qty
37	**Polarization** Use a light sensor to study the effects of polarization on light intensity and to explore Malus' Law.	Data Collection System PASPORT Light Sensor PASPORT Sensor Extension Cable Basic optics diode laser Basic optics aperture bracket Basic optics bench Polarizing disks Polarizing disk accessory holder	1 1 1 1 1 1 2 1
		Sound	
38	**Sound Intensity** Use a sound level sensor to investigate the sound intensity from devices such as tuning forks, musical instruments, and the human voice.	Data Collection System PASPORT Sound Level Sensor PASPORT Sensor Extension Cable (optional) Power amplifier/function generator Meter stick Speaker Tuning fork *Musical instrument*	1 1 1 1 1 1 1 1
		Nuclear Physics	
39	**Radiation** Use a Geiger-Müller tube to measure radiation intensity and to discover how radioactive particles react with various materials.	Data Collection System PASPORT Geiger-Müller Tube with Power Supply Digital adapter Radioactive sources (alpha, beta, gamma) Three-finger clamp Meter stick Rod stand Shielding materials (paper, plastic, lead)	1 1 1 3 1 1 1 Various

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

Activity by PASCO Equipment

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

Items Available from PASCO	Qty	Activity Where Used
Data Collection System	1	All activities
PASPORT Absolute Pressure Sensor	1	26, 27
PASPORT Charge Sensor	1	28
PASPORT Current Sensor	1	30, 31, 32, 34
PASPORT Force Sensor	1	5, 6, 7, 0, 11, 14, 15, 16, 18, 2019
PASPORT Force Sensors	2	10
PASPORT Light Sensor	1	36, 37
PASPORT Magnetic Field Sensor	1	33, 34
PASPORT Motion Sensor	1	1, 2, 3, 4, 8, 9, 12, 14, 15, 16, 17
PASPORT Motion Sensors	2	13
PASPORT Sound Level Sensor	1	38
PASPORT Stainless Steel Temperature Sensor	1	23
PASPORT Stainless Steel Temperature Sensor	2	23
PASPORT Temperature Sensor[1]	1	24, 25, 27
PASPORT Temperature Sensors[1]	2	21
PASPORT Voltage Sensor	1	29, 30, 31, 32, 35
PASPORT Sensor Extension Cable	1	27, 33, 34, 36, 37, 38
PASPORT Digital Adapter	1	20, 39
Geiger-Müller Tube with Power Supply	1	39
Photogates	2	20
Time of Flight Pad	1	20

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

Normal Laboratory Safety Procedures

Overview

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

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

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

General Lab Safety Procedures and Precautions

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

Safety Procedures and Precautions Related to Electrical Equipment

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

Other Safety Precautions

- Experiments involving moving masses can be dangerous. Be aware of moving masses and avoid contact.
- 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 important in an emergency.

Additional Resources

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

Force and Motion

1. Position: Match Graph

Objectives

This activity introduces students to the concept of representing motion as a change of position in a graphical form. Students:

- ♦ Understand the difference between distance and position
- ♦ Experience motion as a change of position
- ♦ Interpret a position versus time graph

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Measuring the position of an object using a motion sensor
- ♦ Tracking the change of position of an object using a graphical representation
- ♦ Interpreting a graphical representation of position versus time

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Object to hold (textbook, basket ball (optional))
- ♦ Motion sensor
- ♦ Rod stand for motion sensor (optional)

Concepts Students Should Already Know

Students should be familiar with the following concept:

♦ *x-y* graphing

Related Labs in This Guide

Labs conceptually related to this one include:

♦ Speed and Velocity

♦ Acceleration

Using Your Data Collection System

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

♦ Starting a new experiment on the data collection system �(1.2)

♦ Connecting a sensor to the data collection system �(2.1)

♦ Starting and stopping data recording �(6.2)

♦ Displaying data in a graph �(7.1.1)

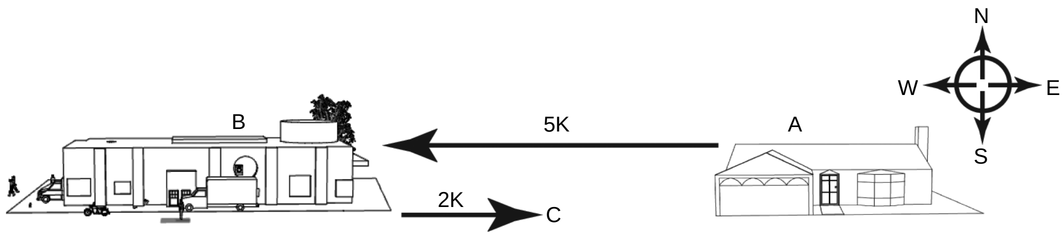
♦ Measuring the distance between two points in a graph �(9.2)

♦ Adding a note to a graph �(7.1.5)

♦ Saving your experiment �(11.1)

Background

The terms *distance*, *position*, and *distance traveled* are often used interchangeably in everyday language. We also describe a fourth term in science, *displacement*. Displacement is the vector quantity describing a change in position. This can cause confusion when students begin their study of motion because the terms often have very different meanings when they are used in science. We have defined motion as a change in position relative to a frame of reference. Distance refers to the amount of space between points. In other words, it is a length. Position refers to the location (distance and direction) of an object relative to a specific frame of reference. To reiterate, position includes both direction and distance from a frame of reference. For example, if you tell someone the distance to your house, you might say, "five kilometers" (5 km). However, if you tell someone the position of your house (point A), you might say, "5 kilometers east of the mall (point B)."



In this description the distance is 5 km, the direction is east, and the frame of reference is the mall. Distance traveled is the total distance required to get from one position to another. Assuming that you travel on a straight road to the mall, your distance traveled is 5 km and your position is 5 km west of your home. Now, imagine that you turn around and travel from this position toward your house, going a distance of 2 km (point C). Your total distance traveled is then 7 km (5 km + 2 km), but your position is 3 km (5 km-2 km) west of your house. In this example the distance is 3 km, the direction is west, and the frame of reference is your house. In this example your displacement is a vector sum of 5km away from your house and 2 km toward your house resulting in a displacement of 3 km west of your house. Frame of reference refers to the location of the observer while measurements are made of position, motion, or both. For this lab, the motion sensor serves as our point of reference. All motion is relative to the face of the motion sensor, with the motion away from the sensor being the positive direction.

Pre-Lab Discussion and Activity

Depending on your students' math proficiency, it may be necessary to review basic X-Y graphing. Lay out a tape measure or other distance measuring device next to the path you will walk to represent the y-axis. The motion sensor uses echolocation to determine the distance to an object. Use a digits display (projected if possible) to show the distance to near-by objects (the floor, the ceiling, or a nearby student). Next use your hand to show how distance changes when an object moves toward and away from the sensor. Also, move your hand side to side to demonstrate what happens when the sensor looses track of an object. This is a good time to reinforce the difference between position, distance, distance traveled, and displacement.

Teacher Tip: When using a motion sensor, it is most common to set the sensor in a fixed position and have the student or object move relative to the sensor. In some instances, it is more appropriate to move the sensor relative to a fixed position, such as a wall. Both methods are completely viable, but you must clarify with students what they will use as a fixed frame of reference.

1. What does the value on the screen represent?

The distance between the motion sensor and the hand

2. How do I make that a position?

Give it a direction and frame of reference (0.5 meters in front of the face of the motion sensor on my desk).

3. If I moved my hand back and forth five times, 0.2 meters away, and then 0.2 back, what is the total distance my hand travelled?

0.4 meters per round trip, five round trips, means my hand traveled approximately 2 meters.

4. If my starting position is 0.5 meters away from the face of the motion sensor, and I move to a final position 1.5 meters from the face of the motion sensor, what is my displacement?

1.0 meters in the positive direction.

Note: In the background it is noted that the direction away from the motion sensor is the positive direction.

Next bring up a graph of Position versus Time. Ask your students to do the following predictions.

Teacher Tip: When using a motion senor to measure a person's movement, it is sometimes easier to have the person hold a target object like a textbook or a basketball. Because the sensor is using an ultrasonic pulse, sound-dampening surfaces like a soft sweater can be difficult for the sensor to track.

5. What do you think the graph will look like if I stand in front of the sensor and collect data for 10 seconds? Sketch your prediction.

The distance will remain constant, and time will increase from 0 to 10 seconds. The graph is a straight line parallel to the *x*-axis.

Stand between one and two meters from the sensor, and have your students estimate your distance from the sensor. Then, collect 10 seconds. of data. Discuss for a moment those predictions that are similar and those that are different.

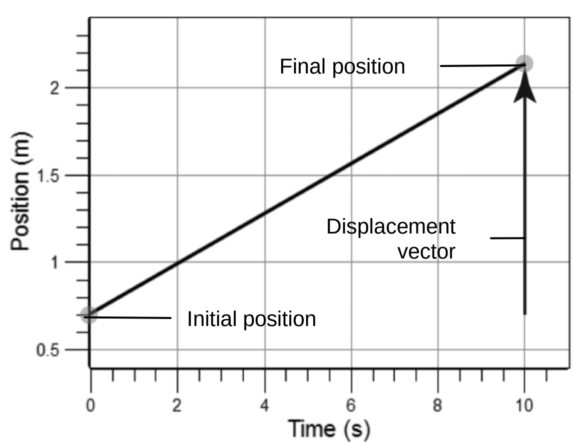
Teacher Tip: If someone willingly shares a significantly different prediction, this can be a good time to work through misconceptions, and review time as the independent variable (*x*-axis) and position as the dependent variable (*y*-axis).

6. What do you think the graph will look like if I move away from the sensor for 10 seconds? Sketch your prediction.

The graph will be a roughly straight line starting at time zero and your initial position with a positive slope.

Stand about one meter from the sensor and have your students estimate your distance from the sensor, then collect 10 seconds. of data while you move slowly and steadily away from the sensor. Briefly discuss those predictions that are similar and those that are different. Then review the key features of the graph.

Teacher Tip: You may want a volunteer to start and stop data collection.



Teacher Tip: Some instructors prefer to start with the Match Graph Challenge available as an EZscreen with Data Studio Software to get students excited about the idea of data collection.

Teacher Tip: Some Instructors prefer to use a cart and track rather than having students acting as the object in motion to reduce the amount of "extra motion" some students bring to the experiment.

Lab Preparation

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

1. Be sure to space the motion sensor stations around the room, and offset the sensors so that they do not directly face each other. The motion sensor will respond to the strongest signal it receives.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Make sure you have at least 2 meters of space in front of the motion sensor.

Sequencing Challenge

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

4	2	1	3
Match the different types of motion you experienced with the different parts of your Position versus Time plot.	Position yourself in front of the motion sensor, and ensure you have adequate space to move.	Connect the motion sensor to the data collection system.	Carefully move and observe Position versus Time graph as you match the motion described.

Procedure with Inquiry

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

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

Part 1 - Moving away from the motion sensor

Set Up

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

2. ☐ Connect the motion sensor to the data collection system, and make sure the motion sensor switch is in the far or "person" position. �(2.1)

3. ☐ Place the motion sensor on a table or rod stand such that you have at least two meters of clear space in front of the sensor and the face of the sensor is level with your midsection.

4. ☐ If you held the motion sensor and pointed it at a fixed position, like a wall, would it change the experiment significantly? Explain?

No, although the wall would now be the fixed position, and therefore the frame of reference, the distance measured would be the same. The fact that, "moving away from the wall is the positive direction," would be the same.

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

6. ☐ What are the independent and dependent variables on your graph?

The x-axis is the independent variable time, and the y-axis is the dependent variable position.

Collect Data

7. ☐ Position yourself approximately 40 cm in front of the motion sensor. You may want to hold a book or ball in front of you as a more easily controlled target.

8. ☐ Have your lab partner start recording a run of data. �(6.2)

9. ☐ Stand completely still for 2 seconds, and then carefully move backwards as smoothly as possible (away from the motion sensor) for a few seconds.

10. ☐ Stand still for 2 more seconds, and then have your lab partner stop recording data. �(6.2)

Analyze Data

11. ☐ Sketch your graph of Position versus Time in the Data Analysis section.

12. ☐ Annotate your graph in the Data Analysis section with descriptions of your motion at different parts of data collection.

Note: If you will be turning in an electronic document only, you can add notes to the graph on your data collection system �(7.1.5)

13. ☐ Find the difference between your initial and final position. �(9.2)

Part 2 - Moving away from and then toward the motion sensor

Set Up

14. ☐ Use the same set up as in Part 1.

Collect Data

15. ☐ Position yourself approximately 40 cm in front of the motion sensor. You may want to hold a book or ball in front of you as a more easily controlled target.

16. ☐ Have your lab partner start recording a run of data. �(6.2)

17. ☐ Carefully move backwards as smoothly as possible (away from the motion sensor) for a few seconds, then stand still for 2 seconds.

18. ☐ Carefully move approximately half way back toward the motion senor, and then have your lab partner stop recording data. �(6.2)

Analyze Data

19. ☐ Add this second data run to your graph of Position versus Time in the Data Analysis section.

20. ☐ Annotate your graph in the Data Analysis section with descriptions of your motion at different parts of data collection.

21. ☐ Find the difference between your initial and final position. �(9.2)

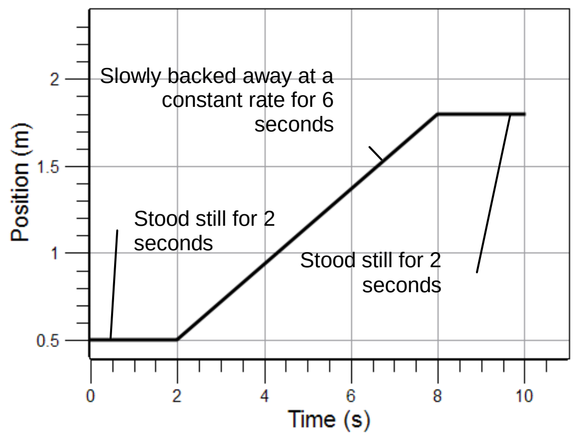
22. ☐ Add a note to your graph with value of the difference. �(7.1.5)

23. ☐ Save your data as described by your teacher. �(11.1)

Data Analysis

- ☐ Sketch the graph that you followed below and annotate each section of the graph with a description of how you were moving to match that section.

Graph 1: Position versus Time



Analysis Questions

1. From the first data run on your sketch in the Data Analysis section, identify your initial position and your final position?

Initial position was 0.5 meters in front of the motion sensor, and the final position was 1.8 meters in front of the motion sensor (using the sample graph above).

2. For the first run, what was the distance you travelled?

1.3 meters.

3. For the first run what was your displacement?

1.3 meters away from the motion sensor

4. From the second data run on your sketch in the Data Analysis section, identify your initial position and your final position?

Initial position was 0.5 meters in front of the motion sensor, and the final position was 1.2 meters in front of the motion sensor.

5. For the second run, what was the distance you travelled?

1.8 meters, 1.25 meters away from the sensor and .55 meters back toward the sensor.

6. For the second run what was your displacement?

0.7 meters away from the motion sensor.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If you were using a motion sensor to measure the motion of a cart on a track, and the graph of the motion was a straight line starting at 0.2 meter at zero seconds and ending at 1.1 meter at 4 seconds, what is the displacement of the cart?

The displacement of the cart is 0.9 meter away from the motion sensor.

2. At a field meet, a runner in a 2 kilometer event runs on a circular track that is exactly 2 kilometers in circumference so he only has to run one lap. What was his distance traveled in meters, and what was his displacement at the end of the lap?

The runner traveled 2000 meters, but his displacement is zero because he started and stopped at the same point.

3. A graph of Position versus Time of a car travelling down a straight road that starts at a driveway and ends at the post office shows the car travelling 5 miles away from the driveway in 15 minutes, and then 2.5 mile toward the driveway in 5 minutes. What distance did the car travel, and what was the car's final position?

The car travelled 7.5 miles, and its final position is 2.5 miles from the driveway in the direction of the post office.

4. An ant follows a straight chemical trail that starts at its nest to a piece of bread 23 centimeters away. At the end of the day it delivers 10 piece of bread to the nest. What was the total distance the ant travelled in meters, its initial position, and its final position?

The ant travelled 4.6 meters. Its initial position and its final position was the nest.

Multiple Choice Questions

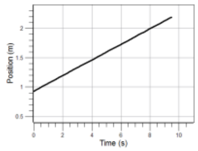
1. When trying to measure a soccer ball's displacement in real time when it is dropped from a height of 1.8 meters, what is the best tool to use?

- **A.** Force sensor
- **B. Motion sensor**
- **C.** Meter stick
- **D.** Acceleration sensor

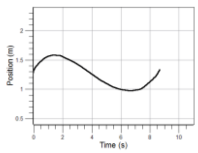
2. A fellow student tells you that her daily walk to school is 6 km. What is this measurement?

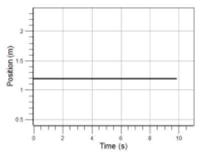
- **A.** Initial position
- **B.** Final position
- **C.** Displacement
- **D. Distance travelled**

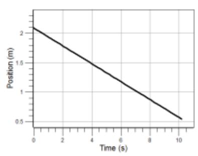
3. Which graph best represents an object moving away from a motion sensor at a constant speed?

A. 

[correct]

B. 

C. 

D. 

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. Motion is defined as a change in **position** relative to a frame of reference. Distance refers to the length of a **path** between points. In other words, it is the scalar value of length. Position refers to the location (distance and direction) of an object relative to a specific **frame of reference**.

2. Position includes both direction and **distance** from a frame of reference. Frame of reference refers to the location of the observer while measurements are made of position and/or **motion**. The vector displacement only includes the distance and a **direction.**

3. A ranger **traveling** through the woods used a pedometer to determine that he had walked 10 miles along the woodland trails. When he checked his map, he found that he was only a mile and a half north of the point that he started. He had no idea when he started that the trail was so twisted and was surprised that his **distance traveled** could be 10 miles, but his **displacement** was only 1.5 miles north.

Extended Inquiry Suggestions

Competition: using the EZscreen software that comes with Data Studio, take the Match Graph Challenge. Using the first Match Graph, ask each student group do several runs, and then send the student with the highest score to the front of the class to compete against the other groups.

Other graphs: ask your students to try the other graphs available in the EZscreen match activity, and discuss with them the similarities and differences. This is also a good opportunity to introduce the idea that the slope of a Position versus Time graph is related to speed and velocity.

2. Speed and Velocity

Objectives

This experiment highlights the similarities and differences between the concepts of speed and velocity. Students predict how the speed and velocity of a cart will differ, and then test their predictions by analyzing graphs generated using a motion sensor.

Procedural Overview

Students gain experience conducting the following procedures:

- Predicting how a velocity versus time and speed versus time graph will look for a cart travelling down a track and back
- Assembling the equipment using a dynamics cart and track, as well as a motion sensor
- Measuring the actual speed and velocity using the motion sensor as the cart travels along a track
- Comparing the predicted graphs to the actual graphs

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dynamics track
- Dynamics track end stop
- Motion sensor
- Dynamics cart

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Vector addition and subtraction
- 1-dimensional motion
- Basic graphical analysis techniques

Related Labs in This Guide

Labs conceptually related to this one include:

- Acceleration
- Position: Match Graph
- Relative Motion

Using Your Data Collection System

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

- Starting a new experiment �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Selecting data points in a graph �(7.1.4)
- Drawing a prediction �(7.1.12)
- Measuring the distance between two points in a graph �(9.2)
- Viewing statistics of data �(9.4)
- Creating calculated data �(10.3)

Background

When a police officer pulls you over for driving too fast, it is not often that he or she is concerned about the velocity of your car, but rather, the speed at which you were traveling. A basic and important difference between *speed* and *velocity* is that velocity is a vector quantity, implying magnitude and direction, while speed is simply a scalar magnitude without direction. *Speed* is defined as the change in distance, regardless of the direction of that displacement, divided by the change in unit time it took to travel that distance. This is otherwise thought of as how fast something is going:

$$\text{Speed} = \frac{\Delta\text{distance}}{\Delta\text{time}}$$

Velocity is generally defined as the unit displacement *in a specific direction* or change in position divided by the unit of time:

$$\text{Velocity}_x = \frac{\Delta\text{position}}{\Delta\text{time}}$$

It is important to understand how these two quantities are related. It is easy to think of the velocity of an object as simply the combination of the object's speed and its direction.

Pre-Lab Discussion and Activity

Students will need a concrete understanding of displacement and distance and how they differ before developing a good understanding of speed and velocity and how they differ. Here is a sample discussion that may better prepare students for this lab activity:

Begin by asking students about their interpretation of distance and how they would define the term mathematically. Many students will simply define the term as, "How far something travels," which is correct. Reinforce this idea by demonstrating with a student walking completely around the room. Make certain the student has returned to the same starting position in preparation for the next demonstration.

1. If the length of each wall is 35 ft, and the student has walked along all four walls, what is the distance he or she has traveled?

Answer: 35 ft × 4 = 140 ft

Now ask the student to walk around the room again, but ask the student to stop just before he or she has returned to the same starting position (several feet away).

2. Determine what the student's *displacement* is?

Commonly students will associate the two terms as being the same; however, the student's displacement is really the distance from his or her starting position to his or her final position.

Explain to students how speed is simply a metric for measuring how fast an object is moving, or rather, the amount of *distance* the object travels per unit of time. It is important that students know that speed is a scalar quantity that indicates magnitude and not direction.

Likewise, students must understand that velocity is a vector quantity that indicates both speed and direction. The formal definition of velocity involves the *displacement* (change in position) of an object rather than the distance the object travels.

Another way of distinguishing between the two is to say, “If you drove to San Francisco from Roseville, and back, how many miles did you put on the car?” (Answer: about 240 miles, if it is 120 miles one way). “But what is your displacement at the end of the trip?” (Answer: zero). That is the difference between distance and displacement.

Lab Preparation

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

This lab does not require any special setup other than having the equipment readily available for student use.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ The cart carries speed and momentum, so be careful not to pinch fingers between the moving cart and the end stop when catching it.
- ♦ The plunger on the dynamics cart may release accidentally, so be careful not to hold the cart near anything breakable when the plunger is loaded.

Sequencing Challenge

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

5	1	3	4	2
Find the average velocity for the trip toward the bumper.	Draw your prediction on your data collection system.	Start data collection.	Gently push the cart toward the bumper.	Assemble the equipment with the Dynamics cart just over 15 cm from the motion sensor.

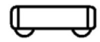
Procedure with Inquiry

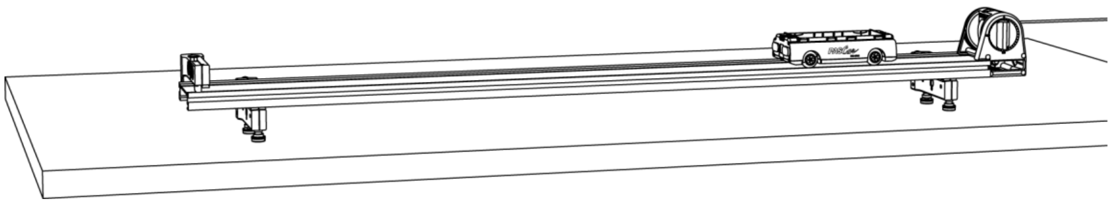
After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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

Set Up

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

2. ☐ Attach the motion sensor to one end of your track with the sensor's sensing element pointing down the length of the track. Make certain that the switch on the top of the motion sensor is set to the cart icon. 



3. ☐ Connect the end stop to the other end of the track.

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

5. ☐ Display Position on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

6. ☐ The concept behind this setup is to push the cart so that it moves away from the motion sensor, increasing its position relative to the motion sensor, until it collides with the end stop and returns, measuring the position, velocity, and speed of the cart the entire time. If you or your lab partners aren't touching the cart as it travels, what do you think a graph of its Position versus Time will look like? Use the data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

7. ☐ What would happen to the cart if there were no bumper on the track?

The cart would roll off the end of the track.

8. ☐ Prepare the following calculation on the data collection system: �(10.3)

Speed = abs(Velocity)

where Velocity is the velocity measurement from the motion sensor.

9. ☐ Display Speed on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

10. ☐ Given the motion described above, what do you think a graph of its Speed versus Time will look like? Use your data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

11. ☐ As was mentioned in the background section, velocity is a vector quantity that implies direction. If the motion sensor measures 2.5 m/s as the velocity of a constant speed cart moving away from the sensor, what would the sensor measure if the same cart was moving towards the sensor? Justify your answer.

It would measure –2.5 m/s because the speed is the same but the direction is opposite, which implies a negative velocity of the same magnitude.

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

13. ☐ Given the motion described above, what do you think a graph of Velocity versus Time will look like? Use the data collection system to draw a prediction, or sketch it in the Data Analysis section. �(7.1.12)

14. ☐ Return to the graph of Position versus Time.

15. ☐ Ensure that the sampling rate of the data collection system is at least 20 samples per second. �(5.1)

Collect Data

16. ☐ Place the cart on the track slightly more than 15 cm from the motion sensor such that either the magnets or extended plunger are facing the bumper so that the cart will rebound from the end of the track.

Note: If you are not using the plunger to collide with the end stop, it is best to press the plunger all the way in and lock it in place so it is out of the way.

17. ☐ Start data collection. �(6.2)

18. ☐ Give the cart a push to start it moving toward the bumper.

19. ☐ Allow the cart to travel down the track, collide with the bumper and return, but catch it before it reaches its initial position.

20. ☐ Stop data collection. �(6.2)

21. ☐ Sketch your Position versus Time, Speed versus Time, and Velocity versus Time graphs on the blank graph axes provided in the Data Analysis section.

Analyze Data

22. ☐ On the Position versus Time graph, select a point just after you released the cart and another point just before the cart collides with the bumper. �(7.1.4)

23. ☐ Use the data collection system to find the difference between the data points you have selected. �(9.2)

24. ☐ Identify the points you used on your sketch of Position versus Time in the Data Analysis section.

25. ☐ Record the difference in time and the difference in position in Table 1 in the Data Analysis section.

26. ☐ From our definition of speed, calculate the speed for this leg of the journey, and record it in Table 1 in the Data Analysis section.

27. ☐ Describe the shape of the data plot in the interval you have selected.

The data plot is linear in the selected interval.

28. ☐ On the graph of Speed versus Time, select the same region you selected on the Position versus Time graph using the time values as your guide. �(7.1.4)

29. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

30. ☐ On the graph of Velocity versus Time, select the same region you selected on the Position versus Time graph using the time values as your guide. �(7.1.4)

31. ☐ Find the average value for velocity for the data you selected, and record it in the table in the Data Analysis section. �(9.4)

32. ☐ On the Speed versus Time graph, select a point just after the cart collides with the bumper and another point just before you catch the cart. Use the data collection system to select this part of the data plot. �(7.1.4)

33. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

34. ☐ Identify the points you used on the sketch of Speed versus Time in the Data Analysis section.

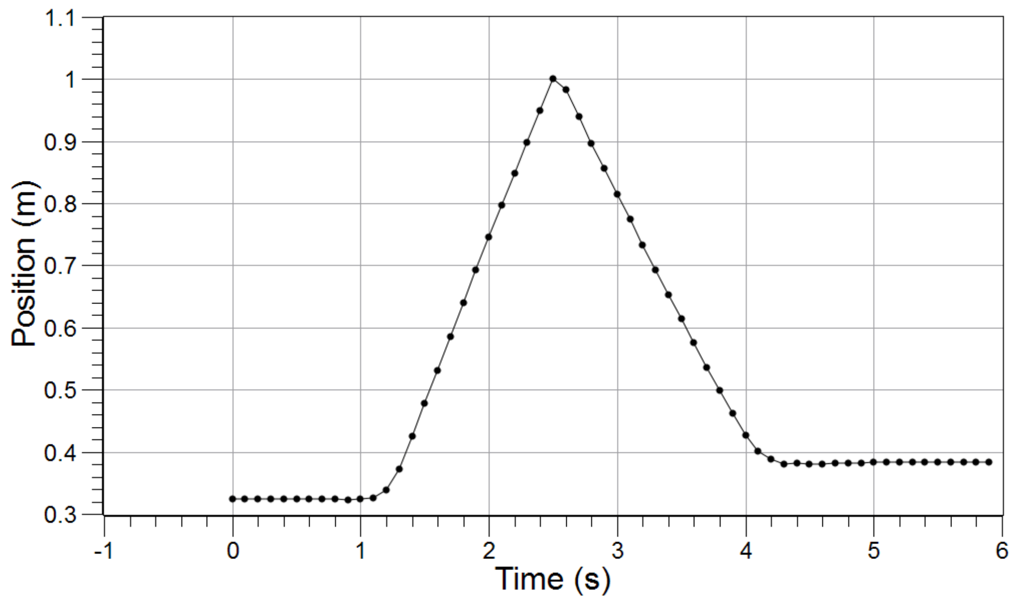
35. ☐ On the graph of Velocity versus Time, select the same region you selected on the speed graph using the time values as your guide. �(7.1.4)

36. ☐ Find the average value for speed for the data you selected, and record it in Table 1 in the Data Analysis section. �(9.4)

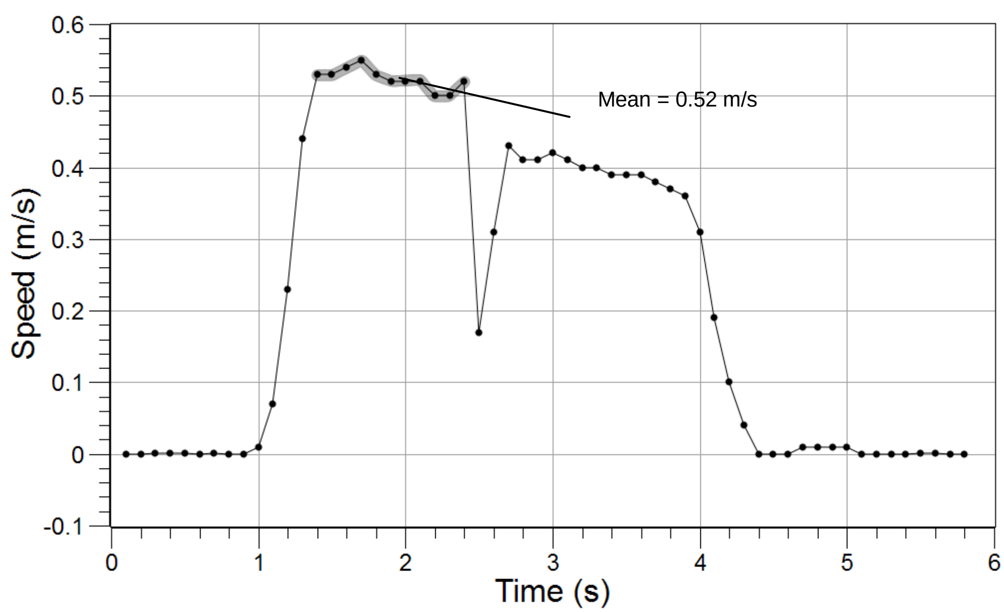
Data Analysis

1. ☐ In the first three spaces provided, sketch your prediction graphs of Position versus Time, Speed versus Time and Velocity versus Time for one trip down the track and back.

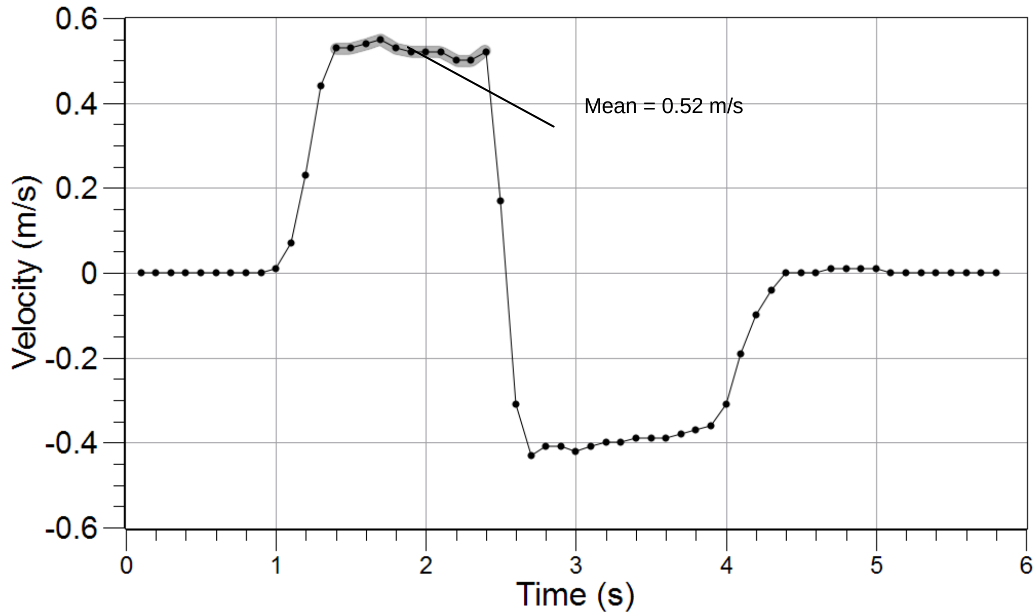
Position versus Time Prediction



Speed versus Time Prediction

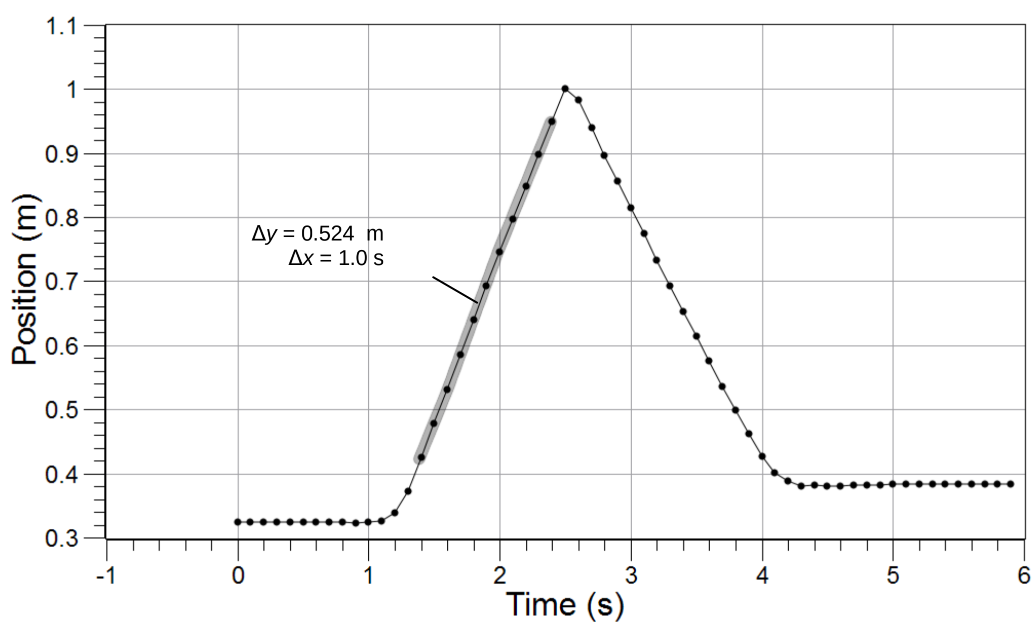


Velocity versus Time Prediction

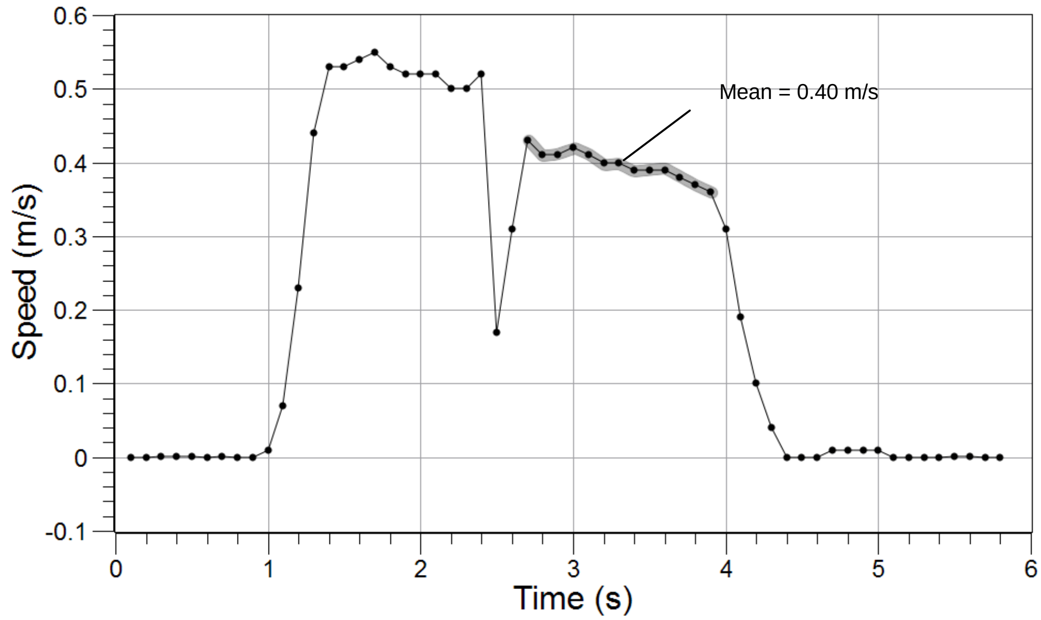


2. ☐ In the next three spaces provided, sketch your data from your graphs of Position versus Time, Speed versus Time and Velocity versus Time for one trip down the track and back.

Position versus Time



Speed versus Time



Velocity versus Time

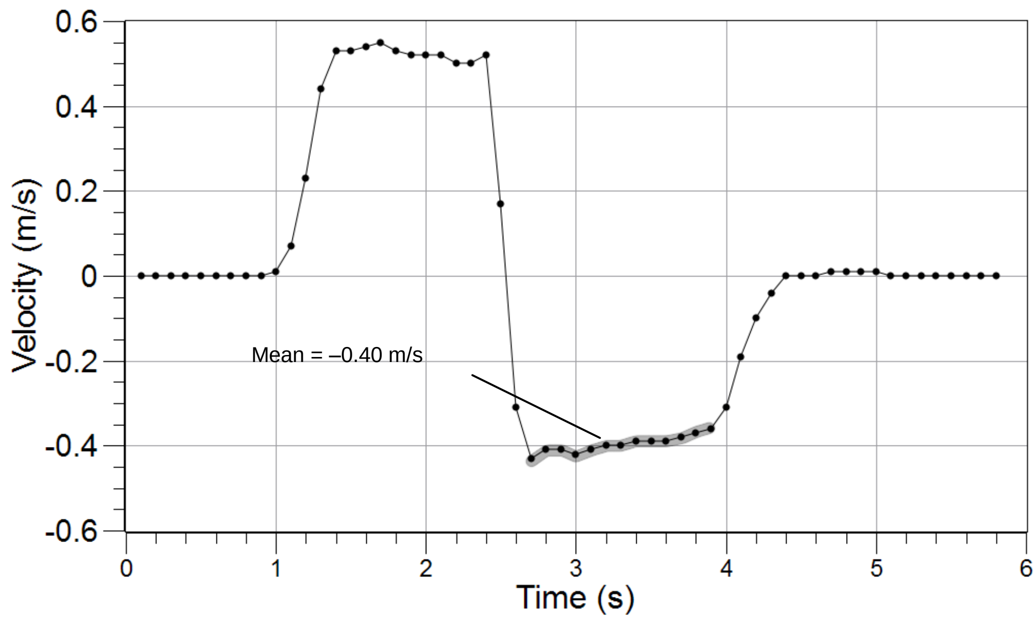


Table 1: Data

Parameter	Values
Difference in position moving away from the motion sensor	0.524 m
Difference in time moving away from the motion sensor	1 s
Calculated speed moving away from the motion sensor	0.524 m/s
Average speed moving away from the motion sensor	0.52 m/s
Average velocity moving away from the motion sensor	0.52 m/s
Average speed moving toward from the motion sensor	0.40 m/s
Average velocity moving toward from the motion sensor	–0.40 m/s

Analysis Questions

1. How does the value you calculated for speed moving away from the motion sensor compare to the value of the average speed over the same interval?

The values are nearly the same.

2. How do your values of speed and velocity moving away from the motion sensor compare to your values of speed and velocity moving toward the motion sensor?

The value for speed moving away from the motion sensor is nearly the same as the value for speed moving toward the motion sensor. However, the value for velocity moving toward the motion sensor was the opposite of the value of Velocity moving away from the sensor.

3. How does your prediction graph of Position versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?

Answers will vary, major differences may include a change in sign or an inversion of the graph.

4. How does your prediction graph of Speed versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?

Answers will vary, major differences may include a negative speed in the prediction.

5. How does your prediction graph of Velocity versus Time compare to the actual graphs on your data collection device? What are some of the major differences, if any?

Answers will vary, major differences may include a change in sign, or a significant slope on the prediction.

6. Describe some of the major differences between your graph of Speed versus Time and Velocity versus Time, and explain why those differences exist.

The major difference is that the velocity graph has both positive and negative values, while the speed graph does not. This is because the cart changed direction when it collided with the bumper. So rather than traveling in the positive direction, it is traveling in the negative direction.

7. Describe how you think the Velocity versus Time graph would be different if the cart had an initial speed that was twice as large as the initial speed used in your experiment.

The shape of the graph would be identical, but the starting point of the graph would be twice as high.

8. You may have noticed that the speed of the cart slightly decreased as the cart moved along the track, both moving away from the motion sensor and moving toward the motion sensor. What do you thing would account for this decrease?

Friction between the wheels and the track, and also between the cart's wheels and its axle.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Imagine you are in a car driving on a highway and notice that the speedometer was constant at 65 miles per hour for several miles. Would this indicate that the speed of the car was constant during that distance, or the velocity of the car was constant? Justify your answer.

This would indicate that the speed was constant not velocity. A car can travel at the same speed but change direction; however, a car cannot change direction without changing velocity.

2. Two trains pass each other on opposing tracks; one train is traveling north at 105 km/hr while another train is traveling south at 85 km/hr. What is the difference between their velocities? What is the difference between their speeds? Show your work.

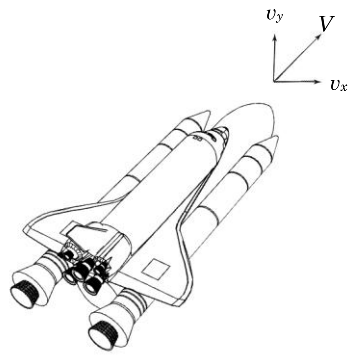
The difference between velocities is:

$$\vec{v}_2 - \vec{v}_1 = 105 \text{ km/hr} - (-85 \text{ km/hr}) = 190 \text{ km/hr}$$

The difference between speeds is:

$$|\vec{v}_2| - |\vec{v}_1| = 105 \text{ km/hr} - 85 \text{ km/hr} = 20 \text{ km/hr}$$

3. **When a space shuttle is launched, it approaches the upper atmosphere at a very specific angle to help it safely reach orbit. At the point it reaches orbit, the shuttle is traveling at some speed *s*, which can be determined from the sum of the shuttle's two component velocity vectors, v_x and v_y. If v_x = 15,768 km/hr and v_y = 11,149 km/hr, what is the shuttle's speed *s*?**



$$s = |\vec{v}| = \sqrt{|\vec{v}_x|^2 + |\vec{v}_y|^2} = \sqrt{(15,768)^2 + (11,149)^2} = 19,311 \text{ km/hr}$$

4. **The average velocity of an object is defined as the total displacement of an object (from its original position) divided by the time elapsed during that displacement.**

$$\bar{\mathbf{v}} = \frac{\textit{final displacement}}{\textit{total time}}$$

a. **If a car drives all the way around a city block at 30 mi/hr and ends 10 minutes later at the same point it began, what is the average velocity of the car?**

$\bar{v} = 0$

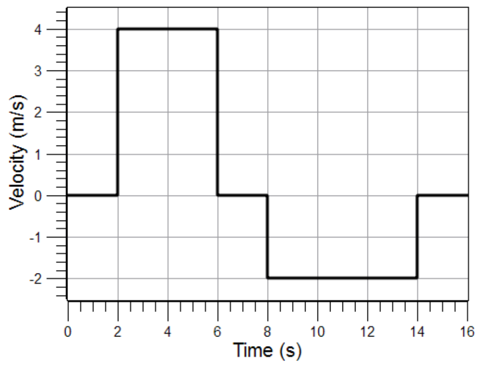
b. **If a car drives north at 65 mi/hr for 48 minutes, turns right and drives east at 45 mi/hr for 23 minutes; and then turns right again and drives south at 30 mi/hr for an hour and 44 minutes, and stops. What was the car's average velocity during that that trip?**

$$\bar{v} = \frac{\vec{d}_1 + \vec{d}_2 + \vec{d}_3}{t_1 + t_2 + t_3} = \frac{52 \text{ mi (north)} + 17.25 \text{ mi (east)} - 52 \text{ mi (south)}}{0.8 \text{ hr} + 0.383 \text{ hr} + 1.73 \text{ hr}} = 5.92 \text{ mi/hr (east)}$$

Multiple Choice Questions

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

1. The graph below shows the velocity of a particle as a function of time. Assume that the particle is traveling in a straight line. Use the graph to determine the particle's total displacement and average velocity.



- **A. 4 m; 0.25 m/s**
- **B.** –4 m; –0.25 m/s
- **C.** 26 m; 2.60 m/s
- **D.** 26 m; 1.63 m/s

2. Average speed is defined as the total distance an object travels divided by the time it took to travel that distance. If a jet flies 2,000 miles from San Francisco to Chicago in 5 hours, refuels for an hour, and then flies 700 miles from Chicago to Washington DC in 2 hours, what was the average speed of the jet for the entire trip?

- **A.** 386 mi/hr
- **B.** 443 mi/hr
- **C.** 250 mi/hr
- **D. 338 mi/hr**

3. What is wrong with this statement?

"A highway patrol officer traveling east with a constant speed of 70 mi/hr passes a speeding motorist traveling west at 110 mi/hr. To catch the speeder, the officer must first travel 0.25 miles to the next highway exit, turn around, and get back on the freeway then drive at a constant speed of –150 mi/hr for 58 seconds to catch-up with the motorist."

- **A.** The officer will pass the speeder if he/she travels at 150 mi/hr for 58 seconds.
- **B.** The officer's original constant velocity should be negative.
- **C. Speed cannot be negative.**
- **D.** There is nothing wrong with the statement.

Key Term Challenge

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

1. Although **speed** and velocity are often used in the same context, the two terms are very different. Speed is a **scalar** quantity while velocity is a **vector** quantity. Velocity values specify **magnitude** as well as **direction** while speed simply specifies magnitude. If the speed of an object is known, it is impossible to determine the object's **velocity** without knowing the direction the object is traveling.

2. When discussing **average** speed and average velocity, one must first understand the difference between distance and displacement. If a boomerang follows a circular 42 meter **path** in 10 seconds and ends at the same point it was thrown, its **distance** traveled is 42 meters but its total **displacement** is zero. Furthermore, the boomerang's average **speed** was 4.2 meters/second, and its average **velocity** is zero.

3. If a ball is initially at **rest** (not moving), its **speed** and velocity are both zero. If the ball is thrown straight up in the air, it will eventually fall back down to the same **position** it was tossed from, at which point its final **velocity** is **equal** and **opposite** to its initial velocity.

Extended Inquiry Suggestions

The graph tools can be used to introduce mathematical concepts like limits. Return to the first leg of the Position versus Time graph. Ask your students to select smaller and smaller intervals for the linear curve fit around a central point. Have them compare the progression of results to the value from the Velocity versus Time graph for the same time, or the slope from the Slope Tool at the central point. This is an opportunity to point out the difference between instantaneous velocity and average velocity.

Follow-up Questions

Continue with the speeding analogy. One way to highlight the difference between average and instantaneous velocity is to ask:

1. Which type of velocity the police officer measures when the officer writes you a citation: instantaneous or average velocity?

Instantaneous

2. What about when the officer points the radar gun at your car as you pass by?

Still instantaneous

3. In some states where toll roads are common (like the New Jersey Turnpike) you can actually get a speeding ticket if you cover the distance between toll booths in too short a time period. Which velocity are they calculating if they give you a ticket in this case?

Average velocity

4. When airplanes are used to track speeding drivers, they use large “mile markers” signs along the road so the airplane can measure how long it took you to travel the distance between mile markers. Which type of velocity are they using in that case?

Average.

This is also a great opportunity to introduce the idea of linear fits. Go back to the idea of change in position over change in time, and tie this back to the mathematical idea of a slope of a line. Ask your students to return to their Position versus Time graph, and apply a linear fit to that first segment of the graph they chose. Then compare the slope to the calculated and average values of velocity in their tables.

A natural progression to this lab is to begin discussions about acceleration as a change in velocity, just as velocity is a change in position. You can discuss with your students the basis of acceleration and how it affects moving object. Then discuss with students what accelerations were present, such as the push to get the cart started and the collision with the bumper. Ask them to look again at the small change in velocity that occurs at each leg of the trip, and apply a curve fit to one of the segments to see what the slope of that line might reveal.

If acceleration is introduced graphically here, it is good to mention that changes in the Velocity versus Time graph are often shown as sudden changes in slope, but in reality, *any* change in velocity must happen over a time interval, otherwise you have infinite acceleration (which no moving object can possibly have). When students see a sudden change in slope on a Velocity versus Time graph, keep in mind that this is theoretical, and in reality that changes in Velocity have a gradual transition from one slope to the next.

3. Relative Motion

Objectives

Students are introduced to the concept of relative motion and frames of reference. Students:

- ♦ Analyze and draw inferences from graphs of the relative velocity between two carts
- ♦ Build a foundational understanding of the meaning of velocity as a vector quantity in one-dimensional motion

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Measuring the relative velocities between two constant velocity carts as the carts move away from and towards each other
- ♦ Analyzing the graphs of Position versus Time for the various motions, and drawing conclusions about how these speeds are measured with the various carts in motion in both directions

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Motion sensor
- ♦ Dynamics track
- ♦ Variable speed motorized cart (2)
- ♦ Cart adapter accessory[1]
- ♦ Note card (card stock, 10 cm × 15 cm)

[1]Used to mount the motion sensor to the top of the motorized cart

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Basic definition and determination of position, speed, and velocity of a moving object
- Graphical analysis of position versus time graphs

Related Labs in This Guide

Labs conceptually related to this one include:

- Position: Match Graph
- Speed and Velocity

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sample rate � (5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Finding the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)

Background

Just as position is a vector measured relative to a fixed point, velocity is a vector measured relative to a fixed point, or frame of reference. If a police officer measures the speed of a vehicle with a radar gun, they are measuring the velocity toward or away from their fixed position on the side of the road. If the same officer were to measure the vehicle's speed by following the vehicle on the road, they would have to keep their car from getting closer or farther away from the other vehicle to correctly estimate that vehicle's speed. However, both vehicles' velocities are being measured relative to the ground the vehicles pass over. What would the other vehicle's speed be if it were measured relative to the officer's vehicle speed? If the officer stays at a constant distance behind the other vehicle, the relative velocity between the two vehicles is zero. This illustrates why relative velocities require a frame of reference to establish a consistent basis for measurement.

To simplify this experiment, we will restrict our study to a single dimension along a track, and motion will be relative to the face of the motion sensor.

Pre-Lab Discussion and Activity

Engage your students with the following questions and demonstration:

1. How fast are you moving right now?

Most often, the response is, "We're not moving at all. So, our velocity is zero."

2. Is that response correct?

"It depends!" or "How fast am I moving, relative to what?" are better responses for students sitting at their desk. Their velocity is zero relative to the classroom, but relative to the center of the galaxy, their velocity is indeed quite large.

Students may benefit from a review of how the motion sensor works. Connect the motion sensor to the data collection system, and place a reflecting surface at a known distance away. Display a graph of Position versus Time, ◆(7.1.1) and then begin data recording. ◆(6.2) Discuss the shape of the graph and why the graph looks as it does. Now have a student move back and forth in front of the sensor while you record data. Again, discuss the shape of the graph and the significance of the slopes of various parts of the graph.

3. What is the shape of the graph when the object in front of the motion sensor is not moving? Where, on the *y*-axis, is the position plotted?

The graph is a straight horizontal line at the value of the object's position in front of the motion sensor.

4. What is the shape of the graph when the object is moving? What is the significance of the slope of this graph?

The graph can curve up or down. If the object moves at a constant velocity, the graph will be a straight line and the slope of the line is the velocity of the object relative to the motion sensor.

Remind your students how the motion sensor gets its data.

The detector sends out an ultrasonic pulse, and then detects the echo of that pulse. By accurately measuring how long that took, and by applying the known speed of sound, the sensor determines the distance of the reflecting object. The point is then plotted on the graph, and the next point is taken. This happens many times each second, resulting in a series of data points drawn on a graph.

Lab Preparation

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

1. Ensure the motorized carts have reasonably fresh batteries.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Be sure that the motorized carts and motion sensor do not fall to the floor during the experiment.

Sequencing Challenge

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

1	4	2	3
Attach the motion sensor to one of the constant velocity carts using the cart adapter.	Find the slope of the Position versus Time plot to determine the velocity.	Create a graph of Position versus Time to observe the motion between the carts.	Begin data collection, and start the first cart rolling down the track.

Procedure with Inquiry

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

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

Part 1 –Velocity of Each Cart Relative to a Fixed Point.

Set Up

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

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

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

4. ☐ Why was a Position versus Time graph chosen to view the data? What is the significance of the slope of this graph?

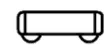
The change of position can show the velocity of the cart. The slope of the line represents the velocity.

5. ☐ Mount the note card reflector on one of the carts, and place the motion sensor on the track.

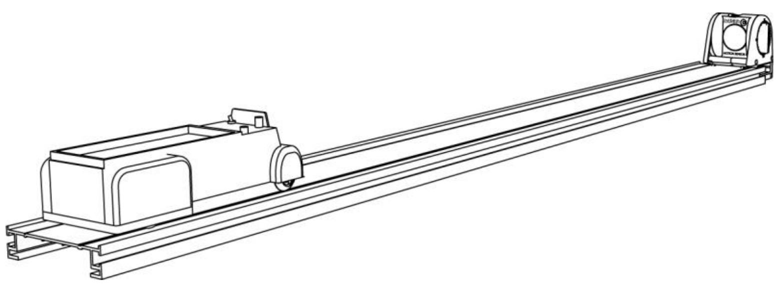
Note: Be sure that the motion sensor is positioned in such a manner that there will not be unwanted reflections from objects on or around the table other than the motorized laboratory carts.

Note: The motion sensor has a minimum distance that it can measure (usually 15 cm.) The apparatus should be set up such that the closest distance of approach for the two motorized carts will never be closer than 15 cm.

6. ☐ Set your sampling rate to at least 20 samples per second, and if your motion sensor has a selector switch, set it in the cart or near setting. �(5.1)



7. ☐ Set the speed switch on the first motorized cart (Cart 1) to the middle speed, and place it on the track (as far away from the motion sensor as possible.)



Collect Data

8. ☐ Start the cart in motion, and then immediately start data recording. �(6.2)

9. ☐ Continue recording Position versus Time data until the cart gets close to the 15 cm minimum distance from the sensor, and then stop data recording. �(6.2)

10. ☐ Repeat the data collection for Cart 2.

Teacher Tip: It is generally good scientific practice to repeat the same procedure for each cart, multiple times. This helps to better understand the repeatability of the equipment and procedure when doing error analysis. In this experiment, students doing multiple runs per cart will note that the speed of each cart is nearly constant. That means we can depend on the speed being the same for each run during the experiment.

Analyze Data

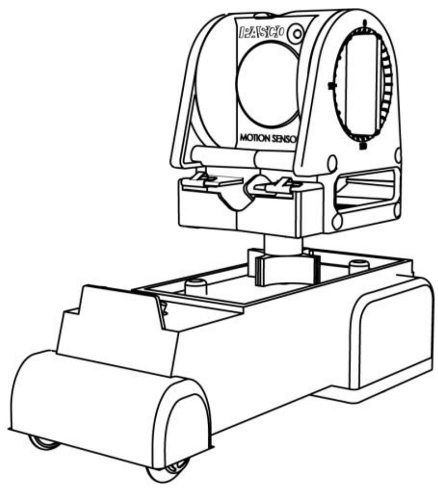
11. ☐ Find the velocity of each cart relative to the motion sensor by finding the slope of the best-fit line on the Position versus Time graph, and record the values in Table 1. �(9.6)

12. ☐ Sketch your graph of Position versus Time for each cart in the Data Analysis section.

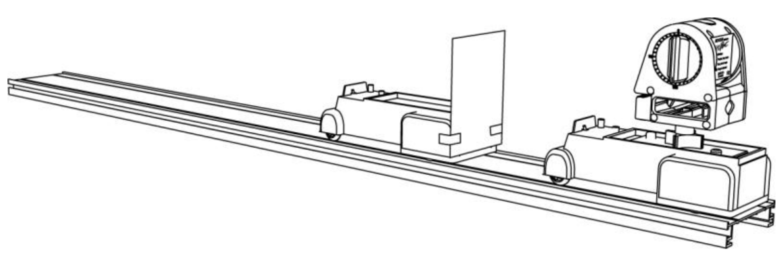
Part 2 – Carts Moving in the Same Direction

Set Up

13. ☐ Use the cart adapter accessory to mount a motion sensor on Cart 1, and mount the card reflector on the back of Cart 2.



14. ☐ Set the carts about 20 cm apart at one end of the track, with both carts pointed in the same direction. Make sure that the face of the motion sensor is pointed at the card.



Collect Data

15. ☐ Start the carts in motion, and then immediately start data recording. �(6.2)

16. ☐ Continue recording Position versus Time data until the carts get closer than the 15 cm minimum distance or Cart 2 reaches the end of the track, and then stop data recording. �(6.2)

Analyze Data

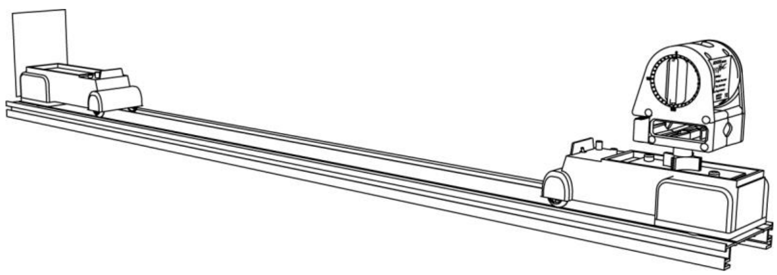
17. ☐ Sketch your graph of Position versus Time in the Data Analysis section.

18. ☐ Find the velocity of Cart 1 relative to Cart 2 by finding the slope of the best fit line on the Position versus Time graph, and then record this value in Table 1. �(9.6)

Part 3 – Carts Moving Toward Each Other

Set Up

19. ☐ Set the carts at either end of the track with the carts pointed at each other. Make sure that the face of the motion sensor is pointed at the card.



Collect Data

20. ☐ Start the carts in motion, and then immediately start data recording. �(6.2)

21. ☐ Continue recording Position versus Time data until the carts get closer than the 15 cm minimum distance, and then stop data recording. �(6.2)

Analyze Data

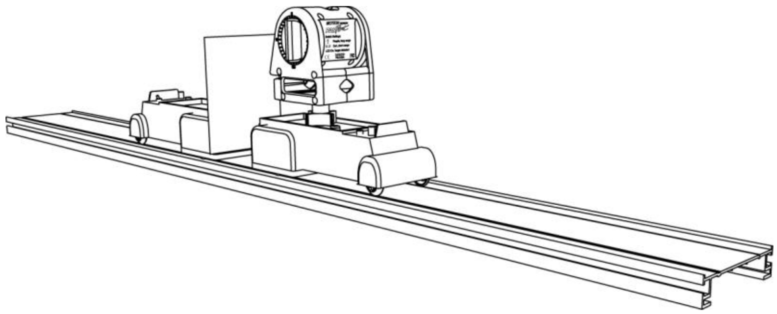
22. ☐ Sketch your graph of Position versus Time in the Data analysis section.

23. ☐ Find the velocity of Cart 1 relative to Cart 2 by finding the slope of the best fit line on the Position versus Time graph, and then record this value in Table 1. �(9.6)

Part 4 – Carts Moving Away From Each Other

Set Up

24. ☐ Set the carts about 15 cm apart in the middle of the track with both carts pointed away from each other. Make sure that the face of the motion sensor is pointed at the card.



Collect Data

25. ☐ Start the carts in motion, and then immediately start data recording. �(6.2)

26. ☐ Continue recording Position versus Time data until one of the carts reaches the end of the track, and then stop data recording. �(6.2)

Analyze Data

27. ☐ Sketch your graph of Position versus Time in the Data analysis section.

28. ☐ Find the velocity of Cart 1 relative to Cart 2 by finding the slope of the best fit line on the Position versus Time graph, and then record this value in Table 1. �(9.6)

29. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Table 1: Motion of the individual carts and velocity vectors

Parameter	Velocity (m/s)
Cart 1 velocity toward a stationary motion sensor	–0.156
Cart 2 velocity toward a stationary motion sensor	–0.180
Cart 1 moving in the same direction as Cart 2	0.0298
Cart 1 and Cart 2 moving toward each other	–0.327
Cart 1 and Cart 2 moving away from each other	0.366
Velocity of Cart 1 added to velocity of Cart 1	–0.336
Velocity of Cart 1 subtracted from velocity of Cart 1	0.0240
Negative velocity of Cart 1 subtracted from velocity of Cart 1	0.336

Because we are observing one dimensional motion, the direction is either positive or negative. The motion sensor measures objects moving away from the sensor as positive. During Parts 2 through 4 of this experiment, the motion sensor remains pointed in the same direction, so we will call that the positive direction.

1. ☐ Use the speed of the carts moving toward the motion sensor in Part 1 as the magnitude of the velocity vectors for each cart. Then, perform the vector operations specified in the Table.

$$\vec{v}_1 + \vec{v}_2 = (-0.156 \text{ m/s}) + (-0.180 \text{ m/s}) = -0.336 \text{ m/s}$$

$$\vec{v}_1 - \vec{v}_2 = (-0.156 \text{ m/s}) - (-0.180 \text{ m/s}) = 0.0240 \text{ m/s}$$

$$-\vec{v}_1 - \vec{v}_2 = -(-0.156 \text{ m/s}) - (-0.180 \text{ m/s}) = 0.336 \text{ m/s}$$

2. ☐ If the relative velocity between two objects is the difference between their velocity vectors, what do the following physically represent for our system?

a) $v_1 + v_2$

Cart 1 travelling in the direction the motion sensor is pointing, and Cart 2 is travelling toward Cart 1 –(–V2).

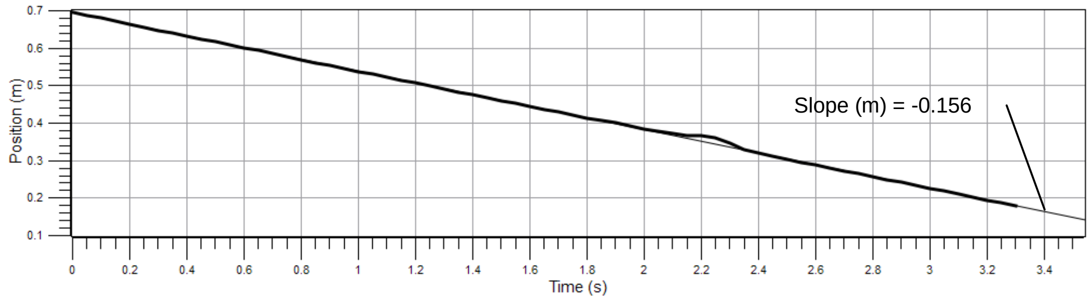
b) $v_1 - v_2$

Cart 1 and Cart 2 are travelling in the same direction.

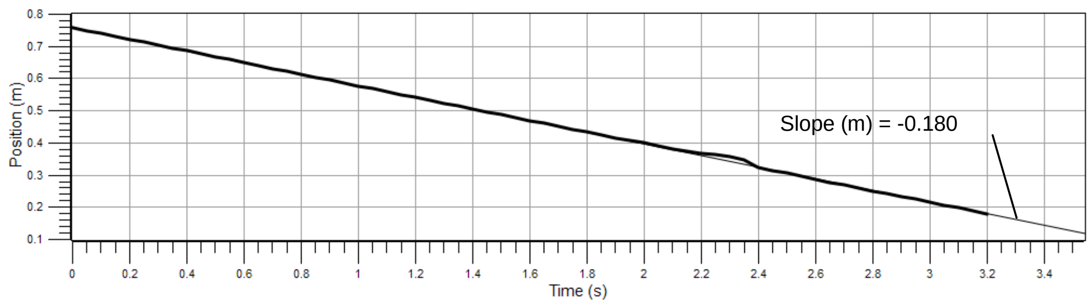
c) $-v_1 - v_2$

Cart 1 travelling in the opposite direction that the motion sensor is pointing, and Cart 2 is moving away from the motion sensor.

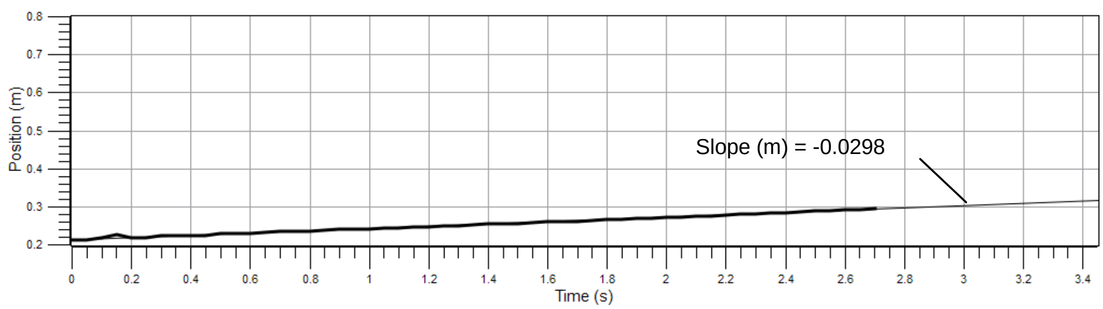
Position versus Time: Cart 1 moving toward the motion sensor



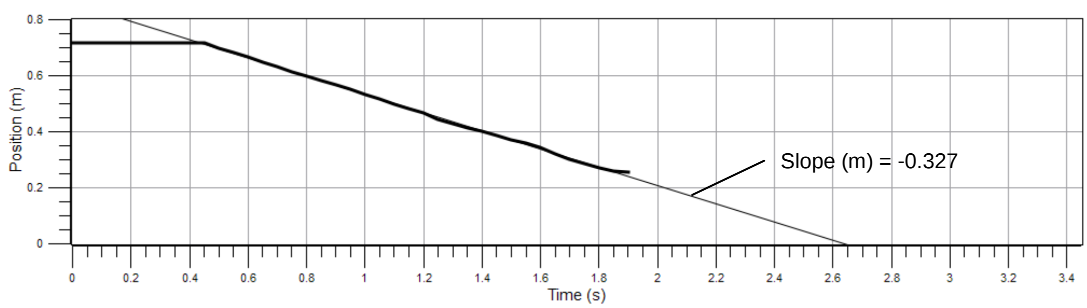
Position versus Time: Cart 2 moving toward the motion sensor



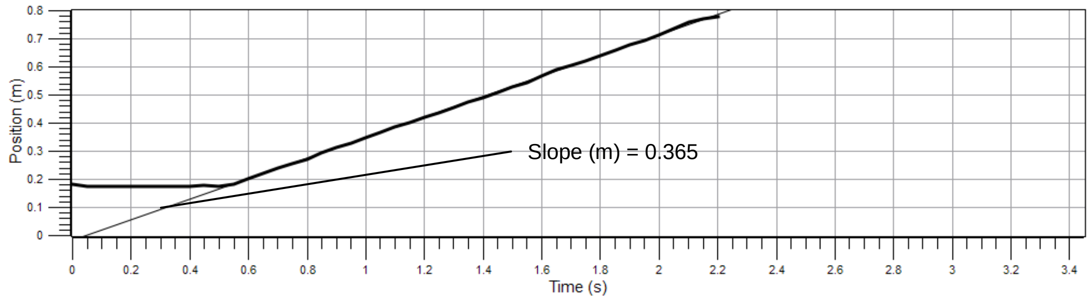
Position versus Time: Carts moving in the same direction



Position versus Time: Carts moving in opposite directions toward each other



Position versus Time: Carts moving in opposite directions away from each other



Analysis Questions

1. How did the relative velocity from Part 2 compare to the relative velocity measured in Part 1? What was different in the setup used in Part 2 compared to the setup from Part 1?

The relative velocity in Part 2 was smaller in magnitude and opposite in sign than the velocity measured in Part 1. In Part 1, the motion sensor was stationary; in Part 2 the motion sensor moved towards the other cart, which was in turn moving away from the sensor.

2. How do the velocity vector differences you calculated compare to the measured relative velocities?

Student answers will vary, but the values will be similar.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If a person riding a bicycle at 20 km/hr is passed by a car travelling at 45 km/hr in the same direction, what is the velocity of the car relative to the bicycle rider after the car has passed?

$$\vec{v}_{\text{relative}} = \vec{v}_{\text{car}} - \vec{v}_{\text{bike}} = (45\text{ km/hr}) - (20\text{ km/hr}) = 25\text{ km/hr}$$

The car is moving away from the bicycle at 25 km/ph.

2. Two trains pass each other while travelling on neighboring tracks in opposite directions. If one train is traveling east with a speed of 31.3 m/s, and the other train is travelling west with a speed of 29.1 m/s, what is the velocity of the westbound train relative to the eastbound train?

$$\vec{v}_{\text{relative}} = \vec{v}_{\text{west}} - \vec{v}_{\text{east}} = (31.3\text{ m/s}) - (-29.1\text{ m/s}) = 60.4\text{ m/s}$$

West with a speed of 60.4 m/s.

3. When a baseball batter bunts, the bat is held stationary in front of the ball as the ball hits the bat. The result is a very softly hit ball that generally doesn't travel much farther than the infield. However, if the batter uses a full swing as the ball hits the bat, the ball travels much farther. What can you say about the velocity of the ball relative to the bat in both cases and why the ball travels further when the batter swings the bat?

The relative velocity of the ball is much greater when the batter swings the bat than when the bat is stationary. Thus, the impact is greater, causing the ball to travel farther.

Multiple Choice Questions

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

1. A car approaches a stop light where a second car has stopped for a red light. The first car approaches at 32 km/hr, and the second car starts backing up at 5 km/hr. What is the relative velocity between the cars?

- **A. 27 km/hr**
- **B.** 32 km/hr
- **C.** 37 km/hr
- **D.** 6.4 km/hr

2. Imagine that a slow-moving runaway truck is about to bump into the back of your car, which is stopped. Of the following choices, which would be most helpful to avoid or lessen the impact of the truck before it hits your car?

- **A.** Increase the relative velocity between your car and the truck.
- **B.** Keep the relative velocity between your car and the truck constant.
- **C. Decrease the relative velocity between your car and the truck.**
- **D.** Jump out of the car, there's no hope.

3. The velocity of Object 1 relative to Object 2 is mathematically described as:

- **A.** The sum of the velocity vectors of Object 1 and Object 2
- **B. The difference between the velocity vectors of Object 1 and Object 2**
- **C.** The product of the velocity vectors of Object 1 and Object 2
- **D.** None of the above

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. The **relative** velocity between two objects is the **difference** between the individual velocity **vectors** of the objects in the same frame of reference. So, a train travelling down a track at 25 km/hr approaches a handcart travelling at 10 km/hr (in the same direction). The train is at the same **speed** as if the hand cart were standing still and the train were travelling at 15 km/hr. The train would also be approaching the handcart at the same rate if its **velocity** was –5 km/hr and the handcart's velocity was –20 km/hr.

Extended Inquiry Suggestions

Once your students have mastered vector addition in one dimension, it is a great time to discuss vector addition in two dimensions. An example is a plane travelling east at 400 km/hr with a 50 km/hr wind coming from the north. What is the speed of the plane? What direction is the plane travelling?

4. Acceleration

Objectives

This activity introduces students to the concept of representing acceleration as a change of velocity in a graphical form. This activity allows students to:

- Understand that average acceleration over a given time is the change in velocity divided by the change in time
- Describe acceleration properly as the change in velocity with respect to time
- Interpret a velocity versus time graph

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the velocity of an object using a motion sensor
- Tracking the change of velocity of an object using a graphical representation
- Interpreting a graphical representation of velocity versus time

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dynamics track
- Dynamics cart
- Rod stand
- Motion sensor
- Dynamics track pivot clamp
- Dynamics track end stop

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Velocity consists of speed and direction
- ♦ Interpreting a position versus time graph for different situations

Related Labs in This Manual

Labs conceptually related to this one include:

- ♦ Position: Match Graph
- ♦ Speed and Velocity

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Connecting multiple sensors to the data collection system �(2.2)
- ♦ Changing the sample rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Displaying multiple variables on the *y*-axis �(7.1.10)
- ♦ Finding the slope and intercept of a best-fit line �(9.6)
- ♦ Saving your experiment �(11.1)

Background

The definitions of velocity and acceleration are often presented very similarly and therefore are easily confused. It is critical that students remember that velocity tells us how much an object's position has changed and that acceleration tells us how much the object's velocity has changed. A graph of position versus time for an object can be used to determine the object's velocity: the slope of a graph of position versus time is equal to velocity. A graph of velocity versus time for an object can be used to determine the object's acceleration: the slope of a graph of velocity versus time is equal to acceleration. It is especially important for the students to note the direction of the acceleration as an object increases or decreases its velocity. Students will have heard of the concept of "deceleration," and you should help them realize that this is *not* a different concept than acceleration. It is just acceleration in a different direction.

Acceleration is the rate at which the velocity of an object changes.

$$\text{acceleration} = \frac{\text{velocity}_{\text{final}} - \text{velocity}_{\text{initial}}}{\Delta\text{time}}$$

Because velocity is the speed and direction of an object's motion, acceleration can mean speeding up, slowing down, or changing direction.

A car can have a positive acceleration when it is speeding up and a negative acceleration when it is slowing down depending on its direction of travel.

When a car is speeding up, its acceleration is in the same direction as its velocity: both acceleration and velocity are positive or negative. When a car is slowing down its acceleration is in the opposite direction of its velocity: velocity and acceleration have opposite signs.

Constant non-zero acceleration means that an object's velocity is changing at a uniform rate.

For example, when you throw a ball into the air, it experiences a velocity change of 9.8 m/s every 1 second. Since the acceleration's direction is pointing toward the earth, the ball will decelerate (slow down) when moving up and accelerate (speed up) when falling down.

Note: In this lab, the direction away from the motion sensor is the positive direction, so down the track will be the positive direction. This is a good time to review frame of reference with you students.

Pre-Lab Discussion and Activity

We commonly use the term acceleration when an object is speeding up. Most of us probably experienced this when someone steps on the gas pedal in the car (even called the accelerator). But if we want to be able to compare objects that are accelerating under different conditions, then we need to have a very precise definition of the term acceleration. We will define acceleration using the data we collect as the slope of the Velocity versus Time graph. This will allow us to see how much the velocity of the object changes in one second.

For a demonstration station:

- Data collection system
- Dynamics track (2)
- Constant velocity cart
- Motion sensor (2)
- Fan cart
- Projection system

1. Set the tracks on a flat table side by side.

2. Connect a motion sensor to each track pointing in the same direction.

3. Place the fan cart and the constant velocity cart each on one track just over 15 cm from the motion sensors with the carts set to move away from the sensor.

4. Connect the motion sensors to the data collection system. �(2.2)

5. Create a Velocity versus Time graph with both sensors on the same graph. �(7.1.10)

6. Ask a student to catch the carts at the opposite end of the track.

7. Start collecting data, and send the carts down the track. �(6.2)

8. Stop collecting data just before the student catches the carts. �(6.2)

Challenge your students to describe the motion of each cart, and identify the one that is accelerating. You may want to show a Position versus Time graph at the same time to tie back to earlier position and velocity discussions.

Lab Preparation

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

1. Remind students that they need sufficient distance between the motion sensor and the cart both when the cart is moving toward the motion sensor and when they start the cart moving away from the motion sensor (greater than 15 cm). The motion sensor will respond to the strongest signal it receives.

2. Be sure that students do not have too steep a slope for the data collection using the dynamics track. This will allow for a more gradual motion and collecting more data points.

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

3	4	2	1
Repeat the data collection procedure this time pushing the cart up the incline away from the motion sensor.	Determine the acceleration of each trial from the slope of the graphed data.	Release the cart from the elevated end of the track to produce a Velocity versus Time graph.	Assemble the inclined track with the end stop at one end and the motion sensor at the opposite end.

Procedure with Inquiry

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

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

Set Up

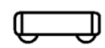
1. ☐ Start a new experiment on the data collection system. �(1.2)

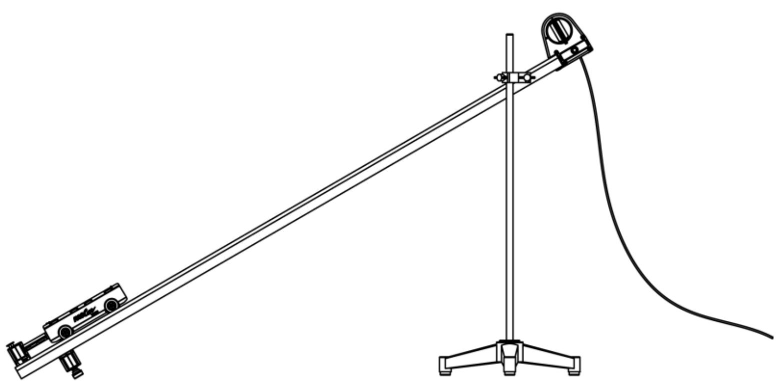
2. ☐ Connect a motion sensor to the data collection system. �(2.1)

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

4. ☐ When a car's acceleration is negative but its velocity is positive, what is the car doing?

Slowing down, or decelerating.

5. ☐ Ensure that your sampling rate is set to at least 20 samples per second. If your motion sensor has a selector switch, ensure that it is in the cart or near setting. �(5.1) 



6. ☐ Attach the end stop to the lower end of the dynamics track.

7. ☐ Mount the track to your rod stand using the pivot clamp, slightly inclining the track at one end.

8. ☐ Attach the motion sensor to the elevated end of the track with the face of the sensor pointed down the length of the track.

Collect Data

9. ☐ Set the cart at the top of the inclined end of the track, holding it just over 15 cm from the motion sensor.

10. ☐ Start data collection, and release the cart allowing it to roll down the track. �(6.2)

11. ☐ Catch the cart at the bottom of the inclined track just before it hits the end stop, and stop data collection. �(6.2)

12. ☐ Set the cart at the bottom of the inclined end of the track.

13. ☐ Start data collection, and give the cart a quick push with your hand up the track. �(6.2)

14. ☐ Allow the cart to roll back down the track, and catch the cart at the bottom of the inclined track just before it hits the end stop, and stop data collection. �(6.2)

Analyze Data

15. ☐ Sketch both runs of data in Velocity versus Time Graph in the Data Analysis section.

16. ☐ Use your data collection system to apply a linear fit to each run (applied only to the data while the cart was in motion), and record the slope in Table 1 in the Data Analysis section. �(9.6)

17. ☐ Save your data as instructed by your teacher. �(11.1)

Data Analysis

Velocity versus Time

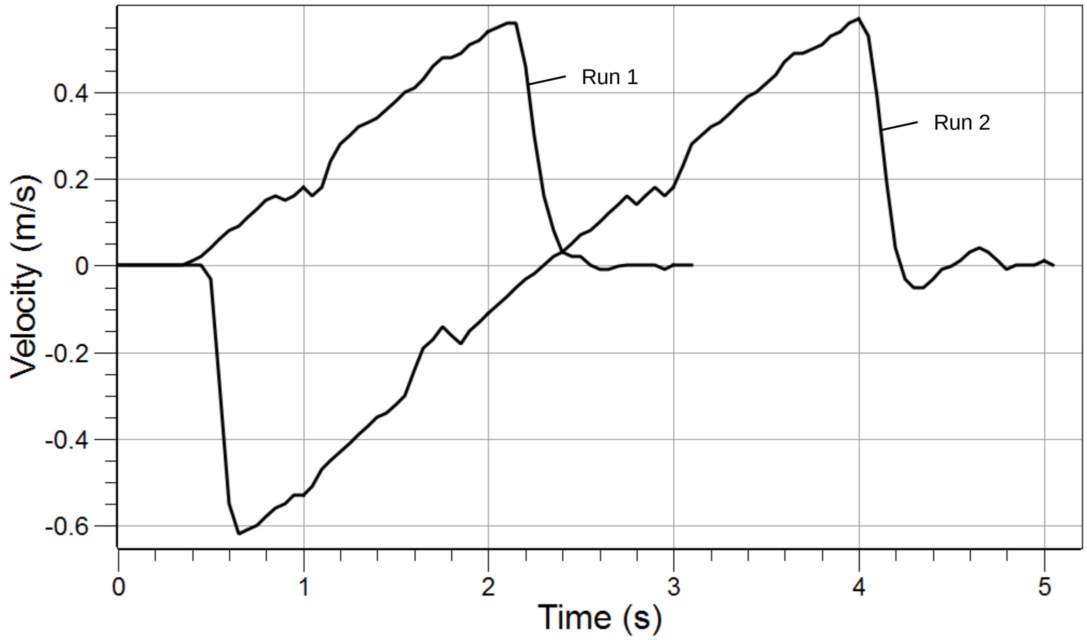


Table 1: Slope of Velocity versus Time

Run	Slope
Run 1	0.778 m/s^2
Run 2	0.738 m/s^2

Analysis Questions

1. During the period when the cart was in motion, are the Velocity versus Time graphs straight lines? Refer to the previous page if necessary. How is the acceleration of the cart changing if your Velocity versus Time graphs are straight lines?

The Velocity versus Time data plots are straight lines. The acceleration is constant if the Velocity versus Time data plot is a straight line.

2. Although the paths of the cart in both trials were different, the slopes of the Velocity versus Time graphs for each trial are the same (during the period in which the cart was in motion). Why is this the case? Justify your answer.

The slopes are the same because the cart is subject to the same acceleration in both trails.

3. Looking at the Velocity versus Time graph, what would a negative slope tell you about the cart's acceleration? What would a positive slope tell you?

A negative slope tells us that the acceleration is negative. A positive slope tells us that the acceleration is positive. Because moving away from the motion sensor, down the track, is the positive direction, the acceleration is positive.

4. What was causing the cart to accelerate after releasing it from rest at the top of the track? Was that acceleration constant?

Gravity. The acceleration was constant because the slope of velocity versus time stayed the same.

5. Describe the motion of an object that has a velocity versus time graph that is a horizontal straight line (a slope of zero).

The velocity of the object is constant, or the object moves at a constant speed in a constant direction. No change in velocity means no acceleration.

Synthesis Questions

Use available resources to help you answer the following questions.

1. The term "acceleration" is used in our everyday lives and language, but is often used in a non-physical context. Now that you have developed a physical definition of "acceleration," give an example of where the physical definition matches the "everyday" definition. Give an example where they are different.

An example where the definitions are similar is how a car accelerates. The car experiences a change in velocity due to acceleration

An example where the definitions are different is when a doctor describes the accelerated heart rate of a patient. Although the rate at which the heart is beating has increased, the actual position of the heart has not changed, thus there is no real velocity and no acceleration.

2. Modern aircraft carriers use a steam powered catapult system to launch jets from a very short range. These catapults can provide a constant acceleration to bring jets up to speed in only 2 seconds. If each jet requires a minimum take-off speed of 82.3 m/s, how much acceleration must the catapult supply so the jet can take off?

$$a = \frac{v_f - v_i}{\Delta t}$$

$$a = \frac{82.3\ \text{m/s} - 0.00\ \text{m/s}}{2\ \text{s}}$$

$$a = 41.2\ \text{m/s}^2$$

3. How many different devices in a car help to accelerate the vehicle? What are they?

Three. The throttle, the brakes, and the steering wheel all cause a change in velocity.

Multiple Choice Questions

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

1. If the acceleration due to gravity is –9.8 m/s^2, which of the following choices would best describe the acceleration of a 0.5 kg frictionless block sliding down the track used in our experiment?

- **A. 3.5 m/s^2 down the ramp**
- **B.** 3.5 m/s^2 up the ramp
- **C.** 0 m/s^2
- **D.** Indefinable

2. A cart with an initial velocity of zero and a final velocity of 12 m/s after 2 s will have an acceleration of?

- **A.** 4 m/s^2
- **B. 6 m/s^2**
- **C.** 8 m/s^2
- **D.** 12 m/s^2

3. A race car starting from rest accelerates uniformly at a rate of 5 m/s^2. What is the car's speed after it has traveled for 5 s?

- **A.** 5 m/s
- **B.** 10 m/s
- **C.** 20 m/s
- **D. 25 m/s**

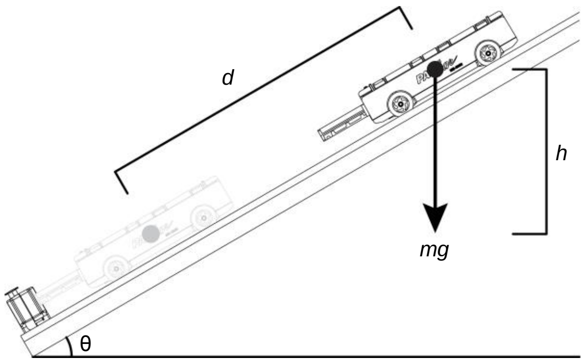
Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. Acceleration is defined as the change in velocity over time. If an object is sitting still or moving at a constant **velocity**, it has an acceleration of zero. If an object has a constant, non-**zero**, acceleration, the velocity of the object is **continuously** changing at the same rate. In common usage, an object with a positive velocity and a negative acceleration is said to be **decelerating**, and an object with a positive velocity and a positive acceleration is said to be accelerating.

Extended Inquiry Suggestions

Ask your students to measure the angle of their track and use trigonometry to determine the acceleration due to gravity based on the component they measured.



Review the answer to Synthesis Question 3. Elaborate on the use of a steering wheel as a means of changing velocity. This can be a tough concept for students to grasp and is a natural lead-in to discussing circular motion.

5. Introduction to Force

Objectives

This lab introduces students to the concept of forces. Primarily, they will measure and experience contact forces, but there will be some inclusion of non-contact forces in relation to gravity. Through direct measurement and experience, students develop the foundations of understanding the vector nature of forces that will carry through to Newton's laws and kinematics, and re-enforce their understanding of units of measure of force and mass.

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring force using a data collection system
- Differentiating between units of mass and units of force
- Differentiating between contact forces and non-contact forces
- Creating free body diagrams of force

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Objects (textbook, ball, carts, etc)
- Short rod
- String, 1 m
- Rod stand
- Masses (at least three different values)
- Balance (1 per classroom, optional)
- Right angle clamp

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The nature of vectors and scalars
- Acceleration

Related Labs in This Guide

Labs conceptually related to this one include:

- Archimedes' Principle
- Hooke's Law
- Newton's First Law
- Newton's Second Law
- Newton's Third Law

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Put ting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- Starting and stopping data recording � (6.2)
- Starting a new data set in manual sampling mode, recording data points, and stopping the data set �(6.3)
- Displaying data in a graph�(7.1.1)
- Changing the variable on the *x*- or *y*-axis �(7.1.9)
- Viewing statistics of data �(9.4)
- Finding the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)

Background

Generally speaking, when someone thinks of a force, they think of a physical push or pull, also known as *contact forces*. Contact forces are all around us. When you kick a ball, when you pull on a rope, or when you push someone on a swing, you are exerting or experiencing contact forces. *Non-contact forces*, or *action-at-a-distance forces*, are forces that can influence an object without touching it. The most prevalent example of this in everyday life is gravity.

Students will use a force sensor to measure some pushes and pulls. The force sensor uses strain gauges attached to a beam to measure very small deflections caused by pushing or pulling. For best results, students should push or pull in a straight line along the axis of the sensor. The idea of using different objects is to expose students to different force versus time plots, so try to use objects of different size, shape, mass, and composition.

Pre-Lab Discussion and Activity

Discuss these questions with your students.

1. What do you think a force is?

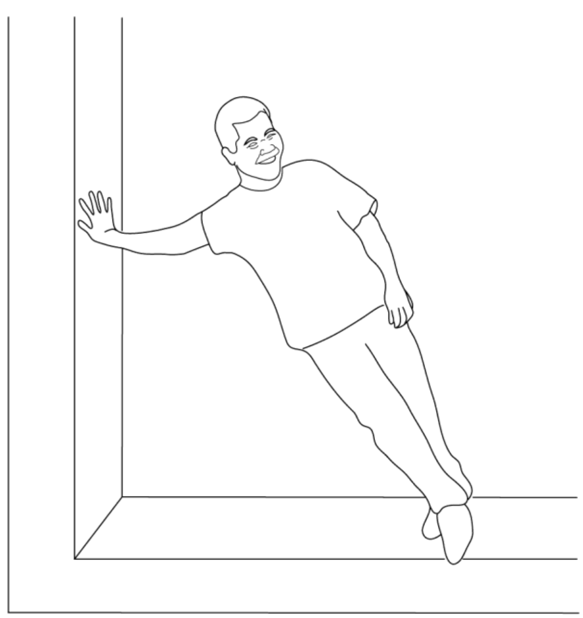
Use a white board (or equivalent) to collect student ideas to review and reference as you go through the discussion.

Use a simple set of objects (ball, book, cart, and track) to show the consequences of pushing or pulling on the objects. Emphasize that these are contact forces that result in motion. If you have a projector and a force sensor, show a graph of Force versus Time, to show the forces that you apply to the objects.

Push on both sides of an object to show that forces are present, but the object does not move. This is because the forces balance, or the net force is zero.

If you have a force platform and a projector, use it to show the actual force being applied to the wall and to the floor in the next section.

Carefully lean against a wall, ask the next questions.



2. Am I applying a force to the wall?

Yes, the force is toward the wall.

3. What kind of force?

This is a contact force.

4. Does applying this force result in motion?

No (hopefully).

5. Is the wall applying a force to my hand?

Yes. The wall applies a force to the hand to balance the applied force.

6. What direction is that force?

The force the wall applies to you is pointed out from the wall as a normal force.

The normal force is the component of the contact force with a surface that is perpendicular to the surface.

7. What would happen if the wall were made of tissue paper?

The force you apply to the wall will exceed the normal force that the surface can exert back, and there will be motion.

Reassert that this is a contact force that does not result in motion.

Stand on a solid low chair, and ask the following questions:

Teacher Tip: The same effect can be accomplished by simply holding an object up with a flat hand then moving your hand out from under the object quickly.

8. Am I applying a force to the chair?

Yes, a force that is proportional to your mass.

9. What direction is that force?

Down, more specifically, a line from my **center of mass** toward the center of mass of the Earth.

10. Is the chair applying a force to me?

Yes, a force that balances the force you are exerting on the chair. This and the force the wall was applying to you are *normal forces.*

11. What happens if the force that the chair is applying is removed?

The force pulling you down is no longer balanced by a force pushing up and you move downward.

Step off the chair.

12. What force is pulling me down?

Gravity

Identify this as a non-contact force because it was pulling you down even when you were not in contact with anything.

Lab Preparation

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

1. Provide a collection of objects for students to push and pull.

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

1	4	2	3
Connect the force sensor to your data collection system.	Record the value of the slope of the best-fit line.	Once the reading has stabilized, record the value for force in your data table.	Find the best-fit line using the linear curve fit tool for Force versus Mass.

Procedure with Inquiry

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

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

Part 1 – Pushing

Set Up

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

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

3. ☐ Attach the rubber bumper to the force sensor.

4. ☐ With the force sensor flat on the surface that you will be pushing and pulling across, press the "zero" button.

5. ☐ Select three objects from the pool of objects available to you, and record your selected items in Table 1 in the Data Analysis section.

6. ☐ Which item do you think will require the greatest force to move, and which item will require the least? Explain.

Answers will vary based on the objects selected.

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

Collect Data

8. ☐ Start data collection. �(6.2)

9. ☐ Use the force sensor to push an object about 20 cm.

10. ☐ Stop data collection. �(6.2)

Analyze Data

11. ☐ Describe the relationship between the contact of the force sensor and the object, the force plot, and the motion that resulted from the applied force.

Answers will vary depending on the objects chosen.

12. ☐ Find the maximum force applied by the sensor to the object on the Force versus Time graph. �(9.4)

13. ☐ Record the value in the Table 1 in the Data Analysis section.

14. ☐ Repeat data collection for each object.

Part 2 – Pulling

Set Up

15. ☐ Remove the rubber bumper from the force sensor, and replace it with the hook.

16. ☐ Set up your objects to be pulled the same 20 cm distance. Use the string if necessary.

17. ☐ Which item do you think will require the greatest force to move, and which item will require the least? Explain.

Answers will vary based on the objects selected.

Collect Data

18. ☐ Start data collection. �(6.2)

19. ☐ Use the force sensor to push an object about 20 cm.

20. ☐ Stop data collection. �(6.2)

Analyze Data

21. ☐ Describe the relationship between the contact of the force sensor and the object, the force plot, and the motion that resulted from the applied force.

Answers will vary depending on the objects chosen.

22. ☐ Find the maximum force applied by the sensor to the object on the Force versus Time graph. �(9.4)

23. ☐ Record the value in the Table 1 in the Data Analysis section.

24. ☐ Repeat data collection for each object.

25. ☐ Save your experiment. �(11.1)

Part 3 – What is a Newton?

Set Up

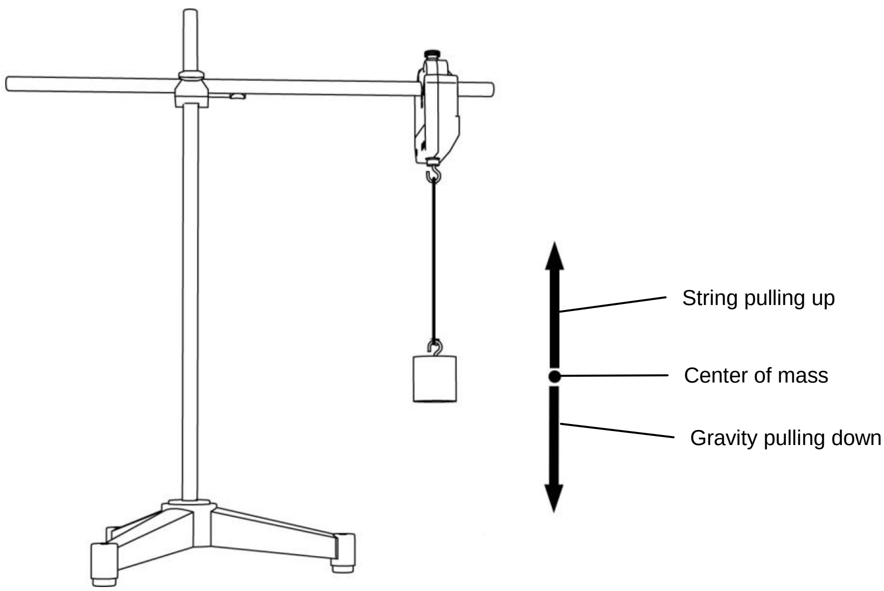
26. ☐ Connect the force sensor to the rod stand using the short rod and the right angle clamp.

27. ☐ Push the “zero” button on the force sensor.

28. ☐ Set up the data collection system to manually collect a force value for each mass value in a table, where mass is the user entered data in units of kg. �(5.2.1)

Collect Data

29. ☐ Hang a mass from the force sensor.



30. ☐ Start a manually entered data set with the first mass, collect a force value for each value of user-entered mass (switching masses between each value you keep), and stop collecting data when you have a force value for each mass. �(6.3)

31. ☐ Copy your values of force and mass to Table 2 in the Data Analysis section. �(9.6)

32. ☐ What two forces are acting on the mass? What kind of forces are they? Sketch them on the setup diagram above.

Gravity, a non-contact force, is pulling the object down, and the string attached to the hook of the force sensor is providing a contact force pulling up that prevents the object from falling.

33. ☐ What is the net force on the mass?

Zero

Analyze Data

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

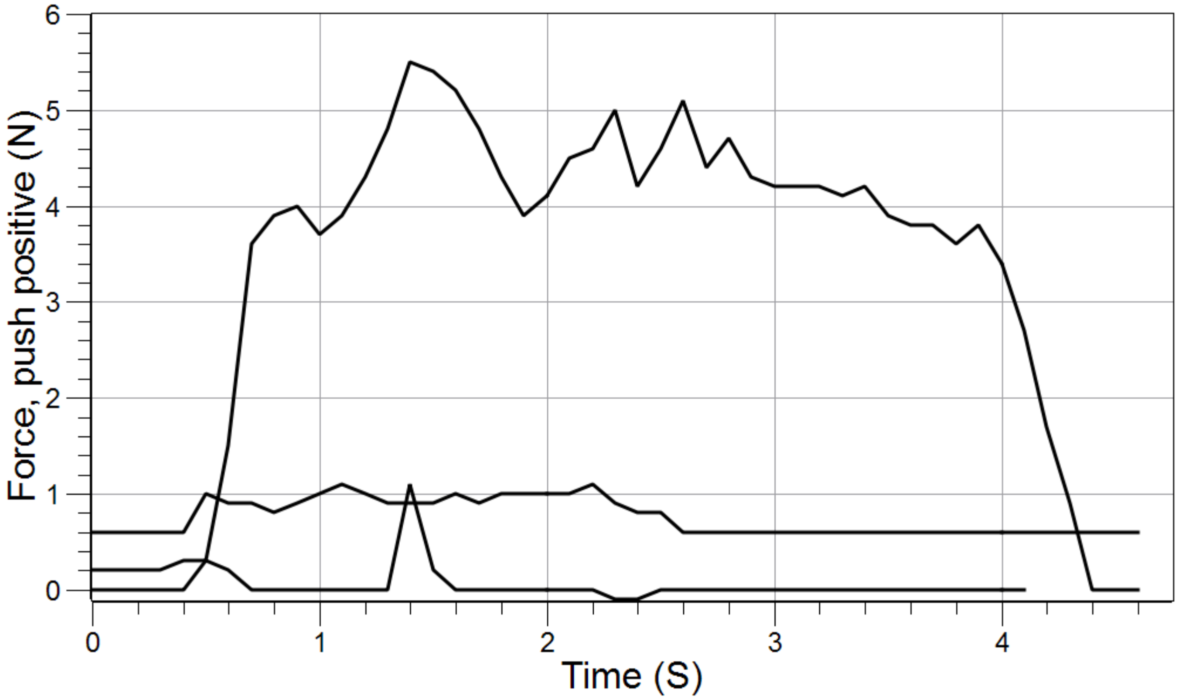
35. ☐ Change the x-axis from Time to Mass. �(7.1.9)

36. ☐ Find the slope of the best-fit line to the data using the linear fit tool. �(9.6)

37. ☐ Save your experiment �(11.1)

38. ☐ Sketch your plot of Force versus Mass in the Data Analysis section, and annotate it with the slope from your best-fit line.

Sample Data



Data Analysis

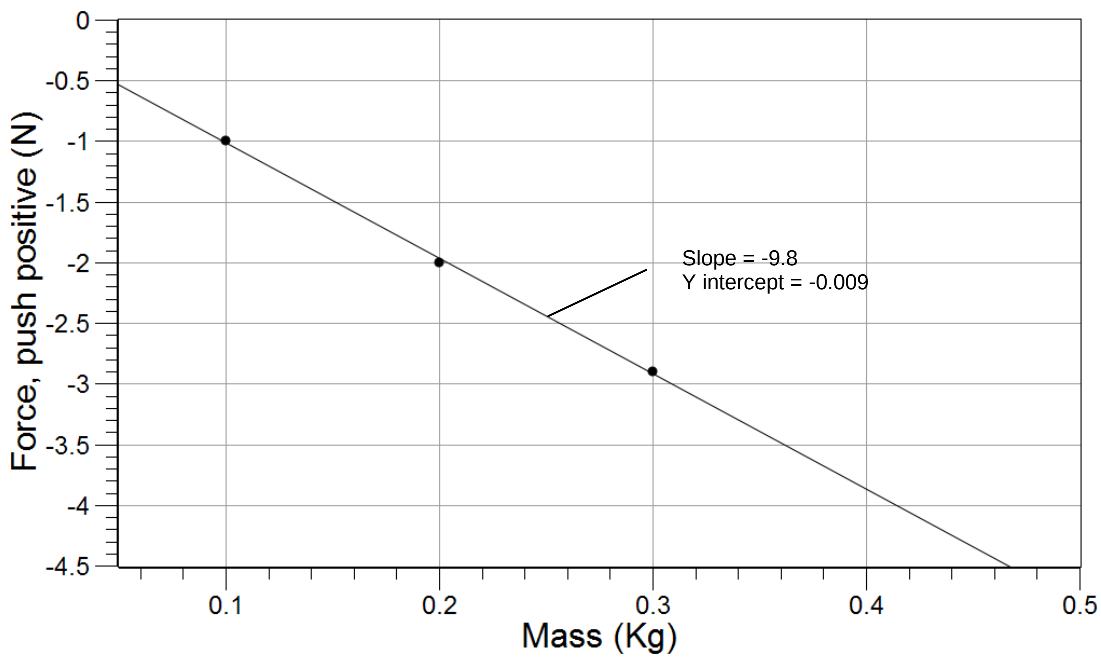
Table 1: Objects and Forces

Object	Maximum Push Force	Maximum Pull Force
Book	5.5 N	-6.0 N
Roll of Tape on its side	1.0 N	-0.8 N
Ball	1.1N	-0.9 N

Table 2: Mass and Force

Mass (kg)	Force (N)
0.1	-1.0
0.2	-2.0
0.3	-3.0

Force versus Mass



Analysis Questions

1. What is the slope of the best-fit line?

-9.8 N/kg

2. Does the value of the slope of the line represent a physical quantity? What are the units of this quantity?

Yes, 9.81 N/s^2 is the acceleration due to gravity at the surface of the earth (g), and 9.8 N/s^2 is remarkably close to this value. The force sensor was set to measure "push is positive," so the pull of the string was in the negative direction. The units of acceleration are m/s^2

3. Given that the force divided by the mass yields a physical quantity with its own units, what units make up a newton?

$$\frac{\text{kg} \cdot \text{m}}{\text{s}^2}$$

Synthesis Questions

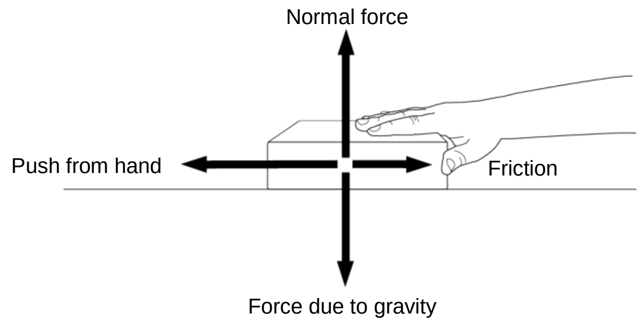
Use available resources to help you answer the following questions.

1. If a car has a mass of 1,000 kg that is evenly distributed to its four tires, how much force does each tire apply to the road?

2,452.5 N.

2. **If you push a book across a table, what are the forces on the book? Draw the forces on the diagram below.**

The forces involved are: the push of my hand, the resistance of the friction between the book and table, the force of the book pushing back against my hand, the force of gravity pulling the book down, and the Normal force of the table pushing back.



Multiple Choice Questions

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

1. **If an object is pushed north with 15 N of force, and friction between the object and the ground pulls back in the opposite direction at 2 N, what is the Net Force on the object?**

- **A.** 17 N north
- **B.** 17 N south
- **C.** **13 N north**
- **D.** 13 N south

2. **If a boat on a river is pushed West with 4 newtons of force by the wind, and pulled South by the current with a force of 3 newtons, what is the Net Force on the object?**

- **A.** **5 N 37 degrees south of west**
- **B.** 7 N south
- **C.** 5 N 37 ° west of south
- **D.** 1 N west

3. **A book sitting on a table experiences a force due to gravity of 20 N when a student pushes down on the book with a force of 90 N. What is the magnitude of the net force on the book ?**

- **A.** 110 N
- **B.** 70 N
- **C.** 1800 N
- **D.** **0 N**

Key Term Challenge

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

1. When two **forces** of equal **magnitude** but opposite direction are applied to the same object, they **balance,** and the net force is zero. If a force is applied to an object that is greater than any opposing forces, the **net force** is not zero, and the object moves. Because forces are **vectors** with both direction and magnitude, we represent them as arrows with lengths proportional to their magnitude in free body **diagrams**.

Extended Inquiry Suggestions

This lab serves as a lead-in to Newton's laws, but it can be used to discuss the idea of impulse. Return to a graph of Force versus Time from the first part of the lab. Ask your students describe in detail the amount of contact between the object and the force sensor, and the resulting motion. Ask them to look at the area under the Force versus Time curve as a way of introducing the idea of momentum.

6. Archimedes' Principle

Objectives

Students explore the relationship between the volume of fluid that a submerged object displaces and the buoyant force experienced by that submerged object. Through this process, students discover:

- The sum of the forces equals zero if the object is not accelerating
- Water provides an upward buoyant force on submerged objects
- That forces are responsible for some objects sinking and other objects floating

Procedural Overview

Students gain experience conducting the following procedures:

- Using a force sensor to measure the net downward force on the object submerged in air and submerged in water
- Measuring the volume of water displaced by the object by using a spill-can
- Calculating the weight of the displaced water using a scale or knowledge of the density of water

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Rod stand
- Short rod
- Overflow can
- Objects to submerge
- Small cup to add water to the overflow can
- Cup or beaker to catch water from overflow can
- Balance (1 per class)
- Right-angle clamp
- String, 25 cm
- Water, 500 mL
- Ruler
- Graduated cylinder, 25-mL (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Force
- ♦ Density
- ♦ Volume
- ♦ Mass

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Introduction to Force
- ♦ Hooke's Law

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Monitoring live data without recording �(6.1)
- ♦ Displaying data in a digits display �(7.3.1)

Background

Archimedes (287 to 211 B.C.) lived in Syracuse, on the island of Sicily and is considered to be one of the greatest mathematicians of all time. Archimedes is widely credited as the principle reason for the failure of the Romans in their first attempt to capture Syracuse. According to several accounts, Archimedes applied his considerable talent to the defense of the city, and he invented several novel machines to repel the Roman siege engines. Archimedes' most famous discovery was that an object submerged in a fluid is buoyed up by a force equal to the weight of the liquid the object displaces. This law is called Archimedes Principle.

Pre-Lab Discussion and Activity

Engage the students in the following discussion and demonstration.

Ask a student why a boulder sinks but a ping-pong ball floats in water. You will likely get a response, "because the boulder is 'heavier' than the ping-pong ball." Ask the student why a log floats, and you might get a response, "because it is made of wood." Finally, ask the student why a nail sinks, and the student is likely to say, "because it is metal."

Continue with the following questions:

1. Which is heavier, a wooden chair or a steel nail?

The wooden chair.

2. Which is denser, a steel nail or a wooden chair?

The steel nail.

3. Which is denser, aluminum or iron?

Iron.

4. Demonstrate the following: submerge an empty aluminum can upside down under water. Does it float? Explain the reason for what you observe.

If the can is submerged upside down such that it traps a lot of air, the can will float because the overall density of the can would be less than that of water.

5. Demonstrate the following: submerge an empty aluminum can right-side up under water. Does it float? Explain the reason for what you observe.

If the can is submerged right-side up such that the can fills with water, then the can would sink because the overall density of the can would be more than that of water.

6. An object is both heavy and made of a dense material. Will the object float or sink in water?

The object will sink if it is solid. It might float if the overall density of the object is less than water's density.

7. Steel sinks in water. Ships are made of steel. Why do ships float in water?

Ships are not solid, and have air pockets, making their overall density less than water's density, so ships do float.

The general idea with this line of discussion is to shift student focus from what something is made of to an object's overall density. It helps to show objects sinking and floating to the whole class. You may want to use large clear container like a fish tank.

An alternate demonstration is to place a diet soda and a regular soda in a large transparent tub filled with water. The diet soda floats while the regular soda sinks. Few people know this, and they're usually quite amused. Sugar is a much more dense substance than aspartame. Hence, the same volume of fluid will sink because it is a much more dense fluid inside the can.

Lab Preparation

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

Teacher Note: Make sure students fill the water level of the spill can past full and allow the water to slowly drain out of the can via the spill tube before inserting the mass. This will yield more accurate volume results than filling the overflow can to the point of "almost full" due to the large surface tension of water. Water surface tension can also be reduced by adding a drop of detergent to the water.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Restate the caution when using electronics around liquids.

Sequencing Challenge

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

3	1	4	2
Calculate the force due to gravity on the volume of displaced water (weight in N).	Completely submerge an object in water, collecting the volume of water displaced by the object.	Show that the change in net force on the object before and after submersion is equal to the weight of displaced water.	Measure the net force acting on the submerged object.

Procedure with Inquiry

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

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

Set Up

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

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

3. ☐ Display force (pull positive, or inverted) in a digits display. �(7.3.1)

4. ☐ Attach the force sensor to the rod stand using a short rod and the right angle clamp.

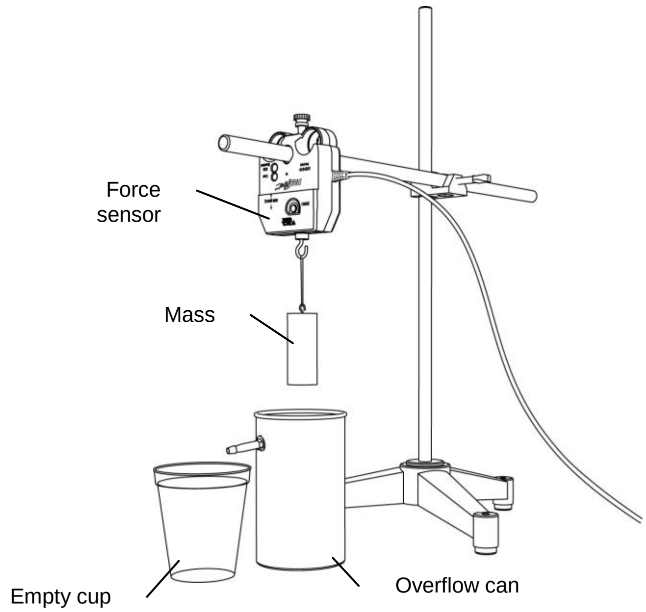
5. ☐ Press the "zero" button on the force sensor.

6. ☐ Why do you think it is important to press the "zero" button on the force sensor?

We are interested in the force on the object hanging from the force sensor, so the sensor should read zero before the mass is added.

7. ☐ Place the overflow can below the force sensor.

8. ☐ Tie a loop of string to the object, long enough to allow the object to be submerged completely in the overflow can when hung and lowered from the force sensor.



9. ☐ Place a dry cup (catch basin) under the spout of the overflow can.

10. ☐ Fill the overflow can with water to the limit.

Note: To reach the fill limit of the can, overfill the can allowing the excess water to pour from the spout. When the spout has stopped dripping, the can will be completely filled. Be sure to empty the catch basin after doing this.

11. ☐ Why is it important to fill the water to the point that it begins to run out of the spout of the overflow can?

This ensures that we capture all the water that is displaced by the mass.

Collect Data

12. ☐ Use the balance to measure the mass of the empty cup (catch basin) in kg, record the mass of the cup in Table 1, and then replace the cup in its original position.

13. ☐ Why is it important to measure the mass of the empty cup?

This ensures that we can get an accurate measurement of the amount of water displaced by the hanging mass.

14. ☐ Measure the mass of the object you will submerge in the water in kg, and record the mass of the object in Table 1.

15. ☐ Use your ruler to measure the dimensions of your object, use your knowledge of geometry to calculate its volume, and then record the volume in Table 1.

16. ☐ Begin monitoring force with your data collection system. �(6.1)

17. ☐ Use the string loop to hang the object from the force sensor hook. Make certain the object is not swinging before recoding data, and then record the force exerted by gravity on the object in Table 1.

18. ☐ Loosen the thumbscrew that holds the right angle clamp to the rod stand, and slowly lower the object into the overflow can. Displaced water from the overflow will pour into the empty cup (catch basin).

19. ☐ Tighten the thumbscrew to hold the object fully submerged, but not touching the bottom of the can.

20. ☐ Record the new “resultant” force measurement in Table 1.

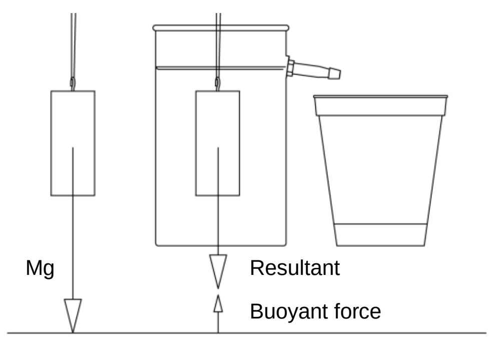
21. ☐ Use the balance to measure the mass of the cup (catch basin) and water that has overflowed from the can, and record the mass in Table 1.

22. ☐ Use the graduated cylinder to measure the volume of the water that has overflowed from the can, and record the volume in Table 1.

If you are not using a graduated cylinder, use the mass of the water calculated in the next step and the conversion of 1,000 cm^3/kg for water to determine the volume.

Analyze Data

If the mass of the object does not change when it is submerged, but the net force does, we must be observing the action of a second force on the object. This force is called Buoyant Force. The force on the submerged object is the resultant of the vector addition of the force of gravity and the buoyant force acting on the object.



23. ☐ Calculate the mass of the displaced water in kilograms by subtracting the mass of the empty cup from the mass of the displaced water and cup together, and record the mass in Table 1.

0.029 kg - 0.006 kg = 0.23 kg

24. ☐ Calculate the weight of the water in newtons by multiplying the mass of the water by the acceleration of gravity (9.81 m/s^2), and record the weight in Table 1.

0.023 kg × 9.81 m/s^2 = 0.23 N

25. ☐ Calculate the buoyant force by subtracting the force on the submerged object from the force due to gravity, and record the force in Table 1.

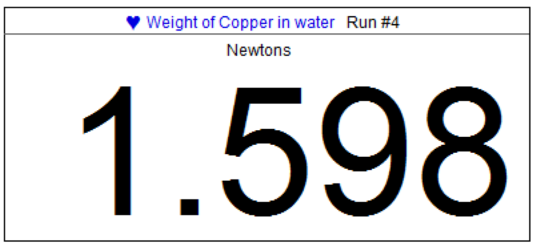
1.598 N - 1.823 N = -0.225 N If gravity, a downward force, is positive then this force must be upward.

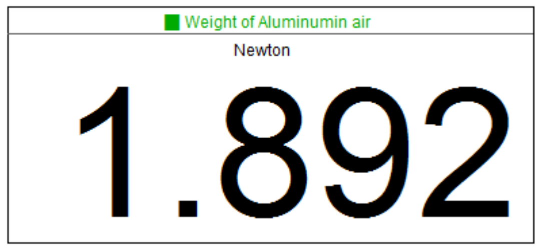
26. ☐ Calculate the density of your object from the measured mass and volume, and record the mass in Table 1.

0.189 kg/21.2 cm^3 = 0.00877 kg/cm^3

27. ☐ Repeat the Collect Data and Analyze Data steps for a second object that has a different mass and record the results in Table 1.

Sample Data





Data Analysis

Table 1: Object buoyancy data

Parameters	Object 1	Object 2
Object	Copper	Aluminum
Mass of the empty cup (kg)	0.006 kg	0.006 kg
Mass of the object (kg)	0.186 kg	0.193 kg
Volume of the object (cm^3)	21.2 cm^3	73.7 cm^3
Force of gravity on the object (N)	1.823 N	1.892 N
Resultant force on submerged object (N)	1.598 N	1.156 N
Mass of cup and water displaced by the object (kg)	0.029 kg	0.081 kg
Volume of water displaced by the object (cm^3)	22.9 cm^3	75.0 cm^3
Mass of the water displaced by the object (kg)	0.023 kg	0.075 kg
Weight of the water displaced (N)	0.225 N	0.736 N
Buoyant force (N)	-0.225 N	-0.736 N
Density of water (kg/cm^3)	0.001 kg/cm^3	0.001 kg/cm^3
Density of the object (kg/cm^3)	0.00877 kg/cm^3	0.00262 g/cm^3

Analysis Questions

1. Compare the mass of the object to the mass of the displaced water.

The mass of the object is greater than the mass of the water it displaces.

2. Compare the volume of the object to the volume of the water displaced.

The volume of water is equal to the volume of the object.

3. Compare the buoyant force to the weight of the water displaced.

The buoyant force is equal to the weight of the water displaced by the object.

4. Compare the density of your object to the density of water.

The density of the object is greater than the density of the water.

5. What do you think is the greatest source of error in your measurements, and why?

Student answers will vary, but most will find measuring the volume of the object the greatest source of error.

6. If you neglected to subtract the mass of the cup in your measurements what would be the percent error due to the cup in the mass of water measurement?

Answers will vary based on the materials used in the experiment. In this example of copper above, the mass measurement of water would be high by 26%.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What would a submerged object do if the buoyancy force were greater than the weight of the object?

The object would float to the surface.

2. Imagine a person in a deep pool. What happens if the person:

a. Let the air out of their lungs? Why?

They sink. The person weighs a little less because they are "filled" with less air, but the amount of water that is displaced is also less. Thus, the force of buoyancy is also less. The weight of a volume of air compared to the same volume of water is much less.

b. Take a deep breath and hold it? Why?

They float. The person weighs a little more because they are "filled" with more air, but the amount of water that is displaced is also more. Thus, the force of buoyancy is also more. The weight of a volume of air compared to the same volume of water is much less.

Multiple-Choice Questions

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

1. A completely submerged object displaces its own:

- **A.** Density of fluid.
- **B.** Weight of object.
- **C.** **Volume**.
- **D.** Weight of the fluid in the container.

2. What is the buoyant force acting on a 20-ton ship floating in the ocean?

- **A.** **20 tons**.
- **B.** Less than 20 tons.
- **C.** More than 20 tons.
- **D.** Depends on the density of seawater.

3. A lobster crawls onto a bathroom scale submerged at the bottom of the ocean. Compared to its weight above the surface, the lobster will have an apparent weight under water that is:

- **A.** **Less**.
- **B.** The same.
- **C.** More.
- **D.** Depends on the density of seawater.

Key Term Challenge

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

1. The weight of an object acts downward, and the **buoyant** force provided by the displaced fluid acts upward. If these two forces are equal, the object does not sink. **Density** is defined as mass per unit of volume. If the density of an object exceeds the density of water, the object will **sink**.

2. **Archimedes'** most famous discovery was that an object submerged in a fluid is buoyed up by a force equal to the **weight** of the liquid the object **displaces**. This law is called "Archimedes Principle."

Extended Inquiry Suggestions

Ask your students to repeat the lab for a second object of different density to compare and contrast them.

Submarine buoyancy

Whether a submarine is floating or descending depends on the ship's buoyancy. Buoyancy is controlled by the ballast tanks, which are found between the submarine's inner and outer hulls.

A submarine resting on the surface has positive buoyancy, which means it is less dense than the water around it and will float. At this time, the ballast tanks are mainly full of air.

To submerge, the submarine must have negative buoyancy. Vents on top of the ballast tanks are opened. Seawater coming in through the flood ports forces air out the vents, and the submarine begins to sink.

The submarine, with ballast tanks now filled with seawater, is denser than the surrounding water. The exact depth can be controlled by adjusting the water to air ratio in the ballast tanks. Submerged, the submarine can obtain neutral buoyancy. That means the weight of the submarine equals the weight of water it displaces. The submarine will neither rise nor sink in this state.

To make the submarine rise again, compressed air is simply blown into the tanks, forcing the seawater out. The submarine gains positive buoyancy and becomes less dense than the water and rises.

A fun way to show this is to make a Cartesian diver. Fill a clear plastic bottle nearly to the top with water. A 2-Liter soda bottle works well. Take a small medicine or eye dropper. Draw in just enough water into the dropper so that it barely floats when inserted into the clear plastic bottle. You'll probably have to try this several times before getting the amount of water just right. With the dropper barely floating, screw on the cap tightly. Increase the pressure inside the bottle by squeezing the bottle. Water will enter the dropper as the air inside the dropper becomes compressed. The dropper will "dive." Reduce the pressure inside the bottle by squeezing less. The air inside the dropper will expand, thus driving water out of the dropper. The dropper will then rise to the surface.

Buoyancy without water

To extend the idea of buoyancy beyond water, add the following demonstration. Get a Mylar® helium balloon and wait a few days until enough helium has leaked out that it loses some buoyancy and is roughly the same density as the room's air. Blowing hot air (from a blow dryer) on the balloon heats and expands the remaining gas in the balloon, and it will rise to the top of the classroom. As it cools, the balloon falls slowly down again, where you can heat it again with the blow dryer to repeat the effect. Buoyancy can be easily calibrated with a few paperclips tied to the bottom of the balloon.

7. Hooke's Law

Objectives

This experiment identifies the relationship between the extension of a spring and the resulting force required to extend the spring, also known as Hooke's Law.

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring and recording the extension on a spring and the force applied to extend the spring.
- Plotting a graph of Force versus Distance (extension of the spring).
- Deriving a relationship between force and extension.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	40 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Spring
- Force sensor
- Meter stick

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Metric conversions: specifically from centimeters to meters
- Force, specifically as a "push" or "pull"

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Introduction to Force
- ♦ Newton's Second Law
- ♦ Simple Harmonic Motion

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Putting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- ♦ Starting a manually sampled data set �(6.3.1)
- ♦ Recording a manually sampled data point �(6.3.2)
- ♦ 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 �(7.1.9)
- ♦ Finding the slope and intercept of a best-fit line �(9.6)
- ♦ Saving your experiment �(11.1)

Background

From toys to cars, springs are useful devices in modern machines. One of the most common springs is the coiled spring, which is generally made of metal. Coiled springs can be compressed (made shorter), extended (made longer), or both. We will limit this particular investigation to extension springs. In this lab, Hooke's Law for springs will be derived:

$$F = -kx$$

where F is the spring force, k is the spring constant, and x is the extension length. The extension length x is measured from the, un-extended, equilibrium position at which no force is pushing or pulling on the spring.

For many springs, Hooke's Law does not apply at the extremes: when the spring is extended or compressed very little and when it is extended or compressed too much. In the region between these two extremes, springs generally obey Hooke's Law. A theoretical spring that follows Hooke's Law is called an "ideal" spring. In addition, comparing the way different coiled springs can be extended or compressed should help determine a spring’s spring constant.

Pre-Lab Discussion and Activity

Engage your students by holding up a spring horizontally and repeatedly stretching it.

1. Observe what happens as I stretch this spring. What do you observe that can be measured?

The spring gets longer.

Guide students to state that it is necessary to measure the extension of the spring.

2. What do we measure? What should be our measuring instrument? What units will our measurements be made in?

We measure displacement and distance. Our measuring instrument is a meter stick. We will use centimeters as our units.

Guide students to convert from centimeters to meters.

3. What is the standard unit of measure for displacement and distance? How do you convert from centimeters to meters?

Meters are the standard unit of measure. Divide meters by 100 cm/m to get centimeters.

Guide students to state that it is necessary to measure the force applied to the spring.

4. What must I do to make the spring stretch? What instrument would I use to measure this? What units will this measurement be made in?

Pull on the spring. Use a force sensor to measure in newtons.

Lab Preparation

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

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

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Prevent students from pulling springs to their maximum extensions to avoid recoiling and the possibility of being struck in the eye by the spring.

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 and record the extension on a spring and the force required to extend it.	Prepare the data collection device to measure force from the force sensor.	Derive a relationship between force and extension.	Convert the extension data from centimeters to meters.	Plot a graph of Force versus Distance in meters.

Procedure with Inquiry

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

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

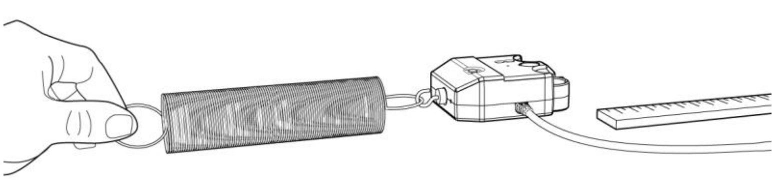
Set Up

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

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

3. ☐ Hold the force sensor horizontally with nothing attached to the hook and press the "zero" button on the top of the sensor.

4. ☐ Anchor one end of the spring and attach the other end to the hook of the force sensor.



5. ☐ Place the meter stick on the table parallel to the spring such that the back end of the force sensor is aligned with the 0 m line on the meter stick.

6. ☐ Put your data collection system into manual sampling mode with manually entered data. Name the manually entered data "Distance" and give it units of meters. �(5.2.1)

7. ☐ Slowly pull on the force sensor until the spring *comfortably* reaches its maximum extension. Measure how much the spring extends from its original (not stretched) length.

Divide this number by 10. This will be the incremental length the spring will be extended between each force measurement. For example: if the spring extends 20 cm, dividing it by 10 gives 2 cm. The extension values placed in Table 1 would be: 2 cm, 4 cm, 6 cm, etc.

Collect Data

8. ☐ Begin recording a manually sampled data set. �(6.3.1)

9. ☐ Pull the force sensor to extend the spring the first interval, and then record the first manually sampled force data point. Manually enter the corresponding distance the spring was stretched. �(6.3.2)

10. ☐ While holding the anchored end of the spring in place, pull the force sensor parallel to the meter stick, extending the spring by the interval extension amount calculated previously. Hold the sensor in place.

11. ☐ Record another manually sampled data point with the spring at its current stretched length. Manually enter the corresponding extension length read from the meter stick. �(6.3.2)

12. ☐ Repeat the previous steps until you have reached the spring's maximum extension length.

13. ☐ Stop data recording. �(6.3.3)

Analyze Data

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

15. ☐ Why do we use pull positive instead of push positive as the direction of the force vector?

The displacement vector is increasing (positive) in the direction of the spring's extension. Using the pull positive measurement aligns the positive direction of the displacement and force vectors.

16. ☐ Change the variable on the x-axis to the manually entered Distance data. �(7.1.9)

17. ☐ Sketch the graph of Force versus Distance in the Data Analysis section.

18. ☐ Is the relationship between the force and distance linear?

Yes, it does appear to be a linear relationship.

19. ☐ Using your data collection system, find the slope of a best-fit line of the Force versus Distance graph. �(9.6)

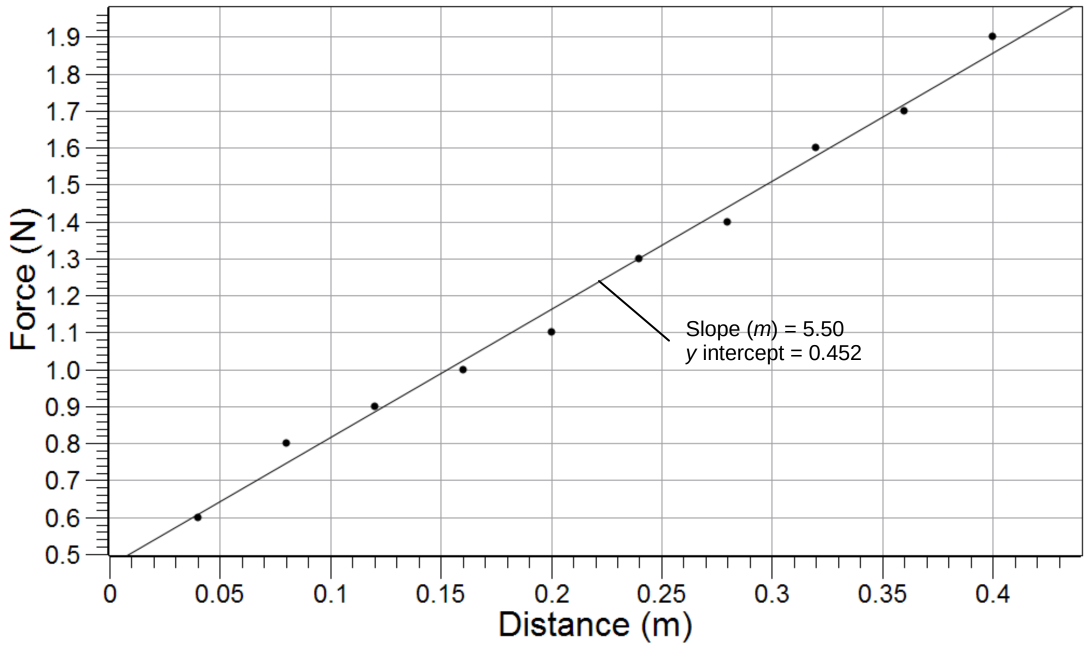
20. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Table 1: Force and Distance

Distance (m)	Force (N)
0.04	0.61
0.08	0.75
0.12	0.87
0.16	0.98
0.20	1.13
0.24	1.27
0.28	1.45
0.32	1.56
0.36	1.74
0.40	1.85

Force versus Distance



Analysis Questions

1. Write the $y = mx + b$ equation for the best fit line on your graph.

Example answer: $F = 3.50x + 0.452$

2. What is the physical meaning of the slope?

The slope represents the spring constant, or the amount of force required to extend the spring a unit of distance.

3. What are the units for the slope?

N/m

4. What is the physical meaning of the vertical intercept? If there is not a vertical intercept, explain why.

One should expect the vertical intercept to be zero. If no force is applied to the spring, there should not be any extension or compression. For an ideal spring this would be true, but for real springs there is a non-linear part of the extension at the beginning this point gives you an approximation of the point where the spring transitions from non-linear to linear behavior.

5. If the force sensor is pulling in the positive direction, what direction is the spring pulling?

The force exerted by the spring must be in the opposite (or negative) direction, or opposing the change in displacement.

6. If we were observing a compression spring such that we measure displacement as positive in the direction of compression, and force as push positive, what direction is the spring pushing?

The spring is pushing in the negative direction, once again opposing the change in displacement.

7. Given the answers above can you write an equation that generally describes the force exerted by an ideal spring as it is extended or compressed using k to represent the spring constant?

$F = -kx$

8. Obtain from your teacher the accepted value of the spring constant. Find the percent difference between the accepted value and your experimental value of the spring constant. Explain the difference, if any.

$$\frac{k_{rated} - k_{measured}}{k_{rated}} \times 100 = \frac{3.60 - 3.50}{3.60} \times 100 = 2.78\%$$

Besides human error, the main differences may arise from the gathering of data beyond the region of linear elasticity. For stiffer springs, a loading force is necessary to bring the spring into the region of linear elasticity. If students do not recognize this and include it in their calculations, a greater spring constant will arise.

Synthesis Questions

Use available resources to help you answer the following questions.

1. For an ideal spring like the one used in your lab, what would be the spring constant if a force of –5.0 N is measured when pulling it 4 cm?

$$-k = \frac{F}{x}$$

$$-k = \frac{-5.0\text{ N}}{0.04\text{ m}} = 125\text{ N/m}$$

2. The same spring (as in the question above) is stretched to 7 cm. What force does this require?

$-(F) = -kx$

$F = (125\text{ N/m})(0.07\text{ m}) = 8.75\text{ N}$

3. Based on the answers from the questions above, what is the relationship between the elastic or spring force and the extension?

Directly proportional or linear

4. The suspension system of a car contains a spring. How would the slope of a Force versus Distance graph for this spring compare to the slope of the Force versus Distance graph in this experiment? Explain.

The slope would be steeper because the spring constant would be greater.

Multiple Choice Questions

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

1. A spring is stretched different lengths. If the applied force is graphed on the vertical axis of a graph and the extension is graphed on the horizontal axis, what does the slope represent?

- **A.** Total Momentum
- **B.** Amplitude
- **C.** Elastic Potential Energy
- **D. Spring Constant**

2. N/m is the unit for…

- **A.** Torque
- **B.** Amplitude
- **C. Spring Constant**
- **D.** Elastic Potential Energy

3. For this question, assume the spring has negligible mass. A spring is suspended vertically from the ceiling of an elevator that is moving upward with constant velocity. When a 200 g mass is connected to the bottom of the spring, it stretches 1 cm. Which value is closest to the spring constant?

- **A. 200 N/m**
- **B.** 20 N/m
- **C.** 2 N/m
- **D.** 2000 N/m

4. The same system as in the question above now accelerates upward at 2 m/s^2. What is the displacement of the mass on the spring from its original "un-stretched" length?

- **A. 0.012 m**
- **B.** 1.2 m
- **C.** 0.120 m
- **D.** 0.001 m

Key Term Challenge

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

1. A force is applied to one end of an ideal spring while the other end of the spring is anchored in place. The applied force causes the spring to stretch. As the **force** increases, so does the extension of the spring. A graph of this applied force versus the spring's corresponding extension will yield a **linear** relationship. The slope of a best fit line of this data represents the spring's **spring constant**. The *y*-intercept of the best fit line should be approximately equal to **zero**. This relationship between force and extension for a spring is an example of **Hooke's Law**.

Extended Inquiry Suggestions

A natural extension of this lab includes the study of:

- The bulk modulus of materials and how they react to compression
- Young's modulus and stress/strain properties of linear materials, like cables
- Combination of springs: parallel and series
- Use a force sensor and rotary motion sensor to observe the non-linear portion of the spring as it is first extended

8. Newton's First Law

Objectives

This experiment investigates the concepts surrounding Newton's First Law of Motion. Students observe a simple cart and track system to determine the influence of force in the motion of an object, and how the absence of an external force means an objects motion is unchanged.

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the velocity of a cart while it undergoes three different forms of motion: constant zero velocity, constant non-zero velocity, constant non-zero acceleration.
- Comparing the velocity associated with each form of motion to determine whether a net force is acting on the cart.

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Motion sensor
- Dynamics cart
- Dynamics track with feet
- Dynamics track end stop
- Mass and hanger set
- Super pulley with clamp
- String, ~1 m

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Kinematics/Motion in 1-Dimension
- Acceleration

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Position: Match Graph
- ♦ Speed and Velocity
- ♦ Acceleration
- ♦ Newton's Second Law
- ♦ Newton's Third Law

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Recording a run of data �(6.2)
- ♦ Displaying data in a graph �(7.1.1)

Background

Aristotle (384 BC to 322 BC) believed that the natural state of an object was to be at rest and therefore all objects in motion will eventually come to a stop. There was much argument between early philosophers and scientists regarding the motion of objects. In the 17th century, Sir Isaac Newton formalized his three laws of motion.

The first law of motion: An object will maintain its state of rest or uniform motion unless acted upon by an external unbalanced force.

This became known as the law of inertia.

Newton's first law indicates that an object traveling with constant velocity will maintain that constant velocity unless otherwise acted upon by a net force. In addition, objects at rest (zero velocity) will stay at rest unless otherwise acted upon by a net force.

In other words, if the net force on an object is zero, its acceleration is also zero. We will investigate this concept by exploring the measured velocities associated with several different types of motion of a cart.

Pre-Lab Discussion and Activity

For the demonstration station:

- Rubber ball
- Text book
- Large flat piece of wood (or other rigid material), Dimensions ≈ 1 m × 1 m

It is important, for now, that students focus on the idea that an object, "...continues to do what it is doing unless acted on by an outside agent."

It is advised that a discussion of inertia not occur in conjunction with these lab experiences. This discussion can occur later on as students investigate the concept of force further.

Begin with the piece of wood laying flat on the demonstration table. Place the ball on the wood near one edge (the ball should remain stationary in place). Inquire with students:

1. What is the ball's velocity?

Zero

2. Is the ball's velocity changing?

No

3. What forces are acting on the ball?

Gravitational and normal force

4. Was there a net "unbalanced" force acting on the ball?

No

Now have students pay close attention as you give the ball a small push slowly rolling it across the piece of wood in straight line. Stop the rolling ball before it rolls off the piece of wood. Inquire with students:

1. Was the ball's velocity equal to zero while it was rolling?

No

2. Ignoring friction, was the ball's velocity changing?

No, its speed and direction remained constant.

3. What forces were acting on the ball while it was rolling?

Gravitational and normal force

4. Was there a net "unbalanced" force acting on the ball while it was rolling?

No

Place the text book under one end of the piece of wood elevating that end slightly. Place the ball on the wood at the elevated edge, holding it in place. Have students predict what how the balls' motion will change when you release it.

Release the ball allowing it to roll down the piece of wood and catch it before it rolls off the far edge. Inquire with students:

1. Was the ball's velocity equal to zero while it was rolling?

No

2. Ignoring friction, was the ball's velocity changing?

Yes, its direction remained constant, but its speed was increasing.

3. What forces were acting on the ball while it was rolling?

Gravitational and normal force

4. Was there a net "unbalanced" force acting on the ball while it was rolling?

Yes, gravitational force was greater than the normal force, thus a net force.

For the final demonstration, leave the text book under one end of the piece of wood elevating that end slightly. Place the ball in the middle of either of the angled edges holding it in place. Tell students, "In this demonstration I will give the ball a slight horizontal push, of the same magnitude as the first demonstration, towards the other angled edge allowing it to roll freely." Have students predict what how the balls' motion will be different from the first demonstration where you gave the ball a slight push on the flat board.

Give the ball a slight push, horizontally, towards the other angled edge of the piece of wood allowing it to roll freely. Students should see the ball roll with the same horizontal speed as the first demonstration, but the ball's direction should change as it rolls across the piece of wood. Catch the ball before it rolls off the piece of wood. Inquire with students:

1. Was the ball's velocity equal to zero while it was rolling?

No

2. Ignoring friction, was the ball's velocity changing?

Yes, its speed and direction were changing

3. What forces were acting on the ball while it was rolling?

Gravitational and normal force

4. Was there a net "unbalanced" force acting on the ball while it was rolling?

Yes, gravitational force was greater than the normal force, thus a net force

5. If we were in space and the force from gravity was negligible, how would the ball's motion be different than we just saw?

Its speed and direction would have stayed constant.

Safety

Add this important safety precaution to your normal laboratory procedures:

♦ Keep water away from any sensitive electronic equipment.

Sequencing Challenge

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

3	2	4	1
Measure the velocity of a cart as a hanging mass acts on the cart.	Measure the velocity of a cart at rest on a flat track before setting the cart in motion.	Use velocity data to determine if any net forces are acting on the cart.	Setup the dynamics track with super pulley at one end and the motion detector at the opposite end.

Procedure with Inquiry

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

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

Set Up

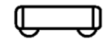
1. ☐ Start a new experiment with your data collection system. �(1.2)

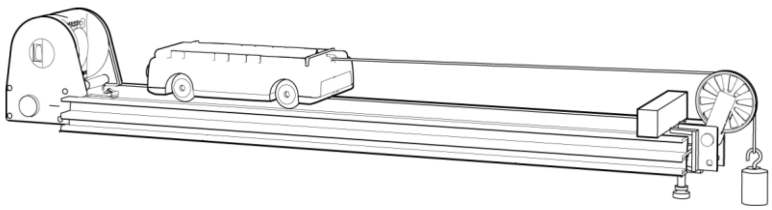
2. ☐ Connect the motion sensor to the data collection system. �(2.1)

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

4. ☐ Set the dynamics track on the lab table with one end of the track aligned with the edge of the lab table (or slightly hanging over the edge).

5. ☐ Attach the end stop and then the super pulley with clamp to the end of the track near the edge of the table.

6. ☐ Attach the motion sensor to the opposite end of the track with the face of the sensor pointed toward the super pulley. Be sure the switch on the sensor is set to the cart position. 



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

8. ☐ Set the cart onto the track, and then adjust the level of the track using its adjustable feet so that the cart remains stationary when left at rest.

9. ☐ Cut a piece of string approximately 1 m long in preparation for data collection.

10. ☐ What will happen to an object at rest if no force is applied?

The object will remain at rest in this frame of reference.

11. ☐ What is required for an object to maintain motion at a constant velocity?

An object will maintain a constant velocity unless it is acted on by a force.

12. ☐ What will happen to an object if there is a constant net force applied to it?

The velocity of the object will increase in the direction of the force

Collect Data

13. ☐ With the cart stationary in the middle of the track, start data recording. �(6.2)

14. ☐ After approximately 5 seconds, stop data recording. �(6.2)

15. ☐ Now place the dynamics cart on the track approximately 15 cm in front of the motion sensor.

16. ☐ Start data recording. �(6.2)

17. ☐ Give the cart a soft push towards the super pulley, then catch the cart just before it hits the super pulley at the end of the track.

18. ☐ Stop data recording. �(6.2)

19. ☐ For the final data run, tie one end of your 1 m piece of string to the front of the dynamics cart, and tie the other end to the mass hanger.

20. ☐ Run the string over the pulley with the mass hanger hanging freely below the pulley.

21. ☐ Hold the cart in place approximately 15 cm in front of the motion sensor, and then attach 20 g of mass to the hanger. Continue to hold the cart.

22. ☐ Start data recording. �(6.2)

23. ☐ Release the cart, and allow it to freely roll down the track.

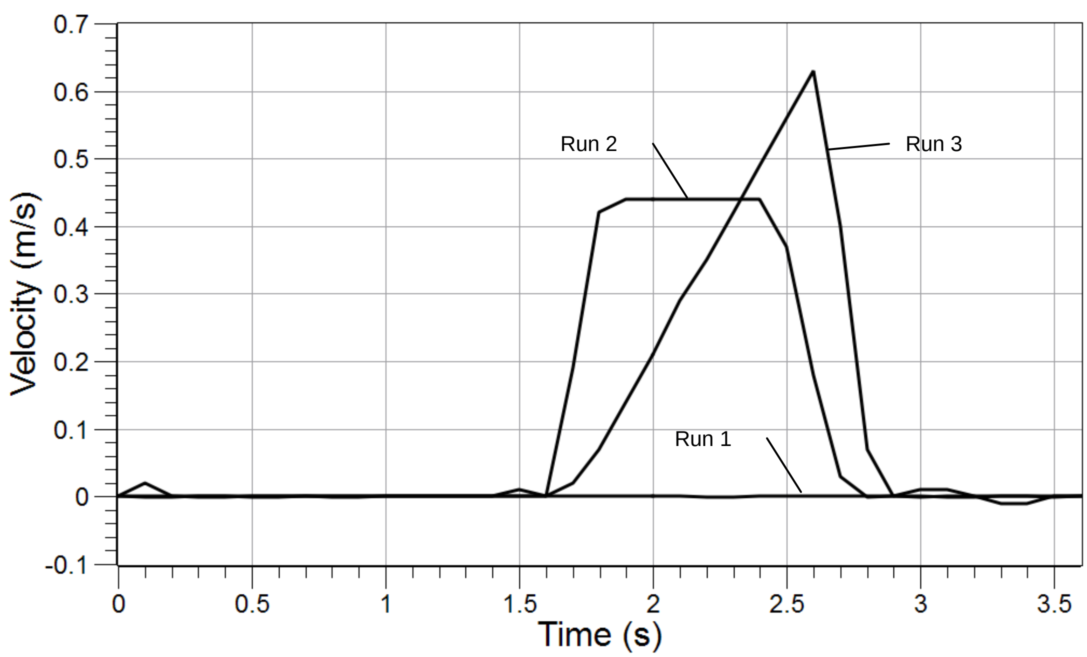
24. ☐ Catch the cart just before it hits the super pulley at the end of the track.

25. ☐ Stop data recording. �(6.2)

Analyze Data

26. ☐ Sketch your graph of Velocity versus Time in the Data Analysis section, and label each run.

Data Analysis



Analysis Questions

1. How was the velocity of the cart in Run #1 changing? Was there a net force acting on the cart? If yes, what is that force caused by?

The velocity of the cart in Run #1 is not changing. There is no net force acting on the cart.

2. Explain how you could tell how the cart's position was changing from a Velocity versus Time graph rather than directly from a Position versus Time graph.

We can determine how the position of the cart was changing from the Velocity versus Time graph because the velocity was zero, which means that the cart's position is not changing.

3. How was the velocity of the cart in Run 2 changing? Was there a net force acting on the cart? If yes, what was that force caused by?

The velocity of the cart in Run #2 is constant. Other than giving the cart a push, there was no net force acting on the cart while it was rolling. Some students may note a slight decrease in velocity due to friction.

4. How was the velocity of the cart in Run 3 changing? Was there a net force acting on the cart? If yes, what was that force caused by?

The velocity of the cart in Run #3 is constantly increasing. There was a force due to gravity experienced by the mass that was in turn pulling on the cart.

5. What evidence from the Velocity versus Time graph for Run 3 indicated there was a net force acting on the cart?

The slope of the Velocity versus Time curve was non-zero, which indicated that there was a net force acting on the cart.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What happens to the velocity of an object if it never experiences an unbalanced force?

The velocity will remain constant and never change.

2. How do forces affect the motion of objects? (Think of a force as a push or pull acting on an object.)

Forces affect motion by pushing or pulling the object out of its constant motion either by speeding up the object, or slowing it down, or changing its direction.

3. Is it possible for an object to experience a net force without physically touching another object? If yes, give an example.

Yes, gravity is an example of a force that acts on freefalling objects, but the objects might not be physically touching the surface of the Earth.

4. An object's resistance to change in motion is called “inertia”. What property of matter gives an object inertia? Give an example of something with a relatively large amount of inertia, and something else with a relatively small amount.

Inertia is related to an object's mass. Student examples will vary. An example of an object with large inertia is a wrecking ball made of steel. An example of an object with small inertia is a balloon.

5. What would happen to a ball if you threw it in deep space where there were no forces acting on it? Describe its motion during the time you are in contact with it and then after you release it.

If you threw a ball in deep space, it would speed up while it was in your hand, stop speeding up after you released it, and maintain a constant velocity from then on because there are no forces in deep space to produce a net force on the ball.

Multiple Choice Questions

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

1. You slide a box across the floor at a constant velocity. Which of the following statements is true?

- **A. Your pushing force exactly equals the resisting force of friction.**
- **B.** Your pushing force must be greater than the force of friction.
- **C.** Your pushing force is less than the force of friction.
- **D.** Once you let go of the box, it will immediately come to a stop.

2. If you continue to push with the same force after the box slides onto a surface with less friction, which of the following statements is true?

- **A.** The box will speed up until it reaches a faster velocity and then continue at that velocity.
- **B. The box will speed up continuously as long as you continue to push with the same force.**
- **C.** The box will continue to slide at its original speed.
- **D.** If you let go of the box it, will continue to move indefinitely.

3. If an object experiences a constant net ___________, it will have a constant_______. However, if no force interacts with an object, that object will maintain a constant __________ indefinitely.

- **A.** Acceleration, force, velocity.
- **B.** Velocity, acceleration, force
- **C. Force, acceleration, velocity**
- **D.** Force, velocity, acceleration

Key Term Challenge

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

1. **Inertia** is a term that refers to an object's resistance to a change in motion. Objects that are more **massive** are harder to accelerate. If an object experiences a constant net **force,** it will have a constant **acceleration**. However, if nothing interacts with an object, it will maintain a constant **velocity** indefinitely. **Nothing** is required for an object to maintain a constant speed in a straight line.

Extended Inquiry Suggestions

In addition to being the first of Newton's three laws of motion, this lab branches out to investigations of friction, and continues discussions around defining reference frames. Something at rest on the surface of the Earth is moving around the axis of the Earth as it rotates and around the sun as it orbits.

Aristotle observed that objects did seem to slow down and stop, as one might conclude today based on their experiences. What are the clues that Aristotle might have used to revise his ideas? Challenge your students to come up with ways to separate the general ideas of motion (Newton's laws) from the specifics of our everyday experience (friction).

9. Newton's Second Law

Objectives

This lab helps students develop an understanding of the relationship between the net force applied to an object, the acceleration of the object, and the object's mass.

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the applied force and resultant motion of an oscillating mass and spring system using a force and motion sensor
- Completing free body diagrams representing the forces imparted to mass in the system
- Interpreting graphs of force and motion to outline the relationships that exist between mass, acceleration, and net force in the system

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Motion sensor
- Right angle clamp
- Hanging mass
- Spring
- Rod stand
- Balance (1 per classroom)
- Short rod

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Hooke's law
- ♦ Acceleration due to gravity
- ♦ Forces

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Hooke's Law
- ♦ Acceleration
- ♦ Introduction to Force

Using Your Data Collection System

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

- ♦ Starting a new experiment with the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data acquisition device �(2.2)
- ♦ Changing the sampling rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Identifying data points on a graph �(7.1.4)
- ♦ Changing the variable on the *x*- or *y*-axis of a graph �(7.1.9)
- ♦ Displaying multiple graphs simultaneously �(7.1.11)
- ♦ Finding the slope and intercept of a best-fit line �(9.6)
- ♦ Saving your experiment �(11.1)

Background

Often, several forces act on an object simultaneously. In such cases, it is the *net force*, or the vector sum of all the forces acting, that is important. Newton's first law of motion states that if no net force acts on an object, the velocity of the object remains unchanged. Newton's second law states that the acceleration of an object is directly proportional to the net force acting on that object and in the same direction as the net force.

$$\boldsymbol{F}_{net} = m\boldsymbol{a}$$

Like Newton, we will observe a simple system to look for a relationship between net force and motion. From earlier studies, we know that a mass hung from a spring experiences a force due to gravity and a restoring force from the spring. In equilibrium the two forces are equal and opposite. When the mass is displaced, one of the two forces is greater, thus causing a non-zero net force pointed towards the equilibrium position. We will investigate how this net force is related to the motion of the system.

Pre-Lab Discussion and Activity

Start with a quick review of a force as a push or a pull. Secure a force sensor to a fixed point (rod and clamp, or heavy base), and show the class that indeed when you push or pull, a digits display does in fact register newtons of force. Move the force sensor to the position it will occupy during the experiment (hanging down from a rod).

Teacher Tip: Be sure to zero the sensor before proceeding.

Teacher Tip: Use a mass that is known and can be dropped on the floor without damage, like a beanbag.

1. **What do you think will happen when I hang this mass from the force sensor?**

Once there is consensus, hang the mass and show the resulting force.

2. **What if the force sensor wasn't here to hold the mass in place?**

Take a moment to remind your students of the acceleration experiment. Then, drop the mass to the floor so the mass experiences an acceleration in the direction the force is applied. This is consistent with our experience. We know that if we apply a small force, an object accelerates a small amount. Push an object on the desk, or a student volunteer, or a cart on a track. If we apply a larger force the object accelerates more. Give the same object a harder push. Therefore, we say that force and acceleration are proportional and deeply tied to the motion of an object.

Lab Preparation

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

1. Remind students that the motion sensor has a minimum distance that it can measure (usually 15 cm). The apparatus should be set up such that the lowest point of the motion of the mass should be well beyond the minimum distance of the motion sensor.

2. If your motion sensor has a sensitivity switch, make sure it is in the "cart" position.

3. Be sure your motion sensor is positioned below the mass such that other objects, like tables or chairs, will not interfere.

4. Be sure your sampling rate is set high enough to capture the motion of your mass (at least 20 samples per second). �(5.1)

Teacher Tip: A 200g mass and a 5 N/m spring with a sampling rate of 20 samples per second works well for this lab. However, a wide variety of combinations are possible depending on what you have available.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Exercise care when stretching and releasing the spring. Be sure that the mass(es) are securely attached.

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
Oscillate the mass on the spring, and begin collecting data.	Plot net force measured by the force sensor versus acceleration.	Use the linear curve fit to determine the slope of the line.	Connect the Motion Sensor and the Force Sensor to your interface

Procedure with Inquiry

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

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

Set Up

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

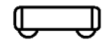
2. ☐ Connect a force and a motion sensor to the data collection system. �(2.2)

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

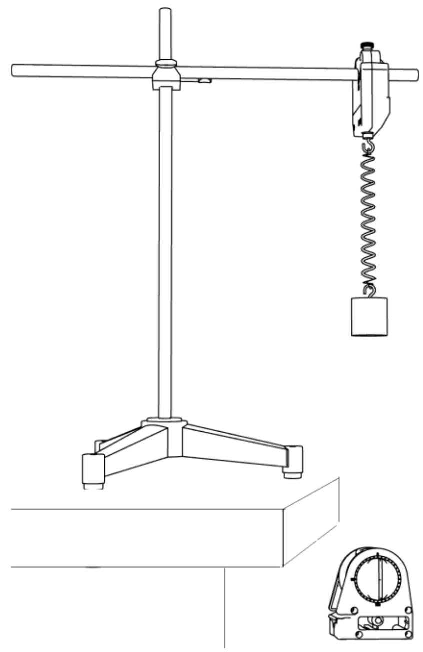
4. ☐ Why is a "Measurement versus Time" graph chosen to view the data? What is another way that might be used to view the data?

The force and acceleration are continuously changing. To compare a matched force and acceleration value, they must be aligned in time. Because we are interested in force and position, we could plot one versus the other.

5. ☐ Make sure that your sampling rate is set to at least 20 samples per second, and if your motion sensor has a selector switch, set it to the cart or near setting. �(5.1)



6. ☐ Connect the force sensor to the short rod and the short rod to the rod stand using the right angle clamp.



7. ☐ Use a spring to hang the mass from the force sensor, and position it above the motion sensor. You may need to place the motion senor on the floor for the mass to have sufficient room to move.

8. ☐ Objects moving away from the motion sensor are moving in the positive direction. Based on the position of the motion sensor, would a push from the force sensor be in the positive direction or a pull?

For this set up, the force sensor is pulling away from the motion sensor, therefore a pull would be in the positive direction.

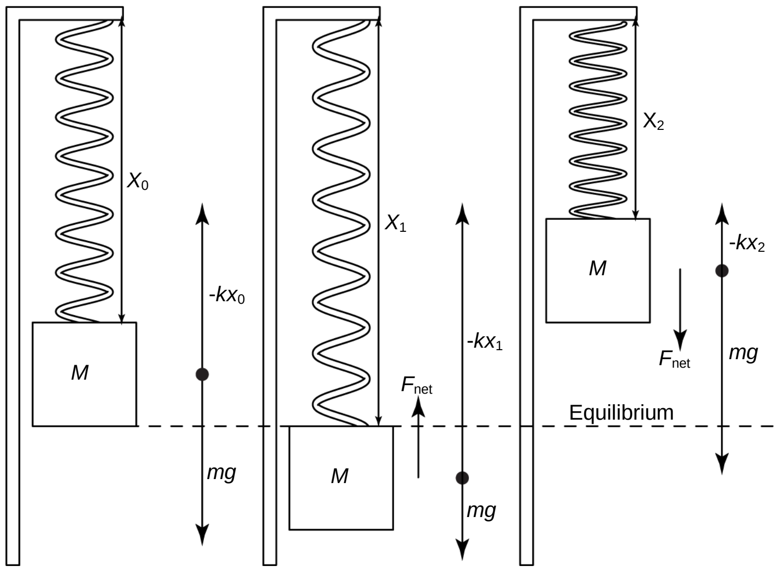
9. ☐ If necessary, change the force measurement so that the direction of the force aligns with the direction of the motion sensor.

10. ☐ With the mass hanging motionless from the force sensor, press the zero button on the force sensor.

11. ☐ Why is it important to zero the force sensor in the equilibrium position before collecting data?

We are interested in the *net force* on the object in the equilibrium position the net force is zero.

12. ☐ From your previous work you learned that the force exerted by a spring is related to distance the spring is stretched $F = -kx$, and the force of gravity is equal to $F = mg$. For each diagram, draw in the forces and the net force experienced by the mass.



Collect Data

13. ☐ Pull on the mass lightly, and let go to start the mass moving up and down. Then, start data recording. �(6.2)

14. ☐ Observe and compare the motion of the object with the real time Position versus Time plot that is generated on the data collection system.

15. ☐ Stop data recording after three to four complete cycles (5 to 10 seconds depending on the spring and mass you are using). �(6.2)

16. ☐ Save your experiment as directed by your teacher. �(11.1)

Analyze Data – Position and Force

17. ☐ Display two graphs simultaneously. On one graph, display Position on the *y*-axis and Time on the *x*-axis. On the second graph, display Force on the *y*-axis and Time on the *x*-axis. �(7.1.11)

18. ☐ Ensure that your Time axes are aligned and then describe the relationship between the position of the object and the force the objects experiences.

Answers will vary, but students should be able to identify that when the position is largest, the force is smallest. Students familiar with sinusoidal motion may express this as being 180 degrees (π radians) out of phase.

19. ☐ Sketch the graphs in the Data Analysis section.

Analyze Data – Velocity and Force

20. ☐ Display two graphs simultaneously. On one graph, display Velocity on the *y*-axis and Time on the *x*-axis. On the second graph, display Force on the *y*-axis and Time on the *x*-axis. �(7.1.11)

21. ☐ Ensure that your Time axes are aligned and then describe the relationship between the velocity of the object and the force the objects experiences.

Answers will vary, but students should be able to identify that when the velocity is largest, the force is near zero. Students familiar with sinusoidal motion may express this as being 90 degrees (π/2 radians) out of phase.

22. ☐ Sketch the graphs in the Data Analysis section.

Analyze Data – Acceleration and Force

23. ☐ Display two graphs simultaneously. On one graph, display Acceleration on the *y*-axis and Time on the *x*-axis. On the second graph, display Force on the *y*-axis and Time on the *x*-axis. �(7.1.11)

24. ☐ Ensure that your Time axes are aligned and then describe the relationship between the acceleration of the object and the force the objects experiences.

Answers will vary, but students should be able to identify that the acceleration is largest when the force is largest. Students familiar with sinusoidal motion may express this as being in phase.

25. ☐ Sketch the graphs in the Data Analysis section.

26. ☐ Display Time, Force, and Acceleration in a table. �(7.2.1)

27. ☐ Select three different time values, and record them in the Table 1 in the Data Analysis Section along with the corresponding force and acceleration values.

Analyze Data – Force versus Acceleration

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

29. ☐ Change the measurement on the *x*-axis from Time to Acceleration. (7.1.9)

30. ☐ Sketch your graph in the Data Analysis Section.

31. ☐ How would you describe the shape of the data plot?

Linear.

32. ☐ Apply a linear curve fit to the data plot. �(9.6)

33. ☐ Add the linear fit to your sketch, and include the slope of the line.

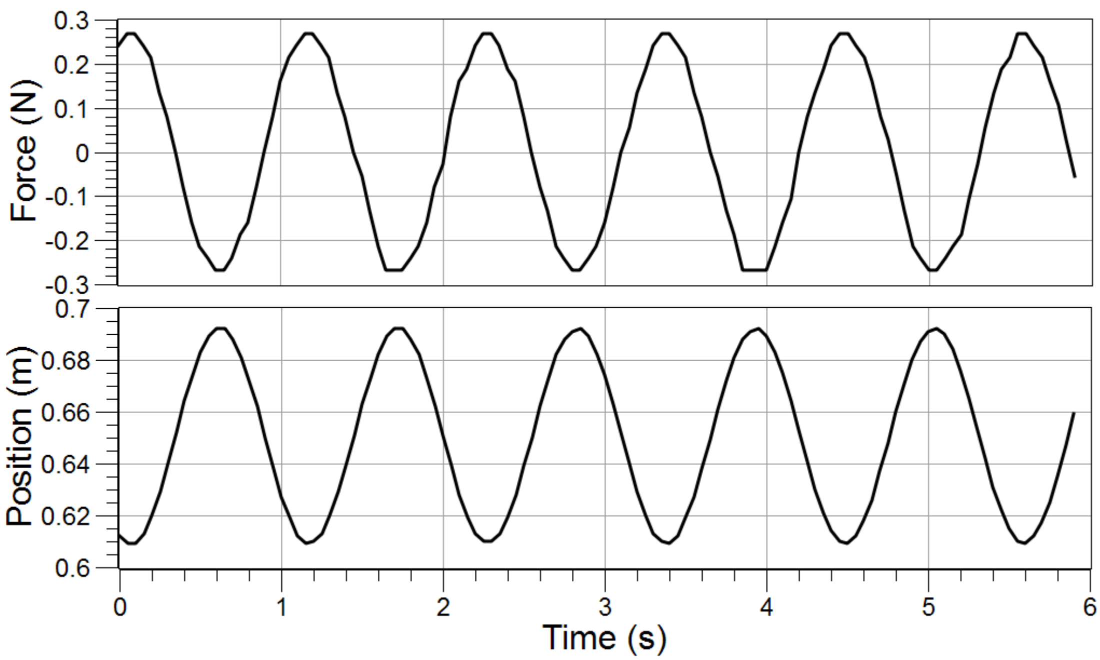
Data Analysis

Drawing the graph: Make sure to label the overall graph, *x*-axis, and *y*-axis, including units on the axes.

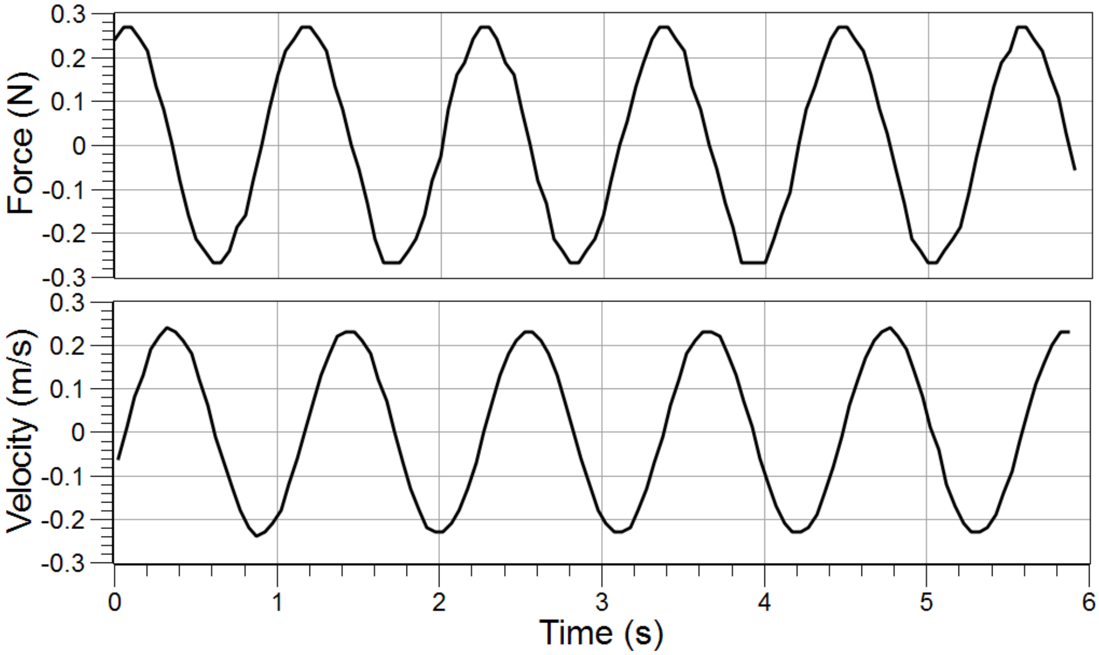
☐ Create a shape and/or color for each data run in the Key. Then draw graphs of your data for a single data run comparing force with position, velocity and acceleration as they change over time.

Make sure to label the overall graph, *x*-axis, and *y*-axis. Also include units on your axes.

Force and Position



Force and Velocity



Force and Acceleration

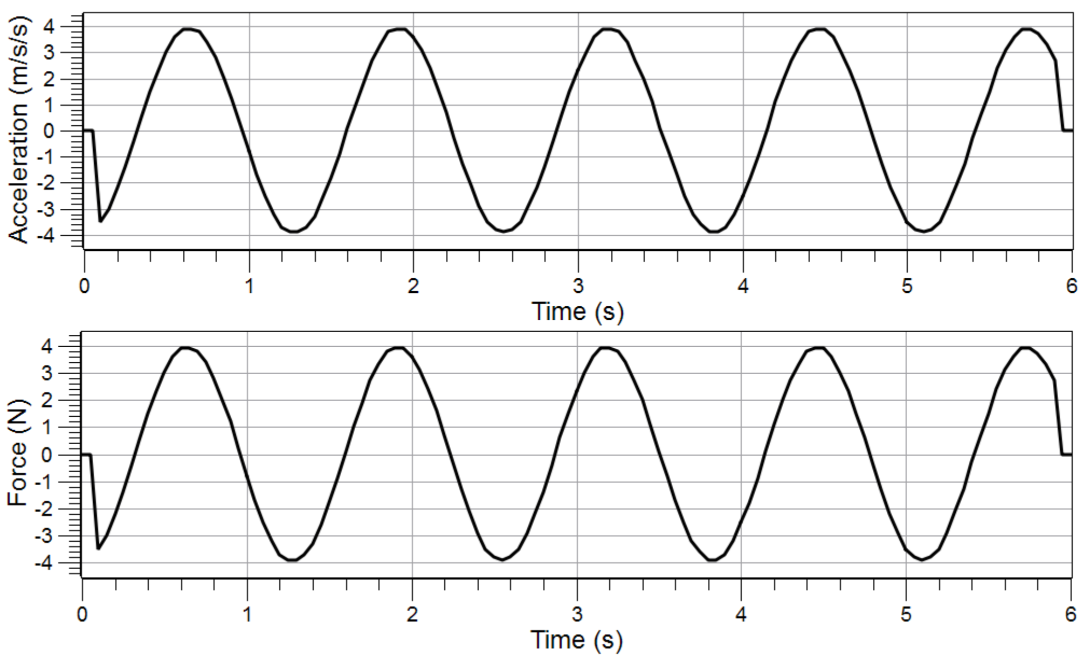
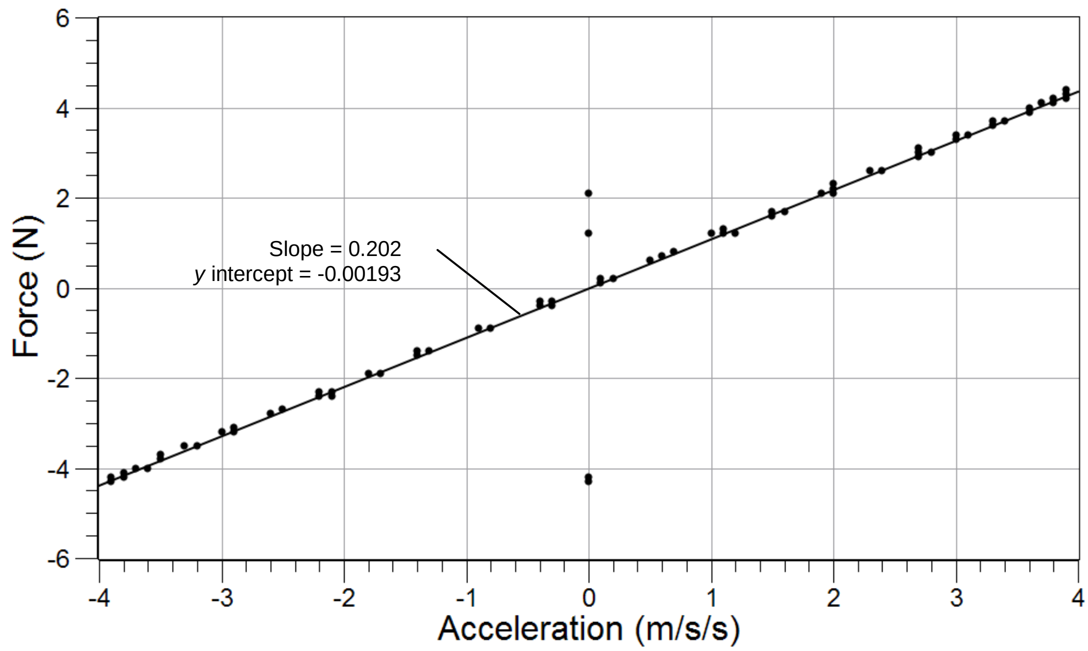


Table 1: Three points of Force and Acceleration

Time (s)	Force (N)	Acceleration (ms²)	Force/Acceleration (kg)
2.50	0.0804	0.412	0.195
1.55	-0.134	-0.687	0.195
4.35	0.188	0.965	0.195
		Average:	0.195

Force versus Acceleration



Analysis Questions

1. For each Time value in Table 1, take the corresponding Force value and divide it by the corresponding Acceleration value. Then, find the average of the results to complete the table. How do the values for each Force divided by an Acceleration compare? And what does this signify?

The values should be very similar signifying that these parameters are proportional.

Teacher Tip: If the acceleration is negative when the force is positive (or 180° out of phase), check for understanding of the questions in the Set Up section. Students may not understand the direction of the motion sensor versus the force sensor.

2. From the table of selected points in the Data Analysis section, does the average value you calculated for ratios of Force to Acceleration appear similar to any other parameter of your experiment?

It is remarkably close to the value of the mass.

3. How does the slope of the best-fit line applied to the Force versus Acceleration graph compare to the average in the Force/Acceleration you calculated in Table 1?

It is very close to the average, and therefore very close to the mass of the object.

4. Using your knowledge of graphing, how would you express the equation of the best fit line from the Force versus Acceleration graph in terms of the variables of this experiment and in mathematical terms?

Force = mass X acceleration, the force is proportional to acceleration, and the proportionality constant is the mass.

5. Do the units of the equation balance?

Yes, $N = kg \cdot m/s^2$

6. For this experimental set up, the calculated values of mass will appear higher than the actual mass of the object. What do you think the apparent systemic error is?

The spring has mass, and a portion of that mass is in motion with the object.

Synthesis Questions

Use available resources to help you answer the following questions.

1. We know from experience that the harder we throw a ball (apply more force), the faster it will be moving (greater initial velocity resulting from acceleration). If you throw a 1 kg softball as hard as you can, and it is traveling at 20 m/s when it leaves your hand, how fast do you think a 5 kg shot put would be traveling with the same throw?

Assuming the "same throw" means that the applied force is equal in both cases, the shot put should be traveling at 4 m/s, or 1/5 the final speed of the softball.

2. We say that force is proportional to acceleration, Given our answer to Question 1, how would you describe the relationship between acceleration and mass?

They are inversely proportional.

3. If we launch a rocket that has been designed to produce a constant force, will the acceleration at initial launch be the same as the acceleration just before the fuel is completely expended? Explain your answer.

Because fuel has mass, the acceleration will be greater when most of the fuel is consumed.

4. A similar experiment is set up such that a force sensor is used to drag a 1.5 kg brick across a table while a motion sensor is used to measure the acceleration. Several trials are conducted, but the slope of the Force versus Acceleration graph is consistently about 2. What might explain the difference? What might you do to improve the results?

The most likely source of this error is friction between brick and table. The friction force always opposes the direction of motion, so the applied force would include the force accelerating the object and the force to overcome the friction. If the applied force is larger to achieve a given acceleration this means the mass would appear to be larger than it is. Reducing friction will improve results. Substituting a cart of the same mass with low friction wheels will dramatically improve results.

Multiple Choice Questions

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

1. Which statement is true if two potatoes of different mass are launched from a potato launcher that applies the same force to each one?

- **A.** The heavier potato will be traveling faster than the lighter one.
- **B. The lighter potato will be traveling faster than the heavier one.**
- **C.** Regardless of their mass, they will be traveling at the same velocity.
- **D.** There is not enough information to draw a conclusion.

2. A rollercoaster is designed to deliver a 3g acceleration at the bottom of a dip. The mass of the cart is 500 kg. and the rider is 100 kg. The track at this point is designed to withstand 15,000 N of force without buckling. Will the cart and rider make it through the dip?

- **A. No, this ride will likely end in disaster.**
- **B.** Yes, the cart and rider will easily make it past the dip.
- **C.** Yes, but a second rider of equal size would not make it through.
- **D.** There is not enough information to draw a conclusion.

3. If a 1,000 kg rocket is launching straight up with its engine producing a force of 39,240 N, what is its acceleration?

- **A.** 9.81 m/s^2
- **B.** 39.24 m/s^2
- **C.** 1000 m/s^2
- **D. 29.43 m/s^2**

4. The acceleration of an object is

- **A.** Proportional to the mass of the object and the force being applied.
- **B**. Proportional to the mass of the object and inversely proportional to the force being applied.
- **C. Proportional to the net force being applied and inversely proportional to the mass of the object.**
- **D.** Always perpendicular to the force of gravity.

5. The net force on an object is

- **A.** Proportional to the force of gravity.
- **B**. **The vector sum of the individual forces acting on the object.**
- **C.** Always balanced by the normal force.
- **D.** Both A and C.

Key Term Challenge

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

1. Newton's **second** law predicts the following relationship between **acceleration**, force, and mass: The acceleration of an object is directly **proportional** to the net force and will always be in the same direction as the net **force**. Acceleration will be inversely proportional to the **mass** of the object, meaning that more massive objects will have less acceleration if subjected to the same net force.

Extended Inquiry Suggestions

Ask your students to repeat the experiment using different masses and different springs to determine if the relationship holds true.

This is a great time to introduce Atwood Machines.

An extended inquiry demo (if you want an opportunity to get your students outside and your school permits, is to load as many students as you can into a vehicle. Then, have three or four strong students push the vehicle with the engine off and the gears disengaged. Try it first with an empty vehicle (with a driver, of course, to steer and brake the vehicle). Notice the acceleration. Then repeat with the vehicle filled with students. It's quite obvious (and memorable) that more massive objects accelerate much less than a less massive object. You can also scale this down to a Kinesthetic Cart and a smooth level floor using students of different sizes

10. Newton's Third Law

Objectives

This experiment clearly illustrates the relationship between an action force and the resulting reaction force. The activity illustrates that:

- Forces occur in pairs, commonly referred to as "action" and "reaction"
- Action and reaction forces never act on the same body
- Action and reaction forces are always equal in magnitude and opposite in direction

Procedural Overview

Determine the force that two dynamics carts exert on each other when they collide on a track. As students explore this interaction, they will vary the mass of the carts as well as which of the carts is moving before the collision occurs.

Determine the force exerted on a friction block as well as the reaction force as the force on a stationary block is gradually increased until it moves with constant velocity.

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor (2)
- Dynamics cart (2)
- Dynamics track
- Compact cart mass, 250-g
- Discover friction accessory
- Spring force sensor bumper[1]
- Collision cup force sensor bumper[1]
- Rubber band
- Balance (1 per classroom)

[1]Part of the Force Accessory Bracket

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Free body diagram
- Newton’s first
- Newton’s second law

Related Labs in this Manual

Labs conceptually related to this one include:

- Introduction to Force
- Newton's First Law
- Newton's Second Law
- Acceleration

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sampling rate �(5.1)
- Recording a run of data �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Showing and hiding data runs in a graph �(7.1.7)
- Changing the variable on the *x*- and *y*-axis �(7.1.9)
- Displaying multiple graphs �(7.1.11)
- Finding the coordinates of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Background

When one object exerts a force on another object, the second object exerts a force of equal magnitude and opposite direction on the first object. Sometimes stated as, "for every action there is an equal and opposite reaction." Newton's third law can be both remarkably clear and perplexing to students, but a clear understanding of Newton's third law will make it much easier for a student to draw free body diagrams and to analyze situations requiring an understanding of Newton's second law. It is important to recognize that forces are like shoes - they occur in pairs. It is impossible to have a single force, for example to have an action force without having a reaction force. Students frequently find it difficult to understand that inanimate objects, like walls and a floor, can exert forces. They may also find it preposterous to believe that walls and a floor exert a gravitational force on the earth that is equal in size to the force the earth exerts on them. The pre-lab discussion and activities address some of these issues. At the end of this activity, students should realize that for every action there is an equal and opposite reaction, without exception.

Pre-Lab Discussion and Activity

Select any number of activities for discussion here.

Forces occur in pairs: Suspend a 1 kg mass from a large stand using a string and pendulum clamp. Give the mass a small push so that it begins to swing. Ask students, "In which direction did I exert a force on the mass?" Then ask them, "Did the mass exert a force on me? If so, in which direction was it? How could I tell that it exerted a force on me?"

Inanimate objects can exert forces: Hold a meter stick with a small mass on the end, and deflect it. Ask the following questions: "How can you tell that I am exerting a force on the meter stick?" It is distorted in shape. “Is the meter stick exerting a force back on me?” Release the meter stick by sliding your finger off the end to show the light mass projected into the air.

Inanimate objects can exert forces: Place a small pane mirror on the floor, and shine a laser pointer on it so that the reflected beam strikes the ceiling. Now ask a student to walk past the mirror so that they step near it. Ask the question, "What does the behavior of the reflected beam tell you about the floor?" The fact that the spot on the ceiling moves means the floor was slightly distorted as the student walked past the mirror.

Objects exert gravitational forces on each other: Ask the questions: "What evidence is there that leads us to believe that the earth exerts a gravitational force on the moon?" The moon orbits the earth. "What evidence is there that leads us to believe that the moon in turn exerts a gravitational force on the earth?" The moon causes tides. On the side of the earth nearest the moon, the water bulges towards the moon. "Why does the gravitational force of the earth on the moon have a much greater effect on the moon's motion than does the gravitational force of the moon on the earth have on the earth's motion? The earth is much more massive than the moon.

Lab Preparation

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

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

3	4	2	1
Give the carts a gentle push so that they collide, and record the results for analysis.	Compare the peak value of force from each sensor.	Zero both force sensors.	Mount a force sensors on each of the carts, and place the cart-force sensor combination on the track.

Procedure with Inquiry

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

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

Part 1 - Action and reaction forces when two bodies push against each other

Set Up

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

2. ☐ Connect the force sensors to the data collection system. �(2.2)

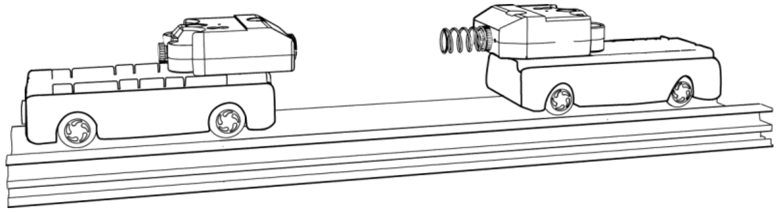
3. ☐ Display two graphs simultaneously, each with Force on the *y*-axis and Time on the *x*-axis, such that the Time axes are aligned and the force measurements can be compared. �(7.1.11)

4. ☐ Change the *y*-axis of one of the two graphs to the opposite force measurement. For example, If both sensors are measuring Force, push positive, change one to Force, pull positive. �(7.1.9)

5. ☐ Why should you change the *y*-axis of one of the two graphs to the opposite force measurement?

The sensors are pointing in opposite directions. So, if a pull is positive for one, it will be negative for the other.

6. ☐ Set the sampling rate to 250 Hz. �(5.1)



7. ☐ Mount a force sensor on each cart, and attach the spring bumper to one force sensor and the collision cup to the other force sensor.

8. ☐ Decide which will be Cart A and which will be Cart B.

9. ☐ Place the carts on the track at either end so that when they collide, the impact will be between the two force sensors.

10. ☐ Press the zero button on each force sensor.

11. ☐ You will examine four different collisions, but before you record data you will predict what the forces associated with each collision will be. Complete the chart below to summarize your predictions. (Your predictions should simply state whether you expect the forces to be the same or different. If you expect the forces to differ in size, specify which you expect to be greater).

Table 1: Predictions - pushing

Collision	Mass		Initial Motion		Predicted Force of Interaction	
Number	**Cart A**	**Cart B**	**Cart A**	**Cart B**	**Force Sensor A**	**Force Sensor B**
1	Same as B	Same as A	Towards B	Towards A	Same	Same
2	Same as B	Same as A	Rest	Towards B	Same	Same
3	Heavy	Light	Towards B	Towards A	Same	Same
4	Heavy	Light	Rest	Towards A	Same	same

Collect Data

12. ☐ Start data recording, and then gently push the carts toward each other. �(6.2)

13. ☐ Allow the carts to collide, and then stop data recording. �(6.2)

14. ☐ Place one cart at the end of the track and the other in the middle of the track.

15. ☐ Start data recording, and then push the cart at the end toward the cart in the middle. �(6.2)

16. ☐ Allow the carts to collide, and then stop data recording. �(6.2)

17. ☐ Place the carts at either end of the track, and place the compact mass in cart A.

18. ☐ Start data recording, and then push the carts toward each other. �(6.2)

19. ☐ Allow the carts to collide, and then stop data recording. �(6.2)

20. ☐ Place one cart at the end of the track and the other in the middle of the track.

21. ☐ Start data recording, and then push the cart at the end toward the cart in the middle. �(6.2)

22. ☐ Allow the carts to collide, and then stop data recording. �(6.2)

Analyze Data

23. ☐ Adjust the scale of your graphs to focus on the first collision, and ensure the Time axes on both graphs are aligned. �(7.1.2)

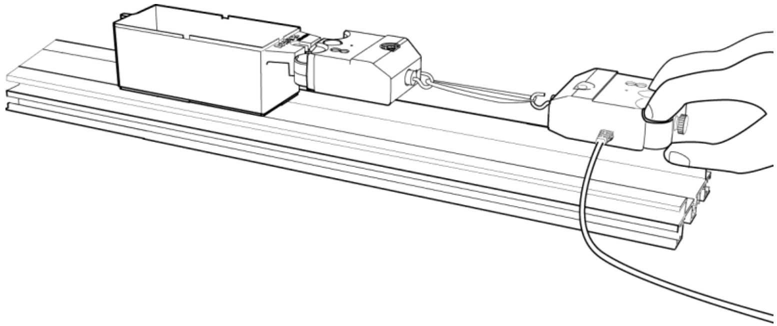
24. ☐ Sketch your graphs of Force versus Time in the Force versus Time – Pushing, blank graph axes in the Data Analysis section.

25. ☐ Find the peak force for each force sensor, and record the peak value in Table 3 in the Data Analysis section. �(9.2)

26. ☐ Show and hide data runs to find the peak force values for each run, and add these values to Table 3 in the Data Analysis section. �(7.1.7)

Part 2 - Action and reaction forces when one body pulls on another

Set Up



27. ☐ Remove the force sensors from the carts and the carts from the track.

28. ☐ Replace the spring bumper and collision cup with the force sensor hooks.

29. ☐ Place a tray from the discover friction accessory on the track, and place the compact cart mass inside the tray.

30. ☐ Attach the first force sensor to the tray from the discover friction accessory, and then connect the hook on the second force sensor to the hook on the first sensor using a rubber band.

31. ☐ As the person holding the second force sensor slowly moves it to the right, the rubber band will be stretched until the force exerted is great enough to cause the tray to start sliding on the track. Complete Table 2 to show your predictions for the size of the force recorded by the hand held force sensor with the size of the force recorded by the force sensor attached to the tray.

Table 2: Predictions - pulling

Stage of Motion	Prediction of How the Two Forces Will Compare
Force is exerted but tray is still at rest	Same
Tray begins to move	Same
Tray moves with a constant velocity	Same

Collect Data

32. ☐ Hold the second force sensor parallel to the track.

33. ☐ Start data recording, and then pull the tray with the second force sensor. �(6.2)

34. ☐ Continue to stretch the rubber band until the tray begins to move.

35. ☐ Drag the tray for a few centimeters, and then stop recording data. �(6.2)

Analyze Data

36. ☐ Adjust the scale of your graphs to show all three parts of the Force versus Time graph, and ensure the Time axes are aligned. �(7.1.2)

37. ☐ Sketch your graphs of Force versus Time in the Force versus Time - Pull, blank graph axes in the Data Analysis section.

38. ☐ Compare the force in each part of the Force versus Time graphs for each force sensor at three points in time, and record these values in each of the three parts of the graph in Table 4 in the Data Analysis section. �(9.2)

39. ☐ How accurate where your predictions? How does the force recorded by the hand held sensor compare to the force recorded by the force sensor attached to the tray when the tray has not yet started to move, when the tray begins to move, and when the tray moves at constant velocity?

In all cases, the force was the same magnitude but opposite in direction.

40. ☐ How does the direction of the force recorded by the hand held force sensor compare with the direction of the force recorded by the force sensor attached to the tray?

The forces are in opposite directions.

41. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Force versus Time - Pushing

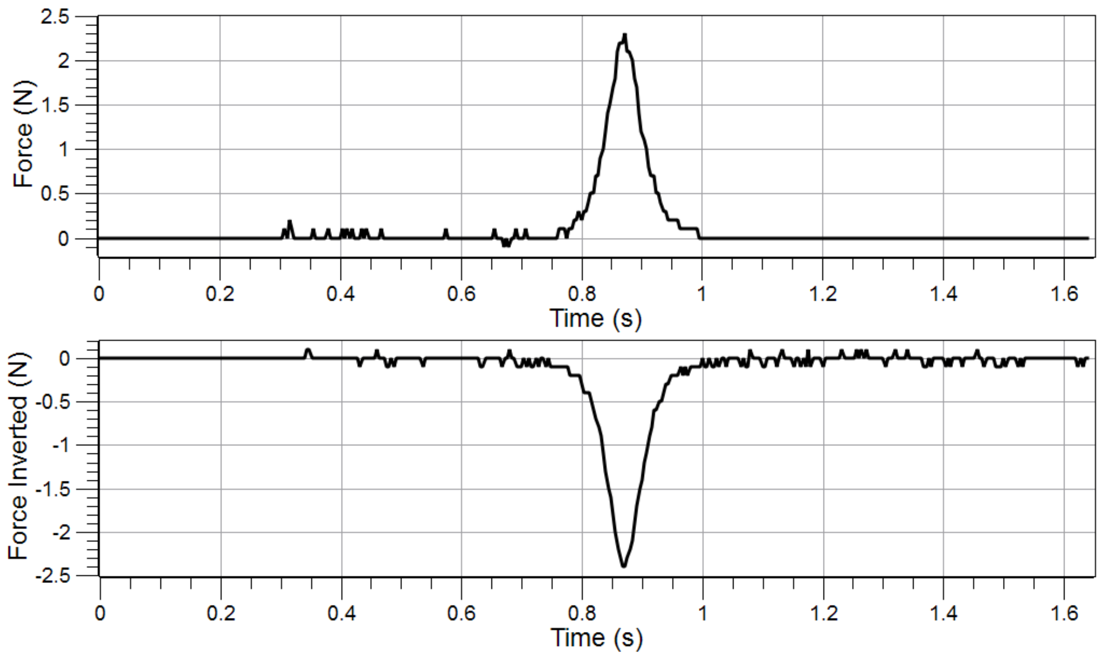


Table 3: Pushing - Peak Forces

Mass		Initial Motion		Peak Force	
Cart A	Cart B	Cart A	Cart B	Force Sensor A	Force Sensor B
Same as B	Same as A	Towards B	Towards A	2.3	-2.3
Same as B	Same as A	Rest	Towards B	1.7	-1.7
Heavy	Light	Towards B	Towards A	2.9	-2.9
Heavy	Light	Rest	Towards A	2.6	-2.6

Force versus Time - Pull

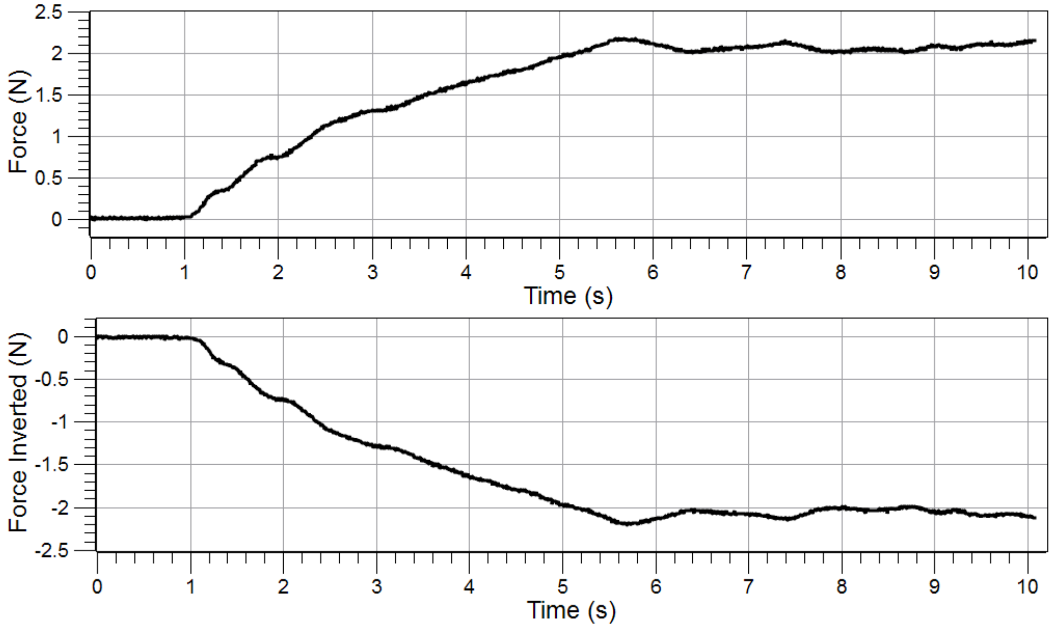


Table 4: Pulling

Stage of Motion	Force Sensor Attached (N)	Force Sensor Pulling (N)
Force is exerted but tray is still at rest	0.8	-0.8
Tray begins to move	2.2	-2.2
Tray moves with a constant velocity	2.0	-2.0

Analysis Questions

1. If you look at all of the interactions studied in this activity, how would you summarize the results in a single sentence?

For every action there is an equal and opposite reaction. Or: When object A exerts a force on object B, object B exerts a force on object A this is equal in size and opposite in direction.

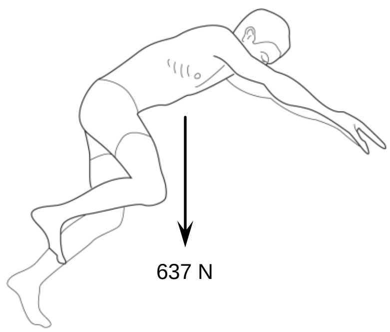
2. In Part 1 of this activity you placed a spring bumpers on the force sensors. What was the advantage in using this modification rather than using the small rubber stopper on the end of each force sensor?

Using the spring bumpers extends the time of interaction. This gives us more data points to examine. If two hard surfaces collided, the interaction time would be very short and it could be more difficult to see the relationship between the action and reaction forces.

Synthesis Questions

Use available resources to help you answer the following questions.

1. **A 65.0 kg Olympic diver dives from a 10 m tower. Consider the instant that the diver is in the air 1 m above the platform. Draw a free-body diagram showing the forces acting on this diver at this instant. In the table below, describe these forces in the "Action" column. Give the size and direction of the force as well as stating what exerts the force. In the "Reaction" column, give a similar detailed description of the reaction force. Assume that the gravitational field strength is 9.80 N/kg.**

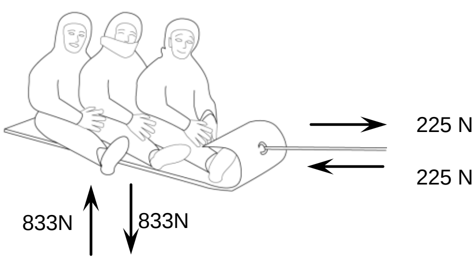


Action	Reaction
A gravitational downward force of 637 N exerted by the earth on the diver.	A gravitational upward force of 637 N exerted by the diver on the earth.

2. **A 65.0 kg tourist is standing in line waiting to get into a theatre. Draw a free-body diagram to show the forces acting on the tourist. In the table below, describe these forces in the "Action" column. In each case, give the size of the force, show its direction, and specify what exerts the force. In the "Reaction" column, describe the reaction for each of the action forces again giving size, direction, and the object that exerts the force.**

Action	Reaction
A gravitational force of 637 N down exerted by the earth on the tourist.	A gravitational force of 637 N up exerted by the tourist on the earth.
A force of 637 N up exerted by the ground on the tourist.	A force of 637 N down exerted by the tourist on the ground.

3. A parent pulls a sled with children at a constant velocity of 0.8 m/s across a level snow covered lawn by exerting a force of 225 N to the west. The mass of the sled and children is 85.0 kg. Draw a free-body diagram to show the forces acting on the loaded sled. In the table below, describe these forces in the "Action" column. In the "Reaction" column, give the size of the force, show its direction, and specify what exerts the force. Assume that the gravitational field strength is 9.80 N/kg.



Action	Reaction
Downward gravitational force of 833 N exerted on the sled by the earth.	An upward gravitational force of 833 N exerted by the sled on the earth.
A westward force of 225 N exerted by the man on the sled.	An eastward force of 225 N exerted by the sled on the man.
An eastward frictional force of 225 N exerted by the snow covered lawn on the sled.	A westward frictional force of 225 N exerted by the sled on the snow covered lawn.
An upward force of 833 N exerted by the snow covered lawn on the sled.	A downward force of 833 N exerted by the sled on the snow covered lawn.

4. A horse that is hitched to a stationary cart begins to pull on the cart. If the force exerted by the cart on the horse is always equal in size and opposite in direction to the force exerted by the horse on the cart, how can the horse move the cart?

The force exerted by the horse on the cart and the force exerted by the cart on the horse act on two different bodies, namely the cart and the horse. Consider the cart. If the horse exerts a force that is greater than the force of friction acting on the cart, then the cart will begin to move.

5. A student holds a force sensor from which a 500 g mass hangs. Suddenly, the force sensor slips out of the student's hand and falls to the floor. What reading does the force sensor show as it falls to the floor?

The force sensor would give a value of 0 N. Earth's gravitational field accelerates the sensor downward at the same rate as the mass so it is impossible for the mass to exert a downward force on the sensor.

6. An astronaut is about 20 m from her space station when the small rocket thrusters she uses to move around run out of fuel. If she is carrying a few tools and can also remove the rocket thruster, what should she do to get back to the space station? Explain your reasoning.

She should take the thruster and or any tools and throw them away in a direction that is opposite to the location of the space station. The force she exerts on these objects will result in an equal and opposite force on her that will give her a brief small acceleration towards the space station. Because there is no friction or air resistance present, she will move at constant velocity toward the space station once her brief period of acceleration is complete.

7. A small economy car experiences a "head-on" collision with a large truck. If the economy car and the truck exert equal and opposite forces on each other, why is the driver of the economy car more likely to suffer serious injuries than the driver of the truck?

The car has a much smaller mass than the truck. As a result the acceleration it will experience as a result of the collision is much greater than that experienced by the truck. For example, if the truck is ten times as heavy as the car, the acceleration experienced by the car will be ten times as large as that experienced by the truck. The two respective drivers will each experience the same acceleration as their vehicle. If the truck is ten times the mass of the car, then the driver of the car will experience ten times the acceleration of the truck driver. Newton's second law tells us that ten times the acceleration means that this driver will experience ten times as much force as well.

8. Two "tug of war" teams are very equally matched. When they pull as hard as they can, the rope they are using is close to the breaking point. If your objective was to break the rope, how could you utilize the two teams to achieve this goal?

Tie one end of the rope to a large sturdy object, such as a massive tree trunk. Now have both teams pull on the rope in the same direction. If the teams pull as hard as before the rope will experience a force twice as large as in the tug-of-war competition. The tree pulls back with the same force as the two teams exert on the rope.

Multiple Choice Questions

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

1. A student attaches a force sensor to a large block on a level surface. The student gradually increases the horizontal force exerted by the force sensor on the block until the block begins to move. If the force sensor records a value of 23.5 N the instant the block begins to move, what is the value of the size of the force exerted by the block back on the force sensor?

A. Less than 23.5 N

B. **23.5 N**

C. More than 23.5 N

D. Either more than 23.5 N or less than 23.5 N depending on the amount of friction present

2. The earth exerts a downward gravitational force on an automobile. The reaction to this force is:

- **A.** The upward force of the ground on the automobile
- **B.** The downward force of the automobile on the ground
- **C. The upward gravitational force of the automobile on the earth**
- **D.** None of the above

3. A soccer player exerts a force of 86 N on a 300 g soccer ball by kicking it. The force exerted by the soccer ball on the player's foot is:

- **A.** 0 N
- **B.** 29.4 N
- **C.** 43 N
- **D. 86 N**
- **E.** 170 N

Key Term Challenge

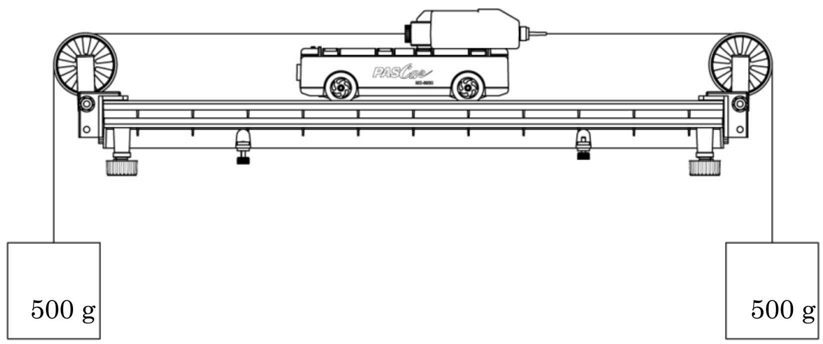
Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

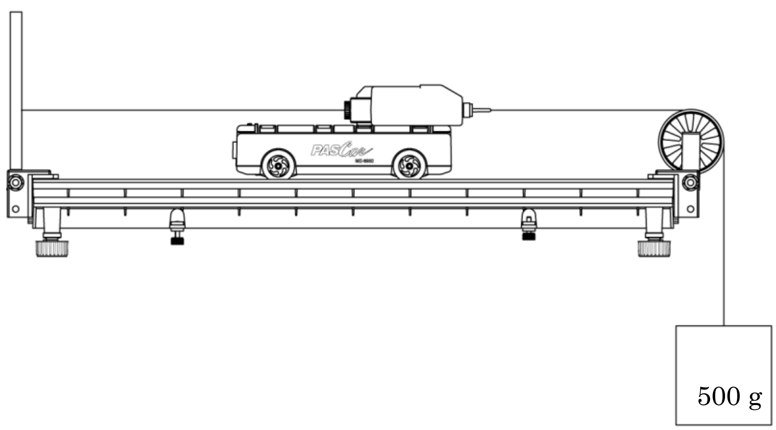
1. If a quarterback exerts a **force** of 150 N [south] on a football, then the **reaction** force is a force of 150 N [north] exerted by the football on the quarterback. If the quarterback is in the air when he makes the throw, the ball will move toward the south and the quarterback will move to the north. The **motion** of the ball will be much more significant because the **mass** of the ball is much less than that of the quarterback.

2. Newton's **third** law is commonly stated as: To every **action** there is an equal and opposite reaction. These forces always occur in **pairs** that are equal in **magnitude** but opposite in **direction**.

Extended Inquiry Suggestions

The diagram below shows two different setups using a dynamics system, super pulley, force sensor, and 500-g mass. The purpose of the cart is to support the force sensor and ensure that friction is negligible. Assuming that g = 9.80 N/kg, predict what the reading the force sensor will record in each of the two situations. Teachers might want to first set up arrangement A, and ask students make a prediction. Then, after predictions are made, the arrangement can be switched to B. Again, ask students to make a prediction. At this point, some students may want to change their prediction for arrangement A. After giving predictions and discussing reasons for predictions, the measurements can be made.





In each case, the force sensor will record a reading of 4.9 N. In situation B, the lab stand pulls to the left with a force of 4.9 N on the force sensor just as the 500 g mass on the left did in situation A.

11. Static and Kinetic Friction

Objectives

This experiment investigates static friction and kinetic (sliding) friction. Students:

- ♦ Compare static and kinetic friction for a system
- ♦ Calculate the static and kinetic coefficients of friction between two surfaces

Procedural Overview

Students gain experience by:

- ♦ Measuring the static and kinetic forces of friction for an object sliding along a track
- ♦ Identifying the static and kinetic forces of friction on a Force versus Time graph
- ♦ Analyzing data collected in the lab to determine the static and kinetic coefficients of friction between two surfaces

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Force sensor
- ♦ Dynamics track[1]
- ♦ Dynamics cart[2]
- ♦ Balance (1 per classroom)
- ♦ Dynamics cart mass (at least 2)[1]
- ♦ Discover friction accessory
- ♦ String, 10 cm (optional)

[1] Any masses and surface can be used. However, the dynamics track and dynamics cart masses give students common results that they can compare with each other. Also, the track is an easy surface to level.

[2] The dynamics cart is only used to level the track.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Normal force
- Newton's second law

Related Labs in This Guide

Labs conceptually related to this one include:

- Introduction to Force
- Position: Match Graph
- Speed and Velocity
- Acceleration

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Selecting data points in a graph �(7.1.4)
- Adding a note to a graph �(7.1.5)
- Finding the values of a point in a graph �(9.1)
- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

Frictional force between an object and a surface is dependent on the normal force acting on the object as well as the composition of the contacting surfaces. There are two forms of frictional force: force of static friction F_s (for stationary objects), and force of kinetic friction F_k (for sliding objects). The direction of frictional force is along the contact surface and generally opposite to the direction of any applied force.

The force of static friction acting on an object stationary on a surface is represented by the equation:

$$F_s = \mu_s F_N \qquad \textbf{Eq.1}$$

where μ_s is the coefficient of static friction between the contacting surfaces and F_N is the magnitude of normal force acting on the object. For objects on flat surfaces, normal force is equal to the mass of the object multiplied by the acceleration due to gravity: $F_N = mg$. The coefficient of static friction is defined as the ratio of maximum static friction force (the maximum amount of force applied laterally before the object begins sliding on the surface) to the normal force acting on the object.

As a force is applied to move an object along a surface, the force of static friction builds up to a maximum just before the object begins to slide along the surface. Kinetic (sliding) friction opposes the motion of an object as it slides over a surface. The force of kinetic friction acting on an object is represented by the equation:

$$F_k = \mu_k F_N \qquad \textbf{Eq.2}$$

Where μ_k is the coefficient of kinetic friction and F_N is the normal force. Typically, the values of kinetic friction are less than those for static friction. In the same way, the coefficient of kinetic friction is less than the coefficient of static friction ($\mu_k < \mu_s$).

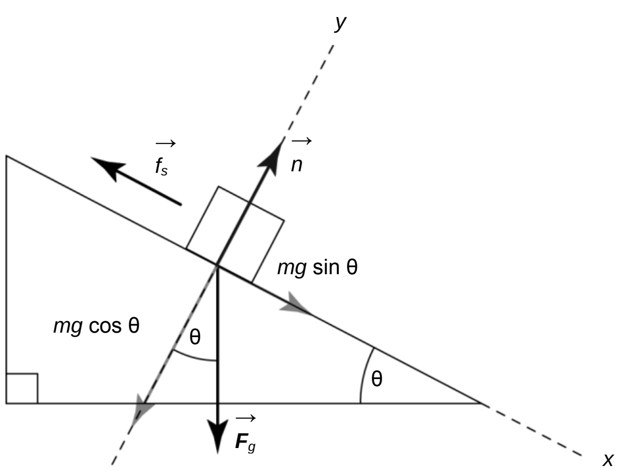
Pre-Lab Discussion and Activity

Engage your students with the following discussion and demonstration:

Start with a quick review of how the force sensor works. Demonstrate how you can use the force sensor to determine the weight of an object hanging from its hook, and how you can also use it to determine the force exerted (both push and pull) on another object. Show how the configuration can be set to make a pulling force either negative or positive. Remind students (and even show them using the sensor) that the force of gravity acting on a body is equal to the object's mass multiplied by the acceleration due to gravity.

1. What experience do you have (or think you have) involving friction? What factors determine the frictional force between objects?

Student answers will vary but the factors involved are the nature of the two surfaces and the normal force acting on the objects.



Show your students how to use the discover friction accessory and how to measure the forces involving friction. Explain that students will get better results if they load the carts with as much mass as possible.

Place a discover friction tray on a dynamics track with additional mass in the tray. Demonstrate how it is possible to tip the track without having the cart move. Continue tipping the track until the cart begins to move, and then reduce the angle until the speed of the cart appears to be constant. Use the diagram (left) to show the components of force involved.

2. Describe what happened.

Tipping the track increased the component of force down the track until it overcame the force of static friction. Reducing the angle of the track until the speed was constant is an attempt to balance the force of kinetic friction and the force exerted by gravity.

3. What does this tell you about the force required to start the object moving versus the force required to keep it moving?

In this case, the force required to start the motion must be larger than the force required to keep the object in motion because a larger angle indicates a greater force down the track.

Note: The angle to begin the motion is usually slightly greater than the angle to keep it moving at constant speed down the plane. The angle to start the motion is called the limiting angle of repose; the angle to maintain a constant speed down the plane is called the angle of uniform slip.

Lab Preparation

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

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

2	5	3	4	1
Start recording Force versus Time data.	Apply statistics to find the average force applied when the cart is pulled at a constant speed.	Begin pulling on the cart, slowly applying more force until it begins to move. Then, pull the cart at a constant speed.	Select the region of the data on your Force versus Time graph that represents the cart moving at a constant speed.	Level the track.

Procedure with Inquiry

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

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

Set Up

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

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

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

4. ☐ Set the data collection system to collect force data at a rate of least 40 samples per second. �(5.1)

5. ☐ Level the dynamics track by placing a dynamics cart on in and adjusting the feet until the car does not move when released on the surface of the track.

6. ☐ Why do you think it is important to level the track?

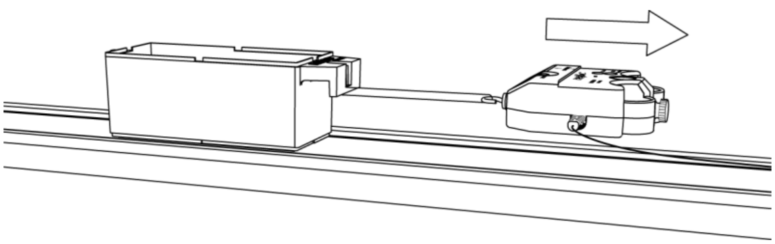
If the track is tilted, there will be a contribution of force from gravity to the force being measured by the force sensor, and the normal force will be slightly less than the weight of the cart and mass.

7. ☐ Place the force sensor flat on the track, and press the zero button on top of the sensor.

8. ☐ Load one of the friction trays with as much mass as possible.

9. ☐ Record the tray's surface type in Table 1 in the Data Analysis section.

10. ☐ Use the balance to determine the mass of the friction tray with load, and then record the mass in kilograms in Table 1 in the Data Analysis section.



11. ☐ Place the friction tray on the track and position the force sensor to pull on the tray with the hook on the force sensor.

Note: you may find it easier to tie a 10 cm piece of string into a loop to pull the friction tray with the force sensor.

Collect Data

12. ☐ Start data recording. �(6.2)

13. ☐ Pulling with the force sensor, slowly and steadily increase the amount of force applied to the friction tray until the cart begins to slide along the track. Once sliding, continue to pull with the force sensor such that the tray moves at a constant speed along the surface of the track for a few seconds.

14. ☐ Stop data recording. �(6.2)

Analyze Data

15. ☐ Add a note to your graph of Force versus Time that identifies the material on the bottom of the friction tray. �(7.1.5)

16. ☐ Find the maximum amount of force that was applied just before the friction tray started to slide, and then record that value as F_s in Table 1 in the Data Analysis section. �(9.1)

17. ☐ Why do you think this point relates to the F_s and therefore the coefficient of static friction for this surface?

This point represents the maximum force of static friction that the surface could apply before the surface breaks free and starts to move.

18. ☐ Select the data points on your graph of Force versus Time that represent the force being applied while the tray moved at a constant speed. �(7.1.4)

19. ☐ Find the average or mean force that was applied while the tray moved at a constant speed, and then record that value as F_k in Table 1 in the Data Analysis section.. �(9.4)

20. ☐ Why do you think we use an average of data points rather than a single point for F_k and therefore the coefficient of kinetic friction for this surface?

There is much more variation in the data when the tray is in motion. Taking an average helps account for random variation in the data.

21. ☐ Sketch your graph of Force versus Time in the Data Analysis section.

22. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Table 1: Object friction data

Parameters	Object 1
Tray's surface material	Cork
Mass of the friction tray and load (kg)	0.600
F_s (N)	3.24
F_k (N)	1.87
F_N (N)	5.89
μ_s	0.55
μ_k	0.32

1. ☐ Calculate the normal force (in this case, it's the weight) of the tray plus its load, and enter this value as F_N in Table 1.

$$F_N = mg = (0.600\,\text{kg})(9.81\,\text{m/s}^2) = 5.89\,\text{N}$$

2. ☐ Why is the normal force equal to the weight in this particular case, but might not be equal to an object's weight in other cases?

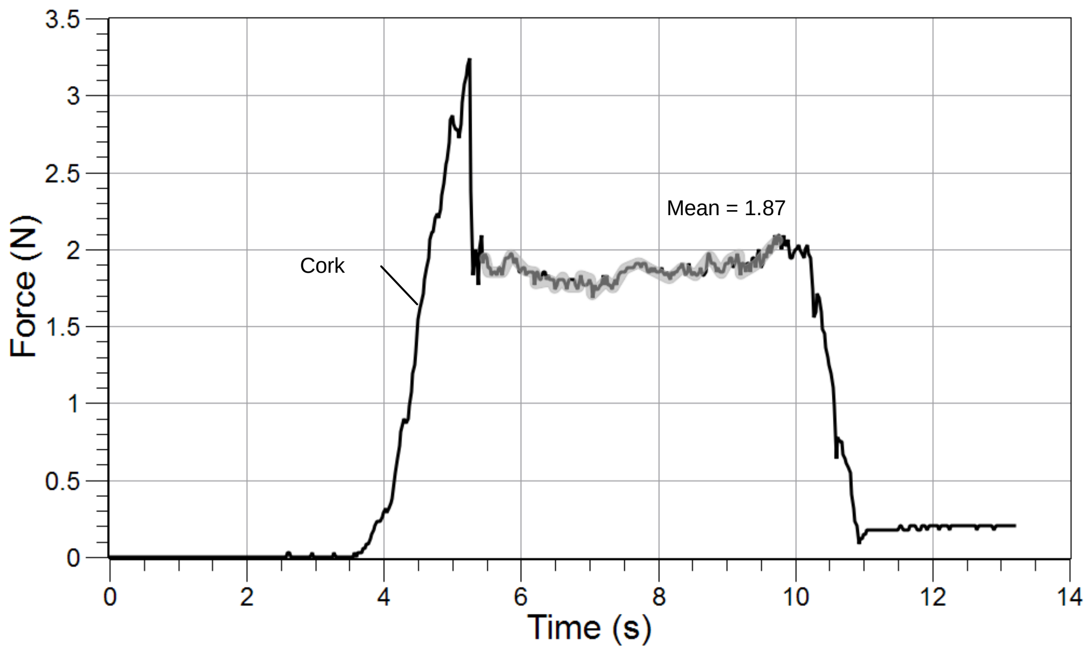
The track is level. So, the force that is perpendicular (or normal) to the surface is the weight of the tray. If the track was not level, then the normal force and the weight would be different forces.

3. ☐ Calculate the static coefficient of friction, and enter this value in Table 1.

$$\mu_s = \frac{F_s}{F_N} = \frac{3.24}{5.89} = 0.55$$

4. ☐ Calculate the kinetic coefficient of friction, and enter this value in Table 1.

$$\mu_s = \frac{F_k}{F_N} = \frac{1.87}{5.89} = 0.32$$



Analysis Questions

1. Why were you asked to put as much mass into the tray as possible?

By loading the friction tray with the largest amount of mass possible, the frictional force required becomes larger as well. All measurements include at lease some small error. By making the force we will measure as large as possible, it makes the error less significant.

2. For the surface you used, was there a noticeable difference between the force of static friction and the force of kinetic friction? Which was larger?

The force of static friction is larger when there is a noticeable difference. In some cases, there truly is not a noticeable difference. This was the case for the felt surface and the rough plastic surface.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If you push on a heavy box that is at rest on a surface, you must exert some force to start its motion. However, once the box is sliding, you can apply a smaller force to maintain its motion. Why?

The force of static friction is larger than the force of kinetic friction.

2. Suppose you are driving a car at a high rate of speed. A driving instructor would tell you that you should avoid rapidly applying your brakes when you want to stop in the shortest possible distance? Using what you have learned in this lab, explain why this is good advice. (Newer cars have antilock brakes that avoid this problem.)

Assuming that the tires' coefficient of static friction is much larger than the coefficient of kinetic friction, you can apply much more force to slow the car if you don't exceed the force of static friction. Once you lock up the wheels, the car is sliding with the smaller force of kinetic friction and therefore takes longer to stop.

3. You place a large crate on the bed of a pickup truck, but do not tie it down.

a. As the truck accelerates forward, the crate remains at rest relative to the bed of the truck. What force causes the crate to accelerate forward?

The force of static friction between the crate and the truck bed causes the crate to accelerate forward.

b. If the driver rapidly applies the brakes, what could happen to the crate? Why?

If the braking generates a force greater than the force of static friction, the crate will continue to move and slide in the bed. (Note that the force of static friction between the crate and the truck bed is certainly going to be substantially less than the force of static friction between the tires and the road.)

Multiple Choice Questions

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

1. A wooden block is launched up an incline plane. After going up the plane, it stops and then slides back down to its starting position. The coefficient of kinetic friction between the block and the plane is 0.25. The time for the trip up the plane:

- **A.** Is the same as the time for the trip down
- **B.** Is more than the time for the trip down
- **C. Is less than the time for the trip down**
- **D.** Cannot be found without knowing the angle of inclination
- **E.** Cannot be found without knowing the mass of the block

2. As a tractor goes up a hill, there is a frictional force between the road and the rear driving tires rolling along the road. The maximum frictional force is equal to:

- **A.** The weight of the tractor multiplied by the coefficient of kinetic friction
- **B.** The normal force of the road multiplied by the coefficient of kinetic friction
- **C. The normal force of the road multiplied by the coefficient of static friction**
- **D.** Zero
- **E.** The weight of the tractor multiplied by the coefficient of static friction

3. **As your car skids with its wheels locked (trying to stop on an icy, snow-covered road), the frictional force between the slippery road and the tires will usually be:**

- **A.** Equal to the normal force of the road multiplied by the coefficient of static friction
- **B.** **Less than the normal force from the road multiplied by the coefficient of static friction**
- **C.** Greater than the normal force of the road multiplied by the coefficient of static friction
- **D.** Greater than the normal force of the road multiplied by the coefficient of kinetic friction
- **E.** Less than the normal force of the road multiplied by the coefficient of kinetic friction

4. **Mary hits a hockey puck and gives it an initial velocity of 6.0 m/s. Assuming that the coefficient of kinetic friction between a rubber hockey puck and a smooth icy surface is 0.050, and assuming that the puck doesn't hit anything along the surface, how far will it slide before stopping?**

- **A.** 19 m
- **B.** 25 m
- **C.** **37 m**
- **D.** 57 m
- **E.** It is not possible to determine the distance without knowing the mass of the puck.

5. **George drives his pickup truck along a straight, horizontal road at 15.0 m/s. In the bed of the truck is a crate of delicate glass crystal chandeliers. George failed to tie down his load. If the coefficient of static friction between the crate and the truck bed is 0.400 and the coefficient of kinetic friction between the crate and the truck bed is 0.300, what is the minimum stopping distance for George's truck so the crate will not slide in the bed?**

- **A.** **28.7 m**
- **B.** 51.0 m
- **C.** 33.6 m
- **D.** 44.4 m
- **E.** It is not possible to determine the stopping distance unless we know the mass of the crate.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. An object sliding freely on a flat surface is subject to three forces: Earth's gravitational force, the normal force opposing the gravitational force, and a **frictional** force between the two surfaces. The frictional force imparted to the sliding object is known as the force of **kinetic** friction. If the object were stationary, the associated frictional force is known as the force of **static** friction. The magnitude of both frictional forces is dependent on the **normal force** imparted to the object by the surface it rests on as well as their respective **coefficients of friction**. Generally speaking, the coefficient of kinetic friction between two surfaces is **less** than the coefficient of static friction between the same surfaces.

Extended Inquiry Suggestions

Ask students to repeat the experiment using friction trays with different surfaces to compare and contrast.

Ask student groups that used the same type surface to compare their results. Ask these groups to build consensus around their results and present their findings to the class.

Ask your students to repeat the experiment with the same friction tray but different masses to explore the effect of mass.

Place a chalkboard eraser on a wooden board, and tip the board up until the eraser begins to move. Then, if you attempt to adjust the angle in such a manner as to have the eraser move down the surface at a constant speed, you would probably find that it is very difficult to achieve that type of motion. Almost always, the eraser will move a short distance and stop. Ask students why they think that is true? The wooden board is highly irregular and actually behaves like many different surfaces. Things such as foreign materials on the board and differences in the texture all can affect the coefficient of friction for areas of the board.

12. Conservation of Energy

Objectives

Students observe the behavior of a cart and track system to see how energy is transformed. By comparing the extremes of the system, the students see that the total energy of the system is conserved. Students:

- Determine the points of maximum gravitational potential energy and kinetic energy
- Calculate values for gravitational potential energy and kinetic energy
- Compare the total energy values to other points in the system to prove that energy is conserved

Procedural Overview

In this investigation, students gain experience with the following tools and techniques:

- Measuring the motion of a cart and track system using a motion sensor
- Interpreting a graph of Position versus Time and Velocity versus Time to determine critical points in the motion of a cart
- Employing basic trigonometric relationships to calculate gravitational potential energy

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes[1]
♦ Lab activity	30 minutes

[1]The roller coaster can take a significant amount of time to set up. If you choose to do this demonstration, you may want to set it up the day before.

Materials and Equipment

For each student or group:

- Data collection system
- Motion sensor
- Dynamics track
- Dynamics track end stop
- Dynamics Cart with plunger
- Dynamics track angle indicator
- Rod stand (to elevate track)
- Balance (1 per classroom)
- Pivot clamp[1]

[1]Most PASCO dynamics systems come with a clamp designed to attach the track to the rod stand. If you are using some other method to elevate your track, like a textbook, this part is not required.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Kinetic energy
- ♦ Gravitational potential energy
- ♦ Spring potential energy

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Position: Match Graph
- ♦ Speed and Velocity
- ♦ Acceleration
- ♦ Work and Energy

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Changing the sample rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adding a note to a graph �(7.1.5)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Measuring the distance between two points in a graph �(9.2)
- ♦ Creating calculated data �(10.3) (see Extended Inquiry Suggestions)
- ♦ Saving your experiment �(11.1)

Background

Energy is a key concept in science, and the law of conservation of energy is one of the most fundamental tenets of Physics. While energy may be converted from one form to another (electrical to light, gravitational potential to mechanical, nuclear to heat), the total energy of any closed system remains conserved. There is a separate equation for each form of energy. For gravitational potential energy GPE, or energy of position, the equation is:

$$\text{GPE} = mgh \qquad \textbf{Eq.1}$$

For an object on earth, the mass m and the acceleration due to gravity g, remain constant. Hence, only the change in height h influences any change in gravitational potential energy. For kinetic energy KE, or energy of motion, the equation is:

$$\text{KE} = \frac{1}{2}mv^2 \qquad \textbf{Eq.2}$$

For this same object, any change in the kinetic energy is influenced by the change in velocity v.

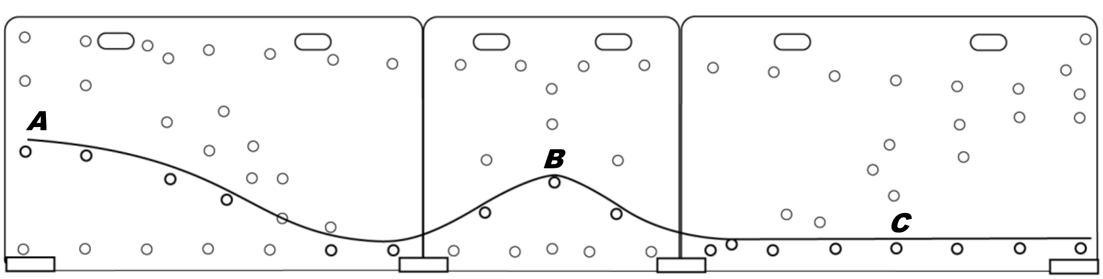
Pre-Lab Discussion and Activity

For Demonstration Station:

- ♦ Data collection system
- ♦ Photogates (2)
- ♦ Rollercoaster system

Engage your students by connecting energy transfer concepts to their real world experience.

Most students have some understanding of how a roller coaster works. For students who are unfamiliar, it may be necessary play a video before getting into the demonstration. The Roller Coaster System ME-9812 can be combined with photogate timing to illustrate the change in energy for a cart in motion at different points on the track. If you do not have photogate timing for your data collection system, you can use the ME-8930 Photogate Timer.



Teacher Tip: Because the backboard for the system is a whiteboard, you can draw diagrams directly on the board using whiteboard pens.

Connect Photogates at points B and C so that velocity can be calculated at these points. Go through the calculation with your class of gravitational potential energy for points A and B relative to point C. If time permits, challenge your students to calculate what the velocity should be at points B and C if energy is conserved. Place the cart at point A, and begin collecting data. You may want to collect several runs to show that the results are consistent. Use the timing data to calculate velocity and then kinetic energy at

points B and C. Identify for your students that A and C represent points where you have extremes. The cart resting at point A has only gravitational potential energy, and the cart at point C has only kinetic energy. Combine the results at point B, and see how they compare to A and C.

1. Although the energy at A and the energy at C are close, the energy at point C is slightly less. Where do you think the energy went?

The energy was lost as heat caused by friction.

Lab Preparation

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

1. Allow ample time for assembling the roller coaster system for demonstration purposes. Set up of the roller coaster system for the pre-lab discussion can take a considerable amount of time. If you choose to do this demonstration, you may want to set it up the day before.

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

1	5	2	4	3
Connect the track to the rod stand using the rod clamp.	Use the distance traveled *d* and the angle of the track θ to calculate the maximum height *h* that the cart traveled.	Collect a run of position data with the cart standing still, and record the initial position of the cart.	From your graph, determine the distance *d* traveled by the cart.	Start collecting data, then tap the release button to launch the cart.

Procedure with Inquiry

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

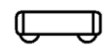
Note: Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these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

Set Up

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

2. ☐ Connect the end stop to the end of the dynamics track. Then use the rod clamp to attach the track to the rod stand near the other end.

3. ☐ Connect the motion sensor to the end of the track with the face of the sensor pointed toward the end stop. Be sure the switch on the sensor is in the cart position.



4. ☐ Use the balance to determine the mass of your cart and record the mass in Table 1.

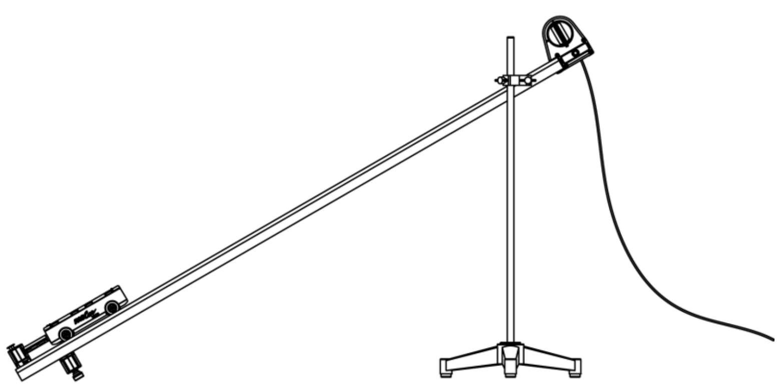
5. ☐ Connect the motion sensor to the data collection system. �(2.1)

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

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

8. ☐ Make sure that the sampling rate of your data collection system is at least 20 samples per second. �(5.1)

9. ☐ Place the cart, with the plunger extended, on the track against the end stop.



10. ☐ Record a data run that shows the initial position of the cart relative to the motion sensor, and record this value in Table 1. �(6.2)

11. ☐ Why do you think we set the cart in position with the plunger extended?

Because kinetic energy is dependent on velocity, we want to be sure to measure the maximum kinetic energy as the cart leaves the bumper. Because potential energy is dependent on height, we want to measure the position consistently from the point where the spring no longer influences the cart.

12. ☐ Cock the plunger and then gently tap the release button to launch the cart. Be sure you use the same plunger position throughout this part of the lab.

13. ☐ Why do you think it is important to use the same plunger position?

We want to ensure that we measure the same initial velocity with each run of data.

14. ☐ Observe the motion of the cart, making certain the cart never gets closer than 15 cm to the motion sensor.

15. ☐ What would you change if the cart gets too close to the motion sensor?

We would increase the angle of the track or use a weaker plunger setting.

16. ☐ Use your angle indicator to record the angle of the track θ in Table 1.

Collect Data

17. ☐ Cock the plunger and place the cart in position on the track with the plunger against the bumper.

18. ☐ Start data recording and then tap the release button to launch the cart. �(6.2)

19. ☐ Allow the cart to bounce once or twice before stopping data recording. �(6.2)

Analyze Data

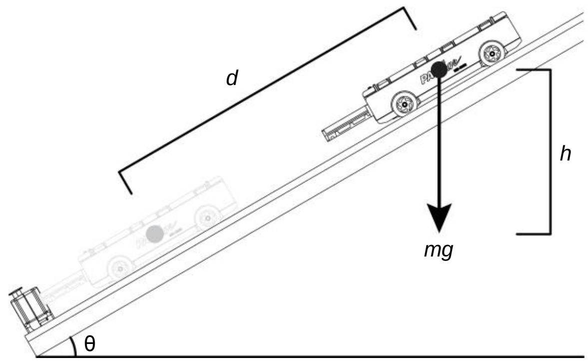
20. ☐ Sketch the graph of Position versus Time in the space provided in the Data Analysis section.

21. ☐ Use your data collection system to determine the difference between the initial position and the closest point to the motion sensor, or the distance traveled d. �(9.2)

22. ☐ Identify the points you used in your sketch.

23. ☐ Record the distance d you measured in Table 1.

24. ☐ Use the distance traveled d and the angle of the track θ to calculate the maximum height h that the cart traveled. Record your answer in Table 1.



$$h = d \cdot \sin\theta$$

$$h = 0.547 \cdot \sin(9.0)$$

$$h = 0.085$$

25. ☐ Use the height h, the acceleration due to gravity g (9.8 m/s^2), and the mass of the cart m to calculate the gravitational potential energy of the system with the cart at the top of the track. Record your answer in Table 1.

$$\text{GPE} = mgh$$

$$\text{GPE} = 0.250 \cdot 9.81 \cdot 0.085$$

$$\text{GPE} = 0.208$$

26. ☐ Given that the cart momentarily comes to a complete stop before rolling back down the track, what is the kinetic energy of the system at this point? Why?

The kinetic energy of the system at this point is zero because the velocity of the cart is zero.

27. ☐ Because the total energy of this system is comprised of the kinetic energy and the gravitational potential energy, what is the total energy of the system at this point?

The total energy of the system at the top of the arch is the gravitational potential energy.

28. ☐ Sketch your graph of Velocity versus Time in the space provided in the Data Analysis section.

29. ☐ Find the maximum velocity v achieved by the cart on the data run. �(9.1)

30. ☐ Identify the point you used in your sketch.

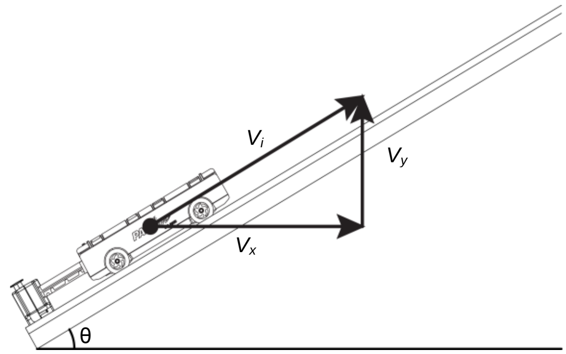
31. ☐ Record the maximum velocity v you measured in Table 1.

32. ☐ Use the maximum velocity of the cart v and the mass of the cart m to calculate the maximum kinetic energy of the system with the cart at the bottom of the track. Record the kinetic energy in Table 1.

$$KE = \frac{1}{2}mv^2$$

$$KE = 0.5 \cdot 0.250 \cdot (-1.26)^2$$

$$KE = 0.199$$



33. ☐ If the point at which the cart leaves the bumper is the lowest point of the system, what is the gravitational potential energy of the system at this point? Why?

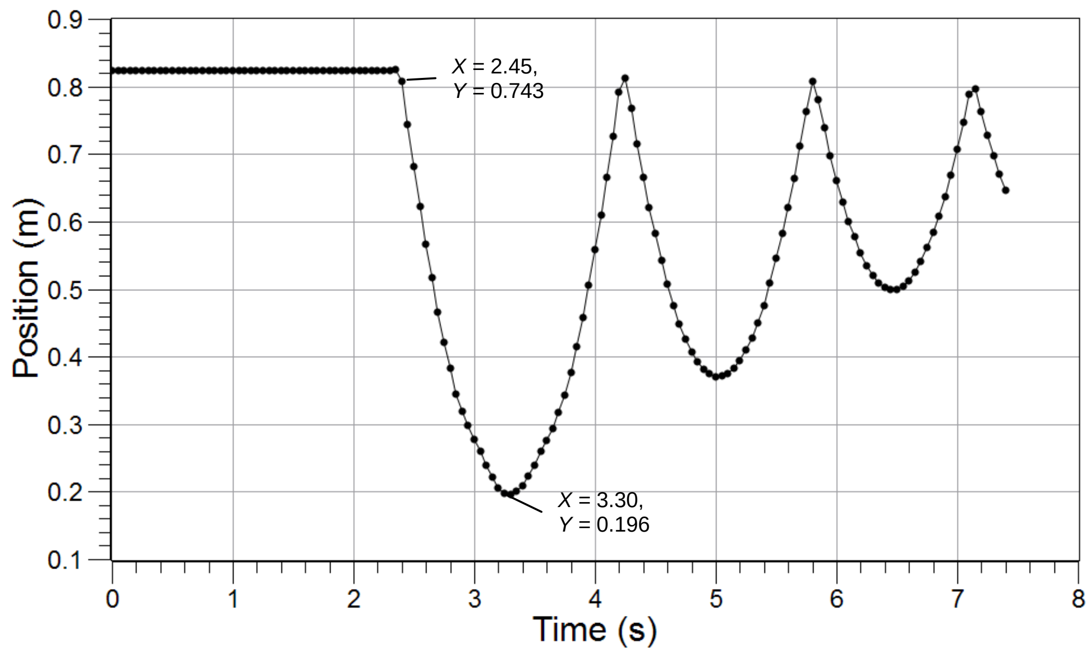
The gravitational potential energy of the system at this point is zero because the height of the cart is zero.

34. ☐ Because the total energy of our system is comprised of the kinetic energy and the gravitational potential energy, what is the total energy of the system at this point?

The total energy of the system at the bottom of the track is the kinetic energy.

Data Analysis

Position versus Time



Velocity versus Time

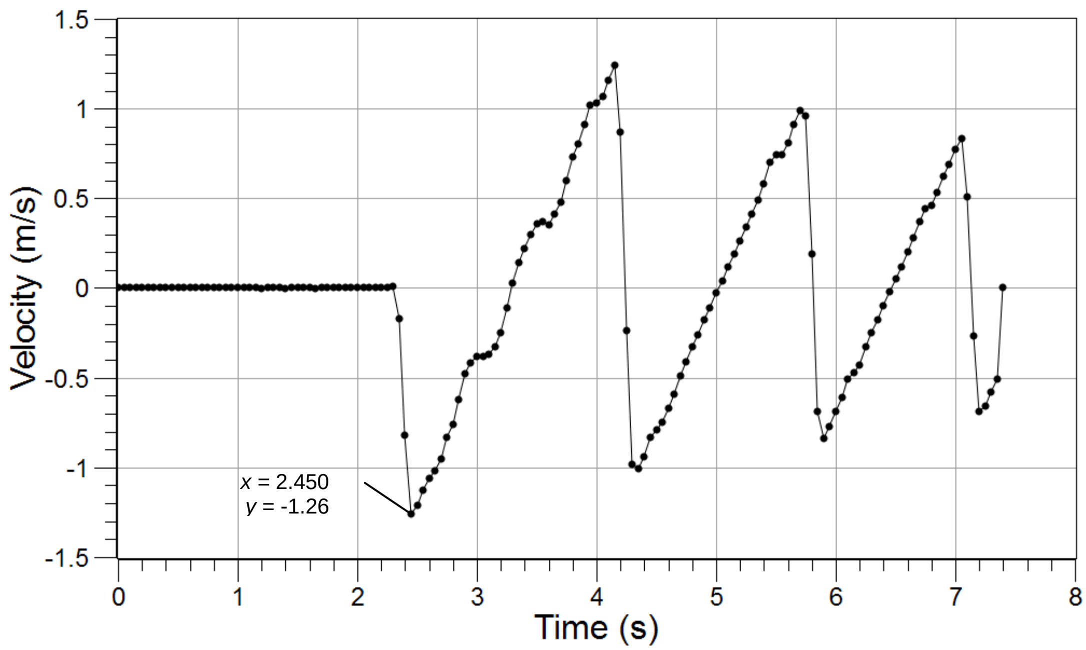


Table 1: System energy determination

Parameter	Values
Mass of cart (kg)	0.250 kg
Initial position (m)	0.776 m
Track angle (degrees)	9°
Distance traveled (m)	0.547 m
Maximum height (m)	0.085 m
Maximum gravitational potential energy (J)	0.208 J
Maximum velocity (m/s)	–1.26 m/s
Maximum kinetic energy (J)	0.199 J
Time of your test point (s)	2.65 s
Kinetic energy of your test point (J)	0.130 J
Gravitation potential energy of your test point (J)	0.087 J
Total energy of the system at your test point (J)	0.217 J

1. ☐ Select a data point between the point of maximum kinetic energy and maximum gravitational potential energy as a test point and record the time of this point in Table 1.

2. ☐ Identify this point on both of the graphs you sketched above. �(7.1.5)

Time = 2.65 s, *h* = 0.035 m, *v* = 1.02 m/s

3. ☐ Calculate the kinetic energy at this point and record the value in Table 1.

$$\mathrm{KE} = \tfrac{1}{2}mv^2$$

$$\mathrm{KE} = 0.5 \cdot 0.250 \cdot (0.102)^2$$

$$\mathrm{KE} = 0.130$$

4. ☐ Calculate the gravitational potential energy at this point, and record the value in Table 1.

$$\mathrm{GPE} = mgh$$

$$\mathrm{GPE} = 0.250 \cdot 9.81 \cdot 0.085$$

$$\mathrm{GPE} = 0.087$$

5. ☐ Calculate the total energy of the system at your test point, and record the value in Table 1.

$$\mathrm{TE} = \mathrm{KE} + \mathrm{GPE}$$

$$\mathrm{TE} = 0.130 + 0.087$$

$$\mathrm{TE} = 0.217$$

Analysis Questions

1. How does the total energy of the system compare at the three different points in time that you investigated? Was energy conserved? Explain your answer.

The total energy of the system at each point is not exactly the same, but they are very close.

2. At what point in the cart's path was the kinetic energy of the system greatest? Where did that original energy come from?

The kinetic energy is greatest when the cart is first launched. This initial energy comes from the mechanical energy stored in the spring of the plunger. Some students may also indicate the initial energy was added to the system when they cocked the plunger.

3. In observing the motion of the cart, the second and third bounces of the cart were lower than the first, indicating less energy. Where did the energy go? In what form was it when it was lost?

The energy of the system is depleted through friction and vibration in the form of heat and sound.

Synthesis Questions

Use available resources to help you answer the following questions.

1. An archer's bow can store 80 J of energy when drawn. If all that energy is converted to kinetic energy when the arrow is released, how fast is the 0.1 kg arrow traveling when it leaves the bow?

$$\text{TE} = \text{PE} = \text{KE} = \tfrac{1}{2}mv^2 = 0.5 \cdot 0.1 \cdot v^2 = 80$$

$$v^2 = \frac{80}{.05}$$

$$v^2 = 1600$$

$$v = 40$$

The arrow is traveling at 40 m/s.

Multiple Choice Questions

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

1. How much gravitational potential energy does a 4 kg jug of milk set on the edge of a counter 1.2 m above the ground have?

- **A. 47.1 J**
- **B.** 471 J
- **C.** 0 J
- **D.** There is not enough information to draw a conclusion.

2. A bobsled and rider have 100 kg of mass combined. They reach the bottom of the hill having attained a speed of 72 km/hr. Assuming all of their gravitational potential energy was converted to kinetic energy, how high was the hill?

- **A.** 204 m
- **B.** 42
- **C. 20.4 m**
- **D.** 264.2 m

3. A giant pendulum swings up to a height of 10 meters above the floor. When it reaches the bottom of its swing it is traveling at 14 m/s. What is the mass of the pendulum?

- **A.** 1000 kg
- **B.** 100 kg
- **C.** 9.81 kg
- **D.** **There is not enough information to draw a conclusion.**

Key Term Challenge

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

1. In an ideal "friction free" environment, a cart poised at the top of a hill has **gravitational potential** energy. As the cart begins to roll down the hill, this **energy** is transformed into **kinetic** energy. When the cart reaches the bottom of the hill the **total** energy of the system is entirely comprised of kinetic energy. In the real world, some of this energy would be lost to **friction** in the form of heat.

2. Increasing the **height** of an object increases its gravitational potential energy. Increasing the **velocity** of an object increases the kinetic energy of the object. If the total **energy** is **conserved,** and the closed system only has these two types of energy, then an increase in one form of energy results in a **decrease** in the other.

Extended Inquiry Suggestions

Ask your student to create a calculation for kinetic energy and for potential energy using their data collection systems. �(10.3) Next, have your students create a calculation for total energy that combines their first two equations. Have your students create a graph for each of the calculations and as a group discuss the meaning of each graph. Try to determine the amount of energy lost to friction using the Total Energy versus Time graph.

13. Conservation of Momentum

Objectives

This lab exposes students to the concept of momentum and its conservation during common types of collisions. Students:

- ♦ Graphically understand both elastic and inelastic collisions
- ♦ Test the idea of Conservation of Momentum in different types of collisions
- ♦ Notice what happens with force, velocity, and linear momentum during the collision

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Set up experimental trials for elastic and inelastic collisions, as well as an "explosion" type separation of two moving vehicles.
- ♦ Measure the velocity of two objects at the same time with motion sensors.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	50 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Motion sensor (2)
- ♦ Dynamics track
- ♦ Dynamics carts with magnet bumpers, Velcro® bumpers, and plungers (2)
- ♦ Balance (1 per classroom)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Definition of momentum
- Transfer of momentum
- Position versus Time graphs and Velocity versus Time graphs

Related Labs in this Manual

Labs conceptually related to this one include:

- Position: Match Graph
- Speed and Velocity
- Acceleration
- Conservation of Energy
- Impulse Momentum

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Selecting data points in a graph �(7.1.4)
- Changing the variables on the *x*- or *y*-axis of a graph �(7.1.9)
- Displaying multiple graphs simultaneously �(7.1.11)
- Creating calculated data �(10.3)

Background

The momentum ***p*** of an object is the product of its mass and velocity:

$$\boldsymbol{p} = m\boldsymbol{v}$$

Because velocity is a vector quantity, momentum is therefore a vector quantity. For a linear system that is not influenced by outside forces, the total momentum of the system is conserved. We will use a cart and track system as the isolated system and observe three different types of momentum exchange.

Elastic collisions occur when two objects bounce off each other, like two billiards balls colliding, or a golf club hitting a golf ball. Linear momentum is transferred from one object to the next, if the two objects are the same mass, all of the momentum of the first is transferred to the second. This is the principle behind a Newton's Cradle. Inelastic collisions occur when two objects hit and stick together, moving as one object after the collision like one train car coasting into another and coupling together. "Explosions" refer to two objects pushing away from each other like two ice skaters facing each other and pushing off. Even though these situations are very different, the principles behind them are the same. As systems get more complex, two dimensional and three dimensional, the underlying behavior is the same.

Pre-Lab Discussion and Activity

Begin this lab discussion by reminding students what momentum is, namely, mass × velocity. A great starting point would be a discussion about billiard balls: what happens when a billiards player hits the cue ball (the white one) directly at another ball of similar mass so that they hit head on? Usually, the cue ball will stop, and the other ball will move away at the same speed as the cue ball's initial speed. Ask students about this situation to check their intuitive understanding of momentum:

1. What is the momentum of the cue ball initially?

Mass (cue ball) × Velocity (cue ball)

2. What is the momentum of the stationary ball initially?

Zero

3. What is the total momentum of the system (both balls together) before the collision?

Mass (cue ball) × Velocity (cue ball) + Mass (other ball) × Velocity (other ball)

4. What about after the collision? What's the momentum of the cue ball after collision?

Zero

5. What is the momentum of the other ball after collision?

Mass (other ball) × Velocity (other ball)

So the total momentum after collision is the same as the total system momentum before collision. Now consider the ball that's moving after the collision. Does it keep moving forever? Of course not; it eventually slows down and comes to rest because of rolling friction with the surface of the billiards table. But if friction is minimized and accurate measurements can be taken both before and after the collision, students should be able to verify (within reasonable error ranges) that momentum is conserved in 3 different types of events.

6. What two quantities must be measured to calculate an object's momentum?

The object's mass and its velocity.

7. If two objects will be moving, what additional equipment will be needed to accurately measure each object's momentum?

Students will need two motion sensors to track the velocity of each cart before and after collisions.

8. If two objects collide, what must be true if their momentum is to be conserved?

No external forces must be present, so friction must be minimized to conserve momentum.

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:

- Make sure students catch dynamics carts before they go off the track or hit the motion sensors.

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	1	4	2
Determine the velocity of the carts before and after the collision from your graph.	Compare the total momentum of the system before the collision to the total momentum of the system after the collision.	Set up a dynamics track with two motion sensors and two carts to engage in collisions.	Calculate the momentum of each cart before and after the collision.	Push one cart toward another stationary cart so that they bounce off each other, and gather data for an elastic collision.

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 - Elastic Collision

Set Up

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

2. ☐ Connect the motion sensors to your data collection system. �(2.2)

3. ☐ Set the track on a level surface with a motion sensor attached to each end. Be sure the sensors are positioned horizontally to best receive signals from the moving carts on the track.

Note: The motion sensors are pointed in opposite directions. Choose which sensor will be your point of reference. Remember that moving away from this sensor will be the positive direction, so the direction reported by the other sensor will need to be corrected.

4. ☐ In the data collection system, create a calculation to reverse the sign of one of your motion sensors. �(10.3)

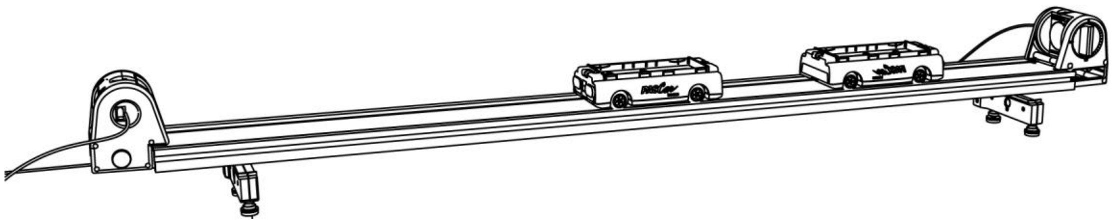
Velocity2 = –[Velocity (m/s)]

5. ☐ Display two graphs simultaneously: one graph will display Velocity on the y-axis and Time on the x-axis and the second will display Velocity2 on the y-axis and Time on the x-axis . �(7.1.11)

6. ☐ Make sure that your sampling rate is set to at least 20 samples per second for each motion sensor. �(5.1) If your motion sensors have a selector switch, make sure that they are in the cart or near setting. 

7. ☐ Find the mass of each cart, and record them in Table 1 in the Data Analysis section.

8. ☐ Place Cart 2 in the middle of the track and Cart 1 near one end of the track (just over 15 cm from the motion sensor) such that their magnetic bumpers are facing each other.



9. ☐ Make sure someone is at the other end of the track to catch the cart before it hits the motion sensor because you will be pushing the cart closet to the motion sensor toward the cart in the middle of the track.

Collect Data

10. ☐ Start data recording. �(6.2)

11. ☐ While keeping hands out of the way of the motion sensors, push Cart 1 toward Cart 2, and let them collide.

12. ☐ Catch Cart 2 before it hits the second motion sensor.

13. ☐ Stop data recording. �(6.2)

Analyze Data

14. ☐ Adjust the scales of your graphs so that all of the data is visible, and the Time scales are aligned. �(7.1.2)

15. ☐ Find the velocity of Cart 1 on the graph just before the collision and just after the collision, and enter the values in Table 1 in the Data Analysis section. �(7.1.4)

16. ☐ Find the velocity of Cart 2 on the graph just before the collision and just after the collision, and enter the values in Table 1 in the Data Analysis section. �(7.1.4)

17. ☐ Sketch your Velocity versus Time graphs in the Velocity versus Time - Elastics Collision blank graph axes in the Data Analysis section.

Part 2 - inelastic Collision

Set Up

18. ☐ Put the carts in position again, but this time orient the carts so that they will hit Velcro to Velcro and stick together.

Collect Data

19. ☐ Start data recording. �(6.2)

20. ☐ While keeping hands out of the way of the motion sensors, push Cart 1 toward Cart 2, and let them collide.

21. ☐ Catch Cart#1 and Cart 2 before they hit the second motion sensor.

22. ☐ Stop data recording. �(6.2)

Analyze Data

23. ☐ Adjust the scales of your graphs so that all of the data is visible, and the Time scales are aligned. �(7.1.2)

24. ☐ Find the velocity of Cart #1 on the graph just before the collision and just after the collision, and then enter the values in Table 2 in the Data Analysis section. �(7.1.4)

25. ☐ Find the velocity of Cart 2 on the graph just before the collision and just after the collision, and then enter the values in Table 2 in the Data Analysis section. �(7.1.4)

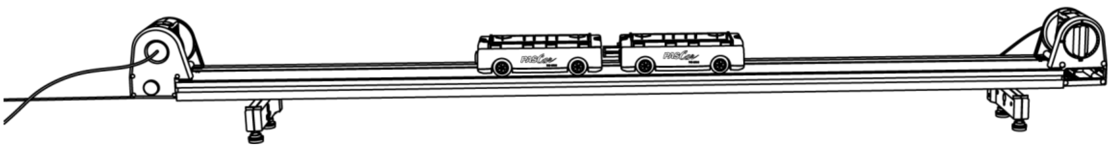
26. ☐ Sketch your Velocity versus Time graphs in the Velocity versus Time - Inelastic Collision blank graph axes in the Data Analysis section.

Part 3 - Explosion

Set Up

27. ☐ Push in the plunger on Cart 1 to the second position so that it is ready to push the carts away from each other in an "explosion."

28. ☐ Place the carts together in the middle of the track with the cocked plunger on Cart 1 just touching the flat end of Cart 2.



Collect Data

29. ☐ Start data recording. �(6.2)

30. ☐ While keeping hands out of the way of the motion sensors, tap the plunger release button to send the carts in opposite directions.

31. ☐ Catch the carts before they hit the motion sensors.

32. ☐ Stop data recording. �(6.2)

Analyze Data

33. ☐ Adjust the scales of your graphs so that all of the data is visible and the Time scales are aligned. �(7.1.2)

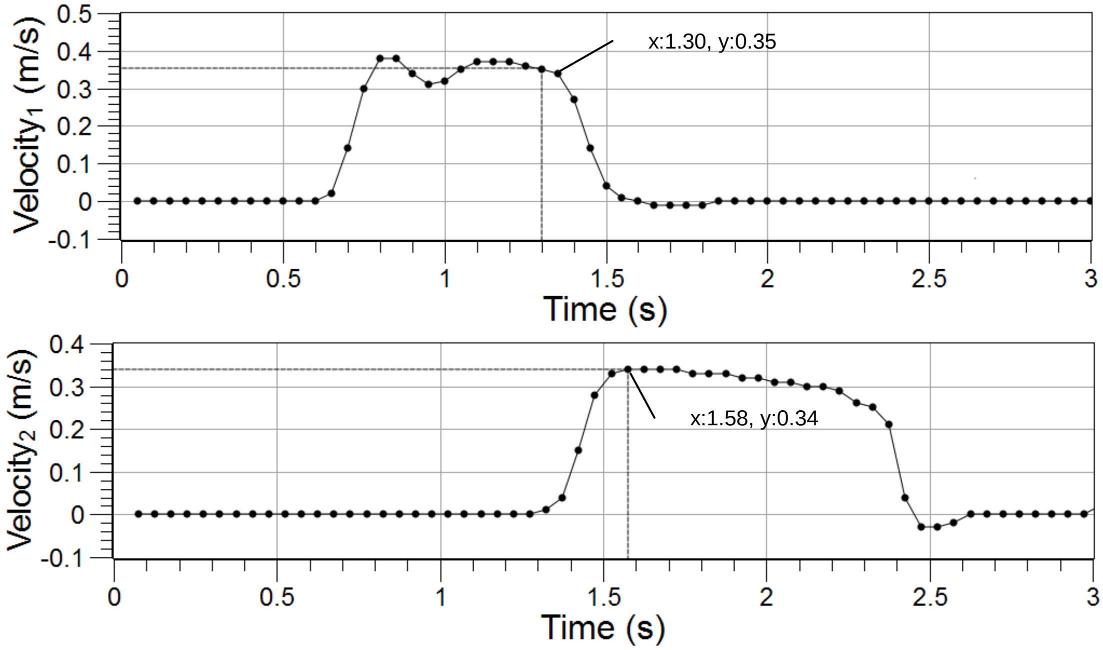
34. ☐ Find the velocity of Cart #1 on the graph just before the collision and just after the collision, and enter the values in Table 2 in the Data Analysis section. �(7.1.4)

35. ☐ Find the velocity of Cart 2 on the graph just before the collision and just after the collision, and enter the values in Table 2 in the Data Analysis section. �(7.1.4)

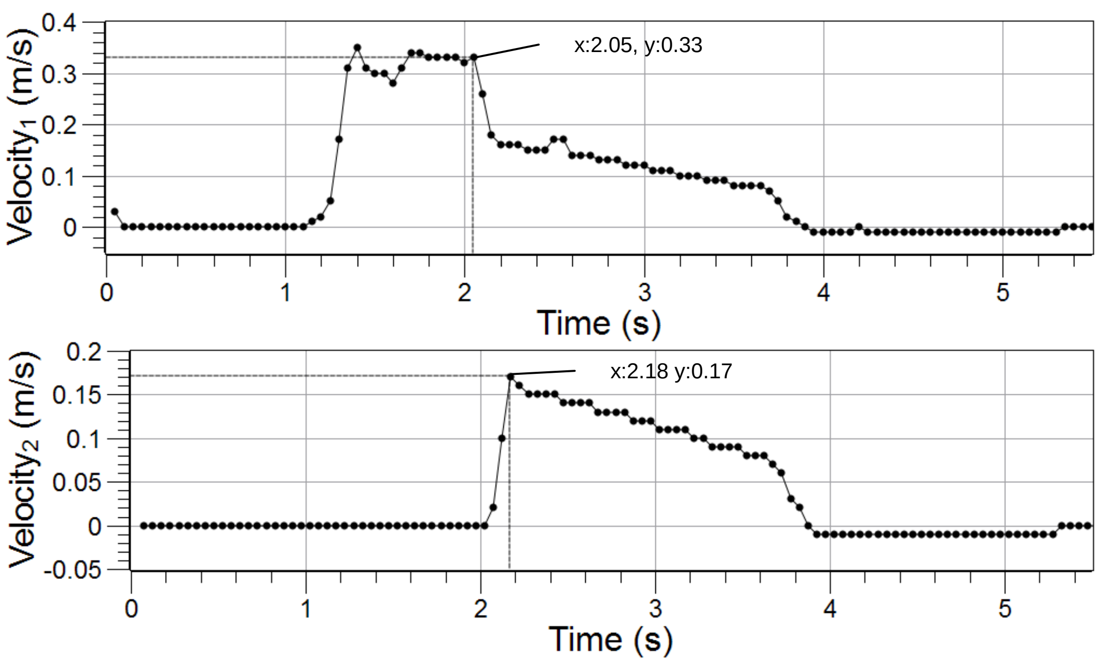
36. ☐ Sketch your Velocity versus Time graphs in the Velocity versus Time - Explosion blank graph axes in the Data Analysis section.

Data Analysis

Velocity versus Time - Elastics Collision



Velocity versus Time - Inelastic Collision



Velocity versus Time - Explosion

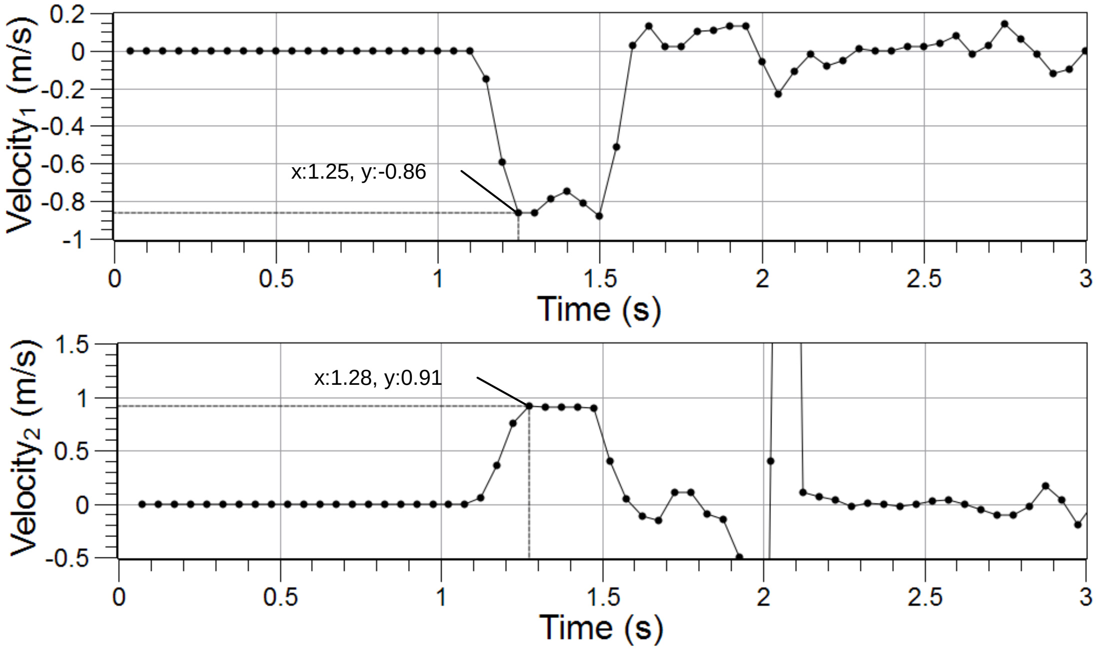


Table 1: Elastic Collision

	Cart 1	Cart 2
Mass	0.258 kg	0.249 kg
Initial Velocity	0.35 m/s	0 m/s
Final Velocity	0 m/s	0.34 m/s
Initial Momentum	0.090 kg·m/s	0 kg·m/s
Final Momentum	0 kg·m/s	0.085 kg·m/s

Table 2: Inelastic Collision

	Cart 1	Cart 2
Mass	0.258 kg	0.249 kg
Initial Velocity	0.33 m/s	0 m/s
Final Velocity	0.17 m/s	0.17 m/s
Initial Momentum	0.085 kg·m/s	0 kg·m/s
Final Momentum of Cart 1 and Cart 2	0.086 kg·m/s	

Table 3: Explosion

	Cart 1	Cart 2
Mass	0.258 kg	0.249 kg
Initial Velocity	0 m/s	0 m/s
Final Velocity	-0.86 m/s	0.91 m/s
Initial Momentum	0 kg·m/s	0 kg·m/s
Final Momentum	-0.22 kg·m/s	0.23 kg·m/s

Analysis Questions

1. Look at your graphs for the elastic collision. How does the velocity of Cart 1 before the collision compare to the velocity of Cart 2 after the collision?

They are about the same.

2. Explain why this is significant, and be sure to include momentum in your explanation, not just velocity.

The velocity of Cart 1 before the collision is very close to the velocity of Cart 2 after the collision. Because the mass of the carts is roughly the same, this quick graphical analysis shows that momentum is conserved in this collision.

2. Consider the graph for your inelastic collision. How does the final velocity of the carts compare to the initial velocity of Cart 1? What does this tell you about the collision?

The velocity after the collision is about half of Cart 1's initial velocity before the collision. Because both carts stick together after the collision (and they have about the same mass), the mass is doubled, so the velocity after the collision should be about half of Cart 1's velocity before collision.

3. Look at your graph for the "explosion" trial. How do the velocities of each cart compare before and after the "explosion?"

The velocities are the same, but in opposite directions.

4. What is the total momentum of the system after the "explosion?"

Zero because the carts are moving in opposite directions at about the same speed with the same mass. Therefore, momentum is equal and opposite, and total momentum is zero, as it was before the "explosion."

5. Calculate the initial and final momentums to complete Tables 1, 2 and 3.

See the tables in the Data Analysis section.

6. **Calculate % Difference for the elastic collision.**

$$\frac{\boldsymbol{p}_{cart\#1} - \boldsymbol{p}_{cart\#2}}{\left(\frac{\boldsymbol{p}_{cart\#1} + \boldsymbol{p}_{cart\#2}}{2}\right)} = \frac{0.090 - 0.085}{\left(\frac{0.090 + 0.085}{2}\right)} = \frac{0.005}{0.088} = 0.0571 = 5.71\%$$

7. **Calculate % Difference for the inelastic collision.**

$$\frac{\boldsymbol{p}_{cart\#1before} - \boldsymbol{p}_{bothcartsafter}}{\left(\frac{\boldsymbol{p}_{cart\#1before} + \boldsymbol{p}_{bothcartsafter}}{2}\right)} = \frac{0.085 - 0.086}{\left(\frac{0.085 + 0.086}{2}\right)} = \frac{0.001}{0.086} = 0.0116 = 1.16\%$$

8. **What do you think is the primary cause of the differences you calculated?**

Friction. Momentum is dependent on velocity, and velocity is lost to friction.

Synthesis Questions

Use available resources to help you answer the following questions.

1. **Two locomotives, each weighing 100,000 kg and having a speed of 100 m/s, race toward each other and collide inelastically. What is the final momentum of the system? Explain.**

Zero, the two locomotives have equal momentum in opposite directions so the vector sum is zero. However, in the real world, the catastrophic nature of this collision would likely impart momentum to large amounts of debris that would imbalance the equation.

2. **A 10 kg bowling ball travelling at 3 m/s collides with a 9 kg bowling ball elastically, after the collision the 10 kg ball is travelling at 0.2 m/s, what is the speed of the 9 kg ball after the collision?**

$$\boldsymbol{p}_{1before} + \boldsymbol{p}_{2before} = \boldsymbol{p}_{1after} + \boldsymbol{p}_{2after} \quad 30 + 0 = 2 + 9(\boldsymbol{v}_{2final}) = \frac{28}{9} = \boldsymbol{v}_{2final} = 3.11 m/s$$

Multiple Choice Questions

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

1. **In an automotive safety test, the first car is launched at high speed at a second car that is sitting sideways across its path. The front end of the first car crushes into the side of the second car, which wraps around the first car. The cars continue spinning until they are stopped by a safety barrier. How would you characterize this collision?**

- **A.** Elastic
- **B.** **Inelastic**
- **C.** Explosion
- **D.** A waist of automobiles

2. **A mother (mass 60 kg) skates across an ice rink with negligible friction toward her child (mass 20 kg), who is standing still on the ice. If the mother moves at 4 m/s before she picks up her child, what will her new velocity be after she picks up her child and holds onto him?**

- **A.** 4 m/s
- **B.** **3 m/s**
- **C.** 2 m/s
- **D.** 1 m/s
- **E.** Can't tell; not enough info

3. **A projectile of mass *M* is moving through the air with speed v_0 to the left when it suddenly explodes into 2 pieces. Afterwards, one piece of the projectile (mass 2/3 *M*) is moving to the left with half its original velocity. What is the velocity of the other piece?**

- **A.** $v_0/2$
- **B.** $v_0/3$
- **C.** $7v_0/5$
- **D.** $3v_0/2$
- **E.** $\mathbf{2v_0}$

4. **A gun is fired so that the bullet (mass = 0.015kg) lodges inside a ballistic pendulum (mass = 5.0 kg), which then swings up to a height after absorbing the momentum of the bullet. If the pendulum recoils with a speed of 2.5 m/s, what is the velocity of the bullet before it collides with the pendulum?**

- **A.** 255.7 m/s
- **B.** **835.8 m/s**
- **C.** 133.3 m/s
- **D.** 0.0075 m/s
- **E.** 800 m/s

Key Term Challenge

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

1. The momentum of an object equals its **mass** multiplied by its **velocity**. When two objects collide, the total momentum of the system is **conserved** as long as there are no outside **forces** acting on the system. This concept is known as the law of **conservation of momentum**, which states the total momentum of the system **before** an event (like a collision) is the same as the momentum **after** the event.

2. There are several types of **collisions,** which are events where **momentum** is often conserved. **Elastic** collisions occur when two objects hit and bounce away from each other, while **inelastic** collisions are when objects hit and stick together. Another type of momentum-related event is the **explosion**, where one object may split into two or more separate objects. In all 3 of these types of events **momentum** is conserved as long as there are no **external forces** acting on the objects involved in the event.

3. If momentum is conserved during a collision or an explosion, this means that the total momentum of the objects will be **the same** both **before** and **after** the event. Consider an inelastic collision with two identical cars, one which is initially moving, and the other stationary. Because the **mass** of each object is the same, the **velocity** of the two carts together after collision must be **half** the initial velocity of the cart that was moving before the collision.

Extended Inquiry Suggestions

Follow this lab with a discussion of Conservation of Energy and in which types of events energy is conserved. There is value in this discussion, as it forces students to think about internal versus external forces, and it relates well to other scientific laws of conservation (mass, momentum). Students must consider the difference between an internal force and an external force. This distinction can reinforce the drawing of boundary lines, which they must do in free body diagrams (force diagrams), Gaussian problems in Electricity and Magnetism, and now systems for momentum.

A logical extension for this lab is Conservation of Momentum in more than one dimension of motion. Demonstrate 2-D momentum principles through a couple of simple demonstrations, including air hockey tables, billiards examples, and projectiles being launched from the same height, but with different horizontal velocities after they collide and fall to the ground.

Sports analogies can make a rich classroom discussion (or outside the class). A kicked soccer ball goes up in the air if the athlete kicks the bottom of the ball instead of the middle or top half of the ball. Football players running down the field and hit from the side will move in which direction after the collision? What causes a baseball player to hit a ground ball or a pop fly instead of a line drive? When a professional golfer uses a sloped club (like a 9-iron), how will it affect the ball's trajectory after collision?

14. Impulse Momentum

Objectives

This laboratory activity explores the change in momentum that occurs in a collision, and how that change is related to the impulse associated with the collision. This activity allows students to:

- Calculate the change in momentum of a cart before and after a collision
- Study the relationship between force and time during the transfer of momentum associated with a collision
- Compare the change in momentum to the impulse associated with a collision

Procedural Overview

Students will gain experience conducting the following procedures:

- Simulating an elastic collision with a cart, track, and force accessory bracket
- Measuring the change in velocity using a motion sensor and the force experienced by the cart during the collision using a force sensor
- Calculating momentum using the measured velocity of the cart
- Determining the impulse of a collision using the area under the graph of Force versus Time

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion	20 minutes
♦ Lab activities	25 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Motion sensor
- Force sensor
- Force accessory bracket
- Dynamics cart
- Dynamics track
- Balance (1 per classroom)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The relationship between force and motion
- The definition of momentum
- Newton's second law
- The definition of impulse

Related Labs in This Guide

Labs conceptually related to this one include:

- Newton's Second Law
- Conservation of Momentum

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Adjust the scale of a graph �(7.1.2)
- Selecting data points in a graph �(7.1.4)
- Displaying multiple variables on the *y*-axis of a graph �(7.1.10)
- Finding the values of a point in a graph �(9.1)
- Finding the area under a curve �(9.7)
- Saving your experiment �(11.1)

Background

There are many examples of using the term *momentum*. In sports, we say that the fullback on a football team uses his momentum to break through a defensive line, a tennis player smashes the ball imparting a high momentum, and a high speed bullet flies with momentum. Momentum $\boldsymbol{p}$ is mathematically defined as the product of an object's mass m multiplied by its velocity $\boldsymbol{v}$.

$$\boldsymbol{p} = m\boldsymbol{v} \qquad \textbf{Eq.1}$$

In general, when two bodies collide they will strike one another exerting equal and oppositely directed forces on one another. In an elastic collision, the two bodies strike and rebound away from one another. In an inelastic collision, the two bodies collide and stick to one another.

The force imparted at the moment of collision occurs over a small time interval. The impulse associated with the collision is calculated by integrating that force with respect to time during the collision.

$$\boldsymbol{I} = \int \boldsymbol{F}dt \qquad \textbf{Eq.2}$$

We know from Newton's Second law that net force is the product of mass and acceleration, and acceleration is calculated from the change in velocity of an object over time. Because momentum is the product of mass and velocity, it stands to reason that momentum and impulse are related.

$$\int \boldsymbol{F}dt = \Delta\boldsymbol{p} \qquad \textbf{Eq.3}$$

There is a brief discussion of integration, or area under the curve for this simple case, in the Extended Inquiry Suggestions section. Students need not know the mathematics to complete this lab, but they should understand that the area under a force versus time curve represents impulse. Students can compare this to the change in momentum by determining the momentum before the collision and the momentum after the collision.

Lab Preparation

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

Safety

Follow all standard laboratory procedures.

Pre-Lab Discussion and Activity

Engage your students by considering the following discussion:

1. What two quantities are used to calculate the momentum of an object? Are these two quantities multiplied? Divided?

The two quantities are mass and velocity. Momentum is the product of mass multiplied by velocity.

2. Consider a 0.2 kg bullet and 2,000 kg wrecking ball. Can they have the same momentum?

Yes, because momentum also includes velocity. At velocity zero, they both have zero momentum.

3. How is Newton's second law written, in terms of force, time, mass and velocity? Can you show that impulse is related to momentum?

$$F = ma$$

$$F = m\left(\frac{\Delta v}{\Delta t}\right)$$

$$F\Delta t = m\Delta v$$

$$I = \Delta p$$

Roll or toss a ball toward a wall. Let the ball bounce off the wall and come back.

4. What forces does the ball experience while moving toward the wall?

The ball experiences gravity and a small amount of friction.

5. What is the momentum of the ball as it moves toward the wall?

The momentum is the product of the ball's mass and velocity v_1.

6. What happens at to the ball when it hits the wall?

The ball exerts a force on the wall, and the wall exerts an equal and opposite force on the ball. The force causes the ball to deform and then bounce back toward you.

7. What happens to the ball's momentum and velocity on the way back?

The ball is now travelling in the opposite direction v_2. The relationship between v_1 and v_2 is unclear and depends on the kind of ball you use and how much energy is lost in the collision. However, the change in momentum is still final momentum minus the initial momentum.

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	3	2	1	4
Subtract the initial momentum from the final momentum to find the change in momentum.	Determine the velocity of the cart before the collision from the Velocity versus Time graph.	Start recording data, and then push the cart toward the force accessory bracket.	Level the track by adjusting the feet.	Calculate the momentum of the cart before the collision.

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

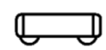
1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect a force sensor and a motion sensor to the data collection system. �(2.2)

3. ☐ Set the track on a table and level the track. Use a bubble level or observe a cart on the track and adjust the track feet until the track is level and the cart does not move.

4. ☐ Connect the force accessory bracket to one end of the track.

5. ☐ Connect the motion sensor to the other end of the track with the face of the sensor pointed toward the force accessory bracket. Be sure the switch on the sensor is in the cart position.



Note: You may need to move the accessory bracket closer to the motion sensor depending on the length of track you are using.

6. ☐ Mount the force sensor to the force accessory bracket in the lower position, and attach the weaker of the two spring bumpers to the force sensor.

7. ☐ Display both Velocity and Force pull positive on the y-axis of a graph with Time on the x-axis so that they can be compared. �(7.1.10)

8. ☐ Why is it important to use the *pull positive* measurement from the force sensor?

Movement away from the motion sensor is in the positive direction. The force sensor must have the same orientation as the motion sensor to accurately compare their measurements. Pulling on the force sensor would be in the positive direction relative to the face of the motion sensor.

9. ☐ Ensure that the sample rate is set to at least 100 samples per second. �(5.1)

Note: If your data collection system allows the sample rate of the sensors to be adjusted separately, set the force sensor to 500 samples per second and the motion sensor to 50 samples per second.

10. ☐ Why do you think a high sample rate is necessary?

The collision happens very fast, and we need a sufficient number of data points to accurately represent the Force versus Time graph.

11. ☐ Push the zero button on the force sensor.

12. ☐ Determine the mass of the cart with a balance, and record the mass in Table 1.

13. ☐ Place the cart on the track just over 15 cm away from the motion sensor.

Collect Data

14. ☐ Start data recording. �(6.2)

15. ☐ Push the cart toward the force accessory bracket. Allow the cart to collide with the force sensor and return.

16. ☐ Catch the cart, and stop data recording. �(6.2)

Analyze Data

17. ☐ Adjust the scale of the graph to show the region around the collision. �(7.1.2)

18. ☐ Sketch your graph of Velocity versus Time and Force versus Time in the space provided in the Data Analysis section.

19. ☐ Use the Velocity versus Time graph on your data collection system to find the velocity of the cart just before the collision, and enter the value in Table 1. �(9.1)

20. ☐ Use the mass of the cart and the velocity just before the collision to determine the momentum of the cart before the collision, and enter the value in Table 1.

$p = mv$

21. ☐ Use the Velocity versus Time graph on your data collection system to find the velocity of the cart after the collision, and enter the value in Table 1. �(9.1)

22. ☐ Use the mass of the cart and the velocity before the collision to determine the momentum of the cart after the collision, and enter the value in Table 1.

$p = mv$

23. ☐ Calculate the change in momentum by subtracting the final momentum from the initial momentum, and enter the value in Table 1.

$$p_{\text{final}} - p_{\text{initial}} = \Delta p$$

24. ☐ What are the units for change in momentum?

$$\frac{\text{kg} \cdot \text{m}}{\text{s}}$$

25. ☐ Select the data points on the Force versus Time graph that represent the force applied during the collision. �(7.1.4)

26. ☐ Find the area under the curve of the region you selected on the Force versus Time graph, and record the value in Table 1. �(9.7)

27. ☐ What are the units for the area under the curve?

$\text{N} \cdot \text{s}$

28. ☐ Are the units of the area under the curve equivalent to the units of momentum? Explain.

Yes.

$$\text{N} \equiv \frac{\text{kg} \cdot \text{m}}{\text{s}^2} \Rightarrow \text{N} \cdot \text{s} = \frac{\text{kg} \cdot \text{m}}{\text{s}}$$

29. ☐ What do you think the area under the curve represents?

The impulse, or force applied over time.

30. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Velocity versus Time and Force versus Time Graph

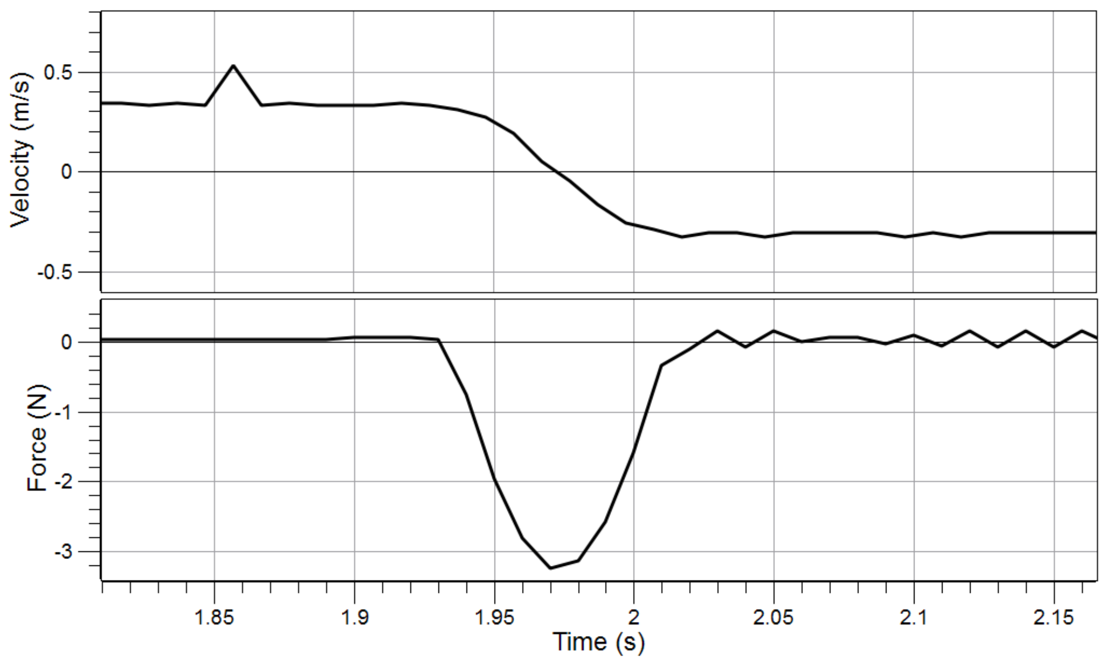


Table 1: Collision Data

Parameters	Value
Cart Mass	0.249 kg
Velocity before collision	0.344 m/s
Momentum before collision	0.0857 kg m/s
Velocity after collision	-0.310 m/s
Momentum after collision	-0.0772 kg m/s
Change in momentum	-0.163 kg m/s
Area under the force curve	-0.165 Ns
Percent difference	1.52%

Analysis Questions

1. How does the momentum before the collision compare to the momentum after the collision? What is the percent difference between the two?

Answers will vary. This experiment depends on the technique, levelness of the track, speed of the cart, friction, etc. Typically, differences between the momentum before and momentum after range from 5% to 25%.

$$\frac{p_{\text{final}} - p_{\text{initial}}}{\left(\frac{p_{\text{final}} + p_{\text{initial}}}{2}\right)} \times 100 = \frac{0.0857\ \text{kg}\cdot\text{m/s} - 0.0772\ \text{kg}\cdot\text{m/s}}{\left(\frac{0.0857\ \text{kg}\cdot\text{m/s} + 0.0772\ \text{kg}\cdot\text{m/s}}{2}\right)} \times 100 = 10.4\%$$

2. How does the change in momentum that resulted from the collision compare to the impulse of the collision? What is the percent difference between the two? Add this answer to Table 1.

Answer will vary, but the values should be very close to each other.

$$\frac{\Delta p - impulse}{\left(\frac{\Delta p + impulse}{2}\right)} \times 100 = \frac{-0.163\ \text{kg}\cdot\text{m/s} - (-0.165\ \text{N}\cdot\text{s})}{\left(\frac{-0.163\ \text{kg}\cdot\text{m/s} + (-0.165\ \text{N}\cdot\text{s})}{2}\right)} \times 100 = 1.52\%$$

3. Why do you think we use the weaker spring to do this experiment?

The spring prolongs the collision. This allows us to capture more data points during the collision, which improves our area under the curve value.

4. What could be done to improve the accuracy of the value for change in momentum?

Answers will vary, but may include: reducing friction, increasing sampling rate to get a better idea of the point right before and after the collision, or averaging several points before and after the collision rather than counting on the accuracy of a single point.

Synthesis Questions

Use available resources to help you answer the following questions.

1. In an automotive crash test, a 1,000 kg car impacts a test barrier, that does not move, and comes to a complete stop. The sensors in the barrier indicate an impulse of 20,000 N·s was associated with the crash. What was the initial velocity of the car in kilometers per hour?

$$\Delta p = mv_{\text{final}} - mv_{\text{initial}} = \int F dt$$

$$(1000\ \text{kg})(0\ \text{m/s}) - (1000\ \text{kg})v_{\text{initial}} = 20{,}000\ \text{N}\cdot\text{s}$$

$$v_{\text{final}} = \frac{20{,}000\ \text{N}\cdot\text{s}}{-1{,}000\ \text{kg}} = -20\ \text{m/s} = -72\ \text{km/hr}$$

2. What does the sign of your answer from the previous question tell you about the orientation of the force sensor in the barrier and the motion of the car?

The positive direction of velocity for the car must oppose the positive direction of the force sensor in the barrier.

3. A ball bounces off a solid wall, but it has half the momentum leaving the wall that it did heading toward the wall. What does this tell you about the ball? And where did the kinetic energy of the ball go?

Because the wall is solid, the ball must be soft. The energy went into deforming the ball, but the ball was not elastic enough to return all the energy as it rebounded.

Multiple Choice Questions

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

1. Which of the following equations describes the change in momentum during a collision?

- **A.** Speed × Time
- **B.** Distance × Time
- **C.** Force × Position
- **D.** **Mass × Velocity**

2. Which of the following is not a vector (directional) quantity?

- **A.** **Mass**
- **B.** Velocity
- **C.** Momentum
- **D.** Force

3. When a moving automobile collides with a parked automobile such that they crunch together and continue moving together a short distance after the collision, this kind of collision is called?

- **A.** **An inelastic collision**
- **B.** An elastic collision
- **C.** A collision of cultures
- **D.** When worlds collide

4. Which of the following equations best represents the impulse during a collision?

- **A.** Position × Time
- **B.** Velocity × Time
- **C.** **Force × Time**
- **D.** Speed × Time

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. **Impulse** imparted to an object during a collision is equal to the area under a Force versus Time graph. **Momentum** is defined as the product of the **mass** and velocity of an object. When two objects collide, a **force** is imparted by both objects onto each other during the collision. In an **elastic** collision, the impulse imparted to one of the objects will be equal to the change in the object's momentum.

Extended Inquiry Suggestions

This is a good opportunity to dig deeper into the meaning of *area under the curve* without fully diving into calculus and discuss orders of approximation. Start with a first order approximation by finding the average force for the region you selected, and multiply this by the total time of the collision. Compare this number to the value your data collection system produced for the area under the curve. For a second order approximation, create a series of rectangles that are the height of the data points and width of a fixed time interval. Find the area of each rectangle (a Force times a Time), and add the areas together. Compare this value to the area under the curve calculated by the data collection system.

Repeat the experiment adding masses to the cart to show that the relationship still holds true.

Use the soft clay bumper for an inelastic collision.

15. Work and Energy

Objectives

Students develop an understanding of the work-energy theorem. In this lab, students investigate:

- The work done on a dynamics cart by a net force
- Graphical representations of force applied over a distance
- Changes in kinetic energy relative to the amount of work done on the cart

Procedural Overview

Students will gain experience conducting the following procedures:

- Assembling a modified Atwood machine using a cart, track, and pulley system
- Measuring the force applied to a cart by the hanging mass, while simultaneously measuring the displacement of the cart as it accelerates
- Analyzing a force versus distance graph in order to evaluate the area under the graph, which is a representation for the mechanical work done on the cart
- Quantifying the magnitude of the cart's change in kinetic energy by calculating and taking the difference in the final and initial kinetic energies using recorded velocity data.
- Comparing measured values for the change in kinetic energy of the cart to the work done on the cart

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Motion sensor
- Force sensor
- Dynamics track
- Dynamics cart
- Dynamics track end stop
- Super pulley with clamp
- Mass and hanger set
- Balance (1 per classroom)
- String, 1.5 m

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Mass and inertia
- ♦ Forces
- ♦ Kinetic and potential energy

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Newton's Second Law
- ♦ Conservation of Energy

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data collection system �(2.2)
- ♦ Changing the sampling rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Changing the variable on the *x*- or *y*-axis �(7.1.9)
- ♦ Viewing the statistics of data �(9.4)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Finding the area under a curve �(9.7)
- ♦ Saving your experiment �(11.1)

Background

Work is defined as the net force applied to an object over distance. The work-energy theorem relates the work done on an object to the change in the object's kinetic energy. If the force acting on an object is in the same direction as the displacement of the object:

$$W = Fd = \Delta \text{KE} = \frac{1}{2}mv^2_{\text{final}} - \frac{1}{2}mv^2_{\text{initial}}$$

A quick unit analysis shows that both sides of the equation have the same units, $\text{kg}\cdot\text{m}^2/\text{s}^2$ or joules (J). Conceptually, work and energy are challenging topics for most students. You will need to develop several working examples using a variety of forces. Examples include pulling a sled with an applied horizontal force, pulling a wagon using a force at an upward angle, a ball falling to the earth, and a spring stretching due to a force. Doing this will show the students a pattern by way of relating the net force on an object acting through a distance to the change in the object's energy state. If your students are familiar with roller coasters, have them try a warm up activity using a toy car track and a toy car. Ask the students to fashion the track with a few curves and they will discover, of course, the starting hill will be the highest. Make a transition from the mechanical work done in the coaster example to the set up in this lesson.

Pre-Lab Discussion and Activity

Engage your students by considering the following questions:

1. There are all different kinds of *work* in everyday life: physical, mental, creative, et cetera. When a mechanical task is being performed, what two things contribute to whether or not work is being done?

Provide examples here, such as mowing the lawn, raking leaves, and pulling a cord on a ceiling fan. The two variables are force and distance.

Describe to the students how a force applied over a distance relates to the energy of the object.

Ask the students what forms of energy exist and what forces contribute to those identified forms of energy. Examples include: potential energy (gravitational) associated with the gravitational force; kinetic energy (of motion) associated with any applied force; potential energy (elastic) associated with a spring force.

2. What units describe the work done on an object?

Students may say horsepower, but this is the unit for mechanical power. Other responses may include the calorie or kilocalorie. Explain to the students that the metric unit is the joule symbolized by J.

Ask students to run, individually, up a flight of stairs. Students should work in teams to measure the average time and the height of the stairs. Ask students to calculate the amount of work done against the force of gravity. Then relate this work to the magnitude in the change in gravitational potential energy the student undergoes during the activity. At this time, you may want to develop the concept of power related to the time rate at which work is accomplished.

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	3	2	1
Calculate the final kinetic energy of the system, and compare the change in kinetic energy with the work done.	Find the maximum velocity in your plot of velocity versus time.	Select a known mass, and place it on the hanger. Begin recording data and release the cart.	Set the cart at least 15 cm in front of the motion sensor on the track with the string over the pulley.	Connect a motion sensor to your data collection system.

Procedure with Inquiry

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

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

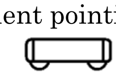
Set Up

1. ☐ Place the dynamics track on a lab table with one end hanging slightly over the edge of the table.

2. ☐ Place the dynamics cart stationary in the middle of the track, and then adjusting the track level until the cart does not roll.

3. ☐ Mount the super pulley with clamp to the end of the track hanging over the edge of the table. Be sure the area below the pulley is clear.

4. ☐ Mount the end stop to the track so as to prevent the cart from colliding with the pulley.

5. ☐ Mount the motion sensor to the other end of the track with the sensing element pointing toward the pulley. Be sure the motion sensor switch is set on the cart  position.

6. ☐ Mount the force sensor to the top of the cart. You will need to adjust the height of the pulley so that the top of the pulley is even with force sensor hook when the cart is on the track.

7. ☐ Why do you think it is important that the force sensor hook be at the same height as the top of the pulley?

This will ensure that the force measured by the sensor is parallel to the motion of the cart.

8. ☐ Measure the mass of the cart and sensor together and record the value in Table 1.

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

10. ☐ Connect the force sensor and motion sensor to the data collection system. �(2.2)

11. ☐ Place the dynamics cart and force sensor on the track, and press the zero button on the force sensor.

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

13. ☐ Change the variable on the *x*-axis from Time to Position. �(7.1.9)

14. ☐ If you are trying to determine the work done, why do you think we want to look at a graph of Force versus Position?

Because work is defined as force applied over a distance.

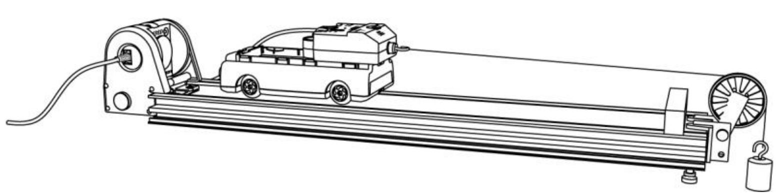
15. ☐ Ensure that the sampling rate of your data collection system is set to at least 20 samples per second. �(5.1)

16. ☐ Set up the cart and mass hanger.

a. Hold the cart on the track at the position you will be releasing it (15 cm away from the motion sensor).

b. Attach a length of string, slightly greater than the distance from the force sensor to just below the pulley, to the force sensor hook. Attach the mass hanger to the opposite end of the string, hanging over the pulley.

c. Place 50 grams on the hanger. Remember to add the mass of the hanger to the 50 grams when doing calculations.



Collect Data

17. ☐ Start data recording. �(6.2)

18. ☐ Release the cart, and let it run the length of the track.

19. ☐ Stop data recording just before the cart collides with the end stop or the mass hits the floor, whichever comes first. �(6.2)

Analyze Data

20. ☐ Determine the work done by using the data collection system to calculate the area under the Force versus Position curve. �(9.7)

Teacher Tip: If "area under a curve" is not a concept that you want to introduce at this point, have your students find the mean force using the statistics tool �(9.4) and the displacement be subtracting the initial position from the final position. Multiply these values together to get a first order approximation of the work done.

21. ☐ Record the value of the work done in Table 1.

22. ☐ Sketch the graph of Force versus Position in the area provided in the Data Analysis section.

23. ☐ On the data collection system, display Velocity on the y-axis of a graph with Time on the x-axis. �(7.1.1)

24. ☐ Find the initial and final velocities of the data run. �(9.1)

25. ☐ Record these values in Table 1.

26. ☐ Why do you think it is important to find initial and final velocity?

Because we need to find the change in kinetic energy.

27. ☐ Sketch your graph of Velocity versus Time in the space provided in the Data Analysis section.

28. ☐ Save your work as instructed by your teacher. �(11.1)

29. ☐ If time permits, repeat the experiment using different masses.

Data Analysis

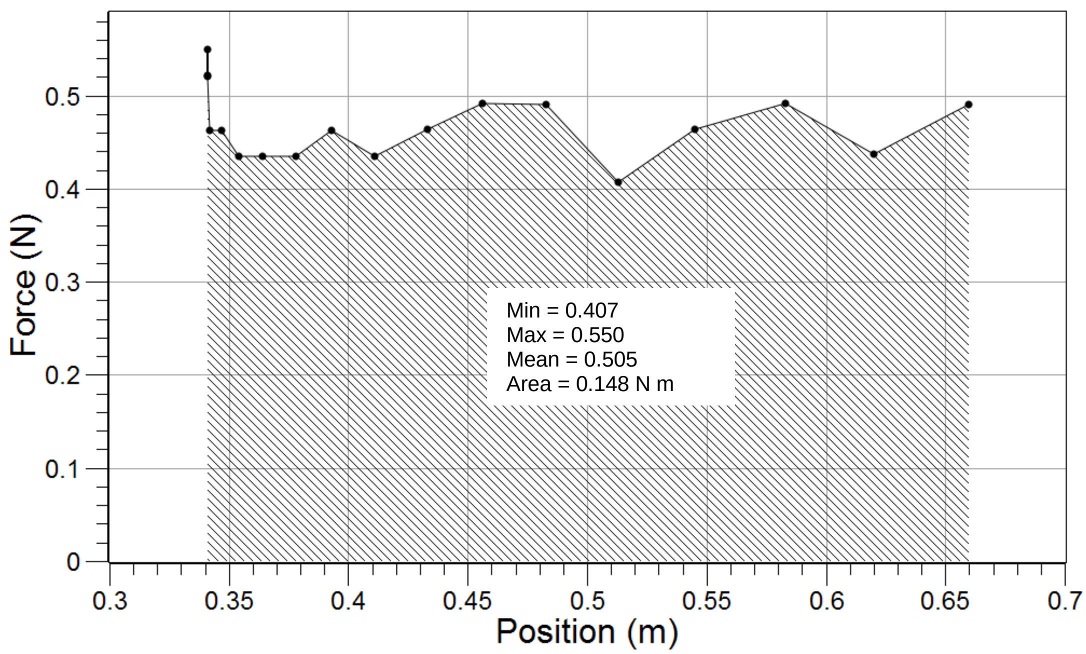
☐ Use the mass of the cart + force sensor and velocities to calculate the initial and final kinetic energy of the cart, and then subtract to complete Table 1.

$$\mathrm{KE}_{final} = \frac{1}{2}mv_{final}^2 = 0.5(0.365\,\mathrm{kg})(0.85\,\mathrm{m/s})^2 = 0.132\,\mathrm{J}$$

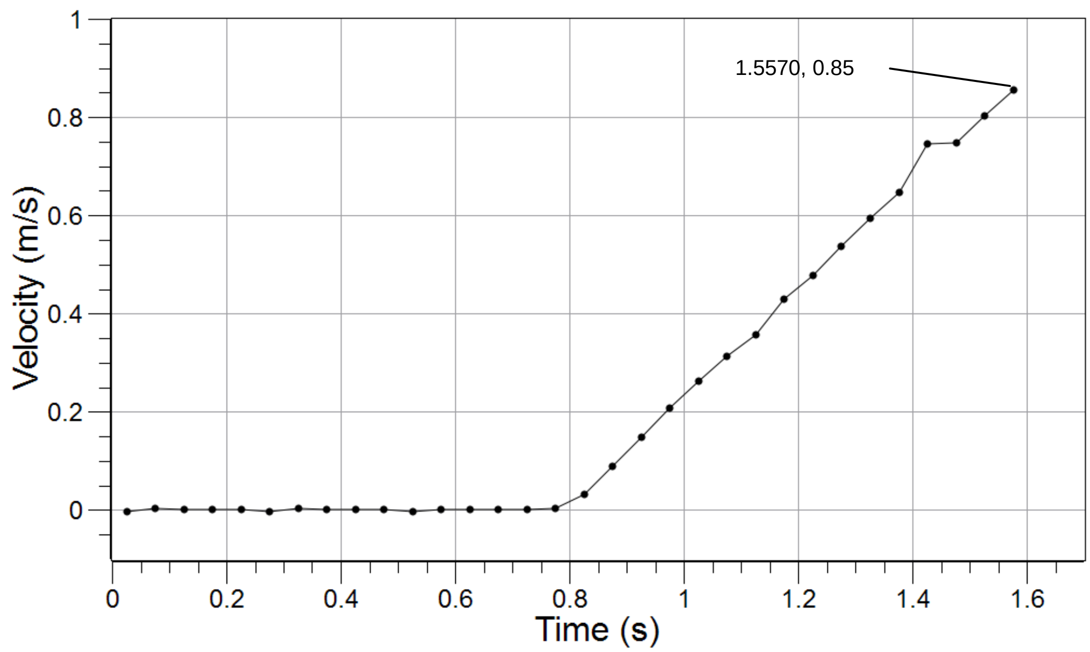
Table 1: Data table

Mass of the cart + force sensor	0.365 kg.
Work done	0.146 J
Initial velocity	0 m/s
Final velocity	0.85 m/s
Initial kinetic energy	0 J
Final kinetic energy	0.132 J
Change in kinetic energy	0.132 J

Force versus Position Graph



Velocity versus Time Graph



Analysis Questions

1. What is the percent difference between the change in kinetic energy and the work done?

Answers will vary. The sample data is 9.7%. However, on average the work is about 10% greater than the maximum kinetic energy.

$$\frac{W - \Delta KE}{\left(\dfrac{W + KE}{2}\right)} \times 100 = \frac{0.146 - 0.132}{\left(\dfrac{0.146 + 0.132}{2}\right)} \times 100 = 9.7\%$$

2. What are some possible reasons for any difference?

Some work must be done to overcome friction.

3. What are other forms of mechanical energy?

Elastic or spring and potential energy

4. Why do you think we can ignore these other forms of energy in this experiment?

There are no springs present in the experiment, and the cart and sensor do not change height.

Synthesis Questions

Use available resources to help you answer the following questions.

1. A ball is thrown straight up into the air and returns to be caught by the thrower. We know that gravity has been acting on the ball the entire time, but the ball has the same kinetic energy when it is caught as when it was released. Can you explain this apparent discrepancy?

The ball goes through two changes in energy state. One from the hand to the top of the arc where kinetic energy reaches zero, and one from the top of the arc back to the hand. The combined changes in kinetic energy will equal the work done by gravity.

2. A 2,000 kg rocket is launched 12 km straight up at a constant acceleration into the sky at which point the rocket is travelling at 750 m/s. How much work was done by the rocket? What is the magnitude of the acceleration of the rocket? And how long did the flight take?

$$W = KE_{\text{final}} - KE_{\text{initial}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = (0.5)(2{,}000\text{ kg})(750\text{ m/s})^2 - 0$$

$$W = 5.625 \times 10^8\text{ J}$$

$$W = F\Delta d = ma\Delta d$$

$$a = \frac{W}{m\Delta d} = \frac{5.625 \times 10^8\text{ J}}{(2{,}000\text{ kg})(12{,}000\text{ m})}$$

$$a = 23.44\text{ m/s}^2$$

$$t = \frac{v_f - v_i}{a} = \frac{750\text{ m/s} - 0}{23.44\text{ m/s}^2}$$

$$t = 32\text{ s}$$

3. A 120kg skier slides straight down a constant 35° frictionless slope for 70 meters. At the end of the slope she is travelling at 30 m/s. What was her initial velocity?

$$W = \Delta KE = F_g d$$

$$\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = mgd\sin\theta$$

$$v_f^2 - v_i^2 = 2gd\sin\theta$$

$$v_i = \sqrt{v_f^2 - 2gd\sin\theta}$$

$$v_i = \sqrt{(30\text{ m/s})^2 - 2(9.81\text{ m/s}^2)(70\text{ m})\sin 35°}$$

$$v_i = 10.6\text{ m/s}$$

Multiple Choice Questions

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

1. Mechanical work is related to which pair of variables?

- **A.** Distance and time
- **B.** **Distance and force**
- **C.** Distance and velocity
- **D.** Distance and acceleration

2. In this experiment, the work done on the cart was directly related to the cart's?

- **A.** Gravitational potential energy
- **B.** Elastic potential energy
- **C.** **Kinetic energy**
- **D.** None of the above

3. The area under a Force versus Distance graph for a moving object subject to a net force is a direct representation of which quantity?

- **A.** Kinetic energy
- **B.** Potential energy
- **C.** Thermal energy
- **D.** **Mechanical work**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. An object subject to an unbalanced force will experience a **displacement**. The work done by that unbalanced fore is equal to the component of the **force** in the direction of the object's displacement multiplied by the magnitude of the displacement. If the **energy** imparted to the object by the force is converted entirely into kinetic energy, the work done by the unbalanced force will equal the change in the object's **kinetic energy**. This concept is known as the **work-energy theorem**.

Extended Inquiry Suggestions

Ask your students to repeat the experiment using different masses and different springs to determine if the relationship holds true.

This is a great time to introduce Atwood Machines.

An extended inquiry demo, if you are looking for an opportunity to get your students outside and your school permits, is to stuff as many students as you can into a vehicle, then have 3 or 4 strong students push the vehicle with the engine off and the gears disengaged. Try it first with an empty vehicle (have the driver stay of course, to steer and brake the vehicle), notice the acceleration, then repeat with the vehicle stuffed full of students. It's quite obvious (and memorable) that more massive objects accelerate much less than a less massive object. You can also scale this down to a Kinesthetic Cart and a smooth level floor using students of different sizes

16. Simple Harmonic Motion

Objectives

This experiment examines one example of simple harmonic motion. A mass that is suspended from a spring is pulled down, released, and allowed to oscillate. The following will be examined:

- Determining the spring constant by measuring the spring extension for each of three different masses suspended from the spring
- The relationship between position and time, velocity and time, and acceleration and time for the moving mass
- The relationship between the period of oscillation T, the spring constant k, and the oscillating mass m

Procedural Overview

Students explore simple harmonic motion by:

- Using a force sensor and meter stick to determine the spring constant of a spring
- Using a motion sensor and force sensor to measure and record force versus time, position versus time, velocity versus time, and acceleration versus time data for a mass vertically oscillating
- Comparing graphs of force versus time, position versus time, velocity versus time, and acceleration versus time to observe relationships between the four measurements
- Analyzing a graph of position versus time to determine which parameters influence the motion of an oscillating object

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Motion sensor
- Meter stick
- Rod stand
- Right-angle clamp
- Short rod
- Spring
- Assorted masses (at least 3)
- Balance (one per class)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Linear position, velocity, and acceleration
- Force
- Determining the gravitational force on a mass given the value of the mass and the gravitational field strength
- Spring constant *k* and how to determine it by measuring force and spring extension

Related Labs in This Guide

Labs conceptually related to this one include:

- Newton's Second Law
- Hooke's Law
- Pendulum
- Circular Motion

Using Your Data Collection System

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

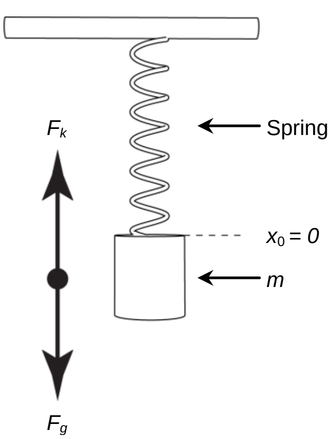
- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sampling rate �(5.1)

- ♦ Putting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- ♦ Recording a run of data �(6.2)
- ♦ Starting a manually sampled data set �(6.3.1)
- ♦ Recording a manually sampled data point �(6.3.2)
- ♦ Stopping a manually sampled data set �(6.3.3)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Changing the variable on the *x*- or *y*-axis of a graph �(7.1.9)
- ♦ Displaying multiple variables on the *y*-axis of a graph �(7.1.10)
- ♦ Measuring the distance between two points in a graph �(9.2)
- ♦ Finding the slope and intercept of a best-fit line �(9.6)
- ♦ Saving your experiment �(11.1)

Background

Simple harmonic motion generally describes the ideal motion of a body or system subject to a force proportional to the distance from some equilibrium position, that causes that body or system to move back and forth at a single natural frequency about that equilibrium position.

Consider a mass m, suspended from a spring.



When at rest, or in its equilibrium position x_0, the downward force of gravity on the mass is balanced by the upward force exerted by the stretched spring.

This upward force is given by:

$$F = -kx \qquad \textbf{Eq.1}$$

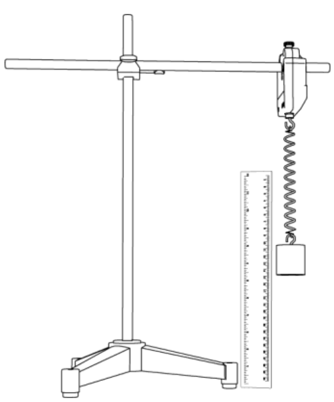
Where F is the force, k is the spring constant, and x is the distance the spring is stretched from its equilibrium position x_0. The negative sign in the equation implies that the force is a restoring force, pulling in the opposite direction as the force being exerted on it (in this case, the gravitational force on the attached mass). When the mass is pulled down a short distance (or moved up a short distance) and released, it will oscillate about its equilibrium position. Three forms of energy are present, kinetic energy, gravitational potential energy, and spring potential energy. In a perfect ideal system where there is no air resistance or internal friction, the sum of these three would be constant. Also, theory predicts that there is a relationship between the spring constant k, the period of oscillation T, and mass m:

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad \textbf{Eq.2}$$

Using graphs of net force, position, velocity, and acceleration versus time for the hanging mass, it is easy to see definite relationships between the four measurements. The graph of net force versus time is in phase with the graph of acceleration versus time showing clearly the relationship between these two variables. It can easily be seen that the velocity versus time plot is one quarter cycle behind the acceleration versus time plot, and the position time graph lags quarter cycle behind the velocity time graph.

Pre-Lab Discussion and Activity

Start with the setup shown below.

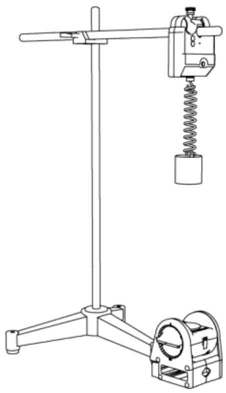


The questions below assume that students are already aware of the fact that a graph of Force versus Extension for the spring is linear.

1. In this activity, different masses will be placed on the end of the spring, one at a time, and the period of oscillation will be determined. How could the spring constant *k* for the spring be determined using these masses?

Measure the spring extension for each mass when it is suspended as shown, and record the force registered by the force sensor. Then, plot the extension *x* on the horizontal axis and the force f on the vertical axis. A slope of the resulting graph will yield the spring constant *k*.

Now add a motion sensor as shown below, and set the mass in vertical oscillation.



2. Which direction is positive as far as the motion sensor is concerned?

Up.

3. If we want "up" to be positive for the force sensor as well, which would we want to be positive from the perspective of grasping the sensor by the finger loops, pushing with the sensor or pulling with the sensor?

Make sure that pull is positive.

4. If the mass at the end of the spring is replaced with a heavier mass, how will the oscillation change?

After getting predictions from the class, demonstrate that the oscillating mass will have a lower frequency (longer period).

5. If a stiffer spring is used, how will the oscillation change?

After getting predictions from the class, demonstrate that a stiffer spring results in a higher frequency (shorter period).

6. What is the relationship between frequency and period for an oscillating object?

They are reciprocals of each other.

Point out that there appears to be a relationship between the size of the mass, the spring constant for the spring, and the period of oscillation. This activity will explore this relationship as well as other characteristics of simple harmonic motion.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Lab Preparation

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

Teacher Note: If your students are already familiar with Hooke's Law, and you have springs with known values of *k*, you can bypass the first part of this lab.

Have enough masses available for your students to select at least three masses per group such that the lightest one will stretch the spring at least 10 cm. Be careful to avoid masses that are too large because they will over stretch the spring to the extent that the spring will not return to its original length when the mass is removed. It is recommended that a spring mass combination be selected that will vibrate with a frequency between 1 and 2 Hz.

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

3	4	1	2	5
Raise the mass straight up, and then quickly remove your hand so that the mass begins to oscillate.	Stop data recording after several complete cycles have been recorded.	Connect the force sensor to the rod stand with the short rod and the right angle clamp.	Zero the force sensor	Compare the graph of Velocity versus Time, and the graph of Force versus Time

Procedure with Inquiry

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

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

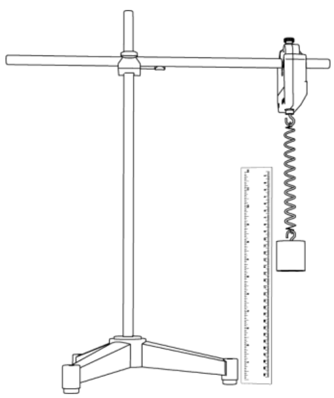
Part 1 – Determining the spring constant

Set Up

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

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

3. ☐ Connect the force sensor to the rod stand using the short rod and the right-angle clamp.



4. ☐ Suspend the spring from the hook of the force sensor.

5. ☐ Push the "zero" button on the force sensor.

6. ☐ Put the data collection system into manual sampling mode with manually entered data. Name the manually entered data "Extension" and give it units of meters. �(5.2.1)

7. ☐ Place the meter stick near the spring with the scale oriented so that values increase in the downward direction.

8. ☐ Suspend the lightest mass you have selected for this activity from the end of the spring, and allow it to settle in its equilibrium position.

Collect Data

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

10. ☐ Starting with the first mass, collect a force value for each value of user-entered extension in meters (switching masses between each value you keep). �(6.3.2)

11. ☐ When you have a force and extension value recorded for each mass, stop data recording. �(6.3.3)

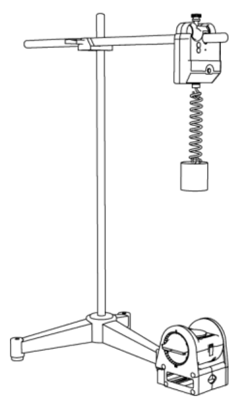
Analyze Data

12. ☐ Display Extension on the *x*-axis of a graph with Force on the *y*-axis. �(7.1.1)

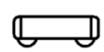
13. ☐ Find the slope of a best fit line for your Force versus Extension data. The slope of the line is the spring constant *k*. Record that value in the Data Analysis section. �(9.6)

Part 2 – Mass oscillating in simple harmonic motion at the end of a spring

Set Up



14. ☐ Place the motion sensor below the mass. Depending on the materials you use, you may need to place the rod stand at the edge of a table and the motion sensor on the floor.

15. ☐ Ensure the motion sensor is set in the cart position. 

16. ☐ Select the smallest mass in the group you chose for this activity and hang the mass from the spring. Adjust the height of the force sensor so that the mass, at its lowest point while oscillating, is at least 15 cm above the motion sensor.

17. ☐ Change the sampling rate on the data collection system to 25 Hz. �(5.1)

18. ☐ Display both Force (pull positive) and Position on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.10)

Collect Data

19. ☐ When the mass is motionless in its equilibrium position, push the “zero” button on the force sensor.

20. ☐ Carefully raise the mass a few centimeters, and then quickly remove your hand so that the mass begins to oscillate along a vertical line.

21. ☐ Start data recording, and then stop data recording after the mass has completed about twelve complete oscillations. �(6.2)

Analyze Data

22. ☐ Sketch a copy of your graphs in the Position versus Time and Force versus Time blank graph axes in the Data Analysis section.

23. ☐ Change the variable on the *y*-axis from Force to Acceleration. �(7.1.9)

24. ☐ Sketch a copy of your graphs in the Position versus Time and Acceleration versus Time blank graph axes in the Data Analysis section.

25. ☐ On the data collection system, change the variable on the *y*-axis from Acceleration to a Velocity. �(7.1.9)

26. ☐ Sketch a copy of your graphs in the Position versus Time and Velocity versus Time blank graph axes in the Data Analysis section.

27. ☐ Using your graph of Position versus Time and the data analysis tools on the data collection system, determine the time it took the spring and mass system to complete ten oscillations, and then record that value in Table 1 in the Data Analysis section. �(9.2)

28. ☐ Using your graph of Position versus Time and the data analysis tools on the data collection system, determine the amplitude of oscillation for the system, and then record that value in Table 1 in the Data Analysis section. �(9.2)

Note: The amplitude is the displacement from the equilibrium position, so you will have to calculate half the distance from a maximum peak to a minimum peak.

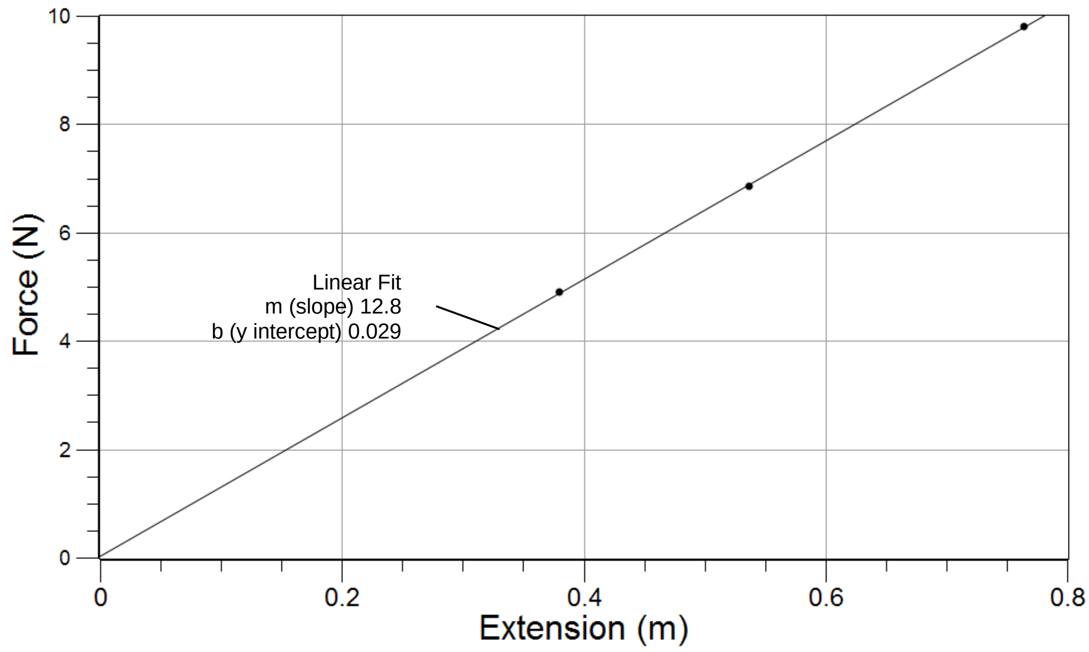
29. ☐ Record data for each of the masses you have, and find the time it takes to complete 10 oscillations and the amplitude of oscillation for each mass.

30. ☐ Complete Table 1 in the Data Collection section.

31. ☐ Save your experiment as instructed by your teacher. �(11.1)

Sample Data

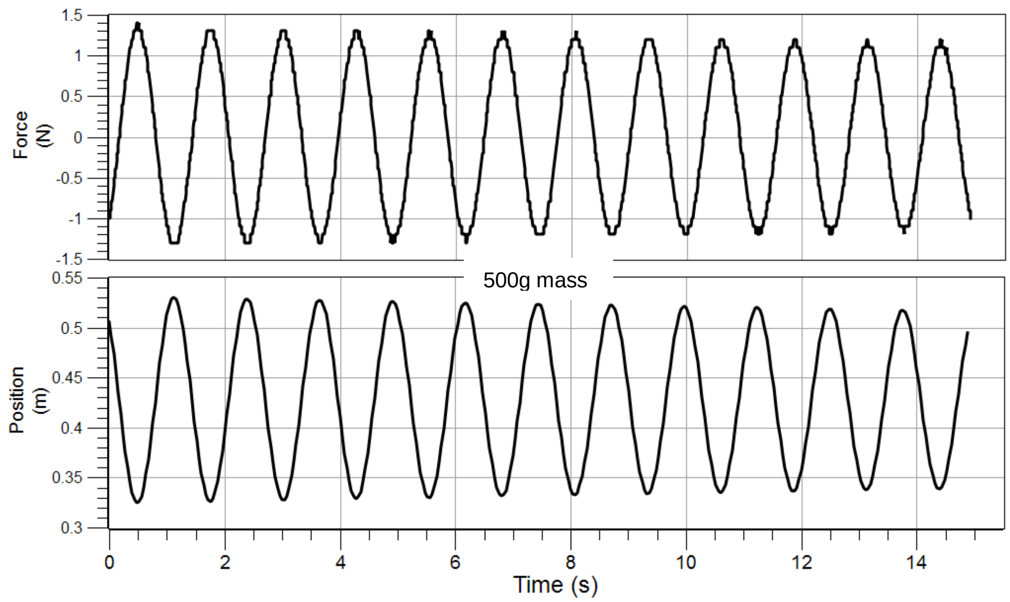
Part 1 - The Force versus Extension graph produced using the masses in the activity is shown below



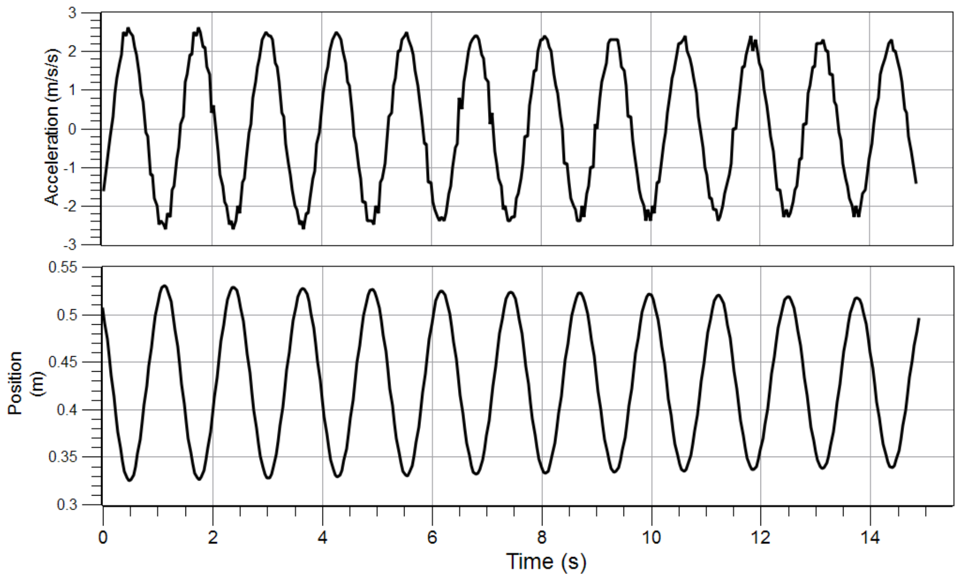
Data Analysis

$k =$ 12.8 N/m

Force versus Time and Position versus Time



Acceleration versus Time and Position versus Time



Velocity versus Time and Position versus Time

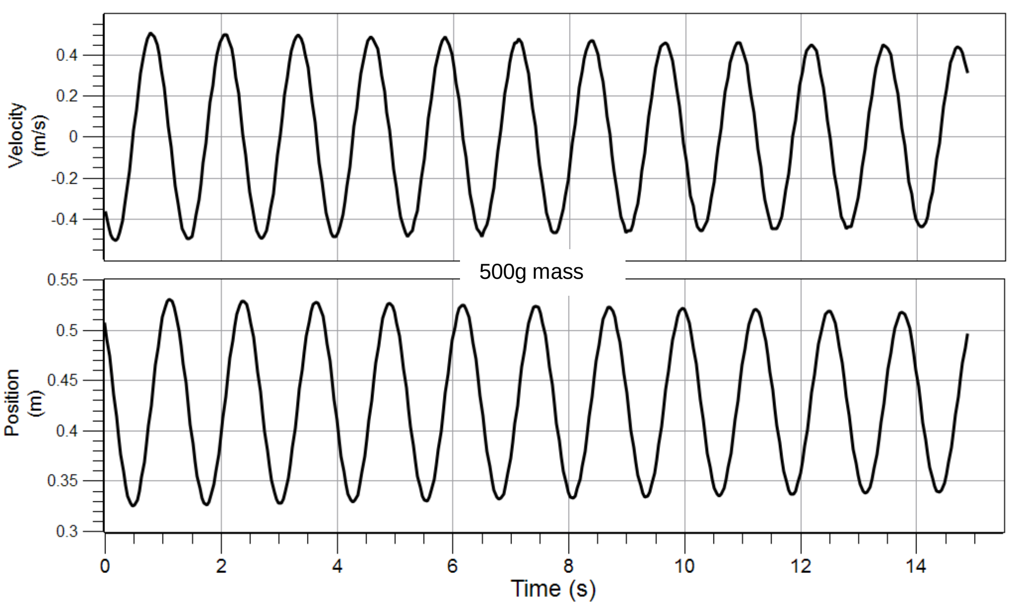


Table 1: Mass and period – measured

Mass (kg)	Time for 10 oscillations (s)	Period of one oscillation (s)	Frequency of oscillation (Hz)	Amplitude of oscillation (m)
0.500	12.6	1.26	0.79	0.102
0.700	14.8	1.48	0.68	0.122
1.000	17.6	1.76	0.57	0.146

1. ☐ The expression shown below shows the theoretical relationship between the spring constant k, the mass m, and the period of oscillation, T.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

For each of the masses used, calculate the theoretical period of oscillation and enter the values into Table 2. Then, calculate the percent error in the measured period values for each mass. Enter the percent error values into Table 2.

$$T = 2\pi\sqrt{\frac{0.5\text{ kg}}{12.8\text{ N/m}}}$$

$$T = 1.25\text{ s}$$

$$\%\text{error} = \frac{\text{Actual} - \text{Theoretical}}{\text{Theoretical}} \cdot 100$$

$$\%\text{error} = \frac{1.26\text{ s} - 1.24\text{ s}}{1.24\text{ s}}$$

$$\%\text{error} = 1.6\%$$

Table 2: Mass and period – theoretical

Mass (kg)	***k* (N/m)**	**Theoretical Period (s)**	**% Error**
0.500	12.8	1.24	1.6%
0.700	12.8	1.47	0.7%
1.000	12.8	1.76	0%

2. ☐ The theoretical relationship assumes that the mass of the spring is zero. Depending on the mass and spring you are using, the size of this systemic error will vary. To correct for this error we will assume that the additional mass added to the system is approximately equal to 1/3 the mass of the spring.

3. ☐ Use a balance to measure the mass of the spring, and then record the value below.

m_{spring} = 0.019 kg

4. ☐ Add one third of the mass of the spring to the total mass *m* used in your theoretical calculations, and then re-calculate new, corrected, theoretical values for the period of oscillation for each mass as well as the percent error associated with your measured values. Record the new mass values and the results of your calculations into Table 3.

$$T = 2\pi\sqrt{\frac{0.519\text{ kg}}{12.8\text{ N/m}}}$$

$$T = 1.28\text{ s}$$

$$\%\text{error} = \frac{\text{Actual} - \text{Theoretical}}{\text{Theoretical}} \cdot 100$$

$$\%\text{error} = \frac{1.26\text{ s} - 1.27\text{ s}}{1.27\text{ s}}$$

$$\%\text{error} = 0.8\%$$

Table 3: Mass and period

Mass + 1/3 Spring (kg)	***k* (N/m)**	**Theoretical Period (s)**	**% error**
0.519	12.8	1.27	0.8%
0.719	12.8	1.49	0.7%
1.019	12.8	1.77	0%

Analysis Questions

1. To determine the period of oscillation for the spring, why is it better to measure the time for 10 oscillations and then divide the value by 10 than it is to simply measure the time for one oscillation?

The actual uncertainty or error in measurement is likely to be the same in both cases. As a percentage, this number will be much greater for the one oscillation measurement than for the ten oscillation measurement.

2. Why was the sampling rate increased to 25 Hz for the experiment?

Higher sampling rates give us a more detailed look at the resulting graphs. Using a higher sampling rate ensures that our estimate of where the peaks are will be more accurate.

3. Which of the motion graphs that resulted from measurements made by the motion sensor is most closely related to the graph of Force versus Time?

The Acceleration versus Time graph is most closely related to the graph of Force versus Time. The two graphs are in phase. Because the force sensor was zeroed when the mass was at rest in the equilibrium position, the reading provided by the force sensor will give the net force acting on the mass at any instant. We know from Newton's second law that the acceleration experienced by a body is always in the same direction as the net force and is proportional to the size of the force.

4. **Describe the relationship between the Position versus Time, Velocity versus Time, and Acceleration versus Time graphs for the oscillating mass.**

The acceleration time graph is one quarter cycle ahead of the velocity time graph, which in turn is one quarter cycle ahead of the position time graph.

5. **All three variables (position, velocity, and acceleration) are constantly changing; but because the motion is repeated over and over, there are some definite relationships.**

a. **What is the value of the acceleration when the velocity has its greatest magnitude? When does this occur during the cycle of one oscillation?**

Zero. This occurs as the mass moves through the equilibrium or rest position (the position it occupies when it is not vibrating).

b. **What is the value of the velocity when the acceleration has its greatest magnitude? When does this occur during the cycle of one oscillation?**

Zero. This occurs when the mass is at its highest point and lowest point in the oscillation.

6. **How did the addition of one third the spring mass affect the percent error in your measured values? How would you spot or verify a systematic error like this?**

Student answers will vary, but generally the error should be reduced by adding this estimation of the influence of the spring mass. One way to determine if the error is systematic is to do many repeated trials to compare the standard deviation of the trials versus the measured percent error. If the error deviation is much larger than the trial deviation, then this is an indication of a possible systemic error.

Synthesis Questions

Use available resources to help you answer the following questions.

1. **If this activity were repeated on the surface of the moon using the same equipment, would the results be the same? Explain.**

The force of gravity on the moon is about one-sixth of what it is on Earth. Consequently, the mass used in this activity would not extend the spring as much. However, a graph of Force versus Extension would be the same as it would be on Earth, resulting in the same spring constant k. As a result, we would expect to get the same period of oscillation as on Earth and the same relationship between T (the period), m (the mass) and k(the spring constant).

2. **If this activity were repeated by astronauts on a space shuttle using the same equipment, would the results be the same? Explain.**

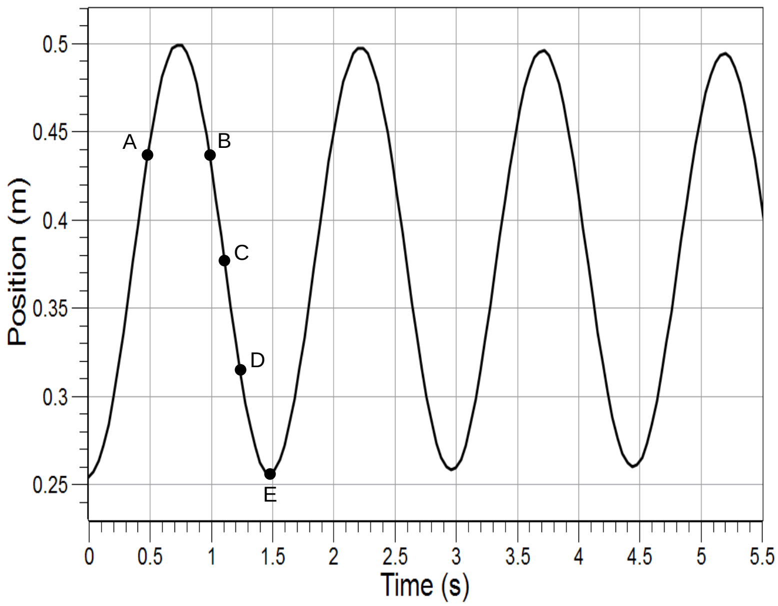
The entire contents of the shuttle, including the shuttle itself are in free fall. As a result, when a mass is placed on the end of a spring, and the spring is not extended, it is impossible for the mass and the spring to exert forces on each other. Therefore, this activity could not be carried out on the space shuttle. However, a spring that allows the mass to be firmly attached and move through both extension and compression could be used. An inertial balance can be used to determine the mass of an object in freefall.

3. **Springs play an important role in the suspension systems of automobiles to give a comfortable ride. However, these suspension systems also include shock absorbers. What is their role?**

A spring compresses when a tire encounters a bump in the road. This keeps the tire in contact with the road and diminishes the impact to the passengers. However, if these springs continue to oscillate, the vehicle would be hard to control. Shock absorbers allow the oscillation to occur but cause it to die down within an oscillation or two.

Multiple Choice Questions

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



The graph above shows the position of a mass as it oscillates vertically on the end of a spring in simple harmonic motion. Five points show various positions of the mass during oscillation. Assume that up is positive and down is negative.

1. **At which position is the mass's acceleration equal to zero?**

- **A.** A
- **B.** B
- **C.** C
- **D.** D
- **E.** E

2. In which two positions is the mass's acceleration negative, or downward?

- **A. A & B**
- **B.** B & D
- **C.** D & E
- **D.** A & E
- **E.** B & E

3. In which two positions is the net force positive, or upward?

- **A.** A & B
- **B.** B & C
- **C.** C & D
- **D. D & E**
- **E.** A & E

4. At which position is the net force zero?

- **A.** A
- **B.** B
- **C. C**
- **D.** D
- **E.** E

5. At which position is the magnitude of the mass's velocity the greatest (when is the mass moving the fastest)?

- **A.** A
- **B.** B
- **C. C**
- **D.** D
- **E.** E

6. Which point represents the greatest displacement from the rest position?

- **A.** A
- **B.** B
- **C.** C
- **D.** D
- **E. E**

7. Which of the following would increase the period of oscillation?

- **A.** Increase the mass
- **B.** Decrease the mass
- **C.** Use a spring with a smaller k value
- **D. Both A and C are correct**
- **E.** Both B and C are correct

8. In which position are velocity and acceleration in the same direction?

- **A.** A
- **B.** B
- **C.** C
- **D.** D
- **E.** E

Key Term Challenge

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

1. For an oscillating mass and spring system, a graph of net force acting on the mass versus time will be in phase with a graph of **acceleration** versus time for the same mass. The two factors that affect the period of oscillation of a mass and spring system are the magnitude of **mass** and the **spring constant** of the spring. If the mass in an oscillating mass and spring system were increased to four times its original mass, the period of oscillation would change by a factor of **two**.

Extended Inquiry Suggestions

If time permits, students can repeat the activity with a spring having a different spring constant.

A second alternative would be to study a simple pendulum consisting of a mass suspended by a string. The relationship between the size of the mass, the length of the string, and the period of the pendulum could be explored.

Ask students to calculate the angular frequency for each mass:

$$\omega = 2\pi f$$

17. Pendulum

Objectives

This activity helps students determine how the mass and length of a simple pendulum affect its period of oscillation. Students determine:

- The period of a simple pendulum with variable mass but constant length
- The period of a simple pendulum with variable length but constant mass
- An experimental value for the acceleration due to gravity using a simple pendulum

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the position of a pendulum bob with respect to time.
- Identifying and measuring the period of oscillation for a simple pendulum from a graph of position versus time.
- Drawing a conclusion concerning the period of a simple pendulum as a function of the mass of the bob.
- Constructing a graph of pendulum arm length versus period and drawing conclusions about the relationship between the two variables.
- Constructing a graph of pendulum arm length versus the square of the period and drawing conclusions about the relationship between the two variables.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	45 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Motion sensor
- ♦ Large table clamp
- ♦ Short Rod
- ♦ Rod stand
- ♦ Metric tape measure
- ♦ Balance (1 per classroom)
- ♦ Pendulum clamp
- ♦ String, 4 m
- ♦ Pendulum bob, (3 of the same size, but made of different materials)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Period of a pendulum
- ♦ The mathematical relationship between period and frequency
- ♦ Graphical analysis – motion.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Position: Match Graph
- ♦ Speed and Velocity
- ♦ Acceleration
- ♦ Hooke's Law
- ♦ Simple Harmonic Motion
- ♦ Circular Motion
- ♦ Centripetal Force

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)

- Changing the sampling rate �(5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adding a note to a graph �(7.1.5)
- Manually entering data into a table �(7.2.3)
- Measuring the distance between two points in a graph �(9.2)
- Applying a curve fit �(9.5)
- Creating calculated data �(10.3)
- Saving your experiment �(11.1)

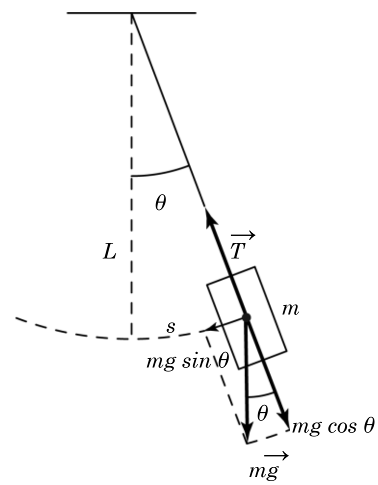
Background

We have learned that simple harmonic motion occurs when a free-moving object experiences a net (restoring) force proportional to the distance x of the object away from some equilibrium position x_0, and always in the direction of that equilibrium position.

$$F = -k(x - x_0) \qquad \textbf{Eq.1}$$

If we examine a free body diagram for a simple pendulum, we can see that the restoring force imparted to the pendulum bob is equal to:

$$F = -mg\sin\theta \qquad \textbf{Eq.2}$$



Because the sine of an angle is not linear with respect to the angle, it would initially seem that this motion cannot be simple harmonic. But recall the small angle approximation:

For small θ:

$$\sin\theta = \tan\theta = \theta$$

Try it! Using your calculator, solve for the sine of each angle from 1° to 10°, and then convert each angle in degrees to an angle in radians. You will find that for these small angles, there is almost no difference between the sine of the angle, the tangent of the angle, and the angle itself (if expressed in radians).

So as long as we keep the angle very small (less than 10°), we could rewrite the restoring force as:

$$F = -mg\tan\theta$$

Or

$$F = -mg\frac{S}{L}$$

And this could actually be rewritten as:

$$F = -\left(\frac{mg}{L}\right)S$$

This is exactly the same form as the formula for Hooke's Law if the spring constant is:

$$k = \left(\frac{mg}{L}\right)$$

So if the equation for the period T of a mass and spring system is:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Then to write the formula for the period T of a simple pendulum, just replace the k with mg/L and we get:

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad \textbf{Eq.3}$$

Where L is the length of the pendulum arm, and g is the acceleration due to gravity.

Pre-Lab Discussion and Activity

Begin the activity by engaging students in a discussion of what factors are involved in the period of a pendulum.

Review the nature of periodic motion.

1. Is the period of a pendulum dependent upon the mass of the bob?

The period of a pendulum is not dependent on the mass of the bob. It is one of the goals of this lab to prove this.

2. How does the length of the pendulum affect its period?

The period of the pendulum will vary as the square root of the length. This concept will be illustrated in the lab activities that follow.

Explore the equation for the period of a simple pendulum in class and examine it with the students. Is mass involved? Why not? Some students will not believe that the mass of the bob will not affect the period, so it will be an excellent chance to have them learn by inquiry.

Lab Preparation

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

1. Collect several pendulum bobs that are the same size but made of different materials to keep the center of mass constant. The bobs should be large enough to be detected by the motion sensor.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Keep the angle of oscillation under 10 degrees to prevent injury and damage to equipment.

Sequencing Challenge

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

2	1	5	3	4
Position to motion sensor at the same height as the pendulum bob.	Connect the pendulum clamp to the rod.	Plot a graph of Length versus Period to determine the nature of the relationship.	Begin collecting Position versus Time data.	Use the time interval between oscillations on a graph of Position versus Time to calculate the period of the pendulum.

Procedure with Inquiry

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

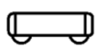
Note: Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these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

Part 1 - Varying the Mass

Set Up

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

2. ☐ Connect the table clamp to the edge of a table, and then mount the short rod vertically to the table clamp. Mount the pendulum clamp near the top of the rod such that the clamp hangs over the edge of the table.

3. ☐ Connect the motion sensor to the rod stand, and be sure the switch on the sensor is in the cart position. 

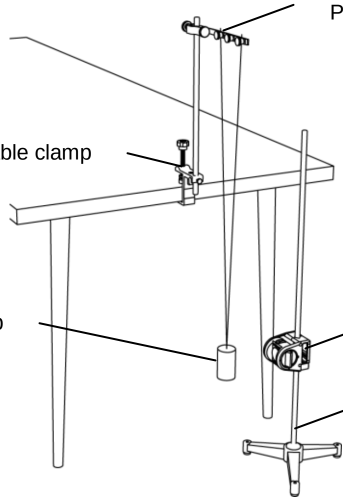
4. ☐ Measure the mass of the first pendulum bob, and record the mass in Table 1 in the Data Analysis section.

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

6. ☐ Display Position versus Time in a graph. �(7.1.1)

7. ☐ Ensure that the sampling rate of your data collection system is at least 20 samples per second. �(5.1)

8. ☐ Put the first pendulum bob in the middle of a piece of string that is about 2.5 meters in length. Attach the ends of the string to the inner and outer clips of the clamp so that the string forms a 'V' shape as it hangs.



9. ☐ Using the metric measuring tape, determine the distance (to the nearest mm) from the bottom of the clamp to the middle of the bob. This measurement represents the pendulum arm length. Record the value in Table 1 in the Data Analysis section.

10. ☐ Why measure to the middle of the bob?

This allows you to approximate measuring to the center of mass of the bob.

11. ☐ Mount the motion sensor to the rod with the brass colored disk on the motion sensor pointing directly at the middle of the pendulum bob, and in-line with the path of the swing. Be certain that the distance between the brass colored disk and the bob is about 25 cm.

12. ☐ How do you think the mass will affect the period of the pendulum?

Student answers will vary; changing the mass should have no effect on the period of the pendulum.

Collect Data

13. ☐ Pull the pendulum bob back about 10 cm, and let it go. After it has oscillated back and forth a few times, begin recording data. Record data through at least 4 cycles, and then stop data recording. �(6.2)

14. ☐ Add a note to the graph indicating the mass of the bob used in this trial. �(7.1.5)

15. ☐ Repeat the data collection steps for each of the pendulum bobs. Be sure not to change the length of the pendulum arm when changing bobs. If necessary, adjust the string to maintain a constant length.

Analyze Data

16. ☐ For each run of data, find the interval of time it takes to complete several cycles. �(9.2)

17. ☐ Record the interval of time for each trial, the number cycles, and the mass of the pendulum bob used in Table 1 in the Data Analysis section.

18. ☐ Complete the Period column in Table 1 in the Data Analysis section by dividing the interval of time by the number of cycles for each mass value.

19. ☐ Sketch one of your Position versus Time plots in the Position versus Time graph in the Data Analysis section.

Part 2 - Varying the Length

Set Up

20. ☐ Choose one of your bobs from Part 1, and record its mass in Table 2 in the Data Analysis section.

21. ☐ Transfer the length and the average period data for this bob from Table 1 to the first line of Table 2.

22. ☐ Place the bob you selected in position on the string.

23. ☐ Loosen one side of the pendulum clamp, pull some string in, and re-clamp the clip to reduce the length of the pendulum by about 10 or 15 cm.

24. ☐ What effect do you think shortening the pendulum will have on its period?

Student predictions may vary. The period will get shorter as the length gets shorter.

Collect Data

25. ☐ Measure, to the nearest millimeter, the length of the new pendulum from the bottom of the pendulum clamp to the center of the bob.

26. ☐ Adjust the height of the motion sensor so that it is at the same height as the bob.

Note: You may need to place the rod stand on a chair to measure the motion when the pendulum arm is above the highest point of the rod stand.

27. ☐ Pull the pendulum bob back a few centimeters and let it go. After it has oscillated back and forth a few times, start data recording. Record data through at least 4 cycles, and then stop data recording. �(6.2)

28. ☐ Add a note to the graph indicating the length of the pendulum arm used in this trial. �(7.1.5)

29. ☐ Repeat the data collection steps for several pendulum lengths, reducing the length by 10 to 15 cm each time.

Analyze Data

30. ☐ For each run of data, find the interval of time it takes to complete several cycles. �(9.2)

31. ☐ Record the interval of time measured, the number cycles, and the length of the pendulum in Table 2 in the Data Analysis section.

32. ☐ Complete the column for Period in Table 2 in the Data Analysis section by dividing the interval of time by the number of cycles for each length.

33. ☐ Create a table of Length and Period on the data collection system, where both variables are user entered data. �(7.2.3)

34. ☐ What can you conclude about the length of the pendulum as the period of the pendulum get larger?

As the values for Period get larger, the values for Length of the Pendulum get larger.

35. ☐ Display Length on the y-axis of a graph with Period on the x-axis. �(7.1.1)

36. ☐ Is the relationship linear? Does the graph form a straight line?

No. It is not linear.

37. ☐ If the relationship is not linear, what shape does the graph seem to be? To put it in different terms, what mathematical relationship forms a graph that looks like this one?

The graph looks very much like a graph of $y = x^2$.

38. ☐ Sketch this plot in the Length versus Period graph in the Data Analysis section.

39. ☐ What would you expect to find if we plotted the length of the pendulum against the square of the period?

Student predictions might vary. But the correct answer is that the graph should be a straight line.

40. ☐ On the data collection system, create a calculation to compute period squared. �(10.3)

Period Squared = [period]^2

41. ☐ Display Length on the y-axis of a graph with Period Squared on the x-axis. �(7.1.1)

42. ☐ Sketch this plot in the Length versus Square of Period graph in the Data Analysis section.

43. ☐ What is the shape of this new graph?

The graph is a straight line.

44. ☐ Apply a linear curve fit to the graph of Length versus Period Squared on the data collection system. �(9.5)

45. ☐ Add the best-fit line to the Length versus Square of Period graph in the Data Analysis section.

46. ☐ Record the slope of the best-fit line in the space provided below the graph.

47. ☐ What can be said (mathematically) about the relationship between pendulum length and the square of the period?

The length of the pendulum is proportional to the square of the period.

48. ☐ Save your work according to your teacher's instructions. �(11.1)

Data Analysis

Position versus Time

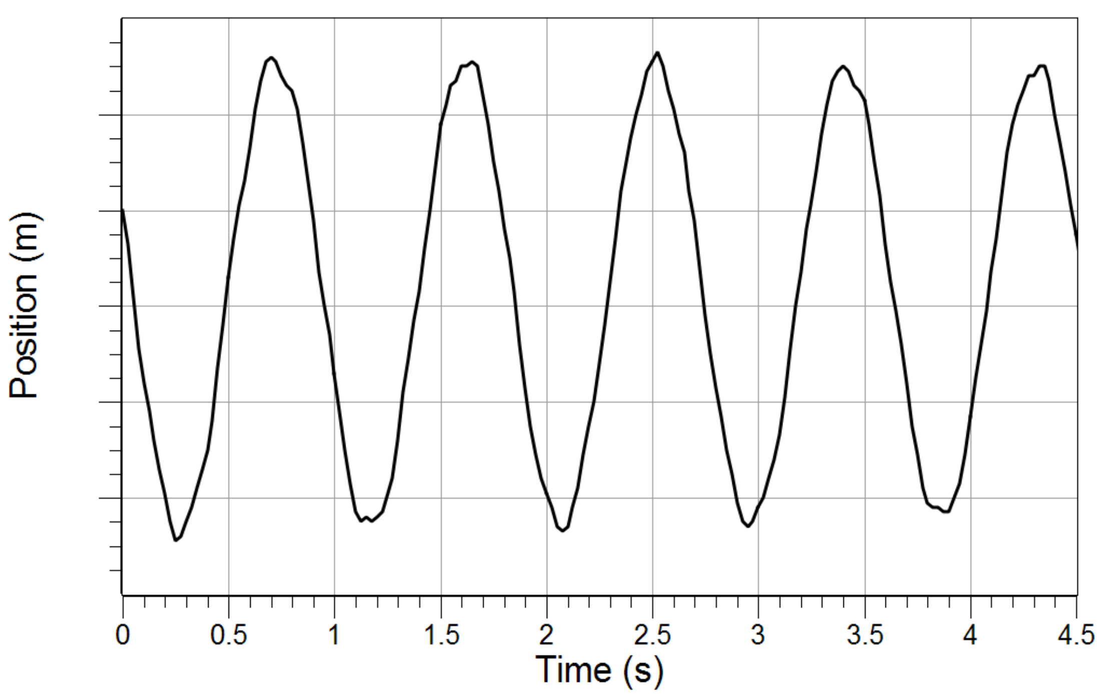


Table 1: Changing Mass

Mass (kg)	Interval of Time (s)	Number of Cycles	Period (s)

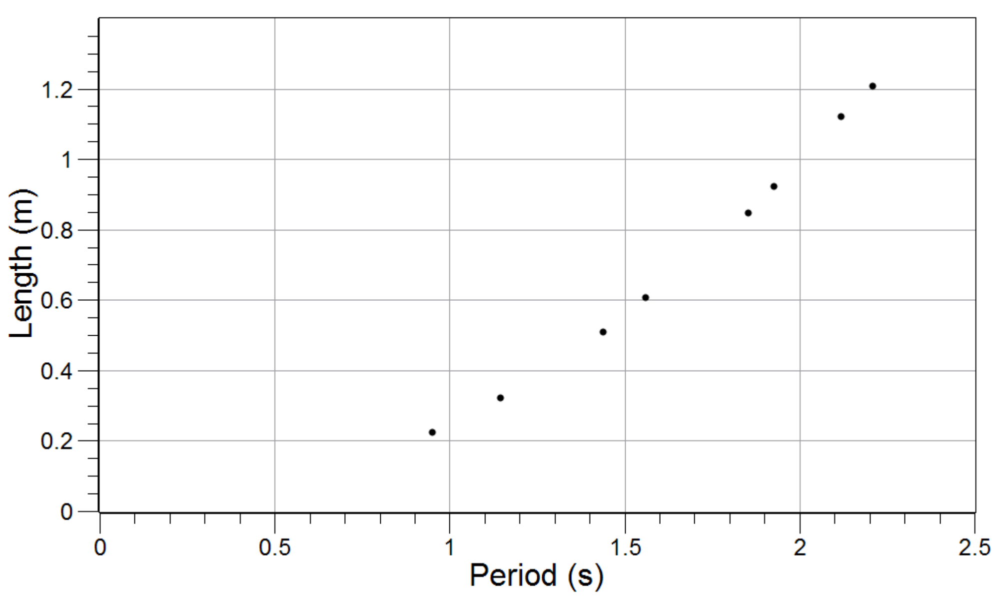
Length of the Pendulum for Part 1:________________

Table 2: Changing Mass

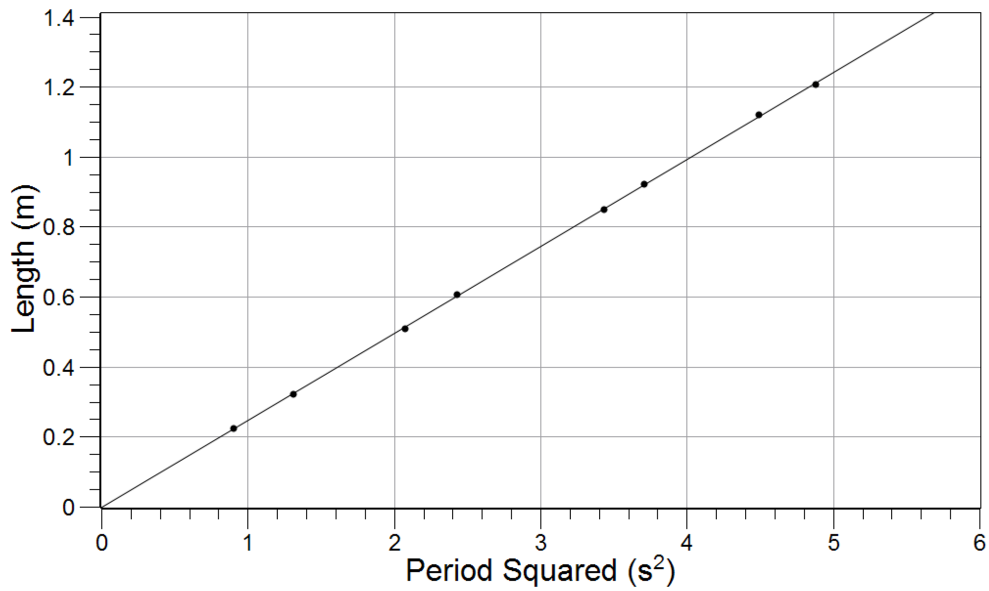
Length (m)	Interval of Time (s)	Number of Cycles	Period (s)
1.206	6.629	3	2.210
1.120	6.360	3	2.120
0.922	5.780	3	1.927
0.848	5.560	3	1.853
0.606	4.680	3	1.560
0.509	4.320	3	1.440
0.320	3.440	3	1.147
0.224	2.850	3	0.950

Mass of the bob for Part 2: 50 g

Length versus Period



Length versus Square of Period



The slope of the best fit line is: 0.2487

Analysis Questions

1. State any conclusions you might be able to draw concerning a pendulum's period and the mass of its bob (provided that the length is held constant.)

The period of a simple pendulum is not dependent on the mass of the bob. Provided that the length is held constant, two pendulums with different mass bobs will have the same period.

2. The period of a pendulum is directly proportional to what quantity?

The square root of the length of the pendulum.

3. Suppose we wanted to construct a pendulum whose period is precisely 1.00 second. How long should we make the pendulum?

Solving the equation for L and entering 1.00 seconds in for T, the length turns out to be 0.248 m.

4. What do you think the greatest source of error is in your experimental procedure?

Student answers will vary, but in most cases it will be the length measurement.

5. If we take the equation for the period of a simple pendulum

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Solve this equation for length

$$L = \left(\frac{g}{4\pi^2}\right)T^2$$

We see that plotting Length versus Period squared would have a slope of

$$\text{Slope} = \left(\frac{g}{4\pi^2}\right)$$

How does this compare to the slope of Length versus Period Squared that you found?

The value is very similar: 0.2485 m versus 0.2487 m.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If a pendulum clock keeps perfect time at the base of a mountain, will it also keep perfect time when it is moved to the top of the mountain? Explain. If the clock does not run at the same rate, explain why it would run slower or faster than normal.

No. The period of the pendulum is inversely proportional to the square root of gravitational acceleration. So as the clock is taken further up the mountain, gravitational acceleration decreases. The square root of the acceleration due to gravity therefore decreases, and a smaller number in the denominator of a fraction makes the value of the fraction get larger. So as we go up the mountain, the period gets larger and the clock runs a bit slower.

2. A simple pendulum is made from a small-diameter glass sphere. The sphere is completely full of a colored liquid. What would happen to the frequency of oscillation of the pendulum if the sphere had a hole in it that allowed the colored liquid to leak out slowly?

Because the diameter of the sphere is small, the loss of liquid will not change the location of the center of mass of the bob appreciably. So, the only thing that changes is the mass of the bob. Because the period of the pendulum is independent of the mass of the bob, the frequency of oscillation will not change.

3. An old-fashioned grandfather clock is dependent upon the period of its pendulum in order to keep correct time. The pendulum arm is made of metal, which expands when heated. Suppose we get our grandfather clock adjusted perfectly, but then the temperature increases in the room where the clock is kept. Does the clock run slow, run fast, or continue to keep good time? Explain your answer fully.

The clock runs a bit slowly. As the temperature increases, the length of the pendulum increases (as it expands thermally). The period of the pendulum is proportional to the square root of the length. So if the length increases, then the square root of the length increases, and the period gets a bit longer. A longer period represents a clock that runs slowly.

Multiple Choice Questions

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

1. If one could transport a simple pendulum of constant length from the Earth's surface to the Moon's surface (where the acceleration due to gravity is one-sixth that on the Earth) by what factor would the pendulum frequency be changed?

- **A.** about 6.0
- **B. about 2.5**
- **C.** about 0.41
- **D.** about 0.17
- **E.** about 0.12

2. Tripling the mass of the bob on a simple pendulum will cause a change in the frequency of the pendulum swing by what factor?

- **A.** 0.33
- **B. 1.0**
- **C.** 3.0
- **D.** 9.0
- **E.** 12

3. By what factor should the length of a simple pendulum be changed if the period of oscillation were to be tripled?

- **A.** 1/9
- **B.** 1/3
- **C.** 3.0
- **D. 9.0**
- **E.** 12

4. A simple pendulum has a period of 2.0 seconds. What is the length of the pendulum?

- **A.** 0.36 m
- **B.** 0.78 m
- **C. 0.99 m**
- **D.** 2.4 m
- **E.** 3.5 m

Key Term Challenge

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

1. The interval of time required for a **pendulum** to move through an entire cycle is referred to as the **period**. The number of complete cycles that a pendulum completes per second is known as the **frequency** of the pendulum. Two factors on which the period of a pendulum depends are **length** and **acceleration** due to gravity.

2. The small massive body at the end of a string that forms a simple pendulum is the **bob.** A real-world device that depends on the science of pendulums is a grandfather **clock**. The period of this kind of clock is usually one **second**. If we know the period of **oscillation** and the length of this pendulum we can determine the acceleration due to **gravity**.

Extended Inquiry Suggestions

You might try setting up the pendulum experiment as before, but this time, take no measurements of the length of the pendulum. Simply set it up with an arbitrary length and determine its period. Using the formula for the period of a simple pendulum, calculate what its length must have been. Check your results by measuring the actual length of the pendulum. Repeat this exercise with several different pendulums of varying length.

Challenge: Construct a pendulum with a period of exactly one second.

Determination of g using the slope of the graph

We know from the Analyze Data section that the slope of the Length versus Period Squared graph is:

$$\text{Slope} = \frac{g}{4\pi^2}$$

So for this particular experiment, we have:

$$4\pi^2(0.2487\,\text{m}) = g$$

Or:

$$g = 9.818\,\text{m/s}^2$$

18. Circular Motion

Objectives

The majority of the experiences your students will have in mechanics center around linear systems. This experiment helps students make the transition from a linear frame of reference to a circular frame of reference. Students:

- Develop a kinesthetic understanding of circular motion
- Apply Newton's laws of motion to an object undergoing uniform circular motion

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the period of rotation of a mass in uniform circular motion
- Calculating the instantaneous velocity of an object in uniform circular motion
- Calculating the acceleration of an object in uniform circular motion
- Comparing force and acceleration values in uniform circular motion

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion	10 minutes
♦ Lab activity	40 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Rubber stopper, #10 single-hole[1]
- Rod, short
- Plastic tube[1]
- Timer
- Balance (1 per classroom)
- Table clamp
- Meter stick
- Plastic tie[1]
- String, 3 m[1]
- Scissors
- Marker

[1]Included in the Discover Centripetal Force Kit.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Linear velocity
- Linear acceleration
- Newton's laws

Related Labs in This Guide

Labs conceptually related to this one include:

- Position: Match Graph
- Speed and Velocity
- Acceleration
- Newton's First Law
- Newton's Second Law
- Newton's Third Law
- Pendulum
- Introduction to Force
- Centripetal Force

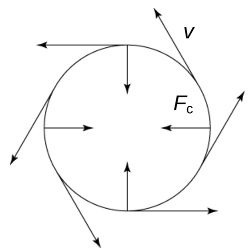
Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Monitoring live data without recording data �(6.1)
- Displaying data in a digits display �(7.3.1)

Background

Your students' prior study of the motion of objects has mostly included linear dynamics. When an object moves in a curved or circular path, the object is subject to a center-seeking force called centripetal force F_c. This force is directly related to the object's net inward acceleration. In uniform circular motion, the object moves with constant speed yet changing direction. Thus, its velocity is not constant, and the acceleration is non-zero.



The centripetal acceleration a_c associated with an object in uniform circular motion with linear velocity v and radius r is defined as:

$$a_c = \frac{v^2}{r}$$ **Eq.1**

If the object has mass m, From Newton's second law:

$$F_c = m\frac{v^2}{r}$$ **Eq.2**

Pre-Lab Discussion and Activity

Engage your students by considering the following.

If your students are not familiar with using radians to describe angles, this is a good time to introduce the concept. 2π radians completes a circle or is equivalent to 360°. This makes it much easier to describe the distance around the arc of a circle as the radius multiplied by the angle in radians.

Toss a ball in a straight path to a student.

1. How do I know that the ball will head toward the student?

There is no force acting on the ball other than gravity.

Tie a string to the ball (like a tetherball), and anchor it to one side. Then toss the ball to the same student.

2. Why did the ball not reach the student even though I tossed the ball with the same velocity?

A force must have acted on the ball, in this case tension from the string.

Rotate a small soft object in circular motion over your head.

3. **If the tension force from the string causes this object to move in a circular path, what would happen if that force were removed?**

The object would continue in a straight line that is tangent to the circle.

Release the object in a safe direction.

Review Newton's second law.

4. **According to Newton's second law, what is the magnitude of the tension force from the string?**

$F = ma$

5. **What is the direction of the tension force in this experiment?**

Pointing toward the center of rotation.

6. **If the force is pulling toward the center of rotation to keep the object in a circular path, what direction is the acceleration that the object experiences?**

Also pointing toward the center of rotation.

Demonstrate how you want students to operate the apparatus. Make sure you instruct students to keep the plane of motion parallel to the floor.

7. **If there is a constant acceleration, what does this tell you about the velocity?**

The velocity must be constantly changing

8. **How is the speed of the object related to the velocity?**

Speed is the scalar magnitude of the velocity.

Because the motion is in a circular path, ask students to consider the direction as if they were riding in circular motion on a merry-go-round.

9. **Is the direction constant or changing?**

Changing. Thus, the velocity is not constant due to changing direction even though the scalar magnitude (speed) is constant under a constant applied force.

10. **As the object moves in circular motion, is it accelerating? Why or why not?**

Ask students to think again about the velocity in terms of speed and direction. Even though the speed is uniform under a constant force, the direction is changing at any point along the circle.

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:

- ♦ Use appropriate eye protection.
- ♦ Have adequate space around your lab stations to rotate the mass above your heads in a 1 m radius.

Sequencing Challenge

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

2	3	5	1	4
Press the "zero" button on the sensor.	Carefully begin rotating the mass above your head at the radius marked on the string.	Calculate the acceleration experienced by the mass.	Connect the force sensor to the data collection system.	Time 10 revolutions of the mass while maintaining a constant force on the sensor.

Procedure with Inquiry

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

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

Set Up

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

2. ☐ Measure the mass of the stopper, and record the value in Table 1 in the Data Analysis section.

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

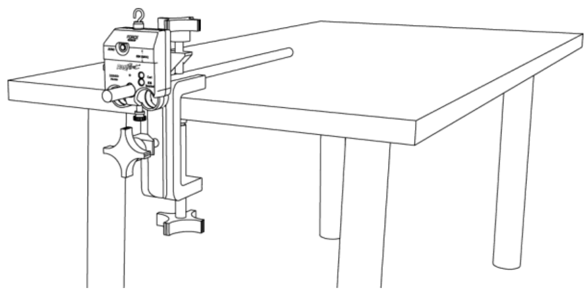
4. ☐ Display Force, pull positive in a digits display. �(7.3.1)

5. ☐ Configure the data collection system to monitor live data without recording. �(6.1)

6. ☐ Attach the table clamp to a table with the rod connector above the table.

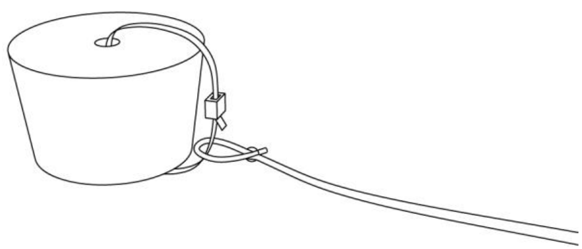
7. ☐ Attach the short rod to the rod connector on the table clamp such that the rod is parallel to the floor.

8. ☐ Attach the force sensor to the short rod such that the hook of the sensor points straight up, and then push the "zero" button on the force sensor.



9. ☐ Attach a plastic tie to the stopper through the hole in the center of the stopper.

10. ☐ Tie the string to the plastic tie.



11. ☐ Measuring from the center hole of the stopper (approximately the center of mass), mark the string at 1.0 meter from the stopper's center of mass. Record the radius in Table 1 in the Data Analysis section.

12. ☐ If the radius of the circle of motion is 1.0 m, what is the distance the stopper travels in one revolution?

$C = 2\pi r$

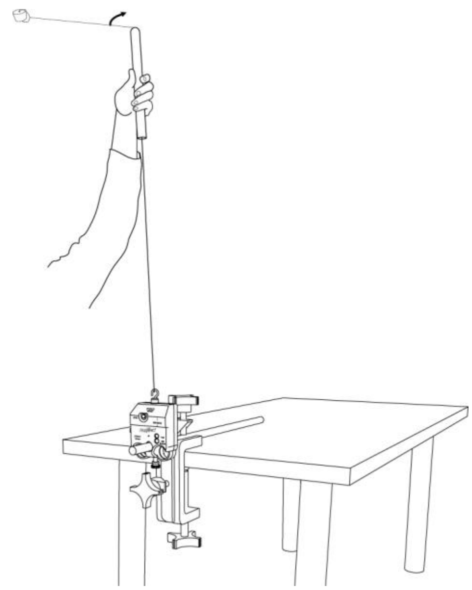
$C = 2\pi(1.0\text{ m})$

$C = 2\pi$

$C = 6.28\text{ m}$

13. ☐ Thread the other end of the string through the plastic tube, and attach the string to the hook of the force sensor. Adjust the length of the string to allow the mass to rotate overhead.

Collect Data



14. ☐ Carefully begin rotating the mass overhead. Keep the mark on the string at the mouth of the tube to insure the radius remains 1 m.

Note: Always try to keep the plane of rotation parallel to the floor.

15. ☐ Use the stopwatch to time 10 revolutions of the mass while maintaining a constant speed.

Note: One way to determine if you are maintaining a constant speed it to maintain a constant force on the force sensor.

16. ☐ Record the force and time of 10 revolutions in Table 1 in the Data Analysis section.

17. ☐ Repeat data collection, rotating the mass at a higher speed

Analyze Data

18. ☐ Calculate the time it took to complete a single cycle, and record the value in Table 1 in the Data Analysis section for both the high speed and low speed data sets.

$$t = \frac{\text{time of 10 revolutions}}{\text{10 revolutions}}$$

$$t = \frac{8.45\text{ s}}{10}$$

$$t = 0.85\text{ s}$$

19. ☐ Calculate the distance travelled by the mass in a single revolution, and record the value in Table 1 in the Data Analysis section for both the high speed and low speed data sets.

$$C = 2\pi r$$

$$C = 2\pi(1.0\text{ m})$$

$$C = 2\pi$$

$$C = 6.28\text{ m}$$

20. ☐ Calculate the speed of the mass in a single revolution, and record the value in Table 1 in the Data Analysis section for both the high speed and low speed data sets.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{speed} = \frac{6.28\text{ m}}{0.85\text{ s}}$$

$$\text{speed} = 7.39\text{ m/s}$$

Data Analysis

Table 1: Circular motion

Experiment parameter	Low speed	High speed
Mass of the stopper (kg)	0.056	0.056
Radius of rotation (m)	1	1
Time for 10 revolutions (s)	8.45	5.02
Time for a single revolution (s)	0.85	0.50
Force, measured (N)	3.35	9.20
Distance traveled in 1 rotation (m)	6.28	6.28
Speed (m/s)	7.39	12.56
Acceleration (m/s^2)	54.61	157.75
Force, calculated (N)	3.06	8.83

Analysis Questions

1. If the centripetal acceleration experienced by a mass undergoing uniform circular motion is v^2/r, calculate the centripetal acceleration experienced by the rotating mass in this experiment for each speed. Record the results in Table 1.

$$a_c = \frac{v^2}{r}$$

$$a_c = \frac{(7.39\ \text{m/s})^2}{1.0\ \text{m}}$$

$$a_c = 54.6\ \text{m/s}^2$$

2. What direction is the acceleration?

The acceleration vector points toward the center of rotation.

3. Using $F = ma$, calculate the force exerted by the string to keep the mass in a circular path. Record the value in Table 1 in the Data Analysis section for both the high speed and low speed data sets.

$$F = ma$$

$$F = (0.056\ \text{kg})(54.6\ \text{m/s}^2)$$

$$F = 3.06\ \text{N}$$

4. How does the calculated force compare to the measured force?

Results will vary. The measured force was relatively close to the calculated force, although not equal.

5. What factors do you think contribute to any difference between the calculated and measured force?

The radius of the string may not have been constant during the 10 revolutions, nor the velocity of the stopper. The string also has mass that was neglected that may have made the measured force value slightly greater than the calculated value.

Synthesis Questions

Use available resources to help you answer the following questions.

1. An automobile with a 750 kg mass goes around a corner in a circular path with a radius of 22 m at 45 km/hr. What is the acceleration experienced by the car?

$$a_c = \frac{v^2}{r}$$

$$a_c = \frac{(45 \text{ km/hr})^2}{22 \text{ m}} = \frac{(45{,}000 \text{ m/hr})^2}{22 \text{ m}} = \frac{(12.5 \text{ m/s})^2}{22 \text{ m}}$$

$$a_c = \frac{156.25 \text{ m}^2/\text{s}^2}{22 \text{ m}} = 7.1 \text{ m/s}^2$$

2. If the moon rotates around the earth once every 28 days at a radius of 384,000 km, what is the speed of the moon in m/s? What is acceleration the moon experiences?

$$v = \frac{C}{28 \text{ days}} = \frac{C}{2.42 \times 10^6 \text{ s}}$$

$$C = 2\pi r$$

$$C = 2\pi(384{,}000 \text{ km}) = 2\pi(3.84 \times 10^8 \text{ m})$$

$$C = 2.41 \times 10^9 \text{ m}$$

$$v = \frac{2.41 \times 10^9 \text{ m}}{2.42 \times 10^6 \text{ s}}$$

$$v = 995.9 \text{ m/s}$$

$$a_c = \frac{v^2}{r}$$

$$a_c = \frac{(995.9 \text{ m/s})^2}{3.84 \times 10^8 \text{ m}}$$

$$a_c = 0.0026 \text{ m/s}^2$$

Multiple Choice Questions

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

1. The inertia of an object is related to the object's

- **A.** Speed
- **B.** **Mass**
- **C.** Velocity
- **D.** Force

2. As the frequency of motion increases, the distance per unit time traveled by the stopper

- **A.** Decreases
- **B.** **Increases**
- **C.** Remains the same
- **D.** Not enough information to answer

3. The direction of the stopper's net acceleration is

- **A.** **Inward toward the center**
- **B.** Outward from the center
- **C.** Tangent to the path at the position of the stopper
- **D.** Upward above the plane of the motion

Key Term Challenge

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

1. The force that acts through a string is referred to as **tension**. A **force** sensor can measure the tension through a string in newtons. An object's speed and direction is called **velocity**. If an object is tied to a string such that its speed remains constant as it travels around a central point, it undergoes uniform **circular** motion. Even though the object's **speed** is constant, its velocity is constantly changing.

2. According to Newton's second law, a one newton force causes a 1 kilogram object to accelerate at 1 m/s^2. An inward, or center-seeking, force is called the **centripetal** force. A constant force means a constant **acceleration**, which makes sense if the object undergoing circular motion has a constantly changing velocity. If the centripetal force is constant, variables such as **mass** and **radius** are proportional to the time it takes to complete a revolution.

Extended Inquiry Suggestions

Once students are comfortable with circular motion you can introduce them to the rotational analogs of force acceleration velocity and mass: Torque, angular acceleration, angular velocity, and Inertia respectively.

This is also a good time to draw the parallels between simple harmonic motion and circular motion.

19. Centripetal Force

Objectives

This experiment helps students understand the factors that affect the centripetal force experienced by an object in uniform circular motion. Students:

- Isolate different variables to study the relationship between pairs of variables involved in circular motion
- Compare the force they measure to ideal calculations to help identify real world factors that affect experimental results

Procedural Overview

Students will gain experience conducting the following procedures:

- Measuring the period of an object in uniform circular motion
- Changing one parameter at a time (mass, radius, and applied constant force) to determine its influence on an object in uniform circular motion
- Graphing parameters to determine the nature of their relationships

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion	10 minutes
♦ Lab activity	40 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Force sensor
- Rubber stopper (4)[1]
- Plastic tube[1]
- Table clamp
- Timer
- Meter stick
- Rod, short
- String, 3 m[1]
- Balance (1 per classroom)
- Scissors
- Marker

[1]Included with the Discover Centripetal Force Kit.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Newton's second law
- Tension force

Related Labs in This Guide

Labs conceptually related to this one include:

- Position: Match Graph
- Speed and Velocity
- Acceleration
- Introduction to Force
- Newton's First Law
- Newton's Second Law
- Circular Motion

Using Your Data Collection System

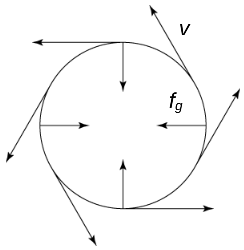
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Monitoring live data without recording �(6.1)

Background

When an object moves in a curved or circular path, the object is subject to a center-seeking action called centripetal force. According to Newton's second law, this force is directly related to the object's net inward acceleration. In uniform circular motion, the object moves with constant speed yet changing direction. Thus, its velocity is not constant, and the acceleration is non-zero. Consider the planets orbiting the sun in their near-circular paths. What is the nature of the force that causes the planetary orbits?

Gravity



In this experiment, your students will conduct several short investigations that examine how the object's mass influences the period of a revolution under a constant force and constant radius. They will also examine how changing the radius of the circular path affects the period of a revolution while the object's mass and applied force remain constant. In the final investigation, students will vary the applied force to determine the effect on the period of a revolution when holding the radius and mass constant.

Pre-Lab Discussion and Activity

Engage your students with the following questions and demonstration:

1. Can you name two mathematical relationships among the variables in Newton's second law? (Hint: force versus acceleration, and acceleration versus mass.)

Force is directly related to acceleration (under constant mass). Acceleration is inversely related to mass (under a constant force).

Define "tension force." Provide some examples for students to consider. For example, consider a rope tied to a sled, a crate suspended by a wire from a crane, a small ball connected to and hanging from a string, and a chain connecting a car-trailer system. Explain that tension is the force that acts through a medium or device, such as a cord, string, twine, or chain. Tension is measured in newtons.

2. What is the direction of the tension force in this experiment?

The tension force points toward the center of rotation.

Demonstrate how you want students to operate the apparatus. Instruct students to keep the plane of motion parallel to the floor.

3. What is the direction of the force?

Inward.

4. Is the force constant during uniform circular motion?

Yes. The velocity is not constant due to changing direction, but the scalar magnitude (speed) is constant under a constant applied force.

Consider a car's motion around a curve where the constant (inward) force due to friction (static) causes a net acceleration directed inward.

Lab Preparation

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

- ♦ Make sure that students have adequate space around their lab stations to rotate the mass above their heads in a 1 m radius.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Be sure to wear impact safety goggles or glasses.

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	3	1	4	2
Examine the graph of Force versus Period.	Monitor the magnitude of the force using the data collection system.	Connect the force sensor to your data collection system.	Use a stopwatch to measure the time of 10 revolutions.	Firmly hold the tube, and start the object in motion by swinging the system overhead.

Procedure with Inquiry

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

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

Part 1 - Different Masses

Set Up

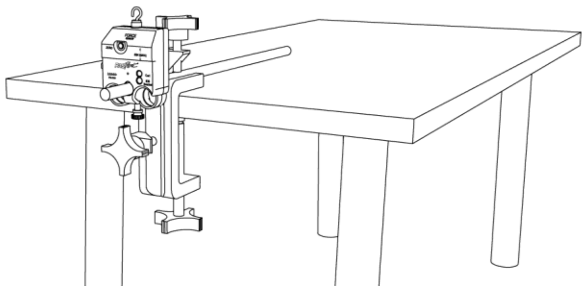
1. ☐ Start a new experiment on the data collection system. �(1.2)

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

3. ☐ Configure the data collection system to monitor Force, pull positive in a digits display. �(6.1)

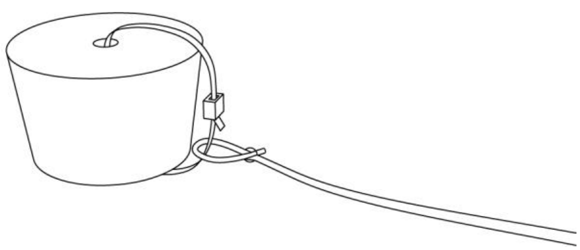
4. ☐ Attach the large table clamp to the edge of a table mount the small rod such that it is parallel to the floor.

5. ☐ Attach the force sensor to the short rod with the hook of the sensor pointed straight up, and then push the "zero" button on the force sensor.



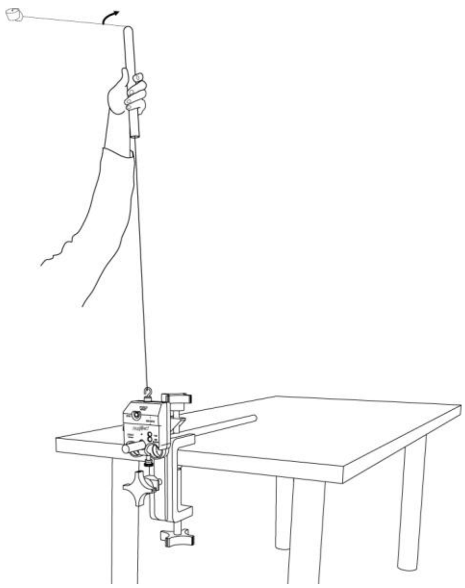
6. ☐ Attach a plastic tie to the stopper through the hole in the center of the stopper.

7. ☐ Tie the string to the plastic tie.



8. ☐ Measuring from the center hole of the stopper (approximately the center of mass), mark the string at 1.0 meter from the stopper's center of mass. Record this value as the radius for Part 1 below Table 1 in the Data Analysis section.

9. ☐ Thread the other end of the string through the plastic tube, and attach the string to the hook on the force sensor. Adjust the length of the string to allow the mass to rotate overhead with the 1 m mark at the top of the tube.



Collect Data

10. ☐ Measure the mass of the stopper, and record the value in Table 1.

11. ☐ Begin swinging the rubber stopper overhead in a circular motion at a constant speed. Watch the force measurements on the data collection system, and try to maintain a constant force while keeping the plane of rotation parallel to the floor.

12. ☐ With the system in uniform circular motion, use the stopwatch to measure the time for 10 full revolutions.

13. ☐ Record the time and number of revolutions in Table 1.

14. ☐ Repeat data collection three additional times, using two stoppers, three stoppers, and four stoppers. (Or, replace the stopper with a stopper of different mass, depending on the equipment you have available.) Be sure to achieve and maintain the same constant force in each trial.

15. ☐ Record the constant applied force used in all four trials as well as the amount of mass used in each trial into Table 1 in the Data Analysis section.

Part 2 - Different Radii

Set Up

16. ☐ Using the same setup as Part 1, select one stopper, and attach it to the end of the string opposite the force sensor.

17. ☐ Measure the mass of the stopper, and record the value below Table 2.

18. ☐ Lay the string along the meter stick with the center of the stopper at the 0 m mark, and then mark the string in 0.25 m intervals from 0 m to 1 m from the stopper.

Collect Data

19. ☐ Begin swinging the rubber stopper overhead in a circular motion at a constant speed. Watch the force measurements on the data collection system, and try to maintain a constant force while keeping the plane of rotation parallel to the floor.

20. ☐ With the system in uniform circular motion, use the stopwatch to measure the time for 10 full revolutions.

21. ☐ Record the time and number of revolutions in Table 2.

22. ☐ Repeat data collection three additional times, using the three different radii (0.75 m, 0.50 m, and 0.25 m). For each additional trial, be sure to achieve and maintain the same constant force as the first trial.

23. ☐ Record the constant applied force in the space below Table 2 in the Data Analysis section.

Part 3 - Different Velocities

Set Up

24. ☐ Using the same set up as Part 1, select one stopper, and begin with a radius of one meter.

During data collection, you will change the force from trial to trial.

Collect Data

25. ☐ Begin swinging the rubber stopper overhead in a circular motion at a constant speed. Watch the force measurements on the data collection system, and try to maintain a constant force while keeping the plane of rotation parallel to the floor.

26. ☐ With the system in uniform circular motion, use the stopwatch to measure the time for 10 full revolutions.

27. ☐ Record the time and number of revolutions in Table 3 in the Data Analysis section.

28. ☐ Record the constant force from the trial in Table 3.

29. ☐ Repeat data collection at least three additional times, using different applied forces for each trial. For example, 1.5 N, 2.0 N, 2.5N, and if possible, 3.0 N.

30. ☐ Record the length of the radius and the mass of the stopper you chose in the spaces below Table 3 in the Data Analysis section.

Data Analysis

Table 1: Changing Mass

Mass (kg)	Interval of Time (s)	Number of Revolutions	Period (s)
0.0374	5.54	10	0.554
0.0565	7.02	10	0.702
0.0858	8.75	10	0.875
0.1096	9.55	10	0.955

Radius for Part 1: 1 m

Constant force for Part 1: 4.5 N

1. ☐ Complete the Period column in Table 1 by dividing the interval of time by the number of revolutions for each mass.

2. ☐ Using your Mass and Period data, plot a graph of Mass versus Period.

Mass versus Period

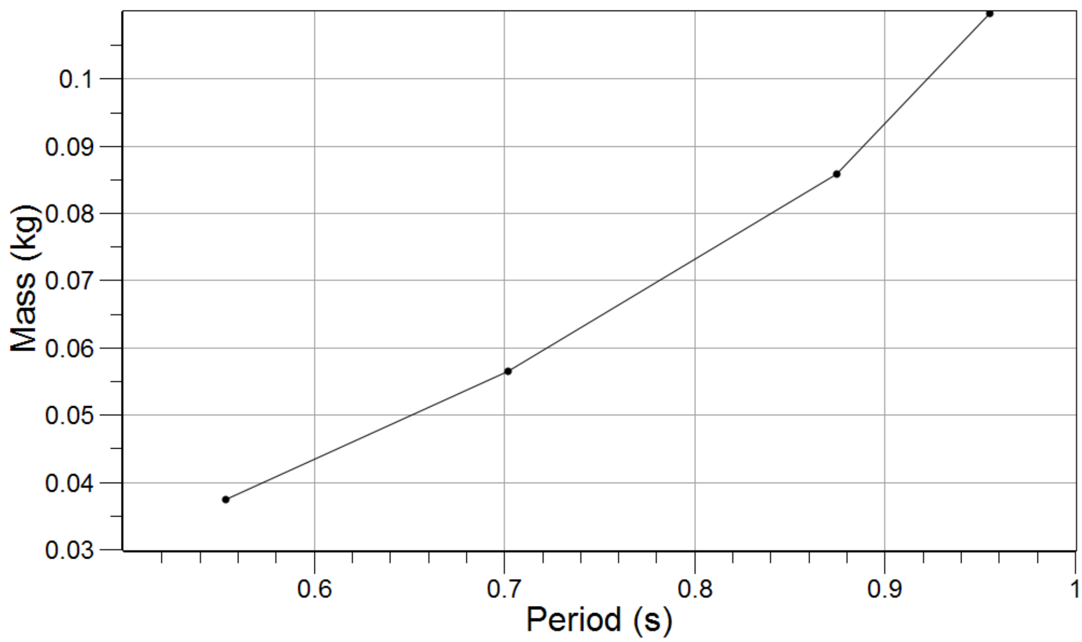


Table 2: Different Radii

Radius (m)	Interval of Time (s)	Number of Revolutions	Period (s)
1.00	7.02	10	0.702
0.75	6.20	10	0.620
0.50	5.30	10	0.530
0.25	3.92	10	0.392

Mass of the stopper for Part 2: 0.0565 kg

Constant force for Part 2: 4.5 N

3. ☐ Complete the Period column in Table 2 by dividing the interval of time by the number of revolutions for each radius.

4. ☐ Using your Radius and Period data, plot a graph of Radius versus Period.

Radius versus Period

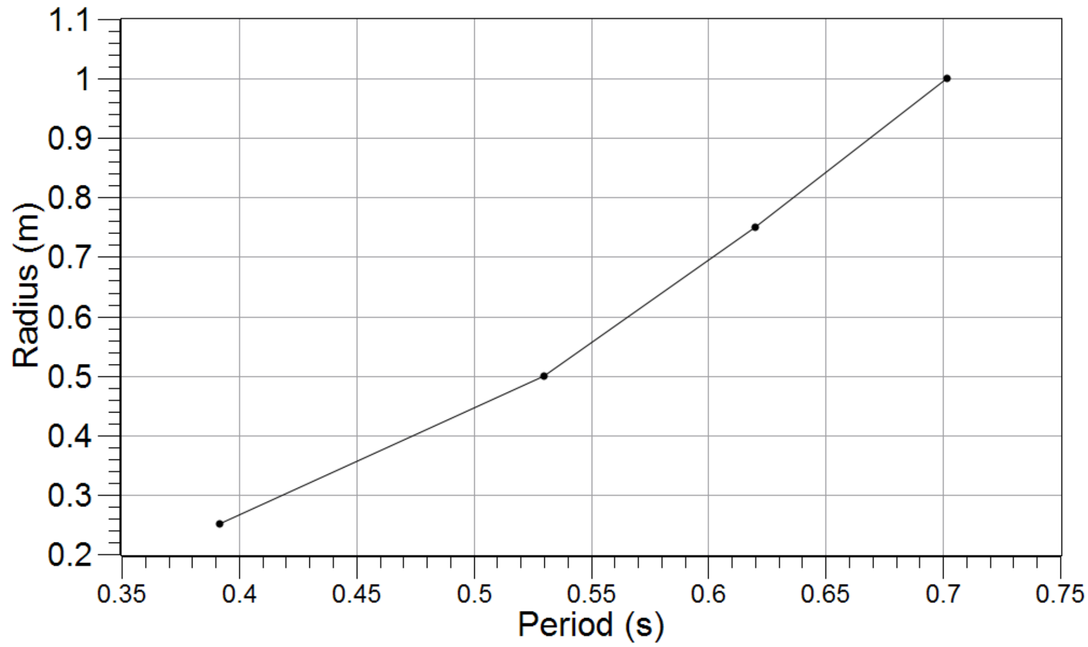


Table 3: Changing velocity

Force (N)	Interval of Time (s)	Number of Revolutions	Period (s)	Velocity (m/s)
3.22	7.87	10	0.787	7.98
3.49	7.77	10	0.777	8.08
4.50	7.02	10	0.702	8.95
8.70	5.08	10	0.508	12.36

Mass of the stopper for Part 3: 0.0565 kg

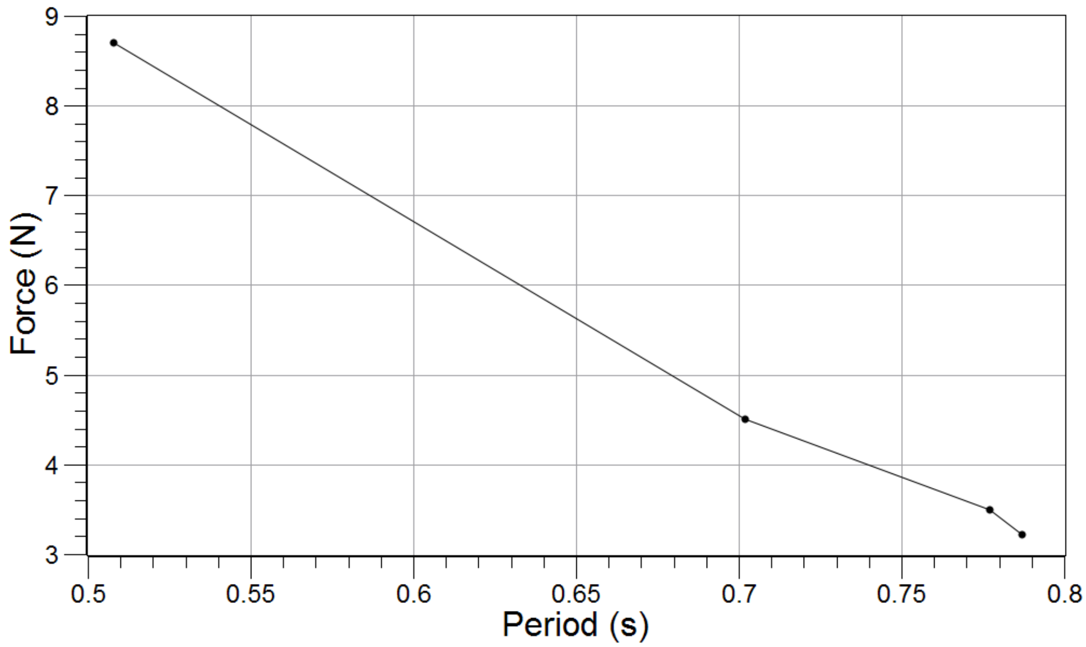
Length of the radius for Part 3: 1 m

5. ☐ Complete the Period column in Table 3 by dividing the interval of time by the number of revolutions for each force.

6. ☐ Complete the Velocity column in Table 3 by dividing the circumference of the circle by the period.

7. ☐ Using your Force and Period data, plot a graph of Force versus Period.

Force versus Period



Analysis Questions

1. How did the period change as a result of increasing the mass of the object?

As the mass increases, the period of a revolution increases to maintain the same force.

2. How did the period change as a result of decreasing the radius?

As the radius decreases, the period of a revolution decreases to maintain the same force.

3. How did the period change as a result of increasing the applied force?

As the force (tension) increases, the period of a revolution decreased.

Synthesis Questions

Use available resources to help you answer the following questions.

1. A space station is built in the form of a large circular structure with a radius of 100 m. The rooms of the station are all built such that the outer surface is the floor of each room. How fast would the space station have to spin for the floor to exert a force on a 75 kg station crew member equivalent to the normal force exerted by a floor on the surface of Earth?

$$F_N = mg$$

$$F_N = 75\ \text{kg}\left(9.81\ \text{m/s}^2\right)$$

$$F_N = 736\ \text{N}$$

$$F_c = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{F_c r}{m}}$$

$$v = \sqrt{\frac{736\ \text{kg}\cdot\text{m/s}^2\cdot 100\ \text{m}}{75\ \text{kg}}}$$

$$v = 31.3\ \text{m/s}$$

2. A 1,200 kg car is driving around a banked circular track with a radius of 500 m and an inward bank of 30°. How fast will the car need to travel so that the inward force of the track is the only force required to keep the car in circular motion?

$$F = ma$$

$$F = mg\sin\theta$$

$$F = 1200\ \text{kg}\cdot 9.81\ \text{m/s}^2\cdot\sin 30°$$

$$F = 5886\ \text{N}$$

$$F = \frac{mv^2}{r}$$

$$5886\ \text{N} = \frac{1200\ \text{kg}\cdot v^2}{500\ \text{m}}$$

$$v = 49.5\ \text{m/s}$$

3. What would happen to this same car if it were travelling at this speed and hit a patch of the track that was nearly frictionless because of an oil spill?

The car would continue in the same circular path.

4. How fast will the car have to travel if the track was only 200 m in diameter?

$F = ma$

$F = mg\sin\theta$

$F = 1200\,\text{kg} \cdot 9.81\,\text{m/s}^2 \cdot \sin 30°$

$F = 5886\,\text{N}$

$F = \frac{mv^2}{r}$

$5886\,\text{N} = \frac{1200\,\text{kg} \cdot v^2}{200\,\text{m}}$

$v = 31.3\,\text{m/s}$

Multiple Choice Questions

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

1. The centripetal force experienced by an object is related to the object's

A. Speed

B. Mass

C. Velocity

D. Radius of rotation

E. All of the above

2. As the frequency of revolutions increase, the centripetal force experienced by the stopper

A. Decreases

B. Increases

C. Remains the same

D. Not enough information to decide

E. Is always equal to zero

3. The direction of the stopper's net acceleration is

A. In the same direction as the centripetal force

B. In the same direction as the velocity

C. Tangent to the circular path of the stopper

D. Downward below the plane of the motion

4. The base units of the newton are represented by

A. kg·m/s

B. kg·m^2/s

C. kg·m/s^2

D. kg·m^2/s^2

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. The force that acts through a string is referred to as **tension**. A **force** sensor can measure the tension through a string in newtons. When an object rotates around a central point with a string, the tension in the string equals the **centripetal** force experienced by the object. An object's **velocity**, mass, and **radius** of rotation all contribute to the magnitude of the centripetal force. Newton's **second** law holds true for rotational motion in that the centripetal acceleration is proportional to centripetal force and is in the same direction. The proportionality constant is the **mass** of the object.

2. If a force of **magnitude** 1 N causes a 1 kg object to accelerate at 1 m/s^2 in a circular path, the **radius** of rotation is equal to the **velocity** squared. Even if an object in circular motion is travelling at a constant speed, it still experiences an **acceleration** due to the change in direction.

Extended Inquiry Suggestions

Students can convert their period data to frequency data (orbits per second), and construct the following graphs:

a) Frequency versus Mass

b) Frequency versus 1/Mass

c) Frequency versus Radius

d) Frequency versus 1/Radius

e) Frequency versus Force

f) Frequency Squared versus Force

Circular motion leads nicely into discussions of Johannes Kepler and orbital mechanics. If your students pick up the concepts quickly, this is also an opportune time to introduce the analogs of linear motion rotational inertia, rotational velocity and rotational acceleration.

20. Projectile Motion

Objectives

This experiment illustrates projectile motion as the sum of two independent motions, horizontal and vertical. Students:

- ♦ Learn how two independent motions are descriptions for the motion of a projectile
- ♦ Apply the equations of motion to a two-dimensional system
- ♦ Investigate how the launch angle of a projectile influences its motion

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Measuring the initial velocity of a projectile
- ♦ Measuring the time of flight of a projectile
- ♦ Interpreting data to predict the angle that will yield the longest range
- ♦ Calculating the correct angle to hit a target at a given range

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
- ♦ Digital adapter
- ♦ Time of flight pad
- ♦ Projectile launcher
- ♦ Projectile[1]
- ♦ Photogate (2)
- ♦ Photogate mounting bracket
- ♦ Short rod
- ♦ Pencil or pen
- ♦ Ram rod[1]
- ♦ Plumb bob
- ♦ Large table clamp
- ♦ Sheet of white paper (10)
- ♦ Tape Measure
- ♦ Tape, 1 roll
- ♦ Digital extension cable[2] (optional)
- ♦ Carbon Paper[3] (optional)

[1]Included with the PASCO projectile launcher
[2] When using a launcher with a maximum range of 3 m or greater
[3]Carbon paper makes it much easier to see where the ball strikes the paper

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Constant speed and velocity
- ♦ Uniform acceleration
- ♦ Vector addition

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Position: Match Graph
- ♦ Speed and Velocity
- ♦ Acceleration

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)

- ♦ Putting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- ♦ Start a manually sampled new data set �(6.3.1)
- ♦ Recording a manually sampled data point �(6.3.2)
- ♦ Stopping a manually sampled data set �(6.3.3)
- ♦ Displaying data in a graph�(7.1.1)
- ♦ Adding a column to a table �(7.2.2)
- ♦ Saving your experiment �(11.1)

Background

In everyday life, we observe many examples of objects moving in two dimensions: a football punt, a tennis volley, a long fly ball in baseball, and even water projected out of a drinking fountain. An object, without the capacity to glide in unpowered flight, is in projectile motion. A previous study of linear motion investigated constant speed and velocity as well as acceleration. To analyze projectile motion requires us to consider how the projectile moves initially, both in the horizontal and vertical directions. Consider a projectile with initial velocity v_0, launched at some angle θ relative to horizontal. The projectile, observed in 2-dimensions within an x-y plane, will have two component initial velocity vectors v_x and v_y describing the object's resultant velocity, where:

$$v_x = v_0 \cos(\theta) \qquad \textbf{Eq.1}$$

$$v_y = v_0 \sin(\theta) \qquad \textbf{Eq.2}$$

Neglecting the effect of air drag, the projectile experiences acceleration in the vertical direction (gravity), but does not experience any acceleration in the horizontal direction. We will calculate the average horizontal velocity of the projectile using values for distance travelled d_x as well as values for the time of flight t. By comparing the average horizontal velocity to the measured initial horizontal velocity, we can show that the horizontal velocity throughout the flight of the projectile remains constant. We will then compare the measured time of flight of the projectile to the same theoretical value for an object launched vertically with the same initial y-component velocity and height. If we make the point at which the projectile lands equal to a height of zero, the theoretical value for time of flight is represented mathematically by:

$$0 = d_i + v_y t + \frac{1}{2}at^2$$

$$t = \frac{-v_y \pm \sqrt{v_y^2 - 2gd_i}}{2d_i} \qquad \textbf{Eq.3}$$

Pre-Lab Discussion and Activity

Engage your students with the following questions and demonstrations.

1. What is a projectile? What is the shape of any projectile's trajectory?

A projectile is any object that undergoes unpowered flight after it has an initial velocity imparted to it by some means such as being launched, fired, kicked, or shot. The shape of a projectile's path is called a trajectory. Near the surface of the earth, the trajectory is parabolic, or curved in shape, due to the force of gravity.

Ask students to state some everyday examples of projectiles. Examples: a football punt, a soccer shot at the goal, launching an arrow from a bow.

Ask students to conduct this simple demonstration using two equal sized coins (for example, two dimes or two pennies). Position one coin on the edge of a desk, and position the second coin behind the first, slightly offset (by one-half diameter). Flick the second coin so it strikes the first coin. Observe what happens. Listen and watch. Both coins will land simultaneously. Hear the click on the floor. The first coin tumbles off the table and falls straight downward. The second coin is launched as a projectile, and it too falls freely to the floor.

Alternately, use a vertical acceleration demonstrator or a drop shoot accessory with a launcher to do this demonstration for the class.

2. An object rolls with constant speed in a straight-line on a table. What is its acceleration?

Any object that moves at constant speed (velocity) has an acceleration of zero.

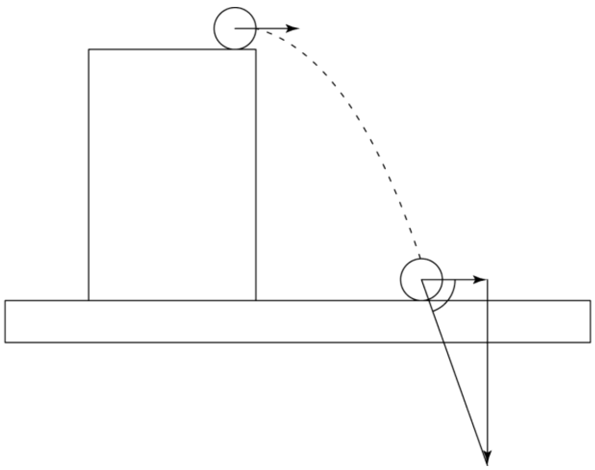
3. An object is releases from rest, falling freely to the earth. Describe the object's speed with respect to time. What is its acceleration?

Any object that freely falls to the earth gains speed uniformly in time. It accelerates at 9.81 m/s^2. This means, the object gains 9.81 m/s of speed for every one second of time.

4. How far does the object fall during the first second of time?

Students may discuss this at some length. Remind them that the initial speed was zero, and after one second, the object's speed increased to 9.8 m/s. So, the object's average speed must be 4.9 m/s. Thus, the object travels 4.9 meters in the first second of free fall.

5. If an object rolls across a table at 2 m/s, rolls off the edge, and falls 1.2 meters to the floor, what is the object's final velocity?



First find the time of the fall:

$$d = \frac{1}{2}at^2 + v_0 t + d_0$$
$$-1.2\text{ m} = \frac{1}{2}(-9.81\text{m/s}^2)t^2 + 0 + 0$$
$$t = \sqrt{\frac{2.4}{9.81}}$$
$$t = 0.49\text{ s}$$

Then calculate the y component of velocity as the object hits the floor:

$$v_y = at + v_0$$
$$v_y = -9.81\text{m/s}^2 \cdot 0.49\text{ s} + 0$$
$$v_y = -4.81\text{m/s}$$

Finally, do the vector addition:

$$v_x^2 + v_y^2 = v_{final}^2$$
$$v_{final} = \sqrt{v_x^2 + v_y^2}$$
$$v_{final} = \sqrt{2.0^2 + 4.8^2}$$
$$v_{final} = 5.2\text{ m/s}$$
$$\theta = \arctan\frac{4.8}{2.0}$$
$$\theta = 67.4°$$

So, the final velocity of this object is 5.2 m/s pointed 67.4 degrees below the horizontal.

Lab Preparation

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

1. The Mini Launcher works well for this activity. However, if you use a different launcher, you will want to make sure to equip each station with a digital extension cable.

2. If there are two digital adapters per lab station, parts one and two can be combined.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ When using the projectile launcher, do not stand directly in front of the launcher at anytime.
- ♦ Always use eye protection when using launchers.

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	1	4	2
Collect an initial velocity value for each angle.	Compare your graph of Launch Angle versus Velocity and your graph of Launch Angle versus Distance.	Securely mount the launcher to the table with the large table clamp.	Display Launch Angle versus Velocity in a graph display.	Use the ram rod to load a projectile into the launcher at the maximum setting.

Procedure with Inquiry

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

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

Part 1 - Initial Velocity and Distance

Set Up

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

2. ☐ Connect the digital adapter to the data collection system. �(2.1)

3. ☐ Connect the photogates to your digital adapter.

4. ☐ Select "velocity between gates" when prompted by your data collection system.

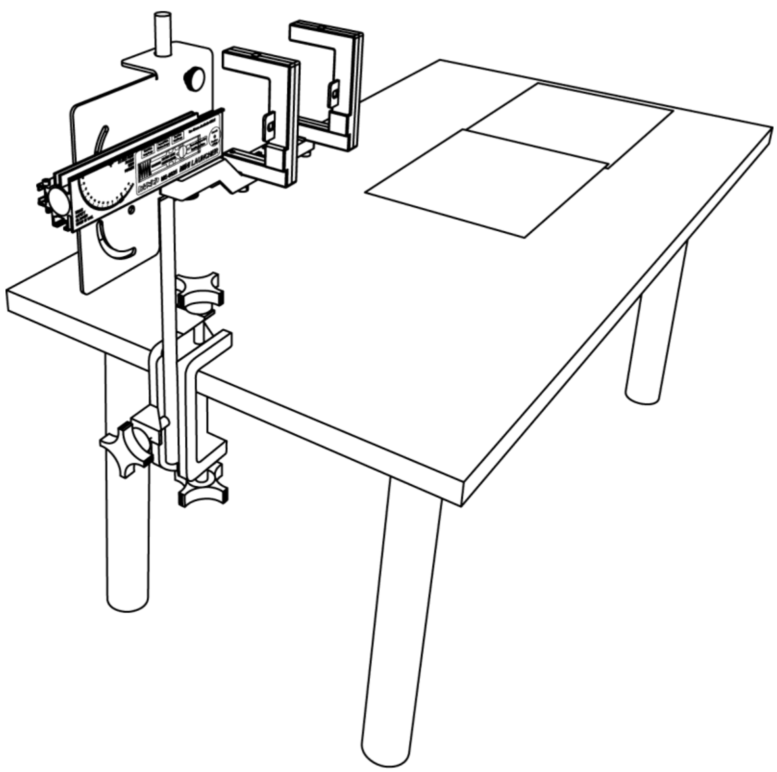
Note: Ensure the space between gates parameter on your data collection system is set to 0.10 m, or the space between your photogates.

5. ☐ Put your data collection system into manual sampling mode with manually entered data. Name the manually entered numerical data "Angle" measured in degrees." �(5.2.1)

6. ☐ Add a column to the table to display distance in meters. �(7.2.2)

7. ☐ Attach the projectile launcher to a table using the large table clamp and short rod so that the projectiles travel across the longest part of the table.

Note: Make sure that the launcher can rotate through 80° with the photogate bracket mounted.



8. ☐ Place sheets of paper end-to-end in a line across the length of the table in front of the projectile launcher, and secure them in place with tape.

9. ☐ Measure the height from where the point the ball is released to the table top, and record this value in the Data Analysis section.

10. ☐ Use the photogate mounting bracket to mount the photogates to the launcher. Be sure to mount the photogate connected to port 1 of the digital adapter, closest to the launcher.

11. ☐ Set the launcher in the horizontal position with a launch angle of 0°.

12. ☐ Use the ram rod to load a projectile into the launcher, and ensure that the launcher is set to its maximum compression.

Note: If you do not have enough space, use a lower setting on the launcher, but be sure to use the same setting each time.

13. ☐ Launch the projectile, and note the point of impact on the paper.

14. ☐ Lay a sheet of carbon paper on top of the white paper over the point of impact, carbon side down, so that when a ball lands on it there will be a mark on the paper. Place a sheet of paper over the carbon paper to prevent damage to the carbon paper by the projectile.

Note: If carbon paper is not available, look for a small indentation on the paper where the ball hits.

15. ☐ Use the ram rod to load a projectile into the launcher, and ensure that the launcher is set to its maximum compression.

16. ☐ What launch angle do you predict will yield the greatest horizontal range (distance)?

Approximately 45 ° (for the ideal case of no air resistance), the angle is actually a little less when air resistance is present.

Collect Data

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

18. ☐ Launch the projectile.

19. ☐ Record a manually sampled Velocity Between Gates data point, and enter the corresponding Angle value. �(6.3.2)

20. ☐ Move the carbon paper, and measure the distance to the mark. Write the Angle next to the mark on the paper.

21. ☐ Loosen the photogate bracket and move the photogates to one side.

Note: When removing and replacing the photogate bracket, be very careful not to block the photogates and to replace the bracket to same position each time.

22. ☐ Use the ram rod to load a projectile into the launcher, and ensure that the launcher is set to its maximum compression.

23. ☐ Put the photogates back in position, and use the angle indicator on the launcher to position the launcher at the next angle, 10°.

24. ☐ Repeat the data collection steps, increasing the angle of inclination by 10° each time until you have recorded a data point every 10° from 0° to 80°.

25. ☐ Stop the manually sampled data set. �(6.3.3)

26. ☐ Measure and enter the horizontal distance for each Angle value into the table on your data collection system, and then copy all the values to Table 1 in the Data Analysis section.

Analyze Data

27. ☐ Display Distance on the *y*-axis of a graph with Angle on the *x*-axis. �(7.1.1)

28. ☐ Sketch the graph of Distance versus Angle in the Data Analysis section.

29. ☐ Display Velocity on the *y*-axis of a graph with Angle on the *x*-axis. �(7.1.1)

30. ☐ Sketch the graph of Distance versus Angle in the Data Analysis section.

31. ☐ Save your experiment as instructed by your teacher. �(11.1)

Part 2 - Time of Flight

Set Up

32. ☐ Start a new experiment on your data collection system. �(1.2)

33. ☐ Remove the photogate furthest from the launcher from the photogate mounting bracket.

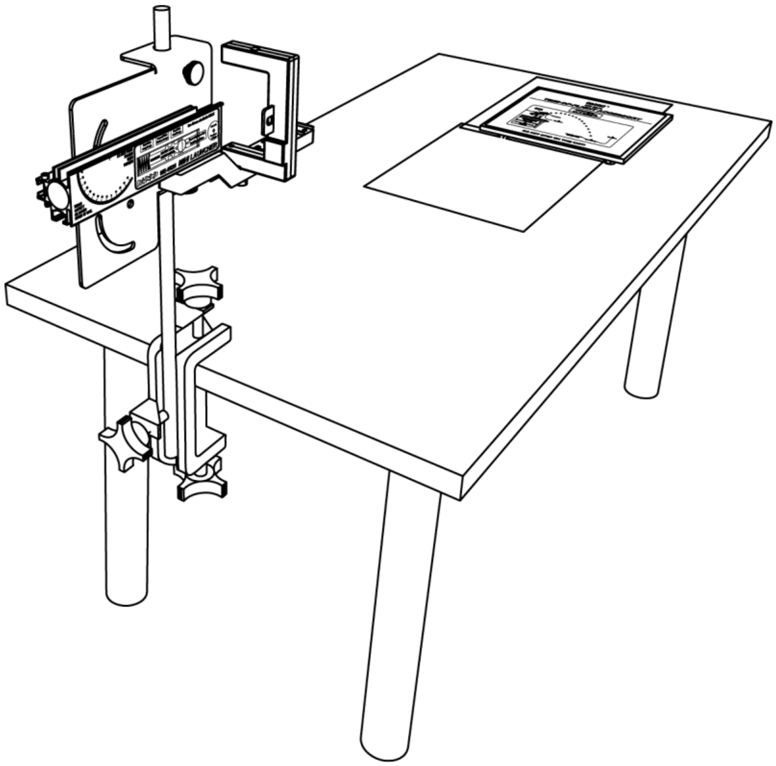
34. ☐ Disconnect this photogate from port 2 of your digital adapter.

35. ☐ Connect the Time of Flight pad to port 2 of your digital adapter.

36. ☐ Select Time of flight when prompted by your data collection system.

37. ☐ Put your data collection system into manually sampling mode with manually entered data. Name the manually entered numerical data “Angle” measured in degrees. �(5.2.1)

38. ☐ Position the time of flight pad over the 0° impact point.



39. ☐ Set the launcher in the horizontal position with a launch angle of 0°.

40. ☐ Use the ram rod to load a projectile into the launcher, and ensure that the launcher is set to its maximum compression.

41. ☐ Which angle do you think will yield the greatest time of flight value?

90°, or slightly less than 90°. A ball launched at 90° will actually hit the launcher, so it won't have the benefit of the extra distance to the table.

Collect Data

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

43. ☐ Launch the projectile.

44. ☐ Record a manually sampled data point, and enter the Angle value. �(6.3.2)

45. ☐ Move the time of flight pad to the next mark in the series.

46. ☐ Loosen the photogate bracket, and move the photogate to one side.

47. ☐ Use the ram rod to load a projectile into the launcher, and ensure that the launcher is set to its maximum compression.

48. ☐ Put the photogates back into position, and use the angle indicator on the launcher to position the launcher at the next angle, and repeat the data collection steps until you have recorded a data point every 10° from 0° to 80°.

49. ☐ Stop the manually sampled data set. �(6.3.3)

50. ☐ Copy all the values in your table to Table 1 in the Data Analysis section.

Analyze Data

51. ☐ Display Time of Flight on the *y*-axis of a graph Angle on the *x*-axis. �(7.1.1)

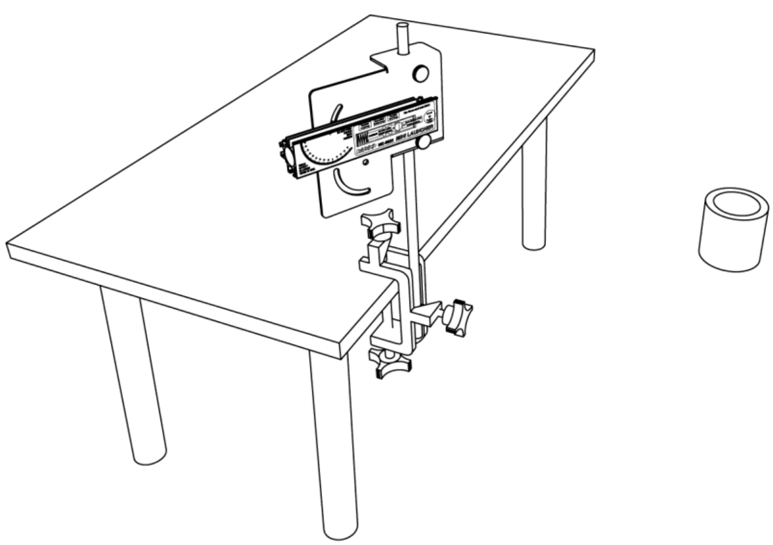
52. ☐ Sketch the graph of Time of Flight versus Angle in the Data Analysis section.

53. ☐ Save your experiment as instructed by your teacher. �(11.1)

Part 3 - The Challenge

54. ☐ Remove the photogate bracket from the launcher.

55. ☐ Move the launcher to the front of your table and into a position so that it will launch to the floor.



56. ☐ Ask your teacher to place a target on the floor in front of the launcher.

57. ☐ Using a plumb bob and measuring tape, measure the vertical and horizontal distance to the target.

58. ☐ Calculate the angle to set your launcher at in order to hit the target, and record this value below.

Note: You may want to find the average of your initial velocities. There is also a trigonometric identity that might help: sin(2θ) = 2sin(θ)cos(θ).

$$x = (v_0 \cos\theta)t$$

$$1.200\text{ m} = (4.84\text{ m/s}\cos\theta)t$$

$$t = \frac{1.20}{4.84\cos\theta} = \frac{0.25}{\cos\theta}$$

$$-0.85 = \frac{1}{2}(g)t^2 + (4.84\sin\theta)t + y_0$$

$$-0.85 = -4.91t^2 + (4.84\sin\theta)t + 0$$

$$-0.85 = -4.91\left(\frac{0.25}{\cos\theta}\right)^2 + 4.84\sin\theta\left(\frac{0.25}{\cos\theta}\right)$$

$$-0.85 = \frac{-1.23}{\cos^2\theta} + \frac{1.21\sin\theta}{\cos\theta}$$

$$-0.85 = -1.23 + 1.21\sin\theta\cos\theta$$

$$0.31 = \sin\theta\cos\theta$$

$$\sin(2\theta) = 2\sin\theta\cos\theta$$

$$0.62 = \sin(2\theta)$$

$$38.32° = 2\theta$$

$$\theta = 19.16°$$

Given the precision of the angle measurement, the launcher could be set to 19° or 71°.

Angle of launcher: 19°

59. ☐ When you are ready, aim your launcher, and inform your teacher.

60. ☐ Launch the projectile.

61. ☐ How close were you to the target?

Student answers will vary.

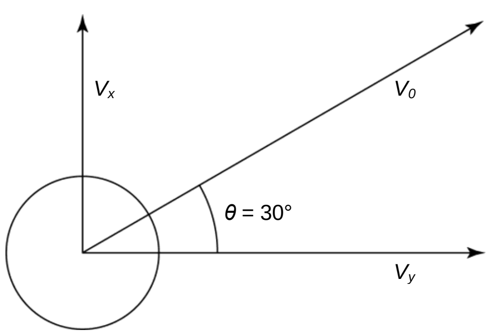
Data Analysis

Height of the launcher: 0.275 m

Table 1: Projectile data

Angle (°)	Velocity (m/s)	Distance (m)	Time of Flight (s)
0	4.964	1.230	0.233
10	4.913	0.741	0.350
20	4.847	2.261	0.476
30	4.770	2.618	0.618
40	4.805	2.781	0.738
50	4.805	2.677	0.857
60	4.805	2.266	0.945
70	4.791	1.652	1.009
80	4.819	0.866	1.058

1. ☐ Choose one of your angles other than 0° , and draw to scale a vector diagram for your projectile at the launch position showing both the horizontal and vertical component velocities. Show how you determine the average initial velocity, and draw the net vector.



2. ☐ Calculate the horizontal and vertical components of velocity for each angle, and fill in the columns in Table 2.

$$v_x = v_0 \cos\theta$$

$$v_x = 4.913 \text{ m/s} \cdot \cos(10°)$$

$$v_x = 4.838 \text{ m/s}$$

$$v_y = v_0 \sin\theta$$

$$v_y = 4.913 \text{ m/s} \cdot \sin(10°)$$

$$v_y = 0.854 \text{ m/s}$$

3. ☐ Use the horizontal distance and time of flight to calculate the average horizontal velocity for each angle, and then fill in the corresponding column in Table 2.

$$v_{\text{average}} = \frac{\Delta d}{\Delta t}$$

$$v_{\text{average}} = \frac{2.261 \text{ m}}{0.476 \text{ s}}$$

$$v_{\text{average}} = 4.750 \text{ m/s}$$

4. ☐ Use the vertical velocity and the height of the launcher for each launch angle to calculate the theoretical time of flight of an object shot straight up. Record the result in Table 2.

$$d = \frac{1}{2}at^2 + v_0 + d_0$$

$$-0.275 = -4.91t^2 + 1.658t + 0$$

$$0 = -4.91t^2 + 1.658t + 0.275$$

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$t = \frac{-1.658 \pm \sqrt{2.749 - 4(-4.91)0.275}}{2(-4.91)}$$

$$t = \frac{-1.658 \pm \sqrt{2.749 + 5.401}}{-9.81}$$

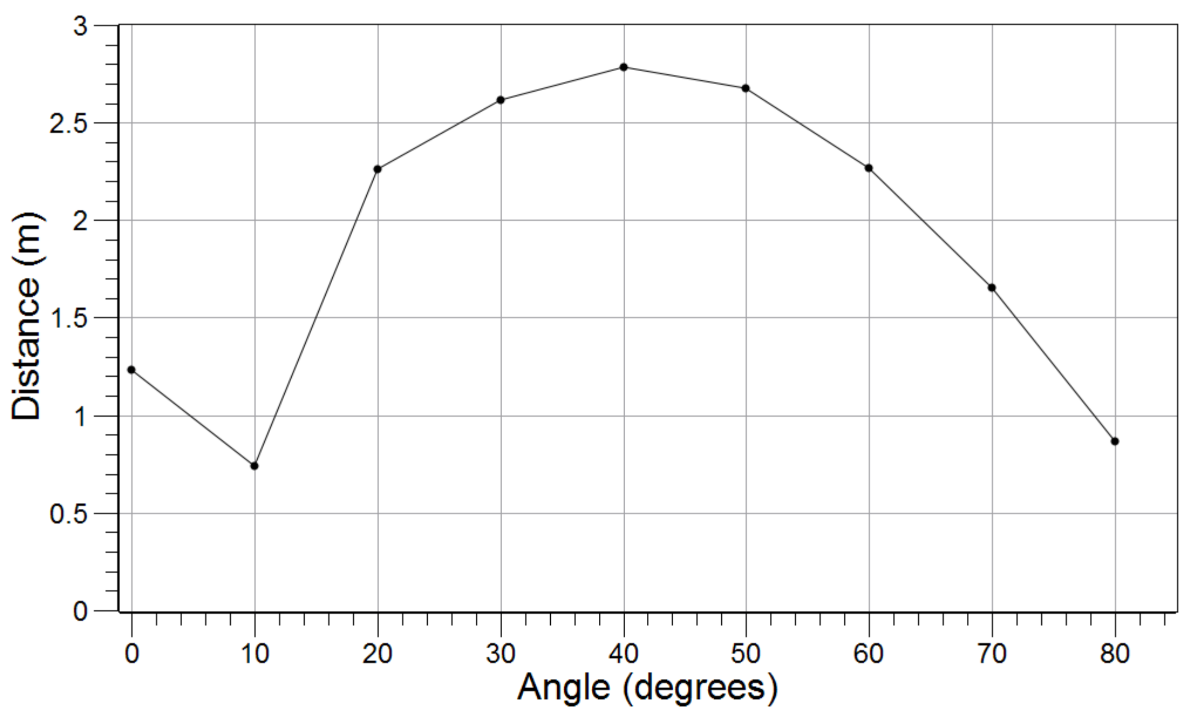
$$t = 0.17 \pm 0.29$$

$$t = 0.46$$

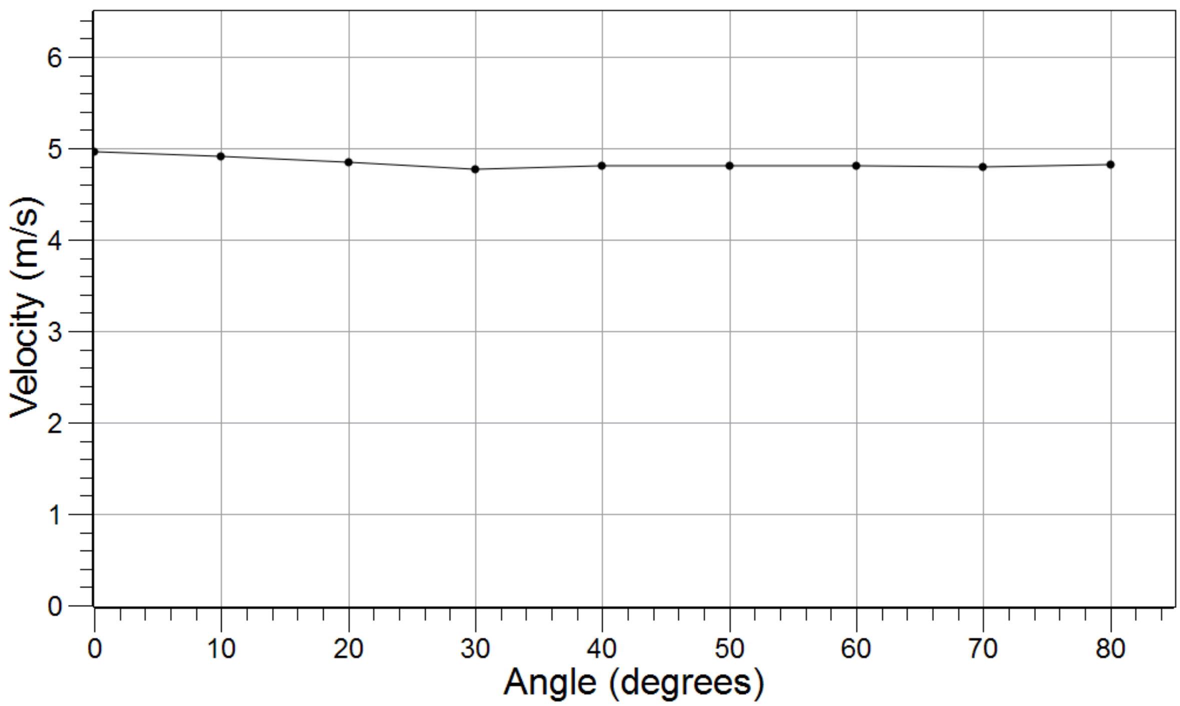
Table 2: Projectile data calculations

Angle (°)	Horizontal Velocity (m/s)	Vertical Velocity (m/s)	Average Horizontal Velocity (m/s)	Theoretical Time of Flight (s)
0	4.964	0	5.279	0.24
10	4.913	0.854	4.838	0.34
20	4.555	1.658	4.750	0.46
30	4.130	2.385	4.237	0.58
40	3.681	3.089	3.760	0.71
50	3.089	3.681	3.124	0.82
60	2.403	4.161	2.298	0.90
70	1.639	4.502	1.637	0.98
80	0.837	4.746	0.818	1.02

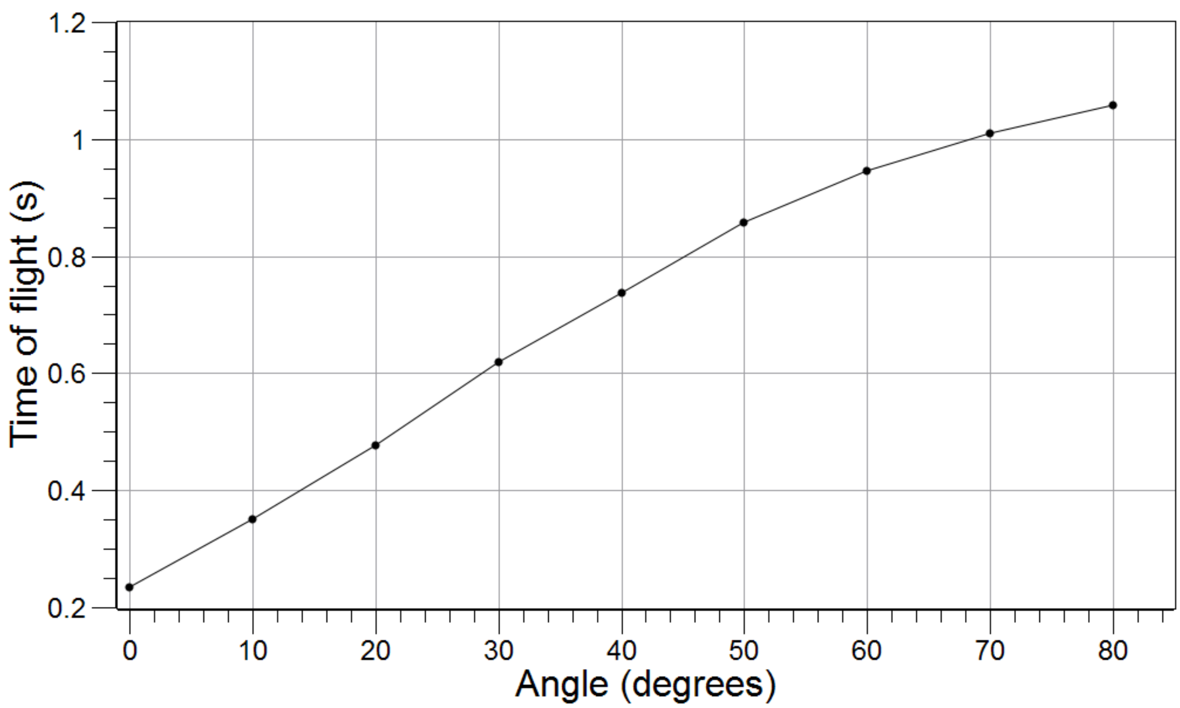
Distance versus Angle



Initial Velocity versus Angle



Time of Flight versus Angle



Analysis Questions

1. How did the measured horizontal velocities compare to the average horizontal velocities?

Answers will vary The values should be very close to one another at each angle.

2. For any projectile launched horizontally, what can you state about the horizontal velocity? Is it constant or does it change over time?

The horizontal component velocity is constant, or uniform. This is for the ideal case where we ignore air resistance.

3. Which launch angle will yield the maximum horizontal range?

Ideally, the launch angle for maximum range is 45 degrees.

4. Which launch angles yield the same results for the horizontal range?

Complementary angles yield the same range, such as 10 and 80 degrees, 20 and 70 degrees, 30 and 60 degrees, for example.

Synthesis Questions

Use available resources to help you answer the following questions.

1. An astronaut on the moon has a small launcher that lets him pass tools to his partner at the same height on the other side of a crater floor. The initial velocity of the launcher is 15 m/s, and his partner is 30 m away. If the gravity on the moon is 1/6 that of Earth, what angle gives the shortest travel time?

$x = (v_0 \cos\theta)t$

$30 = (15\cos\theta)t$

$t = \frac{30}{15\cos\theta} = \frac{2}{\cos\theta}$

$y = \frac{1}{2}\left(\frac{1}{6}g\right)t^2 + (v_0 \sin\theta)t + y_0$

$0 = -0.8175t^2 + (15\sin\theta)t + 0$

$0 = -0.8175\left(\frac{2}{\cos\theta}\right)^2 + 15\sin\theta\left(\frac{2}{\cos\theta}\right)$

$0 = \frac{-3.27}{\cos^2\theta} + \frac{30\sin\theta}{\cos\theta}$

$0 = -3.27 + 30\sin\theta\cos\theta$

$0.109 = \sin\theta\cos\theta$

$\sin(2\theta) = 2\sin\theta\cos\theta$

$.218 = \sin(2\theta)$

$12.6° = 2\theta$

$\theta = 6.3°$

Although the complimentary angle 83.7° would get the tool to its destination, it would take much more time.

Multiple Choice Questions

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

1. What do we call any object fired, launched, or kicked into unpowered flight?

- **A.** Trajectory
- **B. Projectile**
- **C.** Projectory
- **D.** Trajectile

2. The magnitude of the horizontal velocity component of a projectile is based upon which two variables?

- **A.** Distance and time
- **B. Speed and time**
- **C.** Acceleration and time
- **D.** Gravity and time

3. The magnitude of the vertical velocity component of a projectile is based upon which two variables?

- **A.** Distance and time
- **B.** Speed and time
- **C. Acceleration and time**
- **D.** Gravity and time

4. Which of the following pair of angles does not yield the same horizontal range?

- **A.** 22 and 68 degrees
- **B.** 43 and 47 degrees
- **C.** 18 and 72 degrees
- **D. 33 and 59 degrees**

Key Term Challenge

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

1. When a ball falls vertically to the floor, we say it is in a **free fall** state of motion. When we launch a **projectile** horizontally, its horizontal velocity is **constant**. The shape of the ball's flight is called a trajectory and is parabolic in shape. The maximum **range** of flight depends on the launch angle and the launch **velocity**. The force due to **gravity** directly relates to the free fall acceleration of the ball.

Thermodynamics

21. Temperature versus Heat

Objectives

Students establish a fundamental understanding of the relationship between heat transfer and temperature changes in substances. This activity is designed to provide students with an understanding of:

- How dissimilar objects have the capacity to transfer different amounts of heat to a solution although they start at the same temperature.
- How the temperature of dissimilar solutions changes with an identical amount of heat transferred to each solution.
- The ability of a solution or object to transfer heat, and how that transfer is related to increases/decreases in temperature.

Procedural Overview

In this investigation, your students will gain experience with the following tools and techniques:

- Identifying and controlling the correct variables in an experiment
- Measuring the change in temperature of a system from a graph
- Defining the relationship between temperature and heat based on data

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor (2)
- Beaker, 600-mL
- Hot plate
- Calorimetry cup[1] (2)
- Copper mass[1], 200-g (2)
- Aluminum mass[1], 200-g (2)
- Balance (1 per classroom)
- Vegetable oil, 500 g
- Water, 500 g
- String, 15 cm (4)
- Paper clip, (2)

[1] Part of the Basic Calorimetry Set

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Kinetic Energy
- ♦ Conservation of energy
- ♦ Temperature
- ♦ Heat

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Phase Change
- ♦ Specific Heat of a Metal
- ♦ Heat of Fusion
- ♦ Heat of Vaporization

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system � (1.2)
- ♦ Connecting multiple sensors to the data collection system� (2.2)
- ♦ Monitoring live data without recording � (6.1)
- ♦ Starting and stopping data recording � (6.2)
- ♦ Adjusting the scale of a graph � (7.1.2)
- ♦ Displaying multiple variables on the *y*-axis of a graph � (7.1.10)
- ♦ Viewing statistics of data � (9.4)
- ♦ Saving your experiment � (11.1)

Background

Matter, whether liquid, solid, or gas, is made of moving particles. The average kinetic energy of these particles is related to temperature. Because the kinetic energy of each of the individual particles cannot be directly measured, temperature scales, like the Celsius and Fahrenheit scales, are employed on the macroscopic level to measure temperature.

The thermal energy, or internal energy, of a material includes the kinetic energy of the atoms or molecules as well as the potential energy between the atoms and molecules. Heat is a measure of the energy transferred from a hotter material to a cooler material. Heat will continue to flow from hot materials to cold materials until the temperature of the materials is equal.

Pre-Lab Discussion and Activity

Engage your students by connecting temperature, thermal energy, and heat concepts to their real world experiences.

Prior to beginning the demonstration, fill a gallon-sized clear container and a cup-sized clear container with water and allow them to settle to room temperature. Use a temperature sensor to measure the room temperature. Then ask the students the following questions:

1. When I measure the temperature of the room, what am I actually measuring?

The average kinetic energy of the particles of air.

2. Is it possible for a cup of water and a gallon of water to have the same temperature?

Yes.

Use two temperature sensors (if you have them) to show that both the gallon and the cup have the same (room) temperature.

3. If so, do they have the same amount of thermal energy? Why?

No, because the gallon of water has more particles with energy.

Note: An analogy to this is kinetic energy. Two objects can have the same velocity, but the one with more mass will deliver more kinetic energy.

4. If so, can they transfer the same amount of heat? Why?

No, because the gallon of water has more internal energy to transfer because it has more particles with energy.

5. Which has more thermal energy: an iceberg or a cup of water? Why?

The iceberg has more thermal energy because it contains significantly more particles with energy; albeit on average a lower amount of energy.

6. Which can transfer more heat: an iceberg or a cup of water?

The iceberg can transfer more heat because it contains more thermal energy.

Create three digits displays of temperature, one for each scale (Fahrenheit, Celsius, and Kelvin).

7. Which scale have we been using so far?

Celsius.

8. In a room like this (at one atmosphere of pressure), what happens to water at 0 °C, and 100 °C?

Water freezes into ice (becomes a solid) or boils (becomes a gas).

9. So this scale is based on common experience. What do you suppose happens when the temperature reaches zero K?

This is when particles have zero kinetic energy.

Lab Preparation

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

1. Place water and vegetable oil in containers located next to each other in the same area of the lab.

Note: Some insulated cups can allow oils to seep through. Do not use the insulated cups for long term storage.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Do not directly touch hot items like the hot plate, beaker, and water.
- ♦ Keep the boiling water away from other electrical equipment like a computer.
- ♦ Wear an apron, goggles, and gloves as recommended by your teacher.

Sequencing Challenge

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

1	3	4	2
Create a graph of Temperature versus Time.	Stop data collection once the temperature levels out.	Find the difference between the initial and final temperature	Move the mass from hot water bath to the room temperature fluid.

Procedure with Inquiry

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

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

Part 1 – Different Materials in the Same Fluid

Set Up

1. ☐ Measure and record the mass of a copper sample and an aluminum sample in the Data Analysis section.

2. ☐ Why do you think it is important that the mass is similar for the copper and aluminum samples?

The mass of the samples is one of variables being controlled.

3. ☐ Tie approximately 15 cm of string to each of the metal masses.

4. ☐ Carefully place the masses into the 600 mL beaker with the string hanging over the lip of the beaker.

5. ☐ Cut the excess string leaving just enough string so that the masses can be safely lifted out later.

6. ☐ Pour just enough water into the beaker to submerge the masses.

7. ☐ Place the beaker on the hot plate, and then plug-in and turn on the hot plate.

8. ☐ Place the same amount of water in each calorimetry cup.

Note: Make the water level high enough so that the metal sample will be completely submerged when it is placed into the cup; but not so high that the water will overflow.

9. ☐ Use paper clips to attach a temperature sensor to each calorimeter cup so that the tip of each sensor is submerged in water but not touching the wall of the cup.

10. ☐ Why do you think it is important that the mass of water is the same?

The mass of the liquid is one of variables being controlled.

11. ☐ Why do you think it is important to use foam calorimetry cups for this experiment?

We are trying to minimize (control) the amount of heat lost to the environment.

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

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

14. ☐ Display both temperature measurements on the *y*-axis of a graph with Time on the *x*-axis. � (7.1.10)

15. ☐ What is a good method of making sure the temperature of the water is the same in each cup?

Pour water back and forth from one cup to the other.

16. ☐ Make sure the temperature of the water in the calorimetry cups is the same temperature.

17. ☐ Why do you think it is important that the temperature of the water is the same?

The temperature of the liquid is one of the variables being controlled.

Note: Remember to make sure the mass of the water in each cup is the same when done.

Collect Data

18. ☐ When the water bath starts boiling, start data recording. � (6.2)

Note: Keep the water bath hot for Part 2.

19. ☐ Carefully transfer the masses from the water bath to the calorimetry cups. One mass in each cup

20. ☐ After a few minutes, when the Temperature versus Time plot levels off, stop data recording. � (6.2)

Analyze Data

21. ☐ For each metal sample, find the initial water temperature (minimum) and the final water temperature (maximum), and record them into Table 1 in the Data Analysis section. � (9.4)

Part 2 – Similar Materials in Different Fluids

Set Up

22. ☐ Measure and record the mass of two samples of the same metal in the Data Analysis section.

23. ☐ Why do you think it is important that the samples are made of the same materials and have the same mass?

For this part of the lab, the type of material and mass are variables being controlled.

24. ☐ Tie approximately 15 cm of string to each of the metal masses.

25. ☐ Carefully place the masses into the 600 mL beaker filled with hot water with the string hanging over the lip of the beaker.

26. ☐ Cut the excess string leaving just enough string so that the masses can be safely lifted out later.

27. ☐ Turn up the hot plate so that the water will return to a boil.

28. ☐ Place vegetable oil in one of the calorimetry cups, and place the same mass of water as vegetable oil in the other calorimetry cup.

Note: Make the fluid level high enough so that the sample will be completely submerged when it is placed into the cup; but not so high that the fluid overflows.

29. ☐ Use paper clips to attach a temperature sensor to each cup so that the tip of each sensor is submerged in fluid but not touching the wall of the cup.

30. ☐ Monitor the temperature in the cups without recording. � (6.1)

31. ☐ Why do you think it is important that the mass of fluid is the same?

In this part of the lab, the mass of the fluid is one of variables being controlled.

32. ☐ What is a good method of making sure the temperature of the fluid is the same in each cup?

Use water and vegetable fluid that have been sitting in the same location of the room for several hours, or add small amounts of hot or cold water until the water matches the vegetable oil.

33. ☐ Adjust the temperature of the water to match that of the vegetable oil.

34. ☐ Why do you think it is important that the temperature of the fluids is the same?

The temperature of the fluids is one of the variables being controlled.

35. ☐ Stop monitoring live data, and return to your graph display.

Collect Data

36. ☐ When the water bath starts boiling, start recording data. � (6.2)

37. ☐ Turn off the hot plate.

38. ☐ Carefully transfer the masses from the water bath to the calorimetry cups, one mass in each cup.

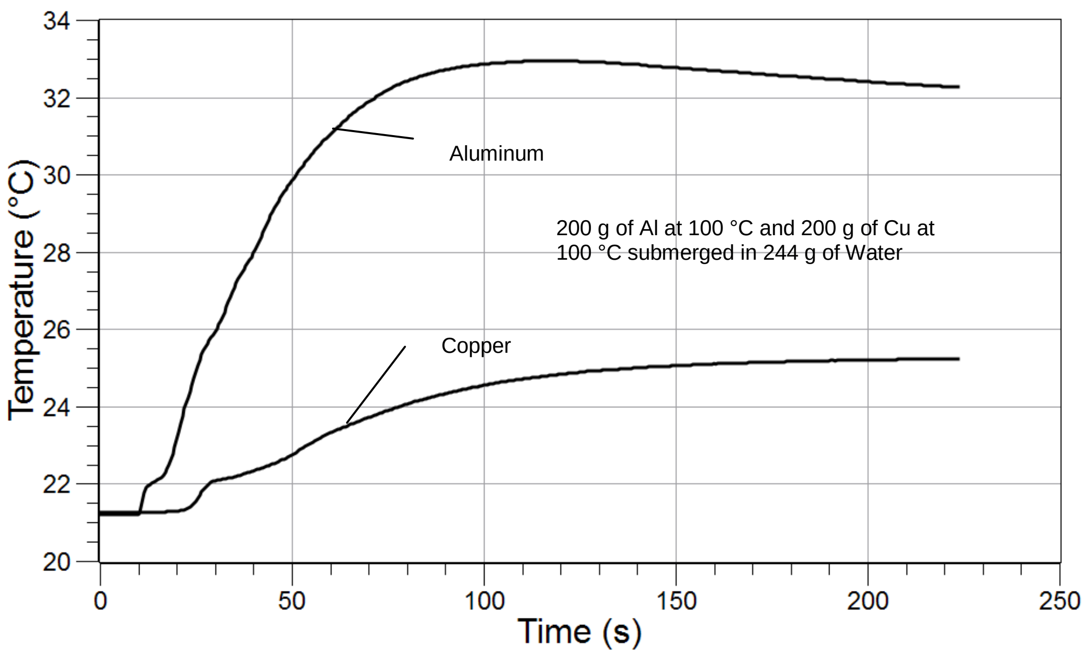
39. ☐ After a few minutes, when the Temperature versus Time plot levels off, stop data recording. � (6.2)

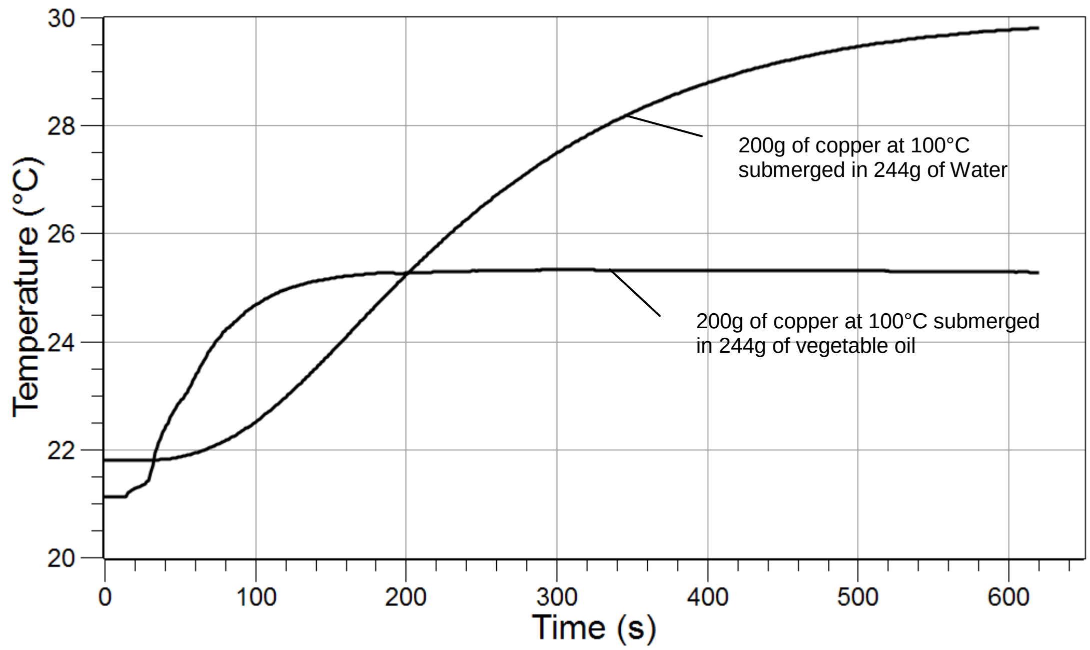
Analyze Data

40. ☐ For each liquid sample, find the initial temperature (minimum) and the final temperature (maximum), and record those values into Table 3 in the Data Analysis section. � (9.4)

41. ☐ Save your experiment as instructed by your teacher. � (11.1)

Sample Data





Data Analysis

Part 1: Mass of the metal samples

Mass Aluminum: 200 g

Mass Copper: 200 g

Table 1: Different Metal Samples

Metal Sample	Initial Temperature (°C)	Final Temperature (°C)
Water with Aluminum	21.2	32.9
Water with Copper	21.3	25.2

1. ☐ Calculate the change in temperature for each sample, and enter the change in Table 2.

Table 2: Change in Temperature, Part 1

Sample	Change in Temperature (°C)
Water with Aluminum	11.7
Water with Copper	3.9

Part 2: Mass of the metal samples

Mass Sample 1: 200 g　　Mass Sample 2: 200 g

Table 3: Different Fluids, Part 2

Fluid	Initial Temperature (°C)	Final Temperature (°C)
Vegetable Oil	21.8	29.8
Water	21.1	25.3

2. ☐ Calculate the change in temperature for each sample, and enter the change in Table 4.

Table 4: Change in Temperature, Part 2

Sample	Change in Temperature (°C)
Vegetable Oil	8.0
Water	4.2

Analysis Questions

1. In each case where you started with a metal that was hot and a liquid at room temperature, what happened to the temperature of the liquid? What does this tell you about the flow of heat?

In each case the temperature of the liquid increased, indicating that its internal energy had increased. Therefore, heat must be flowing from the hot metal sample to the cold liquid.

2. How does the change in water temperature compare for the different metals submerged in the same amount of water?

The change in temperature for the water with the aluminum sample is approximately three times as much as the change in temperature for the water with the copper sample (based on the sample data).

3. The temperature change of the water represents the change in the water's internal energy. Compare the amount of heat delivered by the different metal samples submerged in water. Explain your answer.

Because heat is the amount of energy transferred, and temperature is related to the amount of energy in a material, then more heat was transferred in the aluminum-water system than the copper-water system.

4. The initial temperature of the metal samples was the same, and the initial temperature of the water in the cups was the same. Because the final temperature of the water in the different cups is different, what does this tell you about internal energy of the metal samples when they are at the same temperature in the water bath? Explain?

The aluminum was able to deliver more energy to the water, so it must have more internal energy than copper even though they started at the same temperature.

5. What does the answer from the previous question tell you about the temperature and heat of two different metals?

Two different metals of the same mass can have the same temperature but different internal energies and different capacities to deliver heat.

6. How does the change in temperature compare for the same metal submerged in different fluids?

The change in temperature for the vegetable oil is three times as much as the change in temperature for the water but took much longer (based on the sample data).

7. The copper samples are the same material at the same temperature initially. Therefore, they must start out with the same internal energy. Compare how the heat from the metal samples affects the liquids they are submerged in. Explain your answer.

The same amount of energy coming from the copper causes the oil to increase its temperature more than the water, so different liquids have different capacities to absorb heat.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What is the difference between heat and temperature?

Heat is the amount of energy given off from a warm object to a cold object; whereas, temperature is a measure of the amount of heat in an object.

2. Imagine you have two copper samples, one that is 100 g and one that is 200 g, each at a temperature of 85 °C. If each sample is placed into a cup of room-temperature water, which cup will be the hottest after they both reach equilibrium? Explain.

The 200 g sample will be hotter because it has twice as much heat to deliver to the water. The 200 g sample has twice as much mass; therefore, the amount of heat stored in the 200 g mass will be twice as much as the 100 g sample.

Multiple Choice Questions

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

1. A 200 g mass of copper at 150 °C is placed on top of a 400 g mass of aluminum at 20 °C. The internal energy of the aluminum increases because

- **A.** Heat transfers from the aluminum to the copper.
- **B. Heat transfers from the copper to the aluminum.**
- **C.** The average kinetic energy of the copper increases.
- **D.** It begins to melt.

2. Which of the following best describes heat?

- **A.** The amount of translational kinetic energy in a material
- **B.** The average kinetic energy in a material
- **C.** The total energy in a material
- **D.** **The transfer of energy from one material to another without work being done**

Key Term Challenge

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

1. Two common temperature scales used in science are the **Kelvin** and **Celsius** scales. Temperature is related to the average **kinetic energy** of the particles in a material. Kinetic energy depends upon the mass and **velocity** of particles. The particles move in different ways. Some particles may have **translational** or straight-line motion, while others may vibrate or even spin.

2. The word "heat" is loosely used in common language. However, in science it specifically relates to the **transfer** of energy from one material to another. Sometimes the term "heat" is used interchangeably with the term "thermal energy." Thermal energy is in fact the total amount of **energy** contained in a material. Heat transfers spontaneously from a **hot** object to a **cold** object.

Extended Inquiry Suggestions

Consider different variations of this lab:

- Use lead masses instead of copper and aluminum masses.
- Use different amounts of each mass; for example, 100 g or 400 g masses instead of 200 g masses.
- Use different amounts of each fluid.

22. Phase Change

Objectives

- Understand that adding thermal energy to a substance does not necessarily increase the substance's temperature.
- Explore the idea that the "internal energy" of a substance is the sum of the average kinetic energy (temperature) and potential energy of the molecules in that substance, where the potential energy is associated with the phase or state of matter in which that substance exists.
- Understand that any transfer of heat during a phase change will produce only the phase change without changing the temperature of the substance.

Procedural Overview

Students gain experience conducting the following procedures:

- Observing physical changes in a system undergoing a phase change
- Relating observations of a phase change to features of a graph
- Identifying and annotating important features of a Temperature versus Time graph

Time Requirement

♦ Preparation time	Several hours before the lab occurs: 20 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor, stainless steel (2)
- Beaker, 150-mL (2)
- Test tube, 20-mm × 150-mm
- Lauric acid, 8 g
- Stirring rod
- Rod stand
- Hotplate
- Ice[1]
- Utility clamp (2)
- Water, 200 mL

[1]Please refer to the Lab Preparation section for details

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Difference between heat and temperature
- ♦ Molecular difference between solids, liquids, and gases
- ♦ Correlation between heat and other forms of energy

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Temperature versus Heat
- ♦ Specific Heat of a Metal
- ♦ Heat of Fusion
- ♦ Heat of Vaporization

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Adding a note to a graph �(7.1.5)
- ♦ Finding the slope at a point on a data plot �(9.3)
- ♦ Saving your experiment �(11.1)

Background

What happens to a substance as heat is added to it? Most students will say, "The temperature of the substance will rise." That answer is often correct, but not always! Take ice cubes out of your freezer, and put them into a cup of hot coffee. If the ice cubes started out at –10 °C, the heat flowing from the coffee to the ice cubes will initially cause the cubes to warm up. However, when the ice cubes reach zero °C, heat will continue to flow from the coffee to the cubes, but the cubes will not change temperature! They will remain at zero °C until the ice is no longer ice and has turned to water. Only then will the temperature of what had been ice actually begin to rise again.

Where does the heat from the coffee go if it's not increasing the temperature of the ice? It seems to be hidden. That's precisely why the number that refers to such a change of phase is known as a *latent* heat.

Recall that internal energy is a measure of all the energy associated with the state of the atoms and molecules within a substance or system. It includes the kinetic energy due to the movement of the molecules (temperature), but it also includes the potential energy between and within the molecules making up the substance. It is this potential energy between and within the molecules of the substance that accounts for the phase of matter. Adding or removing energy (heat) to or from a substance will result in a temperature change up to the point at which the substance begins to melt/freeze or boil/condense. At that point, the heat that flows to or from one substance to the other results in a change of phase instead of an increase or decrease in temperature. It is the purpose of this experiment to illustrate this idea, that objects receiving or giving off heat during a phase change do not change temperature.

Pre-Lab Discussion and Activity

Heat and temperature are two of the most commonly confused terms in all of introductory physics. Most students will have difficulty in distinguishing between the two. Engage them by asking them to consider:

1. What is the difference between temperature and heat? Perhaps one way to determine the difference is to establish good working definitions for each term.

Open this up for classroom discussion: Often students will say that temperature is simply the basis on which we measure the amount of heat. This is not correct. Try to guide them into differentiating between the two. Perhaps it might be instructive to allow them to research the question overnight.

Teacher Tip: After such research, students will most likely come in with good word definitions. After they read these definitions, try to provide additional challenge by asking them to explain these definitions in their own words.

Temperature is a measure of the average molecular kinetic energy of a substance.

Heat is the energy transferred from a higher temperature substance through contact to a lower temperature substance because of the difference in temperature.

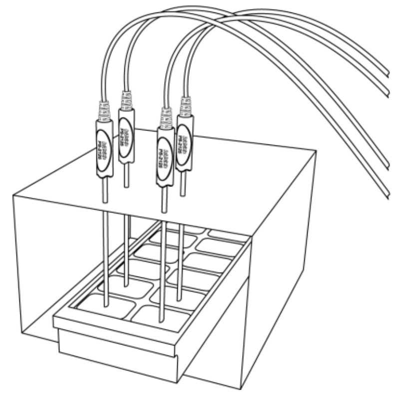
Once it becomes clear that the students understand the distinction, ask them:

2. How can heat be added to an object or a substance without having it increase in temperature?

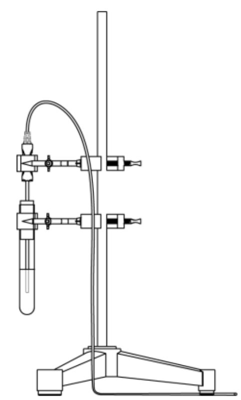
If the kinetic energy of the molecules is not increasing, then the potential energy must be increasing: It is this increase in potential energy that differentiates between phases or states of matter.

Lab Preparation

These are the materials and equipment to set up prior to the lab. This laboratory requires that several preparations be done several hours before the laboratory is scheduled:



1. Insert temperature sensors into the centers of ice cube trays. (See the illustration at the left.) Place the entire tray into a freezer, and freeze the sensors right into the cubes. When the ice has frozen completely, place each tray into a shallow bath of warm water. After a few moments, remove the sensors, now embedded in ice cubes, without exerting forces which might damage the sensors. Immediately return the sensors with attached ice cubes to the freezer, and allow them to once again cool to the internal temperature of the freezer. There should be at least one sensor and ice cube for each group.
2. Prepare a bag of crushed ice, and store it in a freezer as well. Do not remove any of this ice until it is needed for the lab.
3. Sprinkle some powdered Lauric acid into a test tube until it is about 2 centimeters deep. Insert a temperature sensor down into the center of the powder, and insert a spacer around the body of the sensor so that it cannot get displaced from the center of the tube. Also, be sure that the bottom of the temperature sensor is not touching the bottom of the test tube. The sensor needs to be as close to the center of the Lauric acid as possible. (See picture at the left.) Lower the tube into a vessel of very hot water, and allow the powder to completely melt. Remove the tube from the hot water (keeping it upright), and allow it to cool. You will now have a test tube with solid Lauric acid in the bottom and a temperature sensor at the center of the Lauric acid. This is very similar to the sensor with the ice cube at the end. You will need to prepare one of these test tubes for each lab group.



Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Never touch a hotplate or beaker with unprotected hands.
- ♦ Be careful not to spill hot liquids.
- ♦ Keep all walkways and traffic areas clear of electrical cords.
- ♦ The Lauric acid can be saved and reused in the test tubes. If you choose to dispose of the Lauric acid please consult the MSDS and your local regulation for proper disposal.

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
Analyze the graphs of Temperature versus Time for heat added to ice and water.	Add heat to ice and water with the ice starting out below freezing.	Draw conclusions about what happens to the temperature of a body as it changes phase.	Add heat to solid Lauric acid by immersing a test tube containing the Lauric acid into a hot water bath.	Allow heat to flow from melted Lauric acid to a cold water bath by immersing a test tube with the molten acid into a cold 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: 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 – Ice and Water

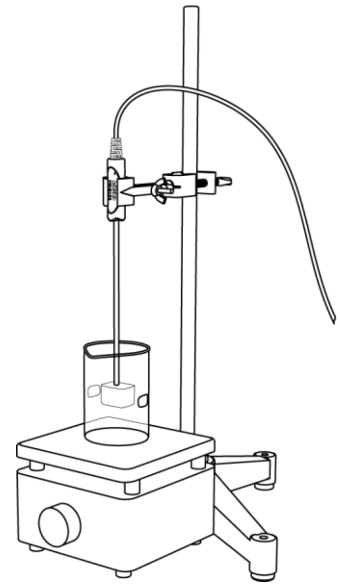
Set Up

1. ☐ Place some crushed ice into a beaker, and set the beaker on a hotplate.

2. ☐ Position a utility clamp and rod stand next to the hotplate such that a temperature sensor can be clamped into position with the actual sensing element as close to the middle of the liquid in the beaker as possible.

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

4. ☐ Take the temperature sensor with the ice cube out of the freezer, clamp it into position so the ice cube is nearly in the center of the crushed ice in the beaker, and then connect the temperature sensor to the data collection system. �(2.1)



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

6. ☐ If necessary, add additional crushed ice to cover the top of the ice cube with the sensor inside.

Collect Data

7. ☐ Start data recording. �(6.2)

8. ☐ Turn on the hotplate to high.

Note: Different hotplates have different power requirements and different maximum power settings. Always use a safe setting for your specific model.

9. ☐ Once the crushed ice has melted enough to allow stirring, carefully and continually stir the liquid in the beaker.

Note: Do not stop stirring and continue to collect data as the ice melts off the sensor, and as the resulting water heats up until the water in the beaker comes to a full, rolling boil. During this entire time, it is critical that the liquid in the beaker be continually stirred. Therefore, it might be a good idea to have two students available to do the stirring; if one student's hand tires, the other can take over immediately.

10. ☐ Once the water is at a full boil, stop data recording, and turn off the hotplate. �(6.2)

Analyze Data

11. ☐ Add a note to the Temperature versus Time graph, that describes the phase or phase change associated with changes in the shape of the graph. �(7.1.5)

12. ☐ Sketch your graph of Temperature versus Time in the space provided in the Data Analysis section.

13. ☐ What happened during the first several seconds when the heat was applied to the very cold ice? Recall that the data was started immediately upon removal of the temperature sensor from the freezer. At this point, the temperature of the ice should have been below zero.

The temperature increased steadily for the first several seconds. It began to level off when the temperature approached zero.

14. ☐ What happened to the slope of the graph several seconds later? And at what temperature did that occur? Use the slope tool on your data collection system if needed. �(9.3)

The temperature will remain zero (or nearly zero) until almost all of the ice has melted. (Actually, it might increase slightly because it is very difficult to keep the beaker stirred well enough to prevent any increase.)

15. ☐ How long did it take for the temperature to start rising again?

The length of time before the temperature begins to increase will vary depending upon how much ice was used and the rate of heating from the burner or hotplate. The temperature stopped increasing.

16. ☐ Why do you think this occurred?

All of the energy was being used to melt the ice.

17. ☐ Describe the shape of the graph for the remainder of the experiment. Can you explain why the temperature didn't simply rise for the rest of the experiment?

The temperature began to noticeably increase again. Once all of the ice melted, it increased at almost a constant rate. Some students may notice that the rate of increase is less than it was for the ice (before it reached zero degrees). The temperature didn't keep rising because the water started to change phase again, from water to gas (boiling).

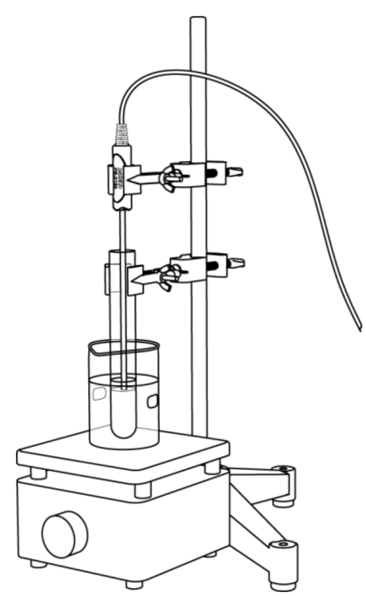
18. ☐ What do you conclude is the consequence of adding heat to a substance? Does adding heat to a substance always result in an increase of temperature? If not, what else can happen?

Adding heat to a substance will either increase the object's temperature, or it will result in some other change. In this case, the change was a phase change of the substance.

Part 2 – Solid and Liquid Lauric Acid

Set Up

19. ☐ Un-clamp disconnect, and remove the temperature sensor from Part 1, and then connect the temperature senor embedded in lauric acid to the data collection system. �(2.1)



20. ☐ Clamp the test tube containing the Lauric acid and the embedded temperature sensor to the rod stand. Use a second clamp to insure that the temperature sensor will remain in position even if the Lauric acid is no longer supporting it. Do not place the test tube into the hot water bath yet.

21. ☐ Prepare a room temperature water bath in a second beaker.

22. ☐ Using the beaker of hot water from Part 1, prepare a hot water bath (to be held at approximately 60 °C) on the hotplate.

23. ☐ Place both beakers at approximately the same height so that the stand, test tube, and sensor can be moved easily from one to the other and so that the end of the test tube filled with Lauric acid will be below the water line in each.

Collect Data

24. ☐ Start data recording. �(6.2)

25. ☐ Immerse the bottom of the test tube in the 60 °C water bath.

26. ☐ Once the measured temperature reaches the temperature of the water bath (it will stop rising), move the stand, test tube, and sensor assembly from the hot water bath to the room temperature water bath (do not stop recording data at any point during this operation).

27. ☐ Once the measured temperature is near room temperature, stop data collection. �(6.2) The Lauric acid will be solid again at this point.

Analyze Data

28. ☐ Add a note to the Temperature versus Time graph, that describes the phase or phase change associated with changes in the shape of the graph. �(7.1.5)

29. ☐ Sketch your graph of Temperature versus Time for the Lauric acid in the space provided in the Data Analysis section.

30. ☐ Initially, what happened to the temperature of the Lauric acid when the heat was applied through the walls of the test tube?

The temperature increased steadily for an interval of time. It began to level off when the temperature approached the melting point of the Lauric acid.

31. ☐ What happened to the slope of the graph during the interval of time when the Lauric acid was actually melting? At what temperature did that occur? Use the slope tool on your data collection system if needed. �(9.3)

The temperature remained steady (or almost steady) during the melting process. No stirring was accomplished, so we didn't expect a perfectly constant temperature.

32. ☐ How long did it take for the temperature to start rising again?

The temperature at which that happened should be close to 45 °C. The temperature remains steady until all of the Lauric acid has melted.

33. ☐ Why do you think this occurred?

The heat was being used to melt the Lauric acid.

34. ☐ Describe the shape of the graph for the remainder of the experiment. Can you explain why the temperature didn't simply rise for the rest of the experiment?

The temperature began to noticeably increase again once the Lauric acid is all in the liquid phase. Once all of it melted, the temperature again increased until the Lauric acid was in thermal equilibrium with the hot water bath.

35. ☐ When the hot water bath was replaced with the cold water bath, what happened to the graph of Temperature versus Time?

The temperature began to decrease steadily for an interval of time. It began to level off when the temperature approached the freezing/melting point of the Lauric acid.

36. ☐ What happened to the slope of the graph during the interval of time when the Lauric acid was actually solidifying? At what temperature did that occur? �(9.3)

The temperature remained steady (or almost steady) during the solidifying (freezing) process. The temperature at which that occurs was approximately 45 °C.

37. ☐ How long did it take for the temperature to start falling again?

The temperature remained steady until all of the Lauric acid was solid.

38. ☐ Why do you think this occurred?

Heat leaving the system caused the Lauric acid to solidify.

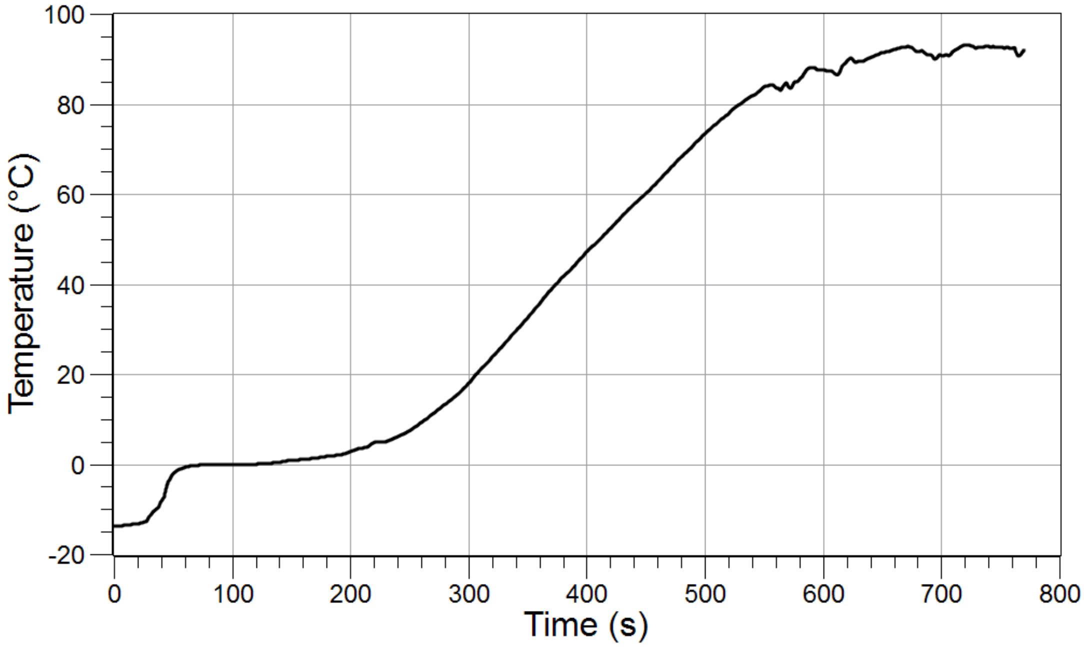
39. ☐ What do you conclude is the consequence of adding heat to a substance? Does adding heat to a substance always result in an increase of temperature? If not, what else can happen?

Adding heat to a substance will either increase the object's temperature or it will result in some other change. In this case, the change was a phase change of the substance. Similarly, as an object gives off heat, it will either change temperature or change phase.

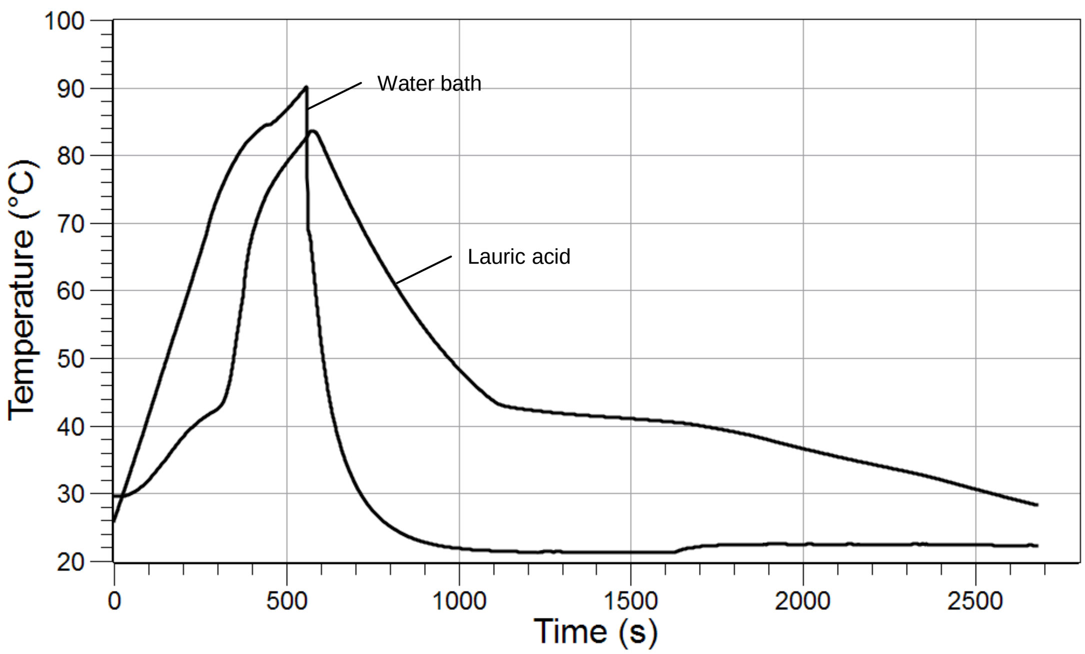
40. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Temperature versus Time: Water



Temperature versus Time: Lauric Acid



Analysis Questions

1. From your data, can you determine the freezing/melting point of water? What about the boiling/condensing point of water?

Yes. The freezing/melting point of water should be near zero °C. The boiling/condensing point of water should be close to 100 °C. (This number could be noticeably affected by elevation.)

2. From your data, can you determine the freezing/melting point of Lauric acid? What about the boiling/condensing point of Lauric acid?

Yes. The melting/freezing point for Lauric acid is about 45 °C. However, you cannot determine the boiling/condensation point for Lauric acid because we did not boil it. The temperature is actually too high to do this in our lab.

3. From your data, can you determine which material (such as ice or water) takes more heat to change its temperature a given amount?

Yes. It takes more heat to cause water to change temperature by a given amount. That is apparent because the slope of temperature versus time is steeper for ice. So, because we were adding heat at the same rate, a smaller amount of heat caused the same temperature increase for ice compared to that for water.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Often, when below-freezing temperatures are predicted for citrus groves in Florida, the growers turn on sprinklers which covers the fruit in a layer of water. How can this protect the fruit from freezing?

Before the fruit can freeze, the surface water must freeze. Although the air temperature might go below freezing, energy must be transferred to the atmosphere to freeze the water on the surface. Because the sprinkling is going on steadily, and the fruit is being covered with water that is above freezing, the water would have to cool to freezing *plus* the additional latent heat would have to be absorbed. Especially because the water is constantly being replaced with fresh water, it would take a much colder temperature to actually freeze the citrus.

2. In the very cold northern part of the United States, open barrels of water are often stored with the fruit in fruit cellars. Why do you suppose this is a good idea?

Before the fruit can freeze, all of the water in the barrels must freeze. That would require much longer freezing conditions, and so it would almost always protect the fruit from freezing, especially if the bitter cold weather was short in duration.

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 the phase of a substance in which the temperature remains constant while at the same time it is experiencing an inward heat flow?

- **A.** Gas
- **B.** Liquid
- **C.** Solid
- **D. Changing phase**

2. In cloud formation, water vapor (water in the gaseous state) turns into liquid water droplets, which get bigger and bigger until it rains. This will cause the temperature of the air in the clouds to:

- **A. Get warmer**
- **B.** Get cooler
- **C.** This would not affect the temperature of the air in the clouds
- **D.** There is no air in clouds
- **E.** The answer depends on the type of clouds

3. If you have a nice campfire going and you put a few logs on it (but the surfaces of the logs are wet), you will notice a sudden reduction in the amount of heat that you feel from the fire. The most likely reason for this is:

- **A.** The water nearly puts out the fire.
- **B.** The water was cold and has to be warmed up before the heat will be felt again.
- **C. The water will absorb heat and have to "boil off" before the heat of the fire will return fully.**
- **D.** The original statement is not true. Putting a wet log on the fire will not really reduce the heat that is felt.

Key Term Challenge

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

1. Take ice cubes out of your freezer, and put them into a cup of hot coffee. If the ice cubes started out at –10 °C, the heat initially **flowing** from the coffee to the ice cubes will cause the cubes to **warm** up. When the ice cubes reach zero °C, heat will continue to flow from the coffee to the cubes, but the cubes will not change temperature! They will remain at zero °C until the ice **melts**. Only then will the **temperature** of what had been ice actually begin to rise again.

2. Temperature is defined as the average **kinetic energy** of the atoms or molecules of a substance. Heat is another form of **energy**. The term **heat** describes the energy being transferred from one body to another without any work being done in the process. As a substance changes from a solid to a liquid or from a liquid to a gas, the object is said to change **phase**. The term that is used to describe the amount of heat that is absorbed or liberated during a phase change is **latent heat.**

Extended Inquiry Suggestions

Experiments to determine the latent heat of fusion of water are common. Typically, they mix some warm water with ice and use the concepts of calorimetry (heat lost = heat gained) to determine the heat of fusion of water.

Challenge your students to create a procedure to approximate the latent heat of fusion of ice:

Place a known mass of ice m_{ice}, just at its melting point, into a known mass of water m_{water}, at some temperature T_i (room temperature). The ice will melt, and the combined water and melted ice mixture will eventually reach some equilibrium temperature T_f. Calculate the amount of heat Q given-off by the water to melt the ice and then bring the melted ice to the final equilibrium temperature:

$$Q = m_{\text{water}}\, c\left(T_f - T_i\right)$$

Because heat lost = heat gained, the amount of heat given-off to melt the ice and bring it to the equilibrium temperature must equal the amount of heat absorbed by the ice during the phase change and temperature increase:

$$Q = m_{\text{ice}} L_f + m_{\text{ice}} c\left(T_f - 0\right)$$

$$L_f = \frac{Q}{m_{\text{ice}}} - cT_f$$

Where c is the specific heat of water (4,186 J/(kg·°C)).

At the conclusion of this activity is a good time to discuss other more exotic phases of matter, such as plasma and Bose-Einstein condensate. Students may have some knowledge based on popular press or prior reading, so it is a good opportunity to show how these more exotic phases fit into the picture. The Bose-Einstein condensate also points to the notion that we are still learning new things about the world around us all the time.

23. Specific Heat Capacity of a Metal

Objectives

In this experiment, students compare the heat transferred by different metals to water. By comparing the heat transfer, students learn:

- How different metals store heat
- That the capacity of a substance to store heat is a characteristic of that substance

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the temperature change caused by introducing a higher temperature metal to a room temperature liquid
- Thermally isolating metal and liquid samples to insure that the heat transfer is only between samples
- Comparing the heat transferred by different metals to determine the heat capacities of the metals

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor, stainless steel
- Beaker, 600-mL
- Calorimetry cup (3)[1]
- Metal sample (3)[1]
- Balance (1 per classroom)
- Hot plate
- Tongs
- Water, 1 L
- String, 15-cm (3)

[1] Part of the Basic Calorimetry Set

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Heat as energy
- Heat transfer

Related Labs in This Guide

Labs conceptually related to this one include:

- Temperature versus Heat
- Phase Change
- Heat of Fusion
- Heat of Vaporization

Using Your Data Collection System

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

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

Background

Doing work can add energy to systems or a substance. Examples include pushing a cart up an inclined track or using a wrench to tighten a bolt. However, this is not the only way to introduce energy to a system or substance. Energy can be added in the form of heat Q. Unlike work energy, energy added by heat has the ability to cause changes in the substance itself, such as changes in temperature and changes in phase.

One can experience an example of this heat (energy) exchange by dropping a cold metal spoon into a pot of hot water. After remaining in the water for a few minutes, the spoon feels hot when removed. When the spoon entered the hot water, the spoon began to absorb energy and convert that energy gain into a change in temperature.

One may have also noticed that after removing the spoon, the temperature of the water dropped slightly. This is a result of energy conservation within the system: as the cold spoon's energy (temperature) increases, the hot water's energy (temperature) must decrease.

The spoon in this example was made out of metal. How would the temperature changes be different if the spoon were plastic? One would expect a cold metal spoon to cause a greater drop in the water temperature than a plastic spoon. However, this is a property of the *specific heat capacity* and mass of the object or substance. Specific heat is informally described as a substance's ability to resist changes in temperature due to the addition or subtraction of heat energy. Some substances require large amounts of energy to change just a slight amount in temperature, while others will change temperature with just a tiny bit of added energy.

The mathematical relationship between energy Q and temperature change ΔT for a substance of mass m is shown here:

$$Q = mc\Delta T \qquad \textbf{Eq.1}$$

where c is the specific heat capacity of the substance.

For positive temperature changes (T_{final} - $T_{\text{initial}} > 0$), energy is added to a substance. When ΔT is negative, Q is also negative, which indicates that energy is leaving a substance. Because of energy conservation, we can relate the changes in temperature from one part of the system to the other using this simple relationship:

$$-Q_{\text{lost}} = Q_{\text{gained}} \qquad \textbf{Eq.2}$$

$$-m_1c_1\Delta T_1 = m_2c_2\Delta T_2 \qquad \textbf{Eq.3}$$

In the spoon example, the right side of Eq.3 corresponds to the energy gained by the spoon; the left corresponds to the energy lost by the hot water; and each has a mass m_n and experiences a change in temperature ΔT_n that is governed by their specific heats c_n.

Pre-Lab Discussion and Activity

Engage your students with the following questions:

1. What do we know about heat at this point?

Heat is a form of energy. Heat flows from higher temperature objects to lower temperature objects through contact.

2. We have seen that heat flows from high temperature substances to low temperature substances. How do you think we can use this fact to find out more about how metals store and transfer heat.

Teacher Tip: Open up the topic to discussion, and collect ideas on a white board.

We can compare the characteristics of a known substance to those of an unknown. Direct the discussion toward the idea of heating the metal to a known temperature and placing them in a substance with a known heat characteristic, like water.

3. What parameters do you think we will need to hold constant, and which will we measure and compare?

Teacher Tip: Open up the topic to discussion, and collect ideas on a white board.

Things to remain constant: initial temperature of the metal, initial temperature of the water mass of the metal sample, and mass of the water. Things to measure and compare: final temperature of the water and the rate of change of the temperature.

Lab Preparation

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

1. Place the water at the lab stations ahead of time to minimize spills.
2. Provide students with two known metal samples and one "unknown" sample.

Lab Safety

Add these important safety precautions to your normal laboratory procedures:

- When using the hot plate, be very careful not to burn your hands or fingers.
- Use a 600-mL beaker for boiling water that can withstand high heat, such as a Pyrex® beaker. Other beakers may shatter when exposed to high heat.
- Boiling water can cause severe burns. Be very careful when using boiling water, and do not carry the beaker without insulated gloves or tongs when it is hot.
- All glass beakers can break when dropped. Be very careful not to drop any of the glassware used in this lab. If an accident does occur, follow the proper cleaning and disposal procedure instituted by your teacher.
- Keep electronic and other sensitive equipment away from water.

Sequencing Challenge

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

4	1	2	5	3
Once the temperature reaches equilibrium (is constant), stop recording data.	Add equal amounts of water to the three calorimeter cups.	Start recording the temperature of the water in the calorimeter cup.	Use the final temperature of the water to calculate the amount of heat energy that was transferred.	Submerge the hot metal sample into the calorimeter water at room 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 your data collection system. �(1.2)

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

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

4. ☐ Create a hot water bath by filling the beaker ¾ full with water and placing the beaker on the hot plate.

5. ☐ Set the hot plate temperature to boil the water in the beaker.

6. ☐ Why is it better to use boiling water to heat the metal sample and not room temperature water?

Water boils at around 100 °C, so we already know the initial temperature, and it will stay constant as the metal heats up. (Boiling water generally doesn't get any hotter than 100 °C.) If we were to use room temperature water, the temperature would change when we introduced the metal.

7. ☐ In this lab, we will use boiling water to heat the metal sample to ~100 °C. Could we have used ice water to cool the sample to ~0 °C so that the temperature of the calorimeter water would drop rather than increase? Explain.

Yes. The ice water would behave the same way the boiling water did by not changing temperature when we introduce the metal. We also know that the temperature should be 0 °C for ice water. The difference would be the direction of heat flow.

8. ☐ Use the balance to measure the mass of the calorimetry cups, and then record the mass of the calorimeter cups in the Data Analysis section.

9. ☐ Add equal amounts of water to the calorimetry cups (approximately ¾ full), and record the mass of the calorimeter with water in the Data Analysis section for each cup.

Note: The calorimeter and beaker are only ¾ full so that the water level does not spill over the edge up the cup when you submerge the metal sample.

10. ☐ Why do we use a calorimetry cup when measuring the change in water temperature and not just another glass beaker?

The calorimeter is insulated and won't lose much energy (heat) through conduction through its walls. A glass beaker is not insulated and would allow heat to escape into the air.

11. ☐ Record the mass of each metal sample in the Data Analysis section.

12. ☐ Tie a 15-cm piece of string to each metal sample to make them easier to move from the hot water bath to the calorimeter cup.

Collect Data

13. ☐ Start data recording. �(6.2)

14. ☐ Check the temperature in each calorimeter to insure it is room temperature, and record this value in the Data Analysis section as the initial temperature of the water in the calorimeters.

15. ☐ Allow the hot water bath to come to a boil, and then use the temperature sensor to measure the temperature of the boiling water.

16. ☐ Why do you think it is important to measure the temperature of the boiling water if we "know" that water boils at 100 °C?

Pressure (or altitude) affects the temperature at which water boils, so it is best to measure. The important factor is that the boiling point will be constant for the local conditions.

17. ☐ Stop data recording. �(6.2)

18. ☐ Remove the temperature sensor from the hot water bath.

19. ☐ Place the first sample in the hot water bath, and allow it to equilibrate for 5 to 10 minutes.

20. ☐ Place the temperature sensor in the first calorimeter.

21. ☐ Start data recording. �(6.2)

22. ☐ Quickly but carefully transfer the first metal sample from the hot water bath to the calorimeter.

23. ☐ Place the second metal sample in the hot water bath.

24. ☐ Once the temperature in the calorimeter reaches equilibrium (remains constant), stop data recording. �(6.2)

25. ☐ Use the graph of Temperature versus Time on your data collection system to find the value of the equilibrium temperature. Record the temperature as the final temperature of both the water and the metal sample in the Data Analysis section. �(9.1)

26. ☐ Place the temperature sensor in the second calorimeter.

27. ☐ Start data recording. �(6.2)

28. ☐ Quickly but carefully transfer the second metal sample from the hot water bath to the calorimeter.

29. ☐ Place the third metal sample in the hot water bath.

30. ☐ Once the temperature in the calorimeter reaches equilibrium (remains constant), stop data recording. �(6.2)

31. ☐ Use the graph of Temperature versus Time on your data collection system to find the value of the equilibrium temperature. Record the temperature as the final temperature of both the water and the metal sample in the Data Analysis section. �(9.1)

32. ☐ Place the temperature sensor in the third calorimeter.

33. ☐ Start data recording. �(6.2)

34. ☐ Quickly but carefully transfer the third metal sample from the hot water bath to the calorimeter.

35. ☐ Once the temperature in the calorimeter reaches equilibrium, (remains constant) stop data recording. �(6.2)

36. ☐ Use the graph of Temperature versus Time on your data collection system to find the value of the equilibrium temperature. Record the temperature as the final temperature of both the water and the metal sample in the Data Analysis section. �(9.1)

37. ☐ Save your experiment as instructed by your teacher. �11.1)

38. ☐ Make sure your hot plate is turned off, and carefully clean-up as instructed by your teacher.

Data Analysis

1. ☐ After recording temperature data for all three of your samples, calculate the change in temperature ΔT for both the calorimeter water and the metal sample. Then, use those values to calculate the specific heat c of the sample.

The Specific heat of water is c_{water} = 4,186 J/(kg·°C).

Mass of the calorimeter cup: 0.019 kg
Mass of the calorimeter cup plus water: 0.188 kg

Table 1: Mass and temperature data

Sample 1	T_{final} (°C)	$T_{initial}$ (°C)	ΔT (°C)	m (kg)	Q (J)
Calorimeter Water	29.0	23.3	5.7	0.169	4,032.4
Aluminum	29.0	98.5	-69.2	0.066	

$Q = mc\Delta T$

$Q = 0.169\ \text{kg} \cdot 4{,}186\ \text{J/(kg}\cdot\text{°C)} \cdot (5.7\ \text{°C})$

$Q = 4{,}032.4\ \text{J}$

$Q = mc\Delta T$

$4{,}032.3\ \text{J} = 0.066\ \text{kg} \cdot c \cdot (-69.2\ \text{°C})$

$c = 882.9\ \text{J/(kg}\cdot\text{°C)}$

Mass of the calorimeter cup: 0.021 kg
Mass of the calorimeter cup plus water: 0.223 kg

Table 2: Mass and temperature data

Sample 2	T_{final} (°C)	$T_{initial}$ (°C)	ΔT (°C)	*m* (kg)	*Q* (J)
Calorimeter Water	33.0	27.5	5.5	0.202	4,719.7
Copper	33.0	98.2	-65.2	0.199	

$Q = mc\Delta T$

$Q = 0.202\text{ kg} \cdot 4{,}186\text{J/(kg} \cdot \text{°C)} \cdot (5.5\text{ °C})$

$Q = 4{,}719.7\text{ J}$

$Q = mc\Delta T$

$4{,}719.7\text{ J} = 0.199\text{ kg} \cdot c \cdot (-65.2\text{ °C})$

$c = 363.8\text{ J/(kg} \cdot \text{°C)}$

Mass of the calorimeter cup: 0.024 kg
Mass of the calorimeter cup plus water: 0.229 kg

Table 3: Mass and temperature data

Unknown Sample	T_{final} (°C)	$T_{initial}$ (°C)	ΔT (°C)	*m* (kg)	*Q* (J)
Calorimeter Water	25.8	23.4	2.4	0.205	2,059.5
Metal Sample	25.8	98.5	-72.7	0.229	

$Q = mc\Delta T$

$Q = 0.205\text{ kg} \cdot 4{,}186\text{ J/(kg} \cdot \text{°C)} \cdot (2.4\text{ °C})$

$Q = 2{,}059.5\text{ J}$

$Q = mc\Delta T$

$2{,}059.5\text{ J} = 0.229\text{ kg} \cdot c \cdot (-72.7\text{ °C})$

$c = 123.7\text{ J/(kg} \cdot \text{°C)}$

Analysis Questions

1. What were your calculated values for the specific heat of your first two sample metals? How did they correspond to the theoretical values shown in the table below? What was your percent error for each?

Sample 1 (Aluminum):

Experimental: 882.9 J/(kg·°C) Theoretical: 900 J/(kg·°C)

%error = |900-882.9|/900 = 1.9%

Sample 2 (Copper):

Experimental: 363.8 J/(kg·°C) Theoretical: 387 J/(kg·°C)

%error = |387-363.8|/387 = 6.0%

Table 3: Specific heat of different metals

Substance	Specific Heat J/(kg·°C)
Aluminum	900
Beryllium	1,830
Cadmium	230
Copper	387
Germanium	322
Gold	129
Iron	448
Lead	128
Silver	234
Brass	380

2. Using the table above, what kind of metal is your unknown sample?

Unknown Metal: Lead

Experimental: 123.7 J/(kg·°C)

The closest theoretical value would be Lead at 128 J/(kg·°C), meaning that the percent error is equal to: |128-123.7|/128 = 3.4%

3. Explain some of the factors that may have caused your calculated values for specific heat c to be inaccurate and how these factors may have been avoided.

When we placed the metal sample in the calorimeter cup, there were still hot droplets of water on the sample. These droplets may have added some energy at a different specific heat than the metal sample, which we did not include in our calculations. This is somewhat unavoidable because anything used to dry the sample will absorb energy when it touches the sample.

Energy was lost in the calorimeter cup even though it did insulate very well. We could have used a more industrial calorimeter that insulated better, but this wouldn't have made too much of a difference because it would heat up as well.

Energy was lost from the surface of the water into the air. We could have used a lid over the calorimeter to help insulate the surface of the water.

The temperature probe used had a stainless steel sleeve on it that may have absorbed or added energy to the system, which was not included in our calculation. We could have heated or cooled the probe in advance to help minimize the energy loss or transfer from the probe.

Synthesis Questions

Use available resources to help you answer the following questions.

1. If one places a 100 g hot piece of copper in a calorimeter containing 200 g of room temperature (25 °C) water, and the final equilibrium temperature of the water + copper was 75 °C, what was the initial temperature of the copper before it was placed in the calorimeter? Show your work.

$$-m_1 c_1 \Delta T_1 = m_2 c_2 \Delta T_2$$

$$-\left(T_f - T_i\right) = \frac{m_{\text{water}} c_{\text{water}} \Delta T_{\text{water}}}{m_{\text{copper}} c_{\text{copper}}}$$

$$T_i = \frac{(0.200\ \text{kg})(4{,}186\ \text{J/(kg}\cdot{}^\circ\text{C)})(50\ {}^\circ\text{C})}{(0.100\ \text{kg})(387\ \text{J/(kg}\cdot{}^\circ\text{C)})} + 75\ {}^\circ\text{C}$$

$$T_i = 1{,}156.7\ {}^\circ\text{C}$$

2. If a piece of iron and a piece of gold (same mass) were both exposed to the same amount of heat (Assume 100 g samples with the addition of 1,200 J of energy), which one would be hotter? Explain.

The specific heat of gold is much smaller than iron, which means that gold is prone to temperature changes with the addition of little energy, compared to iron. Gold will be hotter.

Gold: $$\Delta T = \frac{(1{,}200\ \text{J})}{(0.100\ \text{kg})(129.0\ \text{J/(kg}\cdot{}^\circ\text{C)})} = 93.0\ {}^\circ\text{C}$$

Iron: $$\Delta T = \frac{(1{,}200\ \text{J})}{(0.100\ \text{kg})(448.0\ \text{J/(kg}\cdot{}^\circ\text{C)})} = 26.8\ {}^\circ\text{C}$$

3. Explain in terms of energy why wood is used to insulate homes rather than metal, considering that the specific heat of wood is ~1,800 J/(kg·°C).

Because wood has a much higher specific heat, it resists changes in temperature due to the addition of energy compared better than most metals.

Multiple Choice Questions

1. Which of the following metals requires the most energy to experience a temperature change of 20 °C?

- **A. Copper**
- **B**. Gold.
- **C.** Lead
- **D.** Silver

2. If 300 g of room temperature water (25 °C) is heated and experiences a temperature increase of 40 °C, how much energy has the water absorbed?

- **A.** 75.2 kJ
- **B.** 50.2 J
- **C.** 80.7 J
- **D. 50.2 kJ**

3. If the same water from the previous question was then heated again such that it experiences another temperature increase of 40 °C, how much more energy has the water absorbed?

- **A.** 50.2 kJ
- **B.** 75.2 kJ
- **C.** 725.0 kJ
- **D. Cannot solve this with just Eq.1; water turns to steam at 100 °C.**

Key Term Challenge

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

1. When energy is added to a substance in the form of heat, that substance experience a change in **temperature**. However, not all substances experience the same change in temperature from the same addition of **energy**. The magnitude of temperature change depends on that substance's **specific heat capacity**. A substance with a large specific heat has a tendency to **resist** temperature changes with the addition or subtraction of heat energy, while a substance with a **small** specific heat will easily **increase** in temperature with the addition of heat energy.

2. Energy is a **conserved** quantity, thus indicating that the total energy in a closed system is **constant**. If a closed system consisted of a hot piece of copper submerged in a pool of cold mercury, the **energy** lost by the piece of copper must equal the amount of energy gained by the mercury. The mercury's **temperature** would increase while the copper's temperature would decrease relative to the specific heat and **mass** of each substance.

Extended Inquiry Suggestions

A natural extension to this activity is to ask your students to go back to their data and look at the first thirty seconds of the Temperature versus Time graph for each metal. Ask your students to compare the slope of a best fit line for each metal sample. Discuss the factors that might influence the rate at which heat transfers.

24. Heat of Fusion

Objectives

This experiment improves students' understanding of heat as energy and the transfer of heat during phase change from solid to liquid. Students:

- Enhance their understanding of how heat transfer affects both the temperature and the phase of a substance
- Apply the principle of conservation of energy to heat transfer
- Understand heat of fusion and how to calculate it from measured values

Procedural Overview

Students will gain experience by conducting the following procedures:

- Measuring changes in temperature
- Using the specific heat of a substance, in conjunction with the law of conservation of energy, to calculate the heat of fusion for water
- Comparing a value calculated from an experimental procedure to an accepted value in order to critically think about experimental setup, and quantitative and qualitative error analysis

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
- Beaker, 600-mL
- Calorimetry cup[1]
- Balance (1 per classroom)
- Hot plate
- Stirring rod
- Stir station (optional)
- Water, 300 mL
- Ice (3 or 4 cubes)
- Paper towel

[1]Part of the Basic Calorimetry Set

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Conservation of energy
- Kinetic energy
- Heat as a form of energy
- Phase change
- Specific heat of a substance

Related Labs in This Guide

Labs conceptually related to this one include:

- Phase Change
- Specific Heat of a Metal
- Temperature versus Heat
- Heat of Vaporization

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Monitoring live data without recording �(6.1)
- Displaying data in a digits display �(7.3.1)

Background

On a microscopic level, thermal energy has to do with the energy of molecules. Substances that are perceived as hot have molecules with a large amount of kinetic energy. In addition to kinetic energy, potential energy exists between molecules in the form of inter-molecular bonds. The molecules in a solid or liquid are held together as a result of these inter-molecular attractions. In everyday life, we quantify thermal energy in terms of temperature. The standard unit of measure for temperature is Kelvin. To simplify our experiment, we use the more common, water centric scale, Celsius.

Heat is the energy that transfers from one substance to another as a result of a difference in their temperature. Heat, like all energy, is measured in joules J. An object's heat capacity is its ability to absorb heat; it is the ability of the molecules within the object to acquire kinetic energy. We express this as the specific heat of a substance *c*, or the joules of heat required to raise one kilogram of the substance by 1 °C. The heat lost or gained by a substance is defined as:

$$Q = mc\Delta T \qquad \textbf{Eq.1}$$

where Q is the amount of heat, m is the mass of the substance, c is the specific heat of the substance, and ΔT is the change in temperature of the substance.

In addition to changing the temperature of a substance, heat can also break inter-molecular bonds causing the substance to change phase. When this happens, no energy goes into changing the temperature of the substance; it is all being used to alter the inter-molecular bonds within the substance. The heat energy required for a substance to change phase between solid and liquid is represented by:

$$Q = mL_f \qquad \textbf{Eq.2}$$

where Q is the heat, m is the mass of the substance changing phase, and L_f is the latent heat of fusion of the substance. Like the specific heat of a substance, the latent heat of fusion of a substance is a property dependent on the type of substance and the substance's ability to absorb heat while it changes phase. Heat, like all energy, is conserved. This means that the heat that flows out of one object must equal the heat that flows into another object.

Pre-Lab Discussion and Activity

Engage the students in the following discussion and demonstration.

Begin by reviewing the concept of energy. Energy comes in several forms, the most familiar of which is kinetic. Explain that anything moving has kinetic energy. Next, gather several marbles into a bowl. Shake the bowl slowly at first, and then more rapidly.

1. When I shake the bowl, I am transferring energy from my arms. Where is the energy going? How do you know?

The marbles absorb the energy (kinetic energy). We know this because they are moving faster.

Explain how the marbles in the bowl represent water molecules and how the energy your arms provide represents heat. Faster moving marbles represent hotter water. Next, gather magnetic marbles, and place them into the bowl with a magnet. Ask student volunteers to come up and remove the marbles from the magnet.

2. What do you have to do to remove the marbles from the magnet? Where does this energy go?

You must provide energy. The energy is "absorbed" by the magnetic forces as the marbles are pulled off of the magnet. (They don't change speed).

Explain that the magnetic forces represent the inter-molecular bonds. The students provide the energy that overcomes these bonds. In this case, the marbles aren't moving any faster, so the energy goes into changing the phase of the substance (a solid collection of marbles changes into a more voluminous "liquid" of marbles that are no longer connected to the magnet). Explain how this represents heat of fusion.

Lab Preparation

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

1. Set up the required materials at each station.
2. Immediately before students arrive, gather enough ice cubes for each station to use 3 or 4 cubes.

Teacher Tip: It is best for students to heat the water to 40 °C. Heating the water to a higher temperature will cause it to cool too rapidly, losing more heat into the atmosphere and causing a higher margin of error. Ideally, students will add enough ice to cool the water about 14 °C.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Keep water away from sensitive electronic equipment.
- Be careful using the hot plate. Always be aware that it is on, and be conscious of any loose clothing or papers that could accidently catch fire.

Sequencing Challenge

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

4	2	5	3	1
Calculate the amount of heat lost by the water.	Measure the initial temperature of the water.	Calculate the heat of fusion of ice.	Add ice to the water. After the ice has melted, measure the equilibrium temperature.	Connect the temperature sensor to your data collection system.

Procedure with Inquiry

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

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

Set Up

1. ☐ Heat 300 mL of water to approximately 40 °C in the beaker on the hot plate.

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

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

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

5. ☐ Monitor live temperature data without recording. �(6.1)

6. ☐ Carefully measure the mass of the calorimetry cup, and record this value in Table 1 in the Data Analysis section.

7. ☐ Fill the cup ¾ with heated water (approximately 40 °C).

8. ☐ Quickly (but accurately) measure the weight of the filled cup, and record your value in Table 1 in the Data Analysis section.

Collect Data

9. ☐ Insert the temperature sensor into your cup, and allow the temperature reading to stabilize. Record the initial temperature of the water to the nearest tenth of a degree in Table 1 in the Data Analysis section.

Note: If you choose to use a stir station, place the calorimetry cup on the stir station with the stir bar in the cup.

10. ☐ Dry off 3 or 4 ice cubes using a paper towel.

11. ☐ Place the ice cubes into the cup, slowly stirring until the ice completely melts. Continue stirring for 1 minute, ensuring that the temperature of the water has reached equilibrium. Record the final temperature of the water in the cup in Table 1 in the Data Analysis section.

12. ☐ Why did you dry the ice cubes before you placed them in the beaker?

Drying the ice ensures that none of the heat from the water will be absorbed by colder excess water on the ice cubes. That way, all of the heat from the warmer water will go into melting the ice and not heat the cool water on the ice. Also, excess water on the ice affects the value calculated for the mass of the ice added.

13. ☐ Remove the temperature sensor from the calorimetry cup.

14. ☐ Use the balance to measure the mass of the cup, initial water, and melted ice. Record your answer in Table 1 in the Data Analysis section.

15. ☐ Stop monitoring temperature data. �(6.1)

Data Analysis

Table 1: Temperature and mass data

Parameters	Value
Mass of calorimetry cup (kg)	0.014
Mass of cup and initial water (kg)	0.157
Mass of initial water (kg)	0.143
Mass of cup, initial water and melted ice (kg)	0.177
Mass of ice (kg)	0.019
Initial temperature of water in the cup (°C)	43.2
Final temperature of water in the cup (°C)	29.1
Temperature melted ice (°C)	0
Temperature change of water (°C)	-14.1
Temperature change of melted ice (°C)	29.1

1. ☐ Calculate the initial mass of the water by subtracting the mass of the cup alone from the mass of the water and cup. Record the mass of the initial water in Table 1.

$$m_{\text{water}} = m_{\text{water and cup}} - m_{\text{cup}}$$

$$m_{\text{water}} = 0.157\text{ kg} - 0.014\text{ kg}$$

$$m_{\text{water}} = 0.143\text{ kg}$$

2. ☐ Calculate the mass of the ice that melted in the cup by subtracting the mass of the cup and initial water from the mass of the cup, initial water and melted ice. Record the mass of melted ice in Table 1.

$$m_{\text{water}} = m_{\text{water and cup and condensed vapor}} - m_{\text{water and cup}}$$

$$m_{\text{water}} = 0.177\text{ kg} - 0.157\text{ kg}$$

$$m_{\text{water}} = 0.020\text{ kg}$$

3. ☐ Calculate the change in temperature of the water in the cup by subtracting the initial temperature from the final temperature. Record the temperature change in Table 1.

$$\Delta T_{\text{water}} = T_{\text{final}} + T_{\text{initial}}$$

$$\Delta T_{water} = 29.1\,^{\circ}\text{C} - 43.2\,^{\circ}\text{C}$$

$$\Delta T_{\text{water}} = -14.1\,^{\circ}\text{C}$$

4. ☐ Calculate the change in temperature of the water that is melted from ice by subtracting the initial temperature from the final temperature. Record the temperature change in Table 1.

$$\Delta T_{\text{water}} = T_{\text{final}} + T_{\text{initial}}$$

$$\Delta T_{water} = 29.1°\text{C} - 0.0\,°\text{C}$$

$$\Delta T_{\text{water}} = 29.1°\text{C}$$

Analysis Questions

1. What was the source of heat that melted the ice?

The heat absorbed from the submerged ice was lost by the surrounding higher temperature water.

2. What is the sign of each temperature change that you calculated? And what do they mean?

The temperature change of the water in the cup was negative, indicating that heat was transferring out of the water in the cup. The temperature change of the melted ice was positive, indicating that heat was transferred into the melted ice.

3. Given the specific heat capacity of water *c* is 4,186 J/(kg·°C), use the values from Table 1 to find the heat transferred from the water initially in the cup.

$$Q = cm\Delta T$$

$$Q = \left(4{,}186\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(0.143\ \text{kg})(-14.1°\text{C})$$

$$Q = -8{,}440\ \text{J}$$

4. Use the values in Table 1 to determine how much of the heat transferred out of the water in the cup went into warming the melted ice to the final temperature.

$$\Delta Q = cm\Delta T$$

$$\Delta Q = \left(4{,}186\ \frac{\text{J}}{\text{kg}\cdot°\text{C}}\right)(0.020\ \text{kg})(29.1°\text{C})$$

$$\Delta Q = 2{,}436\ \text{J}$$

5. Conservation of energy means accounting for all of the energy leaving the water in the cup. If the heat needed to warm the melted ice does not account for all the heat transferred from the water, where does the additional heat go? Use your previous heat calculations to determine the amount of additional heat lost by the water that *did not* go into warming the melted ice.

The heat is absorbed as ice changes phase to liquid water.

$$Q_{\text{phase}} = Q_{\text{water}} - Q_{\text{melted ice}}$$

$$Q_{\text{phase}} = 8{,}440\ \text{J} - 2{,}436\ \text{J}$$

$$Q_{\text{phase}} = 6{,}004\ \text{J}$$

6. We know the mass of the ice that was melted into water. If all of the remaining heat can be attributed to phase change, what is the latent heat of fusion L_f of water?

$$Q = mL_f$$

$$L_f = \frac{6{,}004\ \text{J}}{0.020\ \text{kg}}$$

$$L_f = 3.00 \times 10^5\ \text{J/kg}$$

7. If the theoretical value for the latent heat of fusion is 3.340×10^5 J/kg, what is the percent difference between your value and the theoretical value?

$$\left|\frac{(\text{Theory} - \text{Observed})}{\text{Theory}}\right| \times 100$$

$$\frac{3.34 \times 10^5 - 3.00 \times 10^5}{3.34 \times 10^5} \times 100 = 10.2\%$$

8. What are you assuming about the ice, if you assume that you added 0 °C water to the cup after the ice melts?

You are assuming that the ice is initially at 0 °C.

9. How would you need to modify the heat transfer calculations to account for this extra heat absorbed by the ice?

We would have to add a term for the warming of the ice. This would require that we know the initial temperature of the ice, the specific heat of ice, in addition to the mass of the ice to determine the heat required to raise the ice to the 0 °C phase change temperature.

10. Explain any assumptions that you had to make about heat transfer as you were conducting this experiment.

You had to assume that no heat escaped into the atmosphere, all of the heat lost by the water was absorbed by the melting ice, and water warming from 0 °C. In other words no heat was transferred to or from the cup, stirring rod, or temperature sensor.

11. Keeping those assumptions in mind, what could you do to improve the accuracy of your results?

You could put a lid on the calorimeter, use less hot water so it cools slower (Newton's law of cooling), or use a better insulator than a calorimetry cup.

12. What procedural changes would you make to improve your results?

Student answers will vary. One possible change is to collect data in a graph and use graphical analysis tools to find initial and final temperatures.

Teacher Note: If you would like to evaluate the graphical analysis method as an alternative procedure for this lab, review the Heat of Vaporization experiment.

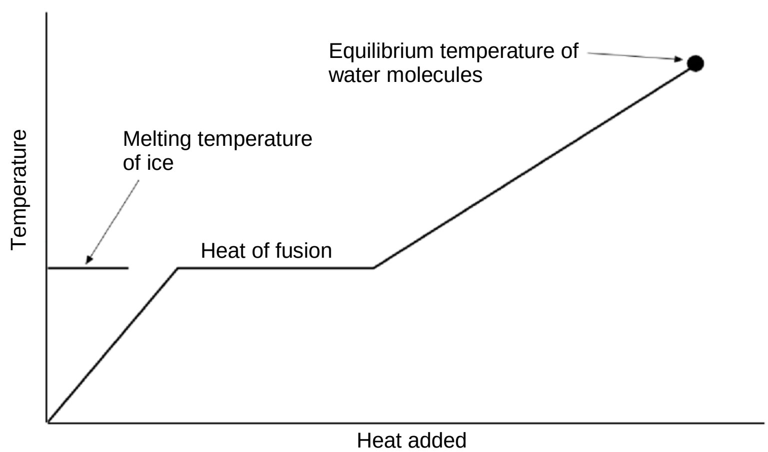
Synthesis Questions

Use available resources to help you answer the following questions.

1. Can an object absorb heat without changing temperature? Explain.

An object can absorb heat without changing temperature when it is undergoing a phase change; the heat goes into breaking bonds, not increasing the kinetic energy of the molecules.

2. Sketch a graph of Heat Added versus Temperature for the collection of water molecules that were originally added in the form of ice. Start at the time when you added the ice to the cup and end at the time the water in the cup reached equilibrium. Don't worry about showing specific temperatures; just show a general trend. However, be sure to include key points on the graph, such as the melting temperature of ice, the heat of fusion, and the final temperature of the water molecules.



3. The volume of Lake Tahoe is 150 km^3. How much heat would be required to raise its temperature 3 °C? Assume the density of water is 1 × 10^{12} kg/km^3.

1 km^3 = 1 x 10^{15} milliliters = 1 x 10^{12} kg of water per cubic kilometer.

$$Q = mc\Delta T$$

$$m = \rho V = (1 \times 10^{12}\ \text{kg/km}^3)(150\ \text{km}^3) = 1.5 \times 10^{14}\ \text{kg}$$

$$Q = (1.50 \times 10^{14}\ \text{kg})\left(4{,}186\ \frac{\text{J}}{\text{kg} \cdot {}^\circ\text{C}}\right)(3\ {}^\circ\text{C})$$

$$Q = 1.88 \times 10^{18}\ \text{J}$$

4. A student adds a measured amount of ice to a cup of hot water. The student records the initial temperature of the water before adding the ice and the final temperature after the ice melts. The student calculates the heat lost by the water and reasons that it equals the heat required to melt the known mass of ice. The student solves for the heat of fusion of the ice and gets a number significantly higher than the accepted value. Explain where the student made a mistake.

The student did not account for the heat absorbed by the cooler water that was left behind after the ice melted. Had the student done this, the student would have gotten a smaller, more accurate answer (more than likely less than the accepted value of the heat of fusion of ice).

5. How much ice must you add to cool 500 mL of water from 50 °C to 25 °C. (Hint: Remember, heat will be lost by the water to melt the ice *and* raise the temperature of the additional 0 °C water).

$$Q = mc\Delta T$$

$$Q = (0.5\ \text{kg})\left(4{,}186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)(25\ {}^\circ\text{C})$$

$$Q = 52{,}325\ \text{J}$$

$$52{,}325\ \text{J} = mL_\text{f} + mc\Delta T$$

$$52{,}325\ \text{J} = m(L_\text{f} + c\Delta T)$$

$$m = \frac{52{,}325\ \text{J}}{L_\text{f} + c\Delta T}$$

$$m = \frac{52{,}325\ \text{J}}{\left(3.34\times10^5\ \frac{\text{J}}{\text{kg}} + \left(4{,}186\ \frac{\text{J}}{\text{kg}\cdot{}^\circ\text{C}}\right)(25\ {}^\circ\text{C})\right)}$$

$$m = 0.119\ \text{kg}$$

Multiple Choice Questions

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

1. Between the time you recorded the initial temperature of the water in the cup and the final temperature, heat energy caused the ice in the cup to undergo the following changes:

- **A.** Heat flowed from the ice, causing it to melt and the water to become warmer. Once the ice melted, heat flowed from the newly formed water into the existing water, causing the temperature to rise even more.
- **B.** Heat flowed from the water and was absorbed by the ice. The temperature of the ice rose as it underwent a phase change into water. By the time the ice melted, all of the water in the cup was at the final temperature.
- **C.** No heat flow occurred at all. The ice melted because liquid is the natural state into which water molecules arrange themselves.
- **D. Heat flowed from the water and was absorbed by the ice. As the ice absorbed the heat, it remained at a constant temperature. The heat energy caused the phase change from solid to liquid. Once the ice melted, heat energy continued to flow from the liquid water into the newly formed liquid water because it was at a cooler temperature. Eventually, all of the liquid water in the cup became the same temperature.**

2. The units of heat of fusion are

- **A. J/(kg·°C)**
- **B.** N/m^2
- **C.** Heat of fusion is unitless
- **D.** Ω/kN

3. On a microscopic level, the sensation of warmth is actually a result of?

- **A. The average kinetic motion of the molecules that make up the substance**
- **B.** The gravitational forces between the molecules of a substance
- **C.** The electrical conductivity of the molecules of a substance
- **D.** None of the above

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. In this **calorimetry** experiment, the amount of **heat** that was lost by the warm water in the cup was equal to the amount of heat that **melted** the ice placed into that cup, plus the amount of heat used to raise the **temperature** of the water from the melted ice to the equilibrium temperature. This is another example of how **energy** is conserved.

2. To calculate the heat **lost** by the water, one needs to know the **final** and initial temperatures, the mass of the water, and the **specific** heat of water. By assuming that the heat lost by the water is equal to the heat absorbed by the **ice**, one can calculate the heat of **fusion** of ice.

Extended Inquiry Suggestions

Ask students to look up the specific heat of foam and include the heat lost to the calorimetry cup made of foam) in their calculations. Ask them to determine how big of an affect this will have on their results. In other words, how safe was there assumption that no heat was lost to the environment?

25. Heat of Vaporization

Objectives

This experiment enhances students' understanding of energy transfer in the form of heat, allowing them to:

- ♦ Develop a better understanding of the phase change from gas to liquid
- ♦ Use a graph of temperature verses time to understand the connection between heat energy transfer and phase change
- ♦ Determine the latent heat of vaporization of water

Procedural Overview

Students gain experience using the following procedures:

- ♦ Assembling an apparatus to isolate and measure the temperature change that results from condensing water vapor into liquid water
- ♦ Analyzing a graph of temperature versus time to determine a change in temperature
- ♦ Calculating the heat of vaporization of water based on energy transfer in the form of heat

Time Requirement

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

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Temperature sensor
- ♦ Calorimetry cup[1]
- ♦ Tubing, 1/4 inch inner diameter, 0.5 m[1]
- ♦ Clip or rigid U-shaped tube
- ♦ Steam generator
- ♦ Scissors
- ♦ Water trap[1]
- ♦ Balance (1 per classroom)
- ♦ Water, 1 L
- ♦ Stir station (optional)
- ♦ Stirring rod (optional)
- ♦ Tape (optional)

[1] Part of the Basic Calorimetry set

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ The specific heat of a substance
- ♦ Heat as a form of energy
- ♦ Phases of matter
- ♦ Kinetic energy
- ♦ Conservation of energy

Related Labs in This Guide

- ♦ Temperature versus Heat
- ♦ Phase Change
- ♦ Specific Heat of a Metal
- ♦ Heat of Fusion

Using Your Data Collection System

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

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

Background

Water molecules contain energy in two forms: kinetic and potential energy. Kinetic energy contained within a substance like water manifests itself as the movement of the water's constituent molecules. That movement assumes any of three forms: the physical change in position of the molecules, the spin of the molecules, or the vibration of the component atoms within the molecules. Potential energy within the same water is stored in the bonds that hold the molecules to each other in the liquid and solid phases.

When a substance like water warms, heat is being transferred *to* the water. When water cools, heat is being transferred *from* the water. The amount of heat transferred Q depends on the mass m of the substance, the specific heat capacity c of the substance, and the change in temperature ΔT associated with the heat exchange. When water changes phase, the potential energy within the water is either increased or decreased as heat energy is introduced or removed, without increasing or decreasing its temperature. If the phase has a higher thermal energy, the substance must absorb heat to make the phase change. If the phase has a lower thermal energy, the substance must release heat. For example, the molecules of a gas have more kinetic energy than the molecules of a liquid.

The phase change of a substance from gas to liquid involves a transfer of heat out of the substance. The amount of heat transferred Q depends on the mass of the substance m and the latent heat of vaporization L_v of the substance.

$$Q = -mL_v \qquad \textbf{Eq.1}$$

The constant L_v, as it applies to some substance, is defined as the amount of energy per kilogram needed for a substance to change phase between gas and liquid. The negative sign indicates that energy is leaving the substance. Once a phase change has occurred and the substance undergoes a temperature change, the total energy transferred is the sum of the energy required for the phase change and the energy used to change the temperature of the substance.

$$Q = -m_1 L_v + m_1 c_{water} \Delta T_1 \qquad \textbf{Eq.2}$$

We will use a cup of water to capture the heat from water vapor. Because the energy of the system is conserved, we know that the energy absorbed by the water in our cup must equal the energy transferred from the incoming water vapor.

$$\begin{aligned} Q_{gained} &= -Q_{lost} \\ m_2 c_{water} \Delta T_2 &= -\left(-m_1 L_v + m_1 c_{water} \Delta T_1\right) \end{aligned} \qquad \textbf{Eq.3}$$

For our system, m_2 is the initial mass of the water in the cup, m_1 is the mass of the water that changes from vapor to liquid, ΔT_1 is the temperature change from the temperature of phase change to the final temperature, and ΔT_2 is the change from room temperature to the final temperature. The specific heat of water is 4,186 J/(kg·°C), and the temperature and mass are quantities we will measure. From this the latent heat of vaporization for water can be calculated.

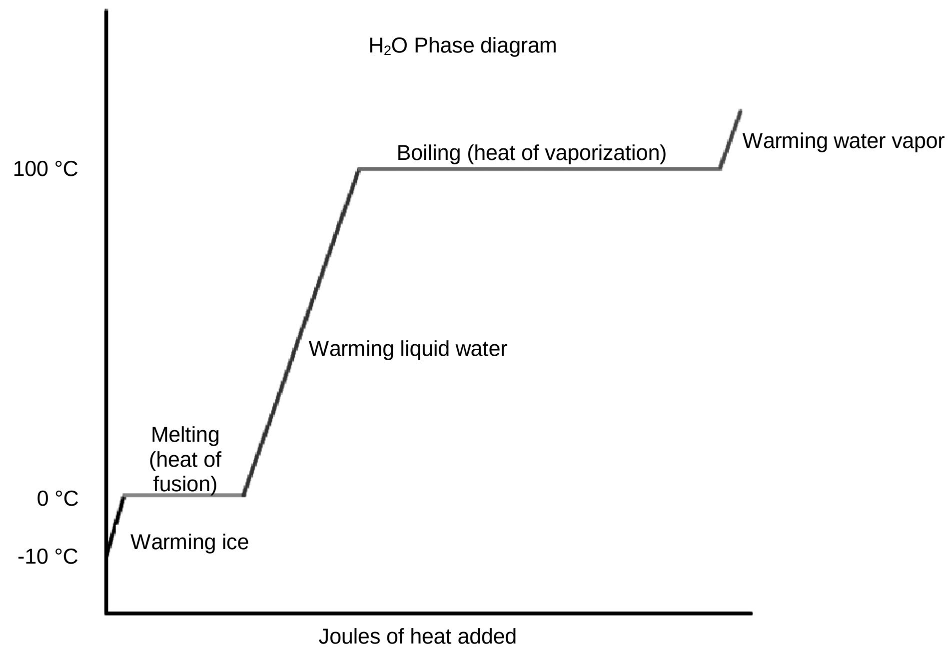
$$L_v = \frac{m_2 c_{water} \Delta T_2 + m_1 c_{water} \Delta T_1}{m_1} \qquad \textbf{Eq.4}$$

Pre-Lab Discussion and Activity

Engage the students in the following discussion and demonstration.

Review phase change with your students.

Recall that temperature remains constant during a phase change. The temperature of a cup of ice-water remains 0 °C until either all of the ice melts or all of the water freezes solid. Likewise, the temperature of boiling water is 100 °C. That is, the temperature of the liquid H_2O, and the temperature of gaseous H_2O is 100 °C until either all of the liquid has boiled away or all of the gaseous H_2O condenses to the liquid phase. This energy is called the "heat of vaporization." It is also referred to as *enthalpy of vaporization*. One may consider the heat of vaporization as the energy required to break the bonds holding liquid H_2O molecules to one another. The heat of vaporization is very similar in concept to the heat of fusion.



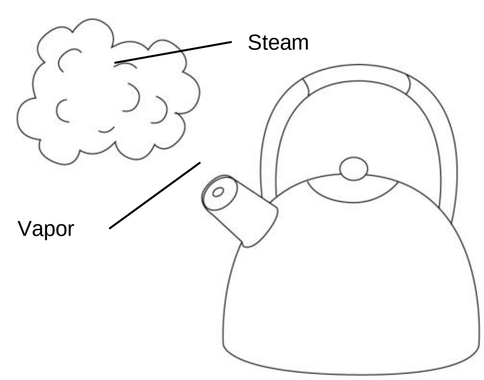
After water in the gaseous phase gives off the heat of vaporization energy, the water molecules will start to cool down (temperature drops) until they are the same temperature as their surroundings.

Discuss the difference between steam and water vapor.

Set up a steam generator or kettle of boiling water to illustrate the difference.

Use two stainless steel temperature sensors and a graph of Temperature versus Time to show that energy is transferred faster in the vapor region than in the steam region.

Water vapor is invisible. "Steam" is actually very tiny water droplets in the liquid phase. Thus, if you can see steam, it isn't in the vapor (gaseous) phase. Nearly everyone has the unfortunate experience of receiving a burn. A burn that turns the skin red is referred to as a 1st degree burn. Such burns are minor compared to 2nd degree burns. A "steam" burn that comes from a whistling tea pot can yield 1st degree burns. A vapor burn however often yields 2nd degree burns (blisters). This is true even if the hand was in the vapor for only a



second. A Vapor burn can occur if a finger or other body part gets between steam and the tea pot opening. This is true even though both the steam and the liquid are 100 °C.

Lab Preparation

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

1. Place water at student stations before the lab begins to minimize spills.

Teacher Tip: It is very important that students are careful with the vapor going through the tubing. Tubing should not be touched while hot. Tape may be used to secure the rubber tube (near the top) to the insulated cup of cold water to reduce the risk of the tube (or U-tube) being accidentally pulled from the cup of water.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Keep water away from electronics.
- Vapor burns can be very serious, be careful handing tubes and the steam generator.
- Place the lab equipment and the steam generator in a location where they will not be knocked over.
- Assure that the vapor tubes and power cord will not be bumped.

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
Fill the calorimetry cup ¾ full with water.	Measure the mass of the dry, empty calorimetry cup.	Calculate the heat of vaporization.	Start recording temperature data, and then turn on the steam generator.	Calculate the mass of the water that condensed from vapor by subtracting the initial mass of the water and cup.

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

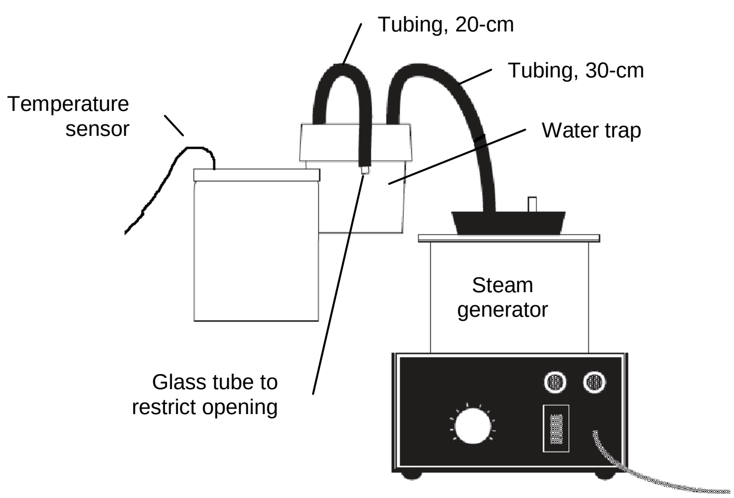
3. ☐ Display Temperature on the y-axis of a graph with Time on the x-axis. �(7.1.1)

4. ☐ Fill the steam generator approximately ¾ full with water.

5. ☐ Measure the mass of the empty calorimetry cup, and record the mass in Table 1 in the Data Analysis section.

6. ☐ Fill the calorimetry cup ¾ full with water.

7. ☐ Measure the mass of the water and cup together, and record the mass in Table 1 in the Data Analysis section.



8. ☐ Cut the tubing into two parts with the scissors, one slightly longer than the other.

9. ☐ Connect the tubing to both ports of the water trap.

10. ☐ Connect the longer tube to the steam generator.

Note: If you are not using the steam generator to power two lab stations, close off the second port of the steam generator.

11. ☐ Use the clip to hold the end of the shorter tube at the bottom of the water-filled calorimetry cup.

Note: If you have a U-tube, connect the tubing to one end, and place the other end into the cup of water.

12. ☐ Why does the end of the tube need to be near the bottom of the cup? What would happen to the mass of vapor that condenses if the end of the tube were barely below the water surface?

We want the vapor to condense as it bubbles through the water. If the tube is just below the surface, much of the vapor will not condense in the water. The greater the distance the vapor has to travel to the surface, the more time it will be in the liquid water allowing more vapor to condense.

13. ☐ What could happen to the vapor if the end of the tube were pressed against the bottom of the cup?

Pressure could build in the tube causing large bubbles to form and creating splashing at the surface. The splashing could spill water as well as increase the evaporation of the water. Evaporation is a cooling process, and should be kept to a minimum.

14. ☐ Press the stopper firmly into the steam generator so that it will not pop out.

15. ☐ Verify that all connections are firm and secure and that the tubes will not be accidently knocked over during the experiment.

Caution: If a tube becomes disconnected during the experiment, do not attempt to reconnect the tubing. Do not touch the tubing. Turn off the steam generator, and notify your teacher.

16. ☐ Insert the temperature sensor into the water. The sensor should not be next to where the vapor will exit the tube.

17. ☐ Why shouldn't the thermometer be next to where the vapor comes out of the tube?

The temperature would be too high.

Note: If you are using a stir station, place it under the calorimetry cup and the stirrer in the cup.

Note: Depending on the apparatus you are using, it may be helpful to use tape to secure items in place.

Collect Data

18. ☐ Start data recording. �(6.2)

19. ☐ Turn on the steam generator. It might take a couple of minutes for the steam to start.

Note: The first bubbles to come out of the tube will be air, not water vapor. It might take a minute for the temperature to start to rise.

20. ☐ Gently stir the water to help distribute the heat through the water, but be careful not to release heat to the environment.

21. ☐ We assume that all of the energy from the vapor transfers to the water. Why would this be a bad assumption?

Some energy will go into the equipment (temperature sensor, any stirring rod, the cup, the tube). Some energy will be lost to the outside environment. The goal is to minimize these losses.

22. ☐ When the temperature of the water in the cup is more than 20 °C above the starting temperature, turn off the steam generator.

23. ☐ Carefully remove the tubing from the calorimetry cup.

24. ☐ Stop data recording. �(6.2)

25. ☐ Measure the mass of the cup and water, and record this value as mass of cup, initial water, and condensed vapor in Table 1 in the Data Analysis section.

Analyze Data

26. ☐ On your graph of Temperature versus Time, find the temperature of the water before adding steam. Record this value as the initial temperature of the water in the cup in Table 1 in the Data Analysis section. �(9.1)

27. ☐ On your graph of Temperature versus Time, find the temperature of the water at its highest point. Record this value as the final temperature of the water in the cup in Table 1 in the Data Analysis section. �(9.1)

28. ☐ The best way to find the temperature at which water changes phase from liquid to gas for your classroom is to measure the temperature of boiling water, but we can approximate the value to be 100 °C. Enter the temperature at which water boils in your classroom in Table 1 in the Data Analysis section.

29. ☐ Sketch your graph of Temperature versus Time in the Data Analysis section.

30. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

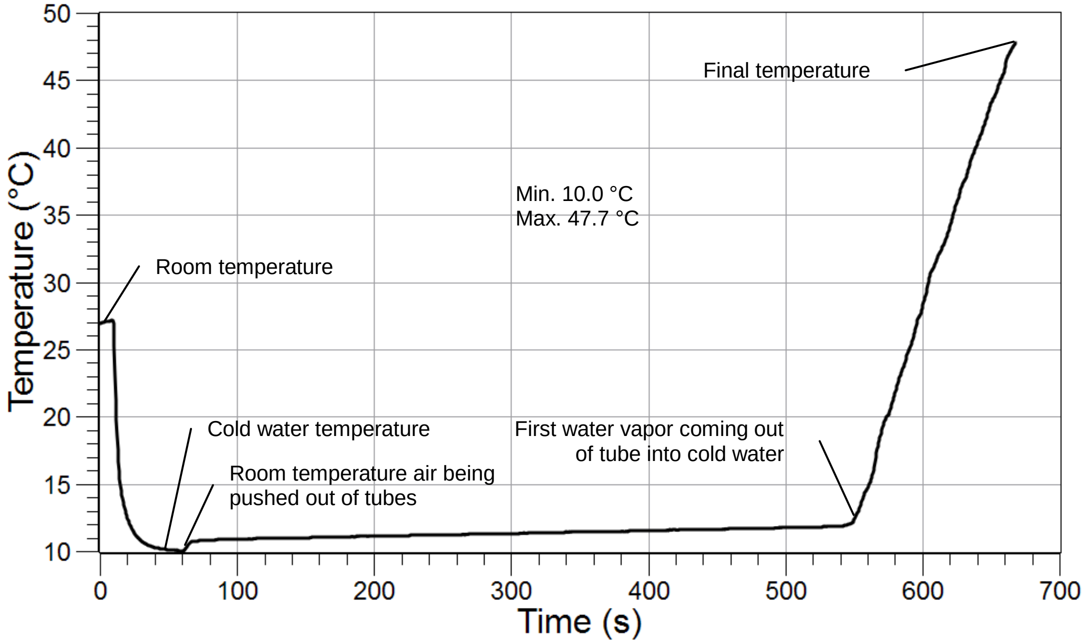


Table 1: Temperature and mass data

Parameters	Value
Mass of calorimetry cup (kg)	0.016
Mass of cup and initial water (kg)	0.187
Mass of initial water (kg)	0.171
Mass of cup, initial water and condensed vapor (kg)	0.198
Mass of condensed vapor (kg)	0.011
Initial temperature of water in the cup (°C)	12.0
Final temperature of water in the cup (°C)	47.7
Temperature of boiling water (°C)	100
Temperature change of water (°C)	35.7
Temperature change of condensed vapor (°C)	-52.3

1. ☐ Calculate the initial mass of the water by subtracting the mass of the cup alone from the mass of the water and cup. Record the mass of the initial water in Table 1.

$$m_{\text{water}} = m_{\text{water and cup}} - m_{\text{cup}}$$

$$m_{\text{water}} = 0.187\text{ kg} - 0.016\text{ kg}$$

$$m_{\text{water}} = 0.171\text{kg}$$

2. ☐ Calculate the mass of the water that was condensed into the cup by subtracting the mass of the cup and initial water from the mass of the cup, initial water and condensed vapor. Record the mass of condensed steam in Table 1.

$$m_{\text{water}} = m_{\text{water and cup and condensed vapor}} - m_{\text{water and cup}}$$

$$m_{\text{water}} = 0.198\text{ kg} - 0.187\text{ kg}$$

$$m_{\text{water}} = 0.011\text{kg}$$

3. ☐ Calculate the change in temperature of the water in the cup by subtracting the initial temperature from the final temperature. Record the temperature change in Table 1.

$$\Delta T_{\text{water}} = T_{\text{final}} + T_{\text{initial}}$$

$$\Delta T_{water} = 47.7\text{ °C} - 12.0\text{ °C}$$

$$\Delta T_{\text{water}} = 35.7\text{ °C}$$

4. ☐ Calculate the change in temperature of the water that is condensed from vapor by subtracting the initial temperature from the final temperature. Record the temperature change in Table 1.

$$\Delta T_{\text{water}} = T_{\text{final}} + T_{\text{initial}}$$

$$\Delta T_{water} = 47.7\text{ °C} - 100.0\text{ °C}$$

$$\Delta T_{\text{water}} = -52.3\text{ °C}$$

Analysis Questions

1. What is the sign of each temperature change that you calculated? And what do they mean?

The temperature change of the water in the cup was positive, indicating that heat was transferring into the water in the cup. The temperature change of the condensed vapor was negative, indicating that heat was transferred out of the condensed vapor.

2. Given the specific heat of water *c* is 4186 J/kg·°C, use the values from Table 1 to find the heat that was transferred to the water initially in the cup.

$$\Delta Q = cm\Delta T$$
$$\Delta Q = 4{,}186\text{ J/(kg}\cdot\text{°C)} \times 0.171\text{kg} \times 35.7\text{ °C}$$
$$\Delta Q = 25{,}554\text{ J}$$

3. Use the values in Table 1 to determine how much of the heat transferred to the water in the cup came from the condensed vapor cooling to the final temperature.

$$\Delta Q = cm\Delta T$$

$$\Delta Q = 4{,}186\text{ J/(kg}\cdot\text{°C)} \times 0.011\text{kg} \times -52.3\text{ °C}$$

$$\Delta Q = -2{,}408\text{ J}$$

4. Conservation of energy means accounting for all of the energy entering the water in the cup. If the heat coming from the cooling condensed vapor does not account for all the heat transferred to the water, from where does the additional heat come? Use your previous heat calculations to determine the amount of heat.

The heat is released as water vapor changes phase to liquid water.

$$\Delta Q_{\text{phase}} = \Delta Q_{\text{water}} - \Delta Q_{\text{condensed vapor}}$$

$$\Delta Q_{\text{phase}} = 25{,}554\text{ J} - 2{,}408\text{ J}$$

$$\Delta Q_{\text{phase}} = 23{,}146\text{ J}$$

5. We know the mass of the vapor that was condensed to water. If all of the remaining heat can be attributed to phase change, what is the latent heat of vaporization L_v of water?

$$\Delta Q = mL_v$$

$$23{,}146\text{ J} = 0.011\text{ kg} \times L_v$$

$$L_v = 2.104 \times 10^6\text{ J/kg}$$

6. If the theoretical value for the latent heat of vaporization of water is 2.260×10^6 J/kg, what is the percent difference between your value and the theoretical value?

$$\left|\frac{(\text{Theory} - \text{Observed})}{\text{Theory}}\right| \times 100$$

$$\frac{2.260 \times 10^6\text{ J/kg} - 2.104 \times 10^6\text{ J/kg}}{2.260 \times 10^6\text{ J/kg}} \times 100 = 6.9\%$$

Synthesis Questions

Use available resources to help you answer the following questions.

1. It is a warm day, so you and a friend go swimming. A light breeze starts as you are drying off. Why do you get so cold even though the air temperature is warm? How does this relate to sweating?

Energy is absorbed from your skin as water evaporates. When your body gets hot, it perspires. The evaporating sweat removes heat from your skin.

2. People who live in the desert say, "it's a dry heat." A bucket of water in the desert (dry climate) will evaporate quicker than in a humid climate. Explain why you feel hotter in a humid region at 90 °F than in a dry region at 95 °F.

Sweat will evaporate more quickly in the dry climate than in the humid climate transporting more heat away from the skin.

3. Swamp coolers are used to cool air. They are common in dry climates. Explain why swamp coolers don't work well in humid climates.

Water evaporates much quicker if the humidity is low. Little water, and therefore heat, will be removed if the humidity is high.

Multiple Choice Questions

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

1. Suppose in the lab procedure that only half as much cold water were used in the insulated cup. How would this affect the time it takes to warm the cold water to its maximum temperature?

- **A.** It would take twice as much time to warm the cold water.
- **B.** It would take the same amount of time to warm the cold water.
- **C. It would take half as much time to warm the cold water.**
- **D.** There is not enough information to know.

2. Suppose you put twice as much water into the steam generator (assuming the steam generator could hold the water). How would this affect the time it takes to warm the cold water in the calorimetry cup once the water started boiling in the steam generator?

- **A.** It would take twice as much time to warm the cold water.
- **B. It would take the same amount of time to warm the cold water.**
- **C.** It would take half as much time to warm the cold water.
- **D.** There is not enough information to know.

Key Term Challenge

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

1. The transfer of **heat** during a **phase** change between liquid water and water vapor has a profound effect on our environment. The temperature doesn't cool much at night in regions of high humidity. However, the temperature in deserts (low humidity) quickly drops after the sun goes down. This is because regions of high humidity have lots of **water** vapor in the air. **Vapor** condensing back into a liquid gives off energy to the air. The condensed water vapor that forms on the ground is called dew. Regions that have lots of water nearby do not get very hot during the summer. This is because much of the sun's **energy** goes into evaporating the water. Areas of the world that get a large amount of rain, or are surrounded by large amounts of water, do not get very cold in the winter. Regions at the same latitude, but on the interior of the continent, can get much colder. Russia gets very cold in the winter, but England doesn't.

Extended Inquiry Suggestions

The large quantity of energy present in water vapor can be further demonstrated by asking students to repeat the experiment using boiling water. Start with the same quantity of cold water in the calorimetry cup. Carefully add the same mass of boiling water rather than vapor. Measure the change in temperature of the cold water after adding the boiling water. Ask students to explain why the temperature didn't warm up nearly as much.

26. Boyle's Law

Objectives

Students observe changes in pressures and volumes of gases as they apply to Boyle's Law. At the end of this lab, students:

- ♦ Understand the relationship between volume and pressure of an enclosed gas at constant temperature.
- ♦ Are able to graph this relationship and derive an equation relating pressure and volume of an enclosed gas
- ♦ Apply the equation to predict gas behavior using Boyle's Law

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Decrease the volume of the gas in a closed system causing pressure to increase.
- ♦ Enclose gas with a 20ml syringe and pressure sensor and decrease the volume increasing pressure
- ♦ Linearization of data to determine the nature of a relationship between to variables.

Time Requirement

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

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Absolute pressure sensor
- ♦ Barbed quick-release connector[1]
- ♦ Syringe[1], 20 mL
- ♦ Tubing[1]

[1] Included with PASCO Pressure Sensors

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Temperature, pressure, and volume of a gas
- Graphing Basics, including inverse and direct relationships

Related Labs in This Guide

Labs conceptually related to this one include:

- Temperature versus Heat
- Absolute Zero

Using Your Data Collection System

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

- Starting a new experiment with the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Manual Sampling mode with manually entered data �(5.2.1)
- Starting a manually sample data set �(6.3.1)
- Recording a manually sampled data point �(6.3.2)
- Stopping a manually sampled data set �(6.3.3)
- Displaying Data in a Graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Changing the variable on the *x*- or *y*-axis �(7.1.9)
- Applying a Curve Fit �(9.5)
- Creating Calculated Data �(10.3)
- Saving data files �(11.1)

Background

If you take an isolated system like a Mylar® balloon filled with helium, and let it cool down, it will contract. If you put it in the sun or blow hot air on it with a blow dryer, it will expand and rise due to its increased buoyancy. But what if you held the temperature constant? What if only pressure and volume were varied while temperature wasn't changed at all?

If you squeeze an enclosed gas, the pressure increases. Boyle and his colleague Robert Hook built vacuum syringes and found that the absolute pressure times the volume of the gas was a constant ($PV = k$).

Another way of writing this relationship is: $P_1V_1 = P_2V_2$

Which relates directly to the ideal gas law of $PV = nRT$. If n and T are held constant (R is the ideal gas constant), it quickly becomes the equation $P_1V_1 = P_2V_2$, which is the most fundamental of all the gas laws.

Pre-Lab Discussion and Activity

A great discussion about Boyle's Law starts with scuba divers. Scuba divers breathe atmospheric air from a canister that is a constant shape and volume, yet it must be filled up and does get empty after a while. How does air get inside a scuba tank? Through pressure, air is packed into the scuba tanks by a compressor, which takes in air from the atmosphere and forces it into the small canisters. Because all that air is crammed into a small space, it's under tremendous pressure. As the air is let out, it expands, and the pressure in the canister decreases as it empties.

1. What is the basic relationship stated in Boyle's Law?

Gas pressure is inversely related to its volume.

2. What mathematical relationship best represents Boyle's Law?

$PV = k$ or $P_1V_1 = P_2V_2$

3. If you double the volume, what would happen to the absolute pressure on an ideal gas?

It would be half the original pressure.

4. What if you decreased the volume to one half its original value?

The absolute pressure would double from its original value.

Connect an absolute pressure sensor to a syringe as you would for the experiment, and then connect the absolute pressure sensor to a data collection system set up to project Pressure to the class. Wrap your hand around the syringe, and show the change in pressure.

Remind the class that we want to observe the relationship between pressure and volume, so keep the system isothermal. Keep the syringe away from heat sources, and hold the syringe so that you are not changing its temperature.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Make sure students don't put too much pressure on the syringe.

Sequencing Challenge

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

3	2	4	1
Compress the gas in the syringe by pushing the plunger. Record the volume and pressure each time.	Configure the data collection system to measure pressure for various volumes.	Graph Pressure versus Volume for at least 6 data points.	Connect a syringe to the absolute pressure sensor.

Procedure with Inquiry

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

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

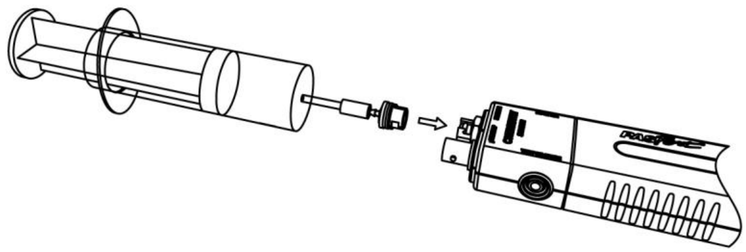
Set Up

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

2. ☐ Connect the absolute pressure sensor to the data collection system. �(2.1)

3. ☐ Set up your data collection system to collect manually entered data in a table with Volume in mL as the user entered measurement. �(5.2.1)

4. ☐ Set the syringe to 20 mL, and connect it to the absolute pressure sensor using the shortest piece of tubing possible and the barbed quick-release connector.



Collect Data

5. ☐ Begin recording a set of manually sampled data starting with the plunger at 20 mL. �(6.3.1)

6. ☐ Record the first manually sampled data point at 20 mL. �(6.3.2)

7. ☐ Squeeze the plunger compressing the volume inside the syringe to 18 mL, then record the next manually sampled data point. �(6.3.2)

8. ☐ Repeat the previous step compressing the volume by an additional 2 mL each time until you have reached a final volume of 10 mL.

9. ☐ Stop recording data then copy the values to Table 1 in the Data Analysis section. �(6.3.3)

Analyze Data

10. ☐ Use your data collection system to create a graph of Pressure versus Time. �(7.1.1)

11. ☐ Change the *x*-axis to the manually entered measurement Volume. �(7.1.9)

12. ☐ Sketch your graph of Pressure versus Volume in the Data Analysis Section.

13. ☐ Look at your graph of Pressure versus. Volume. Is it a linear or curved relationship?

It's a curved relationship, so it's nonlinear.

14. ☐ What simple mathematical relationship do you think this type of curve represent?

The asymptotic curve shows an inverse relationship, where as the *x*-component gets large, the *y*-component goes to zero. Conversely, as the *x*-value goes to zero, the *y*-value goes to infinity.

15. ☐ Try applying different curve fits until you find the one that best represents the trend of the data. �(9.5)

16. ☐ Which curve fit best represented the data trend?

Inverse

17. ☐ How could you manipulate the data (by squaring, doubling, inverting, or taking the square root) to plot a new variable that would give a linear graph with pressure?

If you could plot Pressure vs. (1 / Volume), it would yield a linear graph.

18. ☐ Create the following calculation. �(10.3) VolumeInv = 1/[volume]

19. ☐ Change the *x*-axis from Volume to VolumeInv on the graph of Pressure versus Volume on your data collection system. �(7.1.5)

20. ☐ Sketch your graph of Pressure versus VolumeInv in the Data Analysis section.

21. ☐ Apply a Linear curve fit to your plot of Pressure versus VolumeInv. �(9.5)

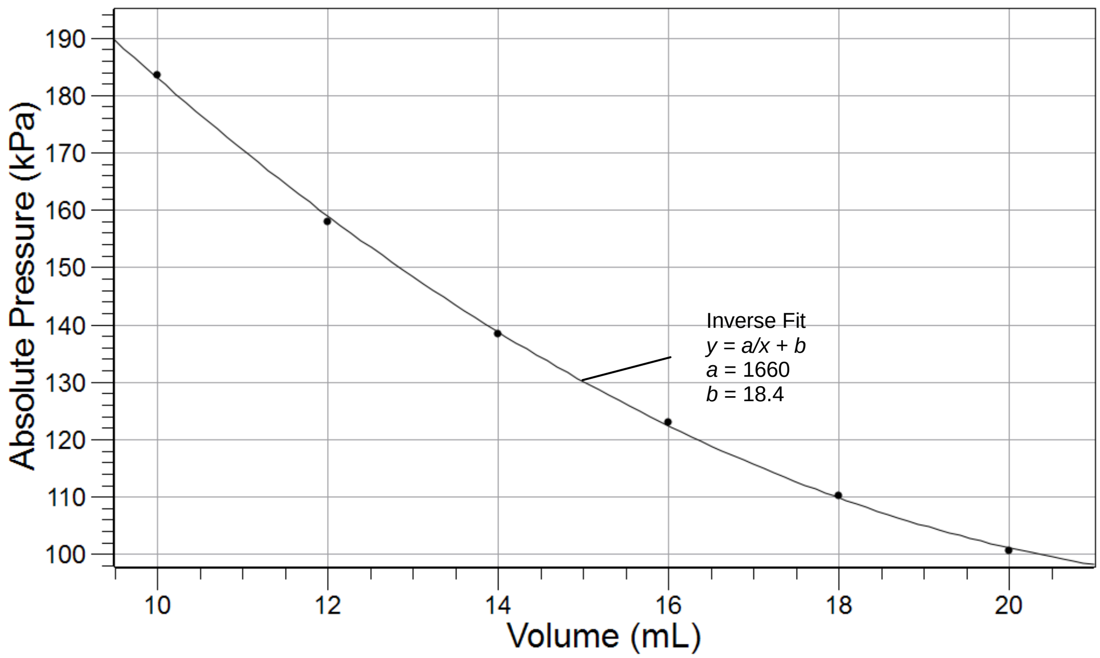
22. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

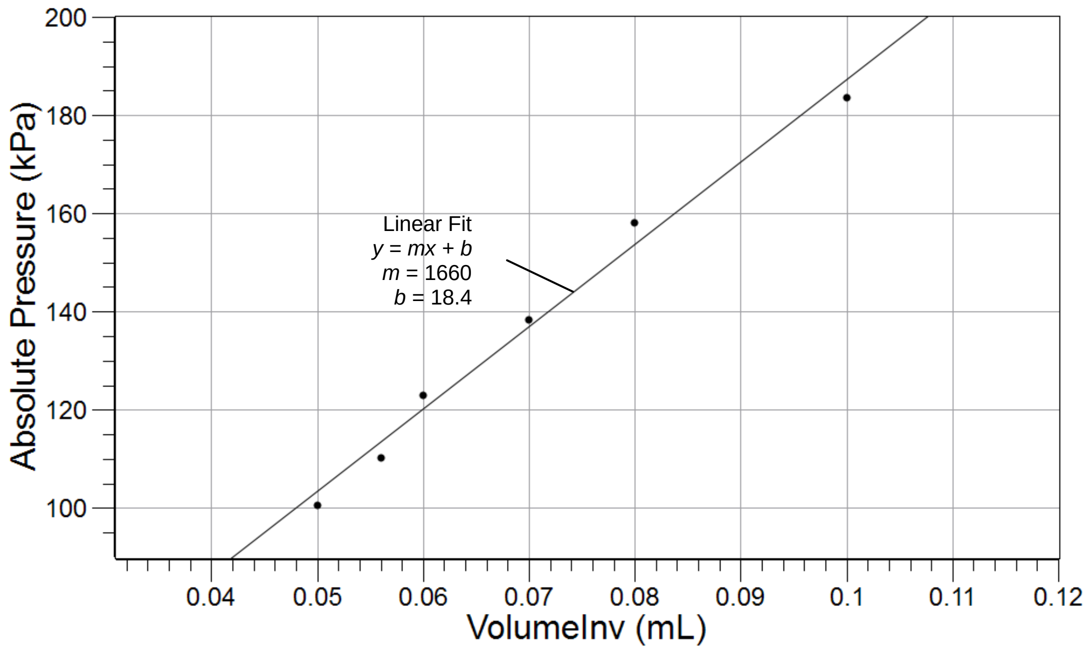
Table 1: Volume and Pressure

Volume (mL)	Pressure (kPa)
20	100.62
18	110.30
16	123.02
14	138.36
12	158.00
10	183.56

Pressure versus Volume



Pressure versus VolumeInv



Analysis Questions

1. Look at your graph of Pressure vs. VolumeInv. How well does the linear curve fit represent the trend of this data? What does this mean?

The linear curve fit strongly represents the trend of the data, which means the original data of Pressure versus Volume is an inverse relationship.

2. What does this mean in general for finding the mathematical relationship of different types of data plots?

A mathematical relationship can be applied to a data set, and if the resulting *x-y* plot is linear, then the mathematical relationship that was applied is a good representation of the trend of the original data plot.

3. How would you describe the relationship between Pressure and Volume in words?

Pressure is proportional to the inverse of volume.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Does the shape of the graph make sense, knowing the common behaviors of gases, volumes, and pressures? Explain why or why not.

The graph makes good sense. Squeezing the gas by applying force to the plunger of the syringe causes the volume to decrease, and the pressure of the gas to increase. Likewise, if a gas is allowed to expand, it will increase its volume so as to decrease its pressure.

2. Volume and pressure of an ideal enclosed gas at a constant temperature are inversely related. What happens if:

a. You cut the volume in half, what would happen to the absolute pressure?

It would double.

b. What if you cut the volume in half again, how would the final pressure relate to the original pressure before you first moved the syringe in part a) above?

It would be four times the original pressure.

3. The surrounding air pressure at high elevations (like in the mountains) is much less than at sea level. Explain how this affects the appearance of a sealed bag of potato chips that you take from sea level to high elevations.

The bag becomes noticeably larger in volume because of lower pressure on the outside of the bag. The pressure inside the bag is fixed, so less pressure on the outside means a higher volume for the bag.

Multiple Choice Questions

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

1. Boyle's Law states that, for an enclosed gas,

- **A.** Pressure is inversely related to volume.
- **B.** Pressure increases as volume increases.
- **C.** (Pressure × volume) equals a constant at a given temperature.
- **D.** Volume increases as temperature decreases.
- **E. Both A and C are correct.**

2. According to Boyle's Law, what must happen to the size of bubbles as they rise to the top of a carbonated beverage?

A. The bubbles stay the same size.

B. The bubbles expand as they rise because the pressure on them is greater.

C. The bubbles contract as they rise because the pressure on them is greater.

D. The bubbles contract as they rise because the pressure on them is lower.

E. The bubbles expand as they rise because the pressure on them is lower.

3. A container of 2.5 Liters of air is under pressure of 85 kPa. What is its volume after the pressure is increased to 105 kPa?

A. 0.494 L

B. 2.02 L

C. 3.09 L

D. 0.324 L

E. none of these

Key Term Challenge

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

1. If a gas is enclosed and held at constant temperature, **Boyle's Law** states that the absolute pressure of the gas is **inversely** proportional to its volume. This means that if the number of gas particles is held **constant** at the same **temperature**, cutting the **volume** in half will double the pressure of the gas. Similarly, if the **pressure** were to be decreased by one-half the volume would have to expand to **double** its original amount.

2. Applications of Boyle's Law are all around us. Scuba divers have to **exhale** the air from their lungs as they **rise** to the surface of the water, because the air in their lungs **expands** greatly as the fluid pressure **decreases** when they near the surface. In fact, since one **atmosphere** of pressure represents the increase for every 10.3 meters of water depth, a scuba diver at a depth of about **21** meters would be at a pressure of 2 atmospheres. This means the air in his lungs would expand to about grow about **2 times** the volume if he did not exhale the air as he rose to the surface.

Extended Inquiry Suggestions

Instructors can follow this lab with a discussion of atmospheric pressure and sealed containers: what do sealed containers do when you take them from sea level to higher elevations? Mention how Boyle's Law leads quickly to Charles' Law, the volume-temperature law, and of course the ideal gas law. Be sure to list exceptions to the ideal gas law. Lastly, instructors can focus on the vast amount of scientific study going on at the time that Boyle published his work (with the assistance of Robert Hooke). French Physicist Edme Mariotte discovered the same gas law working independently of Boyle and Hooke just 4 years after Boyle published his work.

Instructors can quickly combine Boyle's Law with Charles' Law to get the combined gas law, and again combined with Avogadro's Law to get the ideal gas law. It is advantageous for both instructors and students to see Boyle's Law (and the other gas laws) present in the ideal gas law.

27. Absolute Zero

Objectives

Students experimentally determine a numerical value for absolute zero in °C. By doing this, they:

- ♦ Develop an understanding of the direct relationship between temperature and pressure of an enclosed gas with constant volume
- ♦ Apply statistical methods to experimentally gathered data in order to extrapolate values that are not measureable
- ♦ Learn how an ideal gas can be used as a thermometer

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Simultaneously measuring the pressure and temperature of what can be assumed to be an "ideal" gas
- ♦ Changing one variable and measuring another, in order to determine the functional relationship between the two
- ♦ Creating a line of best fit to determine a value that is not directly measureable
- ♦ Comparing an experimentally determined value to a standard in order to critically evaluate their experimental methods, and conduct qualitative and quantitative error analysis

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	55 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Absolute pressure sensor
- ♦ Temperature sensor
- ♦ Sensor extension cable
- ♦ Beaker, 600-mL
- ♦ Test tube, 20-mm ×150 mm
- ♦ Disposable pipet
- ♦ Utility clamp
- ♦ 3-fingered clamp
- ♦ Rod Stand
- ♦ Tubing, approximately 15 cm[1]
- ♦ Barbed quick-release connector[1]
- ♦ Barbed tubing-to-rubber stopper connector[1]
- ♦ Rubber stopper, 1-hole #2
- ♦ Glycerin
- ♦ Hot plate
- ♦ Oven mitt
- ♦ Tape, approximately 6 cm

[1] Included with most PASCO Pressure Sensors

Note: Please see the Lab Preparation section about an alternate set up.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Definitions of force, pressure, and kinetic energy
- ♦ The definition of an ideal gas

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Temperature versus Heat
- ♦ Phase Change
- ♦ Boyles' Law

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data acquisition system �(2.2)
- ♦ Putting the data collection system into manual sampling mode �(5.2)

- Starting a manually sampled new data set �(6.3.1)
- Recording a manually sampled data point �(6.3.2)
- Stopping a manually sampled data set �(6.3.3)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Changing the variable on the *x*- or *y*-axis �(7.1.9)
- Displaying data in a table �(7.2.1)
- Finding the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)

Background

In previous labs, students learned that temperature is a measure of the average kinetic energy of the molecules in a substance. In gases, these molecules have enough kinetic energy to overcome the intermolecular bonds that hold them together. For this reason, gas molecules can be thought of as particles in random motion, flying around in space until they encounter something that will change their path. Ideal gases are gases that are assumed to have no molecular interactions between their molecules. This means that an ideal gas molecule will not change its path until it strikes the wall of its container. For the purposes of this experiment, air can be assumed to be an ideal gas.

When an ideal gas is confined, the moving molecules exert a force on the walls of the container. This is similar to the force that would result on the edge of a bowl if one were to shake marbles in the bowl. Pressure is defined as force per unit area; therefore, the gas is exerting pressure on the walls of its container. Because we have assumed that there are no inter-molecular interactions, the kinetic energy of the molecules contributes to this pressure. The faster that the gas molecules move, the more force they exert on the walls of the container. Therefore, hotter gas molecules (which move faster) exert a higher pressure. It would seem logical that there is a relationship between temperature T and pressure P. It turns out that pressure is directly proportional to temperature.

$$P \propto T \quad \text{or} \quad P = kT + 0$$ where temperature is measured in Kelvin.

Discovered in 1802, this relationship is known as Gay-Lussac's Law.

By considering the definitions of temperature, kinetic energy, and Gay-Lussac's Law, scientists were able to postulate that there should be an absolute minimum temperature. Their thought process was as follows:

It seemed possible that the motion of ideal gas molecules could be completely stopped. Gas molecules that were not moving would exert zero pressure on the walls of the container; therefore, the temperature that corresponds to zero pressure (shown as a y-intercept in our equation) should be the absolute zero temperature. This path of thinking led to the Kelvin temperature scale in which 0 Kelvin is the temperature of absolute zero; however, Kelvin and °C are different units of measure, and the common convention is to use °C for most applications.

In this experiment students will experimentally determine a numerical value for the temperature corresponding to absolute zero in °C by graphing various pressures and temperatures of an ideal gas of constant volume, and then extrapolate a temperature value corresponding to zero pressure. This will be the absolute zero temperature in °C.

Pre-Lab Discussion and Activity

Begin by reviewing the concepts of an ideal gas and kinetic energy. Then, call up a student volunteer. Ask the student to face away from you, and toss a foam ball at the students back. Ask the student:

1. Did you feel the ball hit your back? Why?

Yes, because the ball exerted a force on my back.

Ask the students to imagine thousands of balls, all hitting the student in the back. The force these balls exert over the area of the back represents pressure. Explain how this is analogous to gas molecules hitting the wall of a container.

2. What would happen if I threw the ball harder?

There would be more force.

Explain how this is analogous to gas molecules that are hotter (moving faster). Explain that there is a relationship between the speed of the ball and the force it exerts, just like there is a relationship between the temperature of a gas and the pressure that it exerts.

Lab Preparation

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

1. Place the required materials at each lab station.
2. If desired, pre-construct the stopper and pressure gauge combination.

   a. Add a drop of glycerin to the barbed end of the quick-release connector, and put the barbed end into one end of the 15 cm long piece of tubing.

   b. Attach the other end of the quick-release connector to the pressure sensor.

   c. Put a drop of glycerin on both of the barbed ends on the tubing-to-rubber stopper connector and then insert the tubing barbed ends into the other end of the 15 cm piece of tubing.

   d. Insert the other end of the tubing-to-rubber stopper connector piece into the top of the rubber stopper, creating the top for the gas chamber.

   The pressure sensor is now ready to measure the pressure inside the gas chamber.

Teacher Tip: Make sure the barb is all the way inside the stopper. There can be no air leaks on any of the tube connections.

Alternate Set Up: PASCO makes an Absolute Zero Apparatus that is designed to be connected directly to an Absolute Pressure/Temperature Sensor. If you are using this apparatus you will set up a small number of buckets or tubs with different temperature water. Students will simply submerge the bulb of the apparatus into a tub, allow the temperature to stabilize, and then collect a data point. Each student group collects one point per tub rather than using individual water baths and hot plates. The apparatus replaces the test tube, stopper, tubing, and connectors. The temperature sensor is also replaced by a built-in thermistor inside the absolute zero apparatus, allowing you to measure the temperature of the gas directly.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Keep water away from any sensitive electronic equipment.
- Be careful using the hot plate. Always be aware that it is on, and be conscious of any loose clothing or papers that could accidentally catch fire.

Sequencing Challenge

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

1	4	2	3
Connect the pressure sensor to your data collection system.	Record the value of the *y*-intercept of the best-fit line.	Record values for both pressure and temperature each time the pressure changes by a few kPa.	Find the best-fit line using the linear curve fit tool for Temperature versus Pressure.

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

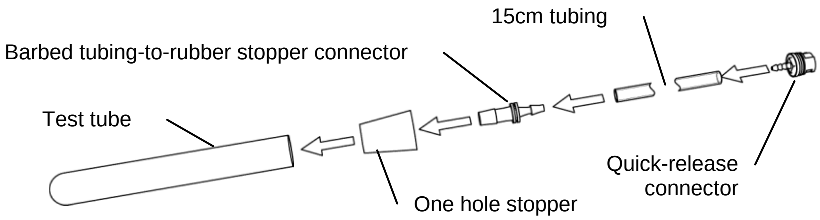
1. ☐ Start a new activity on the data collection system. �(1.2)

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

3. ☐ Add a drop of glycerin to both barbed ends of the tubing-to-rubber stopper connector, and insert one end of the connector into the top of the rubber stopper.

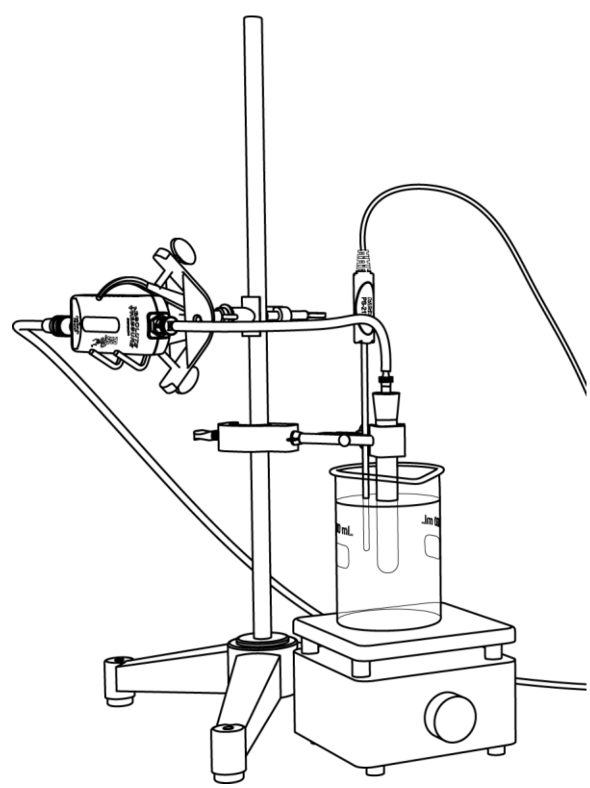
4. ☐ Insert the opposite end into a short piece of tubing (approximately 15 cm).

5. ☐ Add a drop of glycerin to the barbed end of the quick-release connector and insert the connector into the open end of the tubing.



6. ☐ Use a drop of glycerin to firmly insert the rubber stopper into the test tube.

7. ☐ Connect the quick connector to the absolute pressure sensor.



Note: If set up correctly, you should notice a slight increase in pressure when you grasp the test tube in your hand. Otherwise, there is probably a leak somewhere. It is best to solve this problem now, so students don't get frustrated later on.

8. ☐ Why is it important that there are no air leaks in any of the connections on the tubing?

Any leaks will cause the pressure sensor to measure the pressure of the atmosphere, not the pressure inside an isolated gas chamber. This will obscure the pressure and temperature relationship.

9. ☐ Put your data collection system into manually sampling mode without manually entered data. �(5.2.2)

10. ☐ Fill ¾ of a 600 mL beaker with water.

11. ☐ Place the beaker on the hot plate.

12. ☐ Use the rod stand and 3-fingered clamp to hold the pressure sensor out of the way.

13. ☐ Use the utility clamp to submerge the gas chamber in the water and hold it in place.

14. ☐ Place the temperature sensor in the water, ideally in contact with one edge of the test tube. Make sure the sensor does not touch the bottom of the beaker. Use tape to secure the sensor to the clamp and test tube.

15. ☐ How are you measuring the temperature of the gas in the chamber? What assumptions are you making?

The temperature of the water is being measured by the temperature probe. We are assuming that the temperature of the water and the gas in the chamber reach thermal equilibrium. Therefore, we are indirectly measuring the temperature of the gas.

16. ☐ Display temperature and pressure in a table. �(7.2.1)

Collect Data

17. ☐ Start recording data. �(6.3.1)

18. ☐ Record your first manually sampled data point before turning on the hot plate. �(6.3.2)

19. ☐ Turn the hot plate on to medium-high heat to begin heating your water.

Note: Heating water slower allows for more accurate results, if time allows. As you begin heating the water, make sure that the pressure is increasing. By the time the temperature has risen by 5 °C there should have been an increase (of at least one kilopascal) in pressure. If the pressure remains at 100 or 101, there is a leak and the connections need to be checked.

20. ☐ Record the temperature and pressure every time the pressure changes by more that 2 kPa.

Note: The pressure reading will fluctuate back and forth a few times. Wait for the pressure to stabilize, and then take the reading.

21. ☐ Continue this process until the water reaches 65 °C, and then stop recording data. �(6.3.3)

22. ☐ Why are you taking temperature readings as soon as the pressure changes? (Hint: Consider such things as the accuracy of the pressure sensor and the time of heat transfer.)

It takes time for the temperature of the water (which is the measured value) and the temperature of the gas to equilibrate. By taking the temperature as the pressure changes, we know a change has happened in the gas, so this error will be minimized.

Analyze Data

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

24. ☐ Change the variable on the *x*-axis from Time to Pressure. �(7.1.9)

25. ☐ Create a line of best fit for your data. �(9.6)

26. ☐ Sketch your graph of Temperature versus Pressure in the space provided in the Data Analysis section, and include your best fit line.

27. ☐ What kind of relationship exists between temperature and pressure? Does your line of best fit represent this? How do you know?

A linear relationship exists between temperature and pressure. This is indicated by the R^2 value of the best fit line. The closer it is to 1, the more linear the data. For systems that do not report an R^2 value, simply noting the proximity of the data points to the fit line is sufficient.

28. ☐ Read the equation of your best fit line. The temperature corresponding to absolute zero (where the pressure is zero) is represented by the *y*-intercept of your best fit line. Record that value here.

Sample value: –307C.

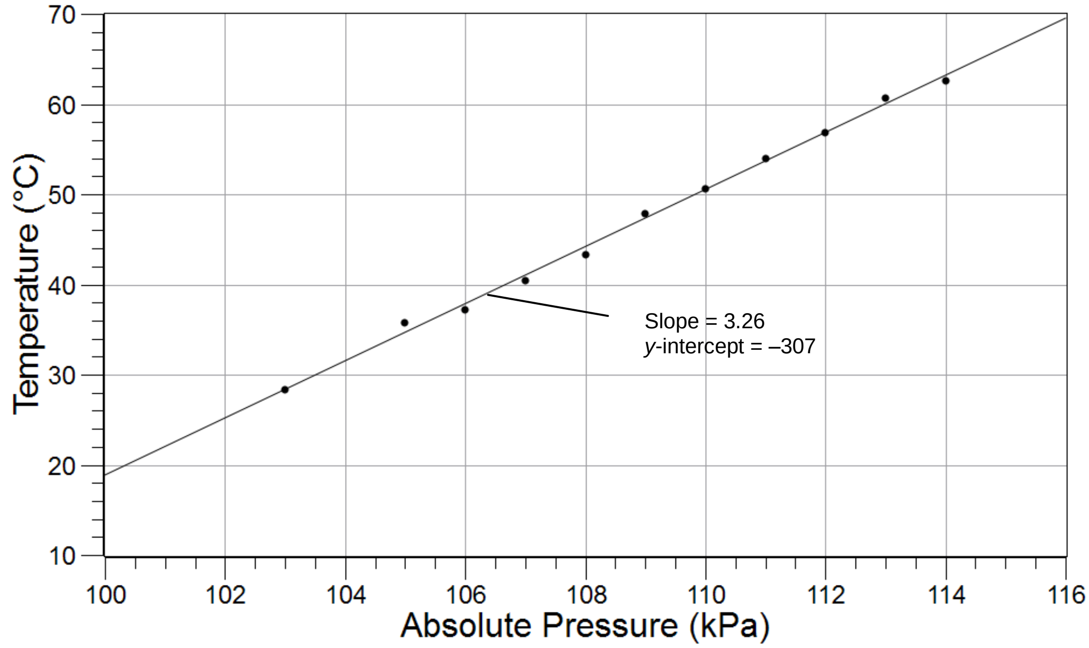
29. ☐ Save your experiment as instructed by your teacher. �(11.1)

Sample Data

Temperature (°C)	Pressure (kPa)
Run #1	Run #1
28.3	103
35.8	105
37.2	106
40.4	107
43.3	108
47.9	109
50.6	110
54	111
56.8	112
60.6	113
62.6	114

Data Analysis

Temperature versus Absolute Pressure Graph



Analysis Questions

1. The accepted value of absolute zero is -273 °C. Compare your value to the accepted value. What is your percent error?

Percent Error Formula : $((Accepted - Experiemental)/Accepted) \times 100$

$((-307-(-273))/-273) \times 100 = 12.5\%$

2. Why do you think your value is different than the accepted value? List at least three reasons for this difference. If your reasons are experimental in nature, how could you correct them?

Some error could result from the fact that the calculated value is the result of a best fit line. If a couple of the data points are significantly off, the best fit line will be altered to try to account for this. Any points that are significantly off should be ignored when calculating the best fit line. Another possibility is that the heat transfer from the water to the gas in the chamber does not happen instantaneously. To remedy this, it would be best to heat the water as slowly as possible. Finally, the pressure sensor is not as accurate as the temperature sensor. For this reason, several different temperatures correspond to the same pressure. It is important to pick the lowest possible temperature that corresponds to that pressure.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Over the years, scientists have developed several different types of thermometers. All thermometers depend on the change of some physical property with temperature. A common type of thermometer is the mercury thermometer. Mercury in a glass tube expands as it is heated. Explain how one could make a thermometer using an ideal gas.

One could first measure the pressure of a constant volume of an ideal gas at a specific temperature (for example equilibrium point of ice and water) and the pressure at another specific temperature (for example equilibrium point of water and steam). One would then assign each of those points values (say 0 and 100 respectively). One could now measure the pressure of that same volume of gas at a temperature in between and use the proportionality between pressure and temperature to calculate the temperature of the substance being measured.

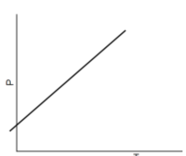
2. What is the difference between the Celsius temperature scale and the Kelvin temperature scale? (Hint: How is zero degrees defined for each of these scales?)

Zero on the Celsius scale is defined as the equilibrium point of an ice and water mixture. Zero on the Kelvin scale is defined as the point where gas molecules exert no pressure. This is why there is a 273 offset between the two scales.

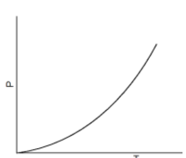
Multiple Choice Questions

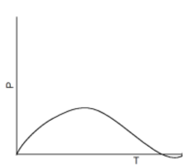
Select the best answer or completion to each of the questions or incomplete statements below.

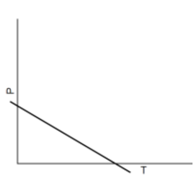
1. Which of the following graphs shows the relationship between temperature and pressure?

A. 

[correct]

B. 

C. 

D. 

2. When the temperature of an ideal gas in a container of fixed volume is doubled, the pressure:

- **A. Doubles**
- **B.** Decreases by a factor of 2
- **C.** Remains constant
- **D.** Decreases by a factor of 4

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. When the **volume** of a gas is held **constant** and the **temperature** is increased, the pressure increases as well. The relationship between Pressure and Temperature of an ideal gas of constant volume is a **linear** relationship. This is known as Gay-Lussac's Law.

2. The temperature of a **gas** is related to the **kinetic** energy of its molecules. In an **ideal** gas, the molecules do not interact with each other, so all of the force they exert is on the walls of the container. A gas with **molecules** that don't move exerts zero pressure on the walls of its container. The temperature of these molecules is known as **absolute** zero.

Extended Inquiry Suggestions

Ask students to determine the volume of their gas chamber. Introduce the ideal gas law, and ask students to use their data, in conjunction with the ideal gas law, to calculate the number of moles of air in their chamber. To do this, the students use the slope of the best fit line. The slope of the best fit line for the Pressure versus Temperature graph (obtainable from the data collection system) = V/nR, where n is the number of moles, R is the gas constant (8.314 J/mol·°C), and V is the volume of the gas chamber. Make sure that students use correct units in their calculations.

Electricity and Magnetism

28. Charge and Electric Field

Objectives

During this investigation, students observe the nature of charging objects by contact and explore the electric field produced by each charge. Students learn to:

- Understand the basic properties of electric charges
- Distinguish between conductors and insulators

Procedural Overview

Students gain experience conducting the following procedures:

- Producing a positive or negative net static charge by rubbing different materials together
- Handling and transferring charge between objects
- Measuring the quantity and polarity of charge on an object with a Faraday ice pail and charge sensor

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Charge sensor
- Faraday ice pail
- Charge producers, pair
- Proof planes (2)
- Plastic rod[1,2]
- Glass rod[1,2]
- Aluminum rod[1,2]
- Silk cloth[1]
- Fur cloth[1]

[1]These specific rods and cloths were used for the sample data collected for this lab. However, the you can use a variety of items that produce different charges, and at least one conductor and one insulator.

[2]Make sure the rods are between 20 cm and 30 cm in length.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Objects can have a positive, negative, or neutral charge
- Like charges repel, and unlike charges attract
- Charged objects produce an electric field and an electric force

Related Labs in This Guide

Labs conceptually related to this one include:

- Voltage: Fruit Battery/Generator

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Monitoring live data without recording �(6.1)
- Displaying data in a digits display �(7.3.1)

Background

We call atoms that lose or gain electrons "electrically charged," and the magnitude of the charge is proportional to the number of electrons gained or lost during the process. Normally, all atoms have a neutral charge, which means that the number of electrons equals the number of protons. If the number of protons exceed the number electrons (or the number of electrons exceed the number of protons), then the atom has a positive charge or negative charge, respectively. Objects with like charge will repel one another, and objects with unlike charge will attract one another.

Benjamin Franklin's model of electricity implies that during any process, the net electric charge of an isolated system remains constant, or the charge is conserved for a closed system. In the right condition, an object can acquire an electric charge by rubbing it with another object, such as rubbing your shoes on a carpet, sliding across a car seat, or rubbing a balloon against your hair. The charged balloon and hair will have the same amount of charge, but opposite polarities. Therefore, they will attract one another. Rubber and plastic are *insulators* (materials that do not transfer a charge easily), which prevents charge from easily moving through the material. In this experiment, we use a charge sensor and a Faraday ice pail to examine the transfer of electric charges form one material to another.

The Faraday ice pail gives us a way to measure the charge on an object. When we place a charged object in the pail, the electric field created by the charged object extends out in all directions. At each conductive layer of the pail, dissimilar charges are drawn inward and similar charges are pushed outward. Because the electric field drops off predictably with distance, the presence of a charge in the pail will always cause a potential difference between the two layers of the ice pail. Because of the fixed orientation and position of the ice pail layers, the potential difference between the layers is proportional to the amount of charge placed inside the pail. The charge sensor is calibrated to report nano-Coulombs nC of charge, where one Coulomb of charge is equivalent to one mole (6.022×10^{23}) of electrons.

Pre-Lab Discussion and Activity

Engage your students with the following discussion and demonstration.

Start by talking about their experiences with static electricity. Explain that static electricity is more noticeable when rubbing certain materials together. Explain to them that the spark they feel or see comes from the discharge between charged objects.

Demonstrate that by brushing or combing your hair, the comb gains a charge. The comb will then attract neutral objects or opposite charged objects like small pieces of paper.

Allow students to experiment with balloons. Have them rub the balloons across their hair, and place the balloon on a wall or next to small papers.

1. What happens when you rub the balloon and hair against each other?

Rubbing the materials together transfers electrons from one substance to the other.

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

Demonstrate setting up the Faraday ice pail, but for this demonstration use a meter display on the data collection system, projected on a screen for the whole class to see. Insert and remove a charged object into the ice pail, and observe the meter deflection.

2. Why do you think we can sense a charge inside the ice pail even without touching the ice pail?

A charge has an electric field that influences the world around it, even at a distance.

Bring a charged rod near a stream of water to show the deflection of the water. Or, pass a charged rod over some small pieces of paper to show that the electric field can exert a force at a distance.

3. What will happen if I touch the inner conductive surface?

A charge will transfer from the charged object to the conductive surface.

Touch the inner conductor with the charged object, and note that the meter does not move. Remove the charged object. and note that the meter does not move very much.

4. Why do you think the meter seems stuck?

The charge remains on the inner conductor.

Demonstrate how to discharge the ice pail by touching the inner and outer mesh simultaneously with a finger.

5. What will happen if I place the charged object back in the ice pail?

The meter will deflect slightly.

Note that the deflection on the meter is approximately the difference between the original deflection and the "stuck" deflection, indicating that charge was conserved.

If your students need additional help understanding polarity and the influence of fields on each other, use the Classic Electrostatics Materials Kit. In addition to rods and cloths like those used in this experiment, the kit has insulated pivot stands that let you show what happens when different fields interact (like charges repel, unlike charges attract).

Lab Preparation

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

1. If the class schedule permits, plan this lab for a day when you expect low humidity.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Keep charged items away from sensitive electronics.

Sequencing Challenge

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

3	1	5	4	2
Lower the charged end of the charge producer into the Faraday ice pail.	Connect the charge sensor to the Faraday ice pail.	Compare the value of the second charge producer to the first.	Record the reading from data collecting system.	Rub the two charge producers together.

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

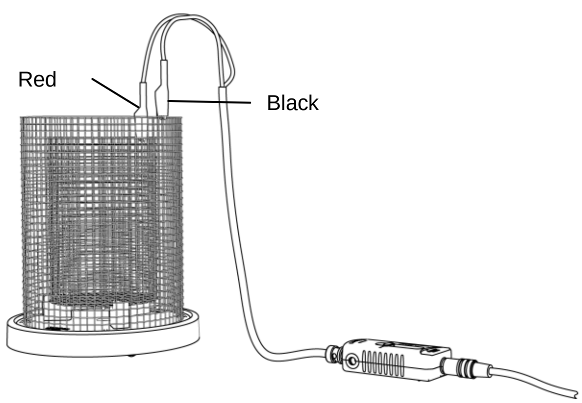
1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect the charge sensor to the data collecting system. �(2.1)

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

4. ☐ Connect the alligator clips from the charge sensor to the Faraday ice pail with the red lead connected to the inner screen and the black lead to the outer screen.

Note: For better results, the charge sensor and the Faraday ice pail should be kept as far away from each other as possible.



5. ☐ Ground the Faraday ice pail by touching the inner and outer screens of the pail with one finger at the same time.

***Teacher Tip*:** This operation technically only neutralizes the ice pail. To actually ground the device, the outer screen should be connected to earth ground.

6. ☐ Initialize the charge sensor by pressing the "Zero" button on the sensor.

Collect Data

7. ☐ Monitor live data without recording. �(6.1)

8. ☐ Verify that the charge reading on the screen is approximately zero, if not, re-ground the Faraday ice pail.

9. ☐ Rub the blue and white surfaces of the charge producers together several times.

Note: Do not touch the white insulating material on the charge producers or proof planes. Any contact with the circular end of a charge producer or proof plane can affect the charge.

10. ☐ Lower the white charge producer into the inner pail without touching the sides or bottom of the screen.

11. ☐ Record the charge value in Table 1 in the data analysis section.

12. ☐ Remove the charge producer.

13. ☐ What do you think the reading will be for the blue charge producer?

The charge should be equal in size and opposite in polarity.

14. ☐ Lower the blue charge producer into the inner pail without touching the sides and bottom of the screen.

15. ☐ Record the charge value in Table 1 in the data analysis section.

16. ☐ Remove the charge producer.

17. ☐ Ground the round end of one of the proof planes.

18. ☐ Place the flat round surface of one of the charge producers against the flat round surface of the proof plane.

19. ☐ Lower the proof plane into the inner pail without touching the sides and bottom of the screen.

20. ☐ Record the charge value in Table 1 in the data analysis section.

21. ☐ Remove the proof plane.

22. ☐ Ground the round end of a second proof plane.

23. ☐ Place the flat round surface of the first proof plane against the flat round surface of the second proof plane.

24. ☐ What do you think the reading will be for the second proof plane?

The charge will be one half the charge of the first proof plane before contact.

25. ☐ Lower the first proof plane into the inner pail without touching the sides and bottom of the screen.

26. ☐ Record the charge value in Table 1 in the data analysis section.

27. ☐ Remove the proof plane.

28. ☐ Lower the second proof plane into the inner pail without touching the sides and bottom of the screen.

29. ☐ Record the charge value in Table 1 in the data analysis section.

30. ☐ Remove the proof plane.

31. ☐ Vigorously rub one end of the plastic rod (about ¼ of its length) with the silk cloth.

32. ☐ Lower the rod into the inner pail without touching the sides and bottom of the screen.

33. ☐ Record the materials used and the charge value in Table 2 in the data analysis section.

34. ☐ Remove the rod.

35. ☐ Without rubbing the rod again, lower the un-rubbed end of the plastic rod into the inner pail without touching the sides and bottom of the screen.

36. ☐ Record the materials and charge value in Table 2 in the data analysis section.

37. ☐ Remove the rod.

38. ☐ Vigorously rub one end of the glass rod (about ¼ of its length) with the silk cloth.

39. ☐ Lower the rod into the inner pail without touching the sides and bottom of the screen.

40. ☐ Record the materials used and the charge value in Table 2 in the data analysis section.

41. ☐ Remove the rod.

42. ☐ Without rubbing the rod again, lower the un-rubbed end of the plastic rod into the inner pail without touching the sides and bottom of the screen.

43. ☐ Record the materials and charge value in Table 2 in the data analysis section.

44. ☐ Remove the rod.

45. ☐ Vigorously rub one end of the aluminum rod (about ¼ of its length) with the fur cloth.

46. ☐ Lower the rod into the inner pail without touching the sides and bottom of the screen.

47. ☐ Record the materials used and the charge value in Table 2 in the data analysis section.

48. ☐ Remove the rod.

49. ☐ Without rubbing the rod again, lower the un-rubbed end of the plastic rod into the inner pail without touching the sides and bottom of the screen.

50. ☐ Record the materials and charge value in Table 2 in the data analysis section.

51. ☐ Remove the rod.

52. ☐ Vigorously rub one end of the plastic rod (about ¾ of its length) with the silk cloth.

53. ☐ Lower the rod into the inner pail without touching the sides and bottom of the screen.

54. ☐ Record the materials used and the charge value in Table 2 in the data analysis section.

55. ☐ Remove the rod.

56. ☐ Without rubbing the rod again, lower the un-rubbed end of the plastic rod into the inner pail without touching the sides and bottom of the screen.

57. ☐ Record the materials and charge value in Table 2 in the data analysis section.

58. ☐ Remove the rod.

Data Analysis

Table 1: Charge data for proof planes and charge producers

Parameters	Charge (nC)
Charge on the white charge producer	5.7
Charge on the blue charge producer	-5.6
Charge on the proof plane	2.7
Charge on the first proof plane, after contact	1.3
Charge on the second proof plane, after contact	1.3

Table 2: Charge data for rods

Parameters	Charge (nC)	Classification
Plastic rod, 1/4 end rubbed with silk	-58.8	insulator
Plastic rod, un-rubbed end	-8.7	
Glass rod, 1/4 end rubbed with silk	10.6	Insulator
Glass rod, un-rubbed end	0.6	
Aluminum rod, 1/4 end rubbed with fur	-1.2	conductor
Aluminum rod, 1/4 end un-rubbed end	-1.2	
Plastic rod, 3/4 end rubbed with silk	-120.0	insulator

A material that transfers charge easily is called a conductor. A material that prevents the movement of charge is an insulator. Classify each of the rod materials, and enter the classification in Table 2.

Analysis Questions

1. According to the data, which rod obtained the greatest charge?

The plastic rod.

2. Which objects gained a negative charge? Which objects gained electrons?

The blue charge producer and the aluminum rod gained a negative charge. Therefore, they gained electrons.

3. What charge did the silk gain when rubbed with the plastic rod? What charge did it gain when rubbed with the glass rod?

The silk cloth gained a positive charge with the plastic rod and negative with the glass rod.

4. Which end of the plastic rod (the rubbed or un-rubbed end) indicated a larger charge?

The rubbed end had a greater charge.

5. What material transferred its charge easier from one end to the other? What material did not?

The aluminum rod transferred charge easily, and glass and plastic did not.

6. Would rubbing the objects longer increase or decrease the electric charge?

There should be no significant change in the amount of electric charge.

7. Describe a method that would increase the amount of charge transferred between two objects.

The amount of charge would increase by increasing the surface area rubbed between the objects.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Why are power cables made with metal wire inside and plastic covering outside?

The metal transfers the charge easily from place to place while the plastic insulates you from the charge.

2. If you were to drag your feet across a carpet and build up a significant charge on your body that you wanted to remove, would you touch the metal frame of a window or the pain of glass? Why?

Touching the metal would allow the charge to flow because it is a conductor and the glass is not.

3. Suppose that you rubbed one end of a balloon on your hair, then lowered it into a Faraday ice pail, and saw a reading of -54.1. Then, when you lowered the other end into the ice pail, it only read -2.1. What would this tell you about the balloon?

The balloon is an insulator and when rubbed against hair, it gains electrons.

Multiple Choice Questions

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

1. If silver is a very good conductor, then silver can:

- **A.** Transfer a charge slowly
- **B. Transfer a charge easily**
- **C.** Not transfer a charge
- **D.** not be considered a metal

2. If Object A has twice the charge as Object B, which statement is correct?

- **A.** Object A has a negative charge.
- **B. Object A has twice the excess electrons or protons as Object B.**
- **C.** Object B has twice the excess electrons or protons as Object A.
- **D.** Object B has a positive charge.

Key Term Challenge

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

1. **Electrostatics** involves the study of electrical charges. A **charge sensor** is a device used to measure the charge of an object. The atoms in an object are normally **neutral** because the number of protons equals the number of electrons. One method of charging objects is by **contact**. When you rub objects together, electrons **transfer** from one object to another. The **polarity** of charge can be determined measuring the field around the object, or by seeing if it attracts or repels an object of a known charge, because a **positively** charged object repels other positively charge objects.

2. Metals, compared to **insulators**, are normally good conductors because they allow charges to move easily. To remove a charge from an object, you should use a **conductor** to connect the object to **ground**. That is why people who work with sensitive electronics are required to wear a grounding strap. Any **electrons** can more easily move through the conductor of the grounding strap than through the components of the circuit.

Extended Inquiry Suggestions

If time and materials permit, extend this lab to objects charged by induction, which is the process of charging a conductor by bringing it near another charged object and grounding the conductor. Further, once you determine the charge, you can calculate the electric forces between charges, including electric fields.

29. Voltage: Fruit Battery/Generator

Objectives

This activity introduces students to voltage. The activity explores both the chemical and physical production of a potential difference and allows students to:

- Produce a potential difference
- Understand the construction of a battery
- Understand the similarities and differences of batteries and generators

Procedural Overview

Students will gain experience conducting the following procedures:

- Using probeware to measure discrete voltages
- Constructing a simple fruit battery
- Comparing voltages of batteries in series
- Comparing voltages of batteries in parallel

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	25 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Voltage sensor
- Piece of copper[1]
- Piece of zinc[2]
- Series/parallel battery holders
- Batteries, "D" cell (3)
- Alligator clips (one red, one black)
- Variety of fruit (minimum of 1 piece per student group)

[1]Heavy gauge, solid bare copper wire works well
[2]Galvanized nails work well

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Charge and units of charge
- ♦ Electric fields
- ♦ Potential Energy

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Charge and Electric Field
- ♦ Ohm's Law
- ♦ Series and Parallel Circuits

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Monitoring live data without recording �(6.1)

Background

Voltage, also known as electric potential or electromotive force (EMF), measures the potential of an electric field to cause charge to move and is measured in volts. Just as with gravitational potential energy, electric potential can be converted into other forms of energy, such as heat or motion.

When we create an electric potential, the potential difference is measured between two reference points (e.g. the potential indicated on a battery is between the two terminals of the battery, usually marked + and –). Because charges can be both positive and negative, electric potentials can be both positive and negative. There are different ways to create electric potential. As you saw from studying charges, we can physically move charge from one object to another and give rise to an imbalance in charge, thus producing an electric potential.

Count Alessandro Giuseppe Antonio Anastasio Volta (1745 – 1827) was a physicist known especially for the development of the electric cell. In 1800, he invented the voltaic pile, an early electric battery which produced a steady electric current. Volta had determined that the most effective pair of dissimilar metals to produce electricity was zinc and silver. He first experimented with individual cells, each cell being a glass filled with brine into which the two dissimilar electrodes were dipped. The electric pile replaced the glasses with cardboard soaked in brine. The battery made by Volta is credited as the first electrochemical cell. For this experiment we replace brine-soaked cardboard with the electrolytes of a piece of fruit.

Michael Faraday (1791 – 1867) discovered the operating principle of electromagnetic generators. The principle, later called Faraday's law, is that a potential difference is generated between the ends of an electrical conductor that moves perpendicular to a magnetic field. He also built the first electromagnetic generator, called the 'Faraday disc,' using a copper disc rotating between the poles of a magnet. It produced a small DC voltage, and large amounts of current.

Pre-Lab Discussion and Activity

For the Demonstration Station:

- Data collection system
- Voltage sensor
- Projection system
- Series/parallel circuit board
- Hand crank generator

Set Up

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

2. Connect the voltage sensor to the data collection system. �(2.1)

3. Connect the terminals from the hand crank generator to the voltage terminals on the voltage sensor.

4. Configure the data collection system to monitor live data without recording. �(6.1)

Demonstration

Have the display from your data collection system projected in front of the class. Review the idea of charges, and the fields between like and dissimilar charges. You may want to simply rub a balloon on your hair and stick it to a wall to show that there are actual forces involved.

Select a student volunteer and have the student volunteer give the crank a few turns to show that a voltage is being produced by the generator.

Connect the terminals from voltage sensor and generator in parallel across one of the small light bulbs on the Series/Parallel Circuit Board (parallel mode).

Ask your volunteer to begin to turn the crank so that the light bulb is clearly lit.

1. **What kind of energy is being converted?**

The mechanical energy is being converted into electrical energy and the electrical energy is being converted into light and heat.

2. Ask the volunteer which was easier, before or after the bulb was added?

Before the bulb.

3. The generator is creating a potential difference across the "load" (the light bulb). Do you think it will be easier or harder to turn the crank on the generator if we double the load?

It will get harder.

Add the second bulb to the circuit, in parallel to the first. Have the volunteer now turn the crank on the generator with two bulbs in parallel.

4. Which was easier, one or two bulbs?

One bulb

Explain to your students that continuous energy must be provided to the system to maintain the potential across the load. This is essentially what happens at the opposite end of the power sockets on the wall, but on a much larger scale.

Explain to students, "As you might imagine, it would be nice to have other ways to make this kind of energy and store it until it is needed, i.e. batteries."

Lab Preparation

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

1. Provide a variety of fruits such that each group will be able to try three different types.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ The fruit should not be consumed after use in this lab.

Sequencing Challenge

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

4	2	1	3
Record the voltage produced by a second piece of fruit to compare to the first.	Insert the copper and the zinc electrodes into your piece of fruit.	Ensure the copper and zinc electrodes are clean and free of corrosion.	Record the voltage value.

Procedure with Inquiry

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

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

Part 1 – Electrochemical Cells

Set Up

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

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

3. ☐ Configure the data collection system to monitor live data without recording. �(6.1)

4. ☐ What happens to two "like" charges (positive and positive, or negative and negative) when they are near each other?

Two like charges will repel each other.

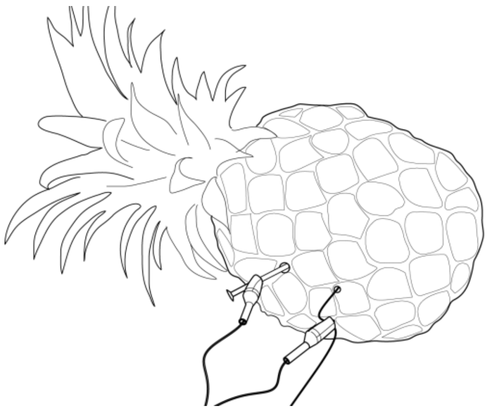
5. ☐ Mount the red and black alligator clips on the voltage sensor's 4 mm banana connector leads.

6. ☐ Choose the first piece of fruit.

7. ☐ Push the copper wire and the zinc-coated nail into the fruit about 5 cm apart. Leave about 2 cm of each electrode exposed.

8. ☐ Connect the red alligator clip to the copper wire.

9. ☐ Connect the black alligator clip to the zinc-coated nail.



10. ☐ As the electrolytic solution decreases the number of positive charges on one of the metal electrodes, is the number of negative charges changing on that same electrode? Is that electrode now positively charged or negatively charged?

The number of negative charges is not changing, but the net charge is now negative, making the electrode negatively charged.

Collect Data

11. ☐ Let the voltage value stabilize, and then record the voltage value and fruit (cell) type in Table 1 in the Data Analysis section.

12. ☐ Remove the electrodes from the fruit, clean them off, and insert them into the next piece of fruit.

13. ☐ Let the voltage value stabilize, and then record the voltage value and fruit (cell) type in Table 1 in the Data Analysis section.

14. ☐ Remove the electrodes from the fruit, clean them off, and insert them into the next piece of fruit.

15. ☐ Let the voltage value stabilize, and then record the voltage value and fruit (cell) type in Table 1 in the Data Analysis section.

16. ☐ Detach the leads of the voltage sensor from the alligator clips.

17. ☐ Hold the red lead to the positive end of a battery and the black lead to the negative end. Let the voltage value stabilize, and then record the voltage value and fruit type (D-cell battery) in Table 1 in the Data Analysis section.

Part 2 – Multiple Cells

Set Up

18. ☐ Place three batteries in individual battery holders.

19. ☐ Connect the voltage sensor across the terminals of one of the batteries, red to positive and black to negative.

Collect Data

20. ☐ Record the voltage value of one cell in Table 2 in the Data Analysis section.

21. ☐ Connect a second battery holder to the first so that the positive terminal of the first is connected to the negative terminal of the second (connected in series).

22. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

23. ☐ Record the voltage value for two cells in series in Table 2.

24. ☐ Connect a third battery holder to the first two so that the positive terminal of the first two is connected to the negative terminal of the third (connected in series).

25. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

26. ☐ Record the voltage value for three cells in series in Table 2.

27. ☐ Disconnect the batteries and connect one of the batteries to the voltage sensor again, and enter the voltage value for one cell in Table 3.

28. ☐ Connect a second battery holder to the first so that the positive terminal of the first is connected to the positive terminal of the second and the negative terminal of the first is connected to the negative terminal (connected in parallel).

29. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

30. ☐ Record the voltage value for two cells in parallel in Table 3.

31. ☐ Connect a third battery holder to the first two so that the positive terminal of the second is connected to the positive terminal of the third (connected in parallel), and the negative terminal of the second is connected to the negative terminal of the third.

32. ☐ Connect the voltage sensor across the outer most terminals of the batteries.

33. ☐ Record the voltage value for three cells in parallel in Table 3.

Data Analysis

Table 1: Fruit and Voltage

Fruit	Voltage (V)
Lemon	0.97
Tomato	0.91
Pineapple	0.93
"D" Battery	1.54

Table 2: Connected in Series

Number of Cells	Voltage (V)
1	1.54
2	3.01
3	4.52

Table 3: Connected in Parallel

Number of Cells	Voltage (V)
1	1.54
2	1.51
3	1.51

Analysis Questions

1. How does the voltage of the first piece of fruit compare to the voltage of the second piece of fruit? Why do you think they are different or similar?

The voltage produced by the fruits were similar because the strength of the electrolyte solution in each piece of fruit was about the same.

2. How does the voltage of either piece of fruit compare to the voltage of the D-Cell battery? Why do you think they are different or similar?

The difference in voltage between the fruit and the battery was over 0.5 volts, more than 50% greater than the fruits. This was due to the strong electrolyte solution (acid) inside the battery.

3. What is one thing that might increase the voltage from the piece of fruit?

One thing that might increase the voltage is using a fruit with a stronger electrolyte solution inside it.

4. Could you light the bulb from a flashlight with the voltage of a piece of fruit? Why or why not?

No, because although the fruit battery produces a sufficient voltage, it can't provide a sufficient current to light the bulb.

Synthesis Questions

Use available resources to help you answer the following questions.

1. An electrochemical cell made from a piece of fruit may supply a sufficient voltage to power some small electrical devices. However, its total charge on each electrode and the rate at which the net charge is produced is not sufficient to produce a proper current for these devices. What is one way to fix this problem using several electrochemical cells?

One way to fix this problem would be to attach several fruit batteries together at once in parallel.

2. What would happen to the voltage measurement from your fruit battery if the two electrodes accidentally touched each other? Justify your answer.

If the electrodes accidentally touched each other, the voltage would drop to zero because the charges would jump across the electrode, equilibrating the net charge on each.

Multiple Choice Questions

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

1. What are two key parts of any electrochemical cell?

- **A.** Copper and zinc
- **B.** **Electrodes and electrolyte**
- **C.** Fruit juice and copper sulphate
- **D.** Unknown

2. If you measured the voltage across two pieces of metal, and that voltage was zero, which of the following statements is true?

- **A.** Each piece of metal has zero charges on it.
- **B.** There are more positive charges on one piece of metal than the other.
- **C.** **Each piece of metal has the same net charge on it.**
- **D.** There are more negative charges on one piece of metal than the other.

3. If you connected the electrodes from two identical fruit batteries together (zinc to zinc and copper to copper), the voltage would be:

- **A.** Twice as much as one fruit battery
- **B.** Half as much as one fruit battery
- **C.** Zero
- **D.** **The same as one fruit battery**

Key Term Challenge

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

1. We have found many ways to turn **generators**. Wind power, hydro power, burning fossil fuels, and splitting atoms have all been used to ultimately turn a generator and provide a **voltage** to the various appliances we use in our everyday life. The need for consistent reliable **electromotive** force to move **charge** across the ever growing consumer **load** has given rise to a global, multi-billion dollar power generation industry.

2. Most electronic devices that have rechargeable batteries use a combination of smaller **cells** connected in **series** to provide just the right voltage required for each device. The manufacturers must balance how long a device will last on a single charge with how much space and weight the **battery** can have when deciding how many cells they can connect in **parallel**.

3. The electric **potential** between the terminals of a battery causes charge to flow in a conductor when it is connected to the **terminals**. If one of the terminals is connected to the Earth, it is said to be grounded. A large potential **difference** can cause charge to flow through things that are not very **conductive**, like a dramatic lightning discharge in air.

Extended Inquiry Suggestions

If the appropriate materials are available, this is a good time to introduce the idea of a changing voltage (AC) and why it is important for power transmission.

This is also a natural time to lead into the idea of current as moving charge.

1 ampere = 1 coulomb per second

If connecting batteries in series gives you more voltage, why do you think it is important to connect batteries in parallel?

This provides more current, or longer battery life.

30. Ohm's Law

Objectives

Students investigate the relationship between current, voltage, and resistance in a circuit.

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring the current through a resistor in a circuit as the voltage applied to the resistor changes.
- Comparing the slopes of Voltage versus Current graphs for two different resistors.
- Measuring the current through a light bulb in a circuit as the voltage applied to the bulb changes.
- Comparing the plot of Voltage versus Current for a circuit with a light bulb to the voltage versus current plots that result from two different resistors.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Voltage sensor
- Current sensor
- Charge/discharge circuit board
- AA cell battery (2)
- Patch cord, 4-mm banana plug (5)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The role of components of a simple circuit, i.e. resistors, capacitors, batteries
- The meaning of voltage and current in a simple circuit
- AC and DC current

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Voltage: Fruit Battery/Generator
- ♦ Series and Parallel Circuits
- ♦ RC Circuit

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data collection system �(2.2)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adding a note to a graph �(7.1.5)
- ♦ Changing the variable on the *x*-or *y*-axis of a graph �(7.1.9)
- ♦ Finding the slope and intercept of a best-fit line �(9.6)
- ♦ Saving your experiment �(11.1)

Background

Georg Simon Ohm observed that as the voltage across a resistor changes, so does the current. For a constant resistance, if the voltage increases, the current increases proportionally. If the voltage decreases, the current decreases proportionally. Conversely, for a constant voltage, if the resistance increases, the current decreases and vice versa. In other words, current is directly proportional to voltage and inversely proportional to resistance. This is expressed in Ohm's law as:

$$I = \frac{V}{R}$$

where I is current, V is voltage, and R is resistance. If voltage across the resistor is changed, a graph of the voltage versus current shows a linear relationship with slope equal to R.

Pre-Lab Discussion and Activity

Write the formulas for Ohm's law and Newton's second law of motion side by side on the board. Challenge students to draw parallels to the relationships between current, voltage, and resistance in Ohm's law to the relationships between force, mass, and acceleration in Newton's second law of motion.

1. How does the relationship between force and mass in Newton's second law compare to the relationship of current and voltage in Ohm's law (holding the other values constant)?

Force increases as mass increases, and similarly current increases as voltage increases. Also, current decreases as voltage decreases, just as force decreases as mass decreases.

2. How does the relationship between mass and acceleration compare to the relationship between current and resistance (when the other values are constant)?

For a constant force, acceleration decreases as mass increases. Similarly, for a constant voltage, current decreases as resistance increases.

3. What type of plot would you expect to see if you graphed voltage versus current?

The plot would be linear for a constant resistance.

Lab Preparation

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

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

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

1	3	2	4
Connect the voltage /current sensor to the data collection system	Determine the slope of the best fit line of the Voltage versus Current data plot	Begin data collection, and then discharge the capacitor across the 10 ohm resistor.	Repeat twice more, once with a 33 ohm resistor, and then with a light bulb.

Procedure with Inquiry

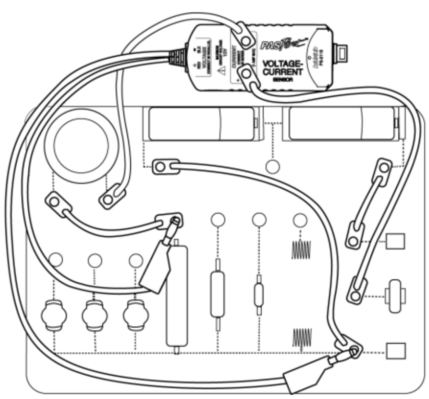
After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

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 – 10 Ω resistor

Set Up

1. ☐ Using the patch cords, circuit board, 2 AA batteries, and voltage/current sensor assemble the simple circuit seen in the figure below.



Note: With the circuit assembled correctly, the 1 F capacitor will act as a variable voltage source across the 10 Ω resistor, ranging from 0 to 1.5 VDC, while the voltage/current sensor simultaneously measures both voltage applied to the resistor, and current through the resistor.

2. ☐ Connect the voltage and current sensors to the data collection system. �(2.2)

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

4. ☐ What is the proper placement of the leads from and to the voltage sensor and current sensor respectively when measuring the voltage and current associated with a resistor?

The leads should be connected so that voltage is measured in parallel with the resistor and the current is measured in series with the resistor.

5. ☐ Close the switch to the "charge" position for at least 15 seconds to charge the capacitor.

6. ☐ Display Voltage on the y-axis of a graph with Time on the x-axis, and then change the x-axis from Time to Current. �(7.1.1) (7.1.9)

Collect Data

7. ☐ Move the switch on the circuit board to the "discharge" position.

8. ☐ Start data recording. �(6.2)

9. ☐ What is the purpose of the capacitor in the circuit?

The capacitor will provide the variable electromotive force (EMF) as it discharges.

10. ☐ When the voltage and current are nearly equal to zero, stop data recording. �(6.2)

11. ☐ Move the switch to the open (upright) position.

12. ☐ Add a note to the graph to indicate the data run was collected using the 10 Ω resistor. �(7.1.5)

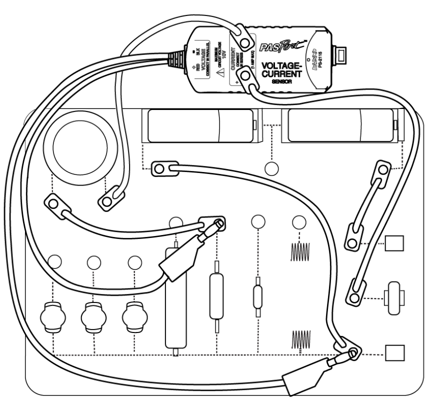
Analyze Data

13. ☐ On the data collection system, find the slope of a best-fit line for your data and record the slope in Table 1 in the Data Analysis section. �(9.6)

Part 2 – 33 Ω resistor

Set Up

14. ☐ Replace the 10 Ω resistor in your circuit with the 33 Ω resistor by moving the 4 mm banana plugs just above the 10 Ω resistor to the terminal just above the 33 Ω resistor.



15. ☐ Close the switch to the "charge" position for at least 30 seconds to charge the capacitor.

16. ☐ How will the graph of Voltage versus Current for the 33 Ω resistor be different from the one for the 10 Ω resistor?

The slope of the voltage versus current graph for the 33 Ω resistor will be greater (steeper) than that of the 10 Ω resistor.

Collect Data

17. ☐ Move the switch to the "discharge" position.

18. ☐ Start data recording. �(6.2)

19. ☐ When the voltage and current are nearly equal to zero, stop data recording. �(6.2)

20. ☐ Move the switch to the open (upright) position.

21. ☐ Add a note to the graph to indicate the data run was collected with a 33 Ω resistor. �(7.1.5)

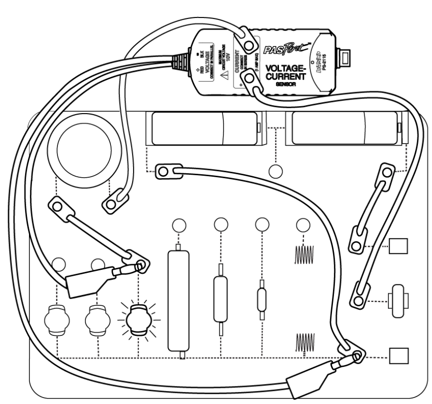
Analyze Data

22. ☐ On the data collection system, find the slope of a best-fit line for your data and record the slope in Table 1 in the Data Analysis section. �(9.6)

Part 3 – Light Bulb

Set Up

23. ☐ Replace the 33 Ω resistor in your circuit with one of the three light bulbs by moving the 4 mm banana plugs just above the 33 Ω resistor to the terminal just above any of the three light bulbs.



24. ☐ A light bulb acts like a resistor in a circuit, however, its resistance value changes as the filament in the bulb heats up. How will the graph of Voltage versus Current for the light bulb be different from either of your resistor curves?

The curve won't be linear like the resistor curves.

25. ☐ Close the switch to the "charge" position for at least five seconds to charge the capacitor.

Collect Data

26. ☐ Move the switch to the "discharge" position.

27. ☐ Start data recording. �(6.2)

28. ☐ When the voltage and current are nearly equal to zero, stop data recording. �(6.2)

29. ☐ Add a note to the graph to indicate the data run was collected with a Light Bulb. �(7.1.5)

Analyze Data

30. ☐ Sketch a copy of your Voltage versus Current graph in the Data Analysis section. Be sure to correctly label the axes of the graph and indicate which run corresponds each resistor used, including the light bulb.

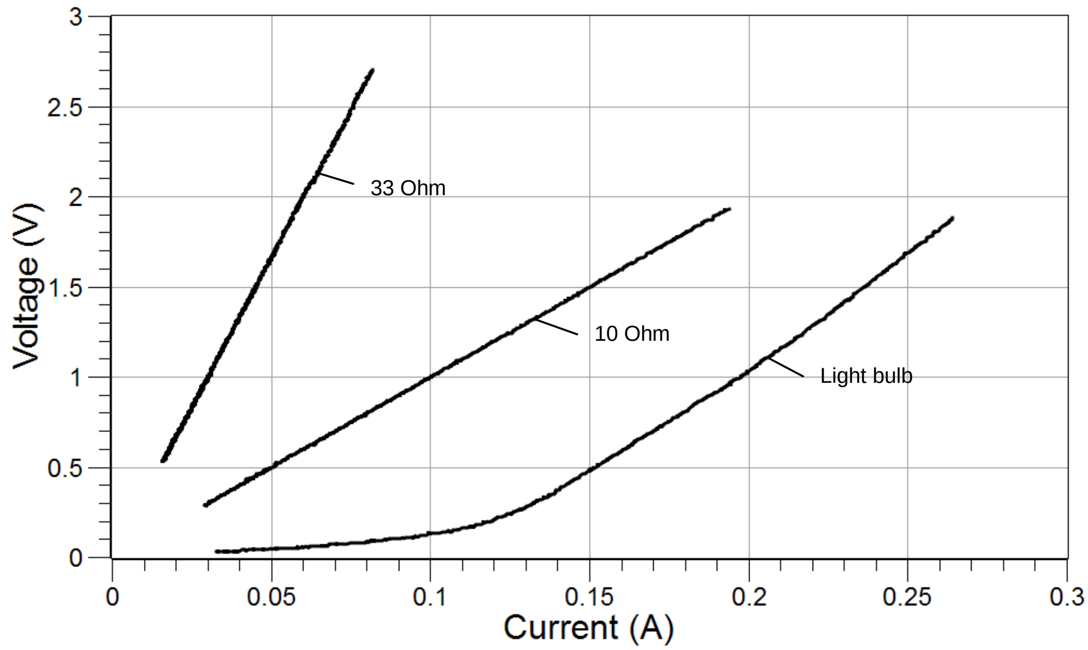
31. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Table 1: Voltage versus Current Slopes

Resistor (Ω)	Slope (V/A)
10	9.9
33	32.9

Voltage versus Current



Analysis Questions

1. Describe the Voltage versus Current curve for the 10 Ω resistor.

The plot of Voltage versus Current is a straight light with a slope of almost 10 V/A.

2. How does the slope of the Voltage versus Current curve for the 10 Ω resistor compare to the resistance value?

The value of the slope is close to the resistance value.

3. Describe the Voltage versus Current curve for the 33 Ω resistor.

The plot of Voltage versus Current is a straight light with a slope of almost 33 V/A.

4. How does the slope of the Voltage versus Current curve for the 33 Ω resistor compare to the resistance value?

The value of the slope is close to the resistance value.

5. Describe the Voltage versus Current curve for the 33 Ω resistor in comparison to the curve for the 10 Ω resistor.

The plot for the 33 Ω resistor has a steeper slope than that of the 10 Ω resistor.

6. How does the curve for the light bulb compare to the curve for either resistor?

The plot of Voltage versus Current for the light bulb is not linear.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What can you conclude about the mathematical relationship between current and voltage for constant resistance?

The current through the circuit is directly proportional to the voltage for a constant resistance.

2. What can you conclude about the relationship between current and resistance?

The current through a circuit is inversely proportional to the resistance for a constant voltage.

Multiple Choice Questions

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

1. The voltage across a 580 Ω resistor is 120 V. How much current is going through the resistor?

- **A.** There isn't enough information to answer this question.
- **B.** 696 mA
- **C.** **207 mA**
- **D.** 460 mA

2. The current through a 100 Ω resistor is 0.150 A. What voltage is being applied?

- **A.** There isn't enough information to answer this question.
- **B.** **15 V**
- **C.** 1.5 V
- **D.** 666 V

3. A circuit with a 3 V battery pack and a resistor has a current of 0.06 A. What is the value of the resistor?

- **A.** There isn't enough information to answer this question.
- **B.** 18 Ω
- **C.** 2 Ω
- **D.** **50 Ω**

Key Term Challenge

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

1. As the voltage across a resistor increases or decreases, **current** increases or decreases respectively, thus they are said to be **directly** proportional. When resistance increases, current decreases and visa versa, thus they are said to be **inversely** proportional. This relationship is called **Ohm's** law.

2. The formula for Ohm's law is written as: $I = V/R$. The plot of voltage versus current for a resistor with constant resistance is a **straight** line with a slope about the same value as the **resistor**.

Extended Inquiry Suggestions

Ask students to repeat the data recording and analysis process for a 100 Ω resistor.

Ask students to design an experiment to measure the current through a diode as the voltage is changed across the diode. Let students compare the plot of Current versus Time for the diode to the plots for the resistors and the plot for the light bulb. In addition to demonstrating the voltage current curve of a new electronic component, this will help students generalize the idea of observing the voltage and current to understand the nature of electronic components.

31. Series and Parallel Circuits

Objectives

This lab explores the properties of both series and parallel circuits by:

- ♦ Measuring both circuit voltage and current while altering the voltage for a given circuit and evaluating how those measurements are related
- ♦ Finding the equivalent resistance of a circuit for both series and parallel resistors

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Setting up series and parallel circuits according to an electrical schematic
- ♦ Using an ammeter and voltmeter to measure current and voltage in a circuit
- ♦ Identifying resistors and their stated (color-coded) resistance (optional)

Time Requirement

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

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Current sensor
- ♦ Voltage sensor
- ♦ Resistors (3-6), at least 3 different known values
- ♦ DC power supply, 10 V, 1A minimum
- ♦ Switch, single-pole single-throw
- ♦ Patch cord, 4 mm banana plug (10)
- ♦ Alligator clip adapters (10) (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Definitions of voltage, resistance, and current

Related Labs in This Guide

Labs conceptually related to this one include:

- Voltage: Fruit Battery/Generator
- Ohm's Law
- RC Circuit

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sample rate �(5.1)
- Monitoring live data without recording �(6.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Changing the variable on the x-or y-axis of a graph �(7.1.9)
- Displaying data in a digits display �(7.3.1)
- Applying a curve fit �(9.5)
- Finding the slope and intercept of a best-fit line �(9.6)
- Saving data files �(11.1)

Background

Ohm's Law identifies that the voltage drop across an electrical resistor is mathematically equal to the current through the resistor multiplied by the resistance. If voltage is held constant and resistance is doubled, the current would be half its original value. Likewise, cutting the resistance in half would double the current. When circuits have multiple resistors connected in either series or parallel, the circuit can be greatly simplified by substituting one resistor that behaves like the many. This is called an *equivalent resistance*. The equivalent resistance R_{eq} for resistors connected in series can be calculated by simply adding the resistance values of each of the resistors R_n:

$$R_{eq} = R_1 + R_2 + R_3 + ... \qquad \text{Resistors connected in series}$$

The equivalent resistance of resistors in parallel can be calculated using the equation:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ... \qquad \text{Resistors connected in parallel}$$

R_{eq} in both equations is the theoretical value for equivalent resistance. Actual resistance will be slightly different due to the intrinsic design of modern electrical components. Considering Ohm's law, one can use different source voltages to experimentally determine the equivalent resistance of a set of resistors.

Pre-Lab Discussion and Activity

We know that voltage is the electromotive force that moves charge through conductors. If a DC voltage source (either a power supply or a set of batteries) is connected to a circuit containing some resistance, current will flow according to Ohm's law. If the resistance in the circuit is held constant and voltage is increased, current in the circuit will subsequently increase. Likewise, decreasing voltage will cause current to decrease.

In this lab you will gradually increase the DC voltage in a circuit with a given set of resistors. As voltage increases you will measure the subsequent changes in current to discover the equivalent resistance for both series and parallel circuits.

1. What is the basic equation for Ohm's Law?

$V = IR$

2. If the resistance in a circuit is held constant and the voltage is doubled, what will happen to the current in the circuit?

It should double.

With electronic components getting smaller and smaller, the resistor color rating chart is becoming the providence of hobbyists and historians, but it can be a good review of exponents for students.

3. What do the bands of a 4-band resistor represent?

The first two represent the value of the resistor, the third represents the power of the exponent of ten, and the fourth represents the tolerance of the resistor.

0 = Black

1 = Brown (±1% Tolerance)

2 = Red (±2% Tolerance)

3 = Orange

4 = Yellow

5 = Green (±0.5% Tolerance)

6 = Blue (±0.25% Tolerance)

7 = Violet (±0.1% Tolerance)

8 = Grey (±0.05% Tolerance)

9 = White

-1 = Gold (±5% Tolerance)

-2 = Silver (±10% Tolerance)

So a resistor that has red, green, brown, silver stripes would be 250 ohms with a 10% tolerance, or 25×10^1 ±10% Tolerance

If you have a wall chart for resistors, now would be a good time to review the chart.

If you want to do a review of experimental errors, you might want to spend a little more time discussing the tolerance band and the idea that tolerances stack.

4. How can you verify experimentally what the equivalent resistance of a circuit is? In what part of the circuit would you place the voltmeter and ammeter?

Change voltage, and measure voltage and current to ensure that the "equivalent resistance" behaves like a regular resistor according to Ohm's Law, across the power supply (or source).

Lab Preparation

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

1. Gather at least 3 color-coded (or otherwise stated) resistors for each lab group, patch cords, and alligator clip adapters.
2. Determine a safe voltage to use based on the resistors you have chosen.

Note: To simplify the math for students when they look at a parallel circuit, you might want to try a combination of resistors for a voltage of 5 volts. For example: first resistor 100 ohms, second resistor 100 ohms, and the third resistor 50 ohms.

Note: If time is an issue, this lab is easily split in half so that series resistance is done one day and parallel resistance is done another.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Exercise caution when using the power supply: use only low voltages (10 VDC or less) and only make changes to the circuit when the circuit switch is open.
- ♦ To reduce chances of spills and subsequent electrical shock, do not allow food or beverages near the equipment.
- ♦ Be sure resistor ratings and power supplies settings are appropriate for your voltage and current sensors.

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	3	2	4
Select three resistors, and identify their stated (color-coded) values (in Ω).	Set up another circuit of resistors in parallel, and repeat the process.	Apply a varying voltage to the circuit, and measure the different voltages and currents.	Set up a circuit of three resistors in series with a power supply.	Plot voltage versus current and determine the equivalent resistance in the circuit from the graph's slope.

Procedure with Inquiry

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

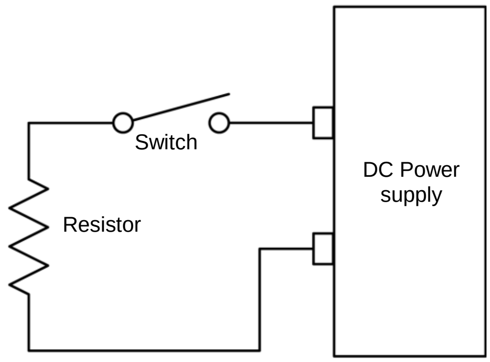
Part 1 - Resistors in Series

Set Up

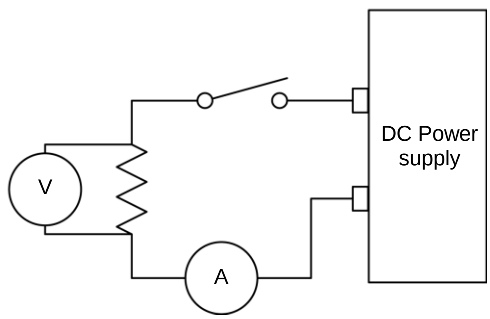
1. ☐ Start a new experiment on the data collection system. [1.2]

2. ☐ Connect your voltage and current sensors to the data collection system. [2.2]

3. ☐ With the power supply off, connect the first resistor and open switch in series to the power supply using the patch cords.



4. ☐ Connect the voltage sensor across the resistor, and then connect the current sensor in series with the resistor and switch. Be sure the switch is open.



5. ☐ Display voltage and current in a digits display. �(7.3.1)

6. ☐ Turn on your power supply, and set output voltage to the fixed voltage provided by your teacher, and record this value in the Data Analysis section; for example, 5 V.

Collect Data

7. ☐ Close the switch, and then record the voltage and current reading in Table 1 in the Data Analysis section. After recording the values, open the switch.

8. ☐ Add the second resistor in series with the first, and then move the voltage sensor leads to measure the total voltage across both resistors,

9. ☐ Close the switch, and then record the voltage and current reading in Table 1 in the Data Analysis section.

10. ☐ Move the voltage sensor leads to now measure the voltage across the first resistor by itself, and then record the voltage in Table 1 in the Data Analysis section.

11. ☐ Move the voltage sensor leads to measure the voltage across the second resistor by itself, and then record the voltage in Table 1 in the Data Analysis section. After recording the values, open the switch.

12. ☐ We have measured the voltage for each component. Why are we not measuring the current for each component as well?

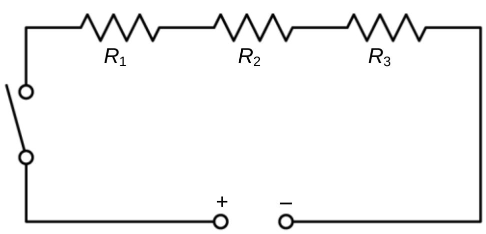
The current has only one path to follow, so the current will be the same at any point in the circuit.

13. ☐ Add the third resistor in series with the first, and then repeat the previous steps recording the voltage and current across all three resistors, then the voltage for each individual resistor in the circuit. Record the values in Table 1 in the Data Analysis section.

Note: Be sure to open the switch in the circuit after you have finished making each measurement.

Part 2 - Combined Resistors in Series

Set Up



14. ☐ Use the series circuit that you have created to determine if the behavior of a series circuit is Ohmic. Ensure the sample rate on your data collection system is set to 10 samples per second. �(5.1)

15. ☐ Display Voltage on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

16. ☐ Change the variable on the *x*-axis from Time to Current. �(7.1.9)

17. ☐ Make sure the switch is open, and set a low voltage on the power supply; for example, 1 V.

18. ☐ Connect the voltage sensor to measure the total voltage drop across all three combined resistors.

19. ☐ Connect the current sensor to measure the total current in the circuit.

Collect Data

20. ☐ Start data recording. �(6.2)

21. ☐ Close the switch, and then gradually change the voltage of the power source, both increasing and decreasing the voltage, but not to exceed the limit specified by your teacher.

22. ☐ Once you have swept through a range of voltages, stop data recording. �(6.2)

23. ☐ Open the switch, turn off the power supply, and disconnect the resistors.

Analyze Data

24. ☐ How would you describe the Voltage versus Current graph? Is this considered Ohmic behavior?

The plot appears to be Linear. Yes, this is Ohmic behavior.

25. ☐ Apply a linear curve fit to the Voltage versus Current graph. �(9.5)

26. ☐ Sketch your Voltage versus Current graph in the space provided in the Data Analysis section. Be sure to include the slope of the linear fit in your sketch.

Part 3 - Resistors in Parallel

Set Up

27. ☐ With the power supply off, connect the first resistor and switch (open) in series to the power supply using the patch cords.

28. ☐ Connect the voltage sensor across the resistor, and then connect the current sensor in series with the resistor and switch. Be sure the switch is open.

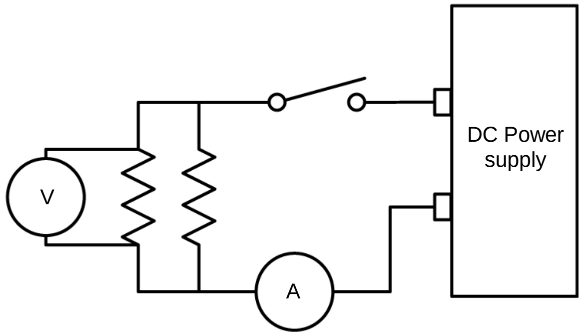
29. ☐ Display voltage and current in digits displays. �(7.3.1)

30. ☐ Turn on your power supply, and set the output voltage to the fixed voltage specified by your teacher, and record this value in the Data Analysis section; for example, 5 V.

Collect Data

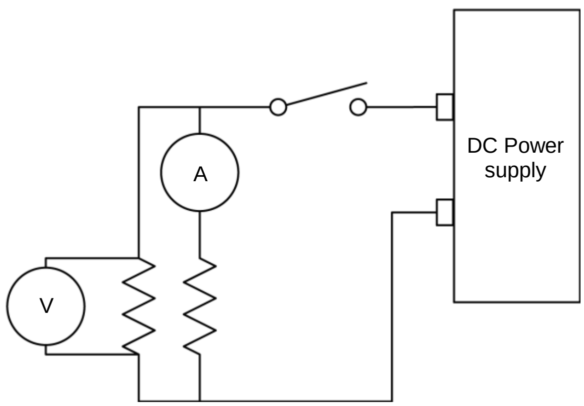
31. ☐ Close the switch, and then record the voltage and current reading in Table 2 in the Data Analysis section. After recording the values, open the switch.

32. ☐ Add the second resistor in parallel with the first.



33. ☐ Close the switch, and then record the voltage and current reading in Table 2 in the Data Analysis section. After recording the values, open the switch.

34. ☐ Move the current sensor leads to measure the current through the first resistor by itself.



35. ☐ Close the switch, and then record the current in Table 2 in the Data Analysis section. After recording the value, open the switch.

36. ☐ Move the current sensor leads to measure the current through the second resistor, close the switch, and then record the current reading in Table 2 in the Data Analysis section. After recording the value, open the switch.

37. ☐ We have measured the current for each component, why are we not measuring the voltage too?

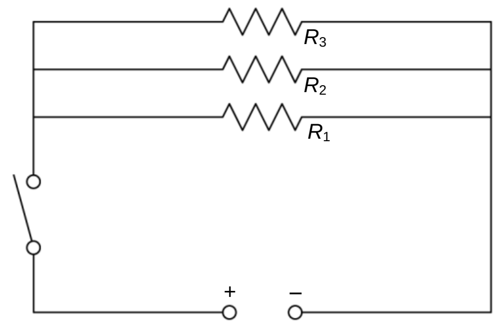
The same voltage is connected to the top and bottom of each resistor.

38. ☐ Add the third resistor in parallel with the first two, and then repeat the previous steps recording the voltage and current across all three resistors, then the current for each individual resistor in the circuit. Record the values in Table 2 in the Data Analysis section.

Note: be sure to open the switch in the circuit after you have finished making each measurement.

Part 4 - Combined Resistors in Parallel

Set Up



39. ☐ Use the parallel circuit that you have created to determine if the behavior of a parallel circuit is Ohmic. Ensure the sample rate on the data collection system is set to 10 samples per second. �(5.1)

40. ☐ Make sure the switch is open, and set a low voltage on the power supply; for example, 1 volt.

41. ☐ Connect the voltage sensor to measure the total voltage drop across all tree combined resistors, and then connect the current sensor in series to measure the total current in the circuit.

42. ☐ Display Voltage on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

43. ☐ Change the variable on the *x*-axis from Time to Current. �(7.1.9)

Collect Data

44. ☐ Start data recording. �(6.2)

45. ☐ Close the switch, and then gradually change the voltage of the power source, both increasing and decreasing the voltage, but not to exceed the limit specified by your teacher.

46. ☐ Once you have swept through a range of voltages, stop data recording. �(6.2)

47. ☐ Open the switch, turn off the power supply, and disconnect the resistors.

Analyze Data

48. ☐ How would you describe the Voltage versus Current graph? Is this considered Ohmic behavior?

The plot appears to be Linear. Yes, this is Ohmic behavior.

49. ☐ Apply a linear curve fit to the Voltage versus Current graph. �(9.6)

50. ☐ Sketch your graph of Voltage versus Current in the space provided in the Data Analysis section. Be sure to include the slope of the linear fit in your sketch.

51. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Voltage from Power Supply: ___1.61________

Table #1: Series Circuit

# of Resistors	Resistor	Voltage across resistor (V)	Current through the resistor (A)	Voltage/Current	Resistor Rating (Ω)
1	First	1.43	0.141	10.14	10
2	First	0.77	0.074	10.4	10
	Second	0.77	0.074	10.4	10
Total voltage for two resistors = 1.54					
3	First	0.31	0.029	10.68	10
	Second	0.31	0.029	10.68	10
	Third	0.94	0.029	32.41	33
Total voltage for three resistors = 1.55					

Series Circuit Voltage versus Current

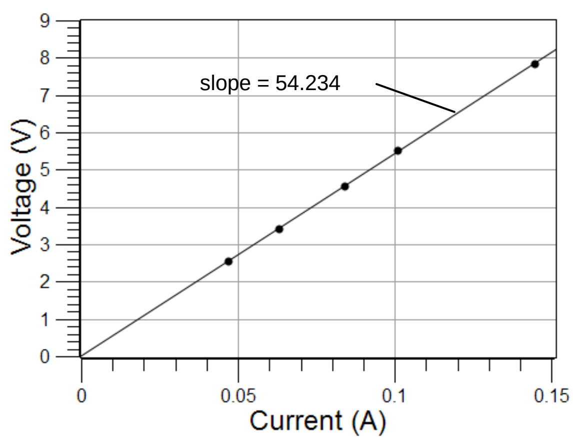
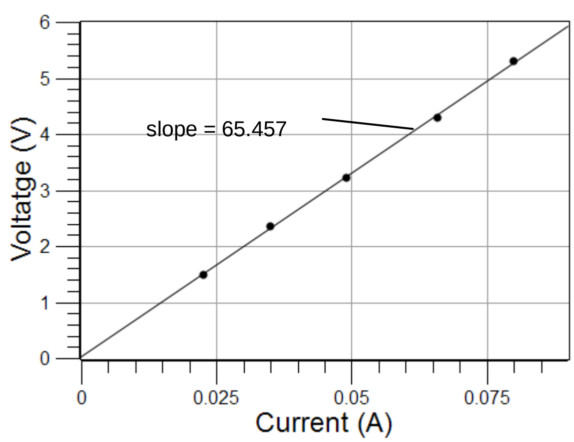


Table #2: Parallel Circuit

# of Resistors	Resistor	Voltage across resistor	Current through the resistor	Voltage/Current	Resistor Rating
1	First	1.59	0.016	99.38	100
2	First	1.59	0.015	106	100
	Second	1.59	0.005	318	330
Total current for two resistors = 0.020					
3	First	1.59	0.016	99.38	100
	Second	1.59	0.005	318	330
	Third	1.59	0.003	530	560
Total current for three resistors = 0.023					

Parallel Circuit Voltage versus Current



Analysis Questions

1. What does the slope of each graph represent, and what values for the slope did you get for each graph you made?

The slope of the Voltage versus Current graph represents the resistance of the system. The slopes will vary depending on the values of resistors used.

2. Add up the resistance values of the three resistors in the series circuit. How does this total resistance compare to the slope of your series circuit graph?

The values should be identical within the tolerances of the resistors.

$$10\Omega + 10\Omega + 33\Omega = 53\Omega$$

3. Add up the resistance values of the three resistors in the parallel circuit. How does this total resistance compare to the slope of your parallel circuit graph?

The values should be very different.

$$100\Omega + 330\Omega + 560\Omega = 990\Omega$$

4. Add up the inverses of the resistance values of three resistors for the parallel circuit, and then take the inverse of that sum (use this equation to solve for R_{eq}):

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

How does R_{eq} compare to the slope of your parallel circuit graph?

The values should be identical within the tolerances of the resistors.

$$\frac{1}{R_{eq}} = \frac{1}{100\Omega} + \frac{1}{330\Omega} + \frac{1}{560\Omega}$$

$$\frac{1}{R_{eq}} = 0.01482$$

$$R_{eq} = 67.49\Omega$$

Synthesis Questions

Use available resources to help you answer the following questions.

1. If one of the bulbs in a parallel circuit goes bad (or is disconnected), what happens to the brightness of the other bulbs?

The brightness of the other bulbs does not change, but the current being drawn by the circuit is reduced.

2. What happens to the brightness of other bulbs if a single bulb goes bad in a series circuit? Explain your answers.

All the bulbs go out. If one bulb goes out, the circuit is broken

3. Many houses display colored lights during winter holiday season, and occasionally one of the bulbs goes out. Does the entire string of lights go out with it? Explain what this tells you regarding series and parallel circuits?

Student answers will vary, but the general idea is to identify that bulbs in series will go out and bulbs in parallel will remain lit.

Multiple Choice Questions

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

1. What would happen to the current from a power supply if you added more resistors to a series circuit?

- **A.** The current increases
- **B.** **The current decreases**
- **C.** The current stays the same
- **D.** Not enough info provided

2. What would happen to the current from a power supply if you added more resistors to a parallel circuit?

- **A.** **The current increases**
- **B.** The current decreases
- **C.** The current stays the same
- **D.** Not enough info provided

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. There is a predictable relationship between current, **voltage**, and resistance: For a circuit with constant resistance, as voltage increases or decreases, **current** increases or decreases respectively. Thus, they are said to be **directly** proportional. For the same circuit, when resistance increases, current decreases, and visa versa. Thus, they are said to be **inversely** proportional. This relationship is called **Ohm's law**.

2. The formula for Ohm's law can be written as: $R = V/I$. When the plot of voltage versus current is a **straight** line, the circuit obeys Ohm's Law with a slope about the same value as the total circuit **resistance**, or the **equivalent** resistance of the **circuit**.

Extended Inquiry Suggestions

Ask students to predict voltages and current for various circuits using only Ohm's law and the equations for equivalent resistance. Make the connection (pun is fully intended!) that engineers must know these laws so they can design circuits confidently knowing how they'll behave before actually building them. Challenge your students to simplify complicated circuits by reducing a set of resistors into one total resistor. Students relish the challenge of this, and simplifying a complicated circuit into one power supply and one equivalent resistor prepares them for Thévenin's circuit concepts at the college level.

For more hands-on challenges, set up series and parallel circuits with small light bulbs of equal resistance, and notice how the brightness changes as the circuitry is varied. More bulbs in a series circuit means less overall current, so ask students what will happen to the brightness of each bulb as more are added. Similarly, add bulbs in parallel and have students calculate what will happen according to their equations. Then prove their calculations correct by doing a demo of this situation.

Finally, many students refuse to believe the overall resistance of a parallel circuit is less than that of the smallest resistor. Demonstrate this by getting a hand-cranked generator and using it as the power supply in a circuit. (Be ready to discuss AC versus DC currents!) Set up three bulbs in series, ask a student to crank the generator, and notice the difficulty in turning the crank. Then rewire the circuit so the bulbs are in parallel and repeat. See what happens!

32. RC Circuit

Objectives

This experiment explores the behavior of a simple series resistor and capacitor circuit. During this investigation, students compare:

- The relationship between voltage across a capacitor as part of a simple RC circuit, and the current in the circuit as the capacitor charges and discharges.
- The relationship between voltage across a resistor as part of a simple RC circuit, and the current in the circuit as the capacitor charges and discharges.

Procedural Overview

Students will gain experience conducting the following procedures:

- Constructing a simple RC circuit
- Using a voltage and current sensor to acquire data as the capacitor in the circuit is charged and discharged using a constant voltage source
- Measuring a changing voltage
- Measuring a changing current

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	25 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Voltage sensor
- Current sensor
- AA-cell battery (2)
- Charge/discharge circuit board
- Patch cord, 4 mm banana plug (5)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Ohm's law
- Voltage and current

Related Labs in this Manual

Labs conceptually related to this one include:

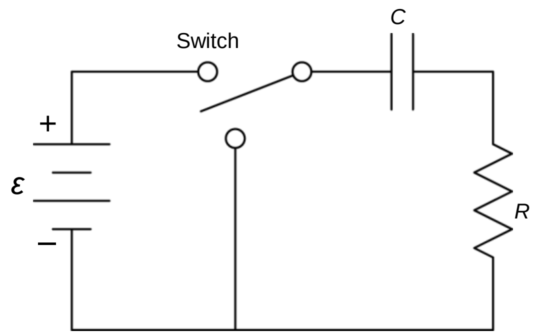
- Ohm's Law
- Series and Parallel Circuits

Using Your Data Collection System

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

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple variables on the *y*-axis of a graph �(7.1.10)
- Finding the values of a point in a graph �(9.1)
- Measuring the distance between two points in a graph �(9.2)
- Saving your experiment �(11.1)

Background



RC circuit diagram

The circuit diagram above shows a simple RC circuit containing some resistance R and capacitance C, connected in series, and driven by a voltage source providing a constant voltage ε. Let us assume that with the switch open at time = 0, the capacitor is completely discharged. This means that there is no charge stored in the capacitor. As soon as we close the switch, current in the circuit begins to flow, and the capacitor begins to collect charge provided by the constant voltage source. As the charge in the capacitor increases, the voltage across the capacitor also increases. This relationship is described by:

$$Q = CV \qquad \textbf{Eq.1}$$

Where Q is the charge in the capacitor, V is the voltage across the capacitor, and C is the capacitance.

Leaving the switch closed in our circuit will cause more and more charge to build-up inside the capacitor. As charge crowds inside the capacitor, the charge begins to repel the addition of more charge due to their electrostatic repulsion; this is seen as a decrease in current in the circuit. Although it is easy to assume that the current must stop flowing at some point (when the capacitor is fully charged), the reality is that current never stops. Rather, it asymptotically approaches zero (constantly decreasing but never actually reaching zero). The equation describing the current in our circuit as the capacitor charges is:

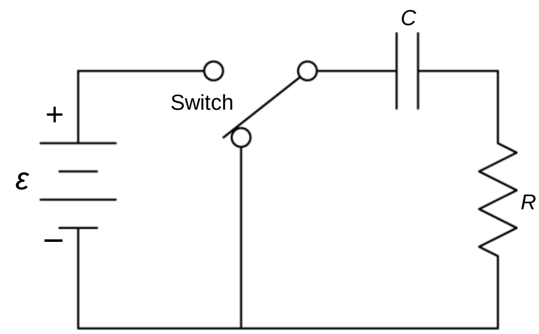
$$I(t) = I_0 e^{-t/RC} \qquad \textbf{Eq.2}$$

Where $I(t)$ is equal to the current in the circuit at time t seconds after closing the switch, R is equal to the resistance in the circuit, C is equal to the capacitance, and $I_0 = \varepsilon / R$ (ε = battery voltage).

Because the capacitor never *fully* charges, early physicists used an important value from Equation 2 to help categorize different RC circuits, and the speed at which they charge and discharge. It was deemed that the *time constant* τ for an RC circuit is equal to just that $R \times C$, or the time it takes for the current in the circuit to decrease by 63%, or the charge on the capacitor plates to reach 63% of full capacity. This quantity comes in very handy when dealing with complex circuits and most modern electronics.

It is important to note for the equation of current that when $t = 0$, $I(t = 0) = I_0$, or $I(t = 0) = \varepsilon / R$ which according to Ohm's law means that when the capacitor is fully discharged, the circuit acts as if the capacitor is not even there (shorted). Also important: when $t = \infty$, $I(t = \infty) = 0$ which, according to Ohm's law, means the voltage across the resistor is now zero, and the voltage across the capacitor is maximum ($V_C = \varepsilon$).

We assume that the capacitor will eventually reach a V_C voltage equal to the voltage of the battery after the switch has been closed for a long time. Once charged, the capacitor will maintain this voltage until it is discharged.



Simple RC circuit diagram, discharging

When the switch is flipped, the charge in the capacitor flows through resistance R, slowing the rate at which the charge in the capacitor flows. In fact, the relationship is simply the opposite as we saw for charging:

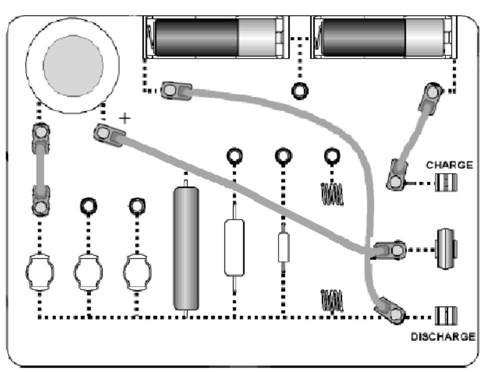
$$I(t) = -I_0 e^{-t/RC} \qquad \textbf{Eq.3}$$

This is all assuming that the capacitor was fully charged ($V_C = \varepsilon$) at the time the capacitor began to discharge.

Pre-Lab Discussion and Activity

Students may benefit from a short demonstration on charging and discharging a capacitor using a battery and a light bulb. This demonstration will also serve as a quick look into the proper way of connecting electronic components such as resistors and capacitors using a component board like the Charge/Discharge circuit board.

Connect a simple RC circuit using the large 1 F capacitor on the Charge/Discharge circuit board and one of the 3 V light bulbs.



Simple RC circuit using a light bulb

Leave the circuit open at first, and indicate how the bulb acts as the resistor in the circuit (about 6 Ω).

Close the circuit, and explain that the capacitor is fully discharged at first, which allows electrons to move freely in the circuit.

After several seconds, the light bulb will grow dim as the current in the circuit decreases relative to the charge building-up on the capacitor plates.

Eventually, the light will be too dim to see any light, which indicates that the capacitor is charged-up (but not fully, as we would need an infinite amount of time to reach a full charge).

To prove to students that the capacitor is charged and that there is charge stored within it, carefully disconnect it from the circuit (avoid touching the leads as this will discharge the capacitor), and connect the light bulb directly across the capacitor.

The bulb should light and slowly dim as time passes.

Ask students to compare the amount of time that passed as the capacitor discharged and the time required to charge the capacitor.

1. When a capacitor is being charged, does current flow across one capacitor plate to the other? Justify your answer.

The capacitor plates are separated by a gap, or dielectric substance, that prevents electrons from flowing from one plate to the other.

2. What would you expect to happen to the voltage of a charged capacitor if you touched the two leads together?

The charge on the capacitor plates would equilibrate, causing the voltage on the capacitor to drop to zero.

3. In the light bulb demonstration, if we close the circuit and begin charging the capacitor, the light bulb comes on very bright and continues to dim over about 10 seconds as the capacitor fills. If we were to let the light bulb dim for only two seconds, and then disconnect the capacitor from the batteries and discharge it back through the light bulb, how bright do you think the bulb will be when we connect it to the capacitor?

The bulb will be very dim. The capacitor was only slightly charged during that 2 second interval.

The voltage across the capacitor is dependent on the time it was given to charge. Because we charged the capacitor for only 2 seconds the voltage across the capacitor is very low. When we hook the bulb up to the low voltage, the current produced is very low, causing the bulb to be dim.

Lab Preparation

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

1. Check all the AA-cell batteries using a voltage sensor or digital multi-meter to make certain they all produce 1.5 V.

Safety

Add this important safety precaution to your normal laboratory procedures:

- If you choose to use a voltage source other than the 2 AA batteries, do not exceed the ratings of the components in your circuit.

Sequencing Challenge

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

1	5	2	4	3
Drain the capacitor by shorting (electrically connecting together) the two terminals from the capacitor.	Indicate on the Voltage versus Time graph the point where voltage is 36% of its original value.	Connect the voltage sensor in parallel across the capacitor and the current sensor in series in the circuit.	Charge the capacitor by closing the switch to the "Charge" position.	Begin recording voltage and current data.

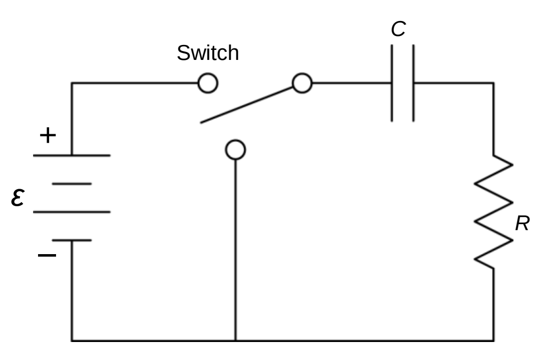
Procedure with Inquiry

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 – Measuring Capacitor Voltage

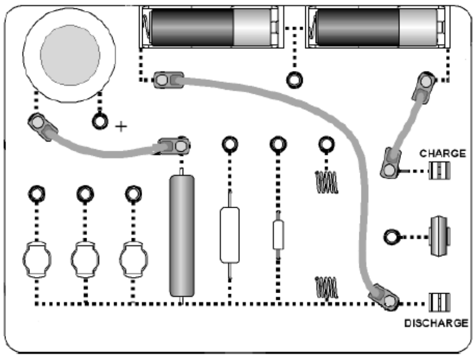
Set Up



1. ☐ Install the "AA" batteries in the battery holders of the charge/discharge circuit board with both positive terminals facing to the right.

2. ☐ Momentarily connect a patch cord across the terminals of the capacitor to insure it is discharged before you begin assembling your circuit.

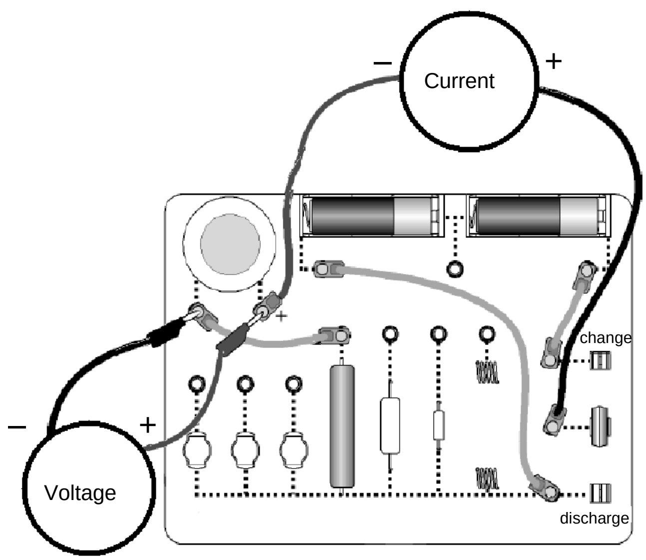
3. ☐ Assemble your circuit on the charge/discharge circuit board using 4 mm banana plug patch cords. Your circuit will consist of a 1 F capacitor and a 10 Ω resistor powered by a 3 VDC source (batteries).



RC circuit using a the 10 Ω resistor

NOTE: The solid lines represent the patch cords.

4. ☐ Connect your current sensor in series between the positive capacitor terminal and the middle pole of the switch, and connect your voltage sensor in parallel across the terminals on the capacitor.



RC circuit using a the 10 Ω resistor measuring capacitor voltage

5. ☐ After having connected all of the components in your RC circuit, do you think that the capacitor is now charged-up or empty? Explain your answer.

Empty. We started by discharging the capacitor, and the switch has not been closed yet. The batteries are disconnected from the circuit until the switch is moved to the "Charge" position.

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

7. ☐ Connect the voltage and current sensor to the data collection system. �(2.1)

8. ☐ Display both Voltage and Current on the y-axis of a graph with Time on the x-axis so that they can be directly compared. �(7.1.10)

9. ☐ Change the sample rate to acquire data at a minimum rate of 10 Hz. �(5.1)

Collect Data

10. ☐ Start data recording. �(6.2)

11. ☐ Close the switch in the "Charge" position, thus closing the circuit and allowing current to flow.

12. ☐ At this point, which direction do you think current is flowing through the resistor? Why?

Current flows from positive to negative. Because the components in the circuit are in series with the battery, the current flows from the positive terminal of the batteries to the negative terminal.

13. ☐ Observe the current data on your data collection system. Is the current positive or negative? What would happen if the two current sensor leads swapped places on the circuit board?

The current should be positive. If the leads were switched, the current would appear to be negative: flowing in the opposite direction.

14. ☐ Wait until the current and voltage readings stabilize, and then proceed to the next step.

15. ☐ Move the switch from the "Charge" position to the "Discharge" position.

16. ☐ At this point, which direction do you think current is flowing through the resistor: up or down? Why?

The current will reverse direction through the resistor because the battery is no longer in the circuit and the capacitor is driving the current.

17. ☐ Wait until the readings stabilize, and then proceed to the next step.

18. ☐ Stop data recording. �(6.2)

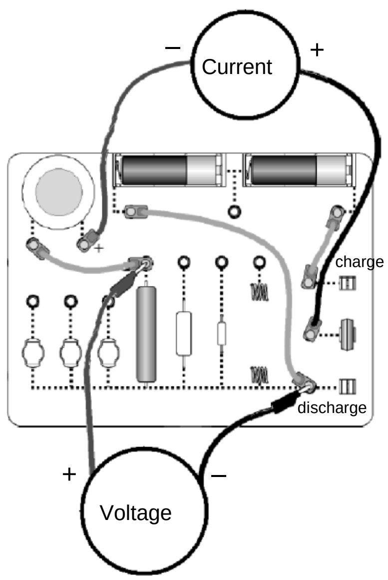
Analyze Data

19. ☐ Sketch your graphs of Voltage versus Time and Current versus Time in the space provided in the Data Analysis section.

Part 2 – Measuring Resistor Voltage

Set Up

20. ☐ Remove the voltage sensor from the circuit, and then reattach it across the 10 Ω resistor.



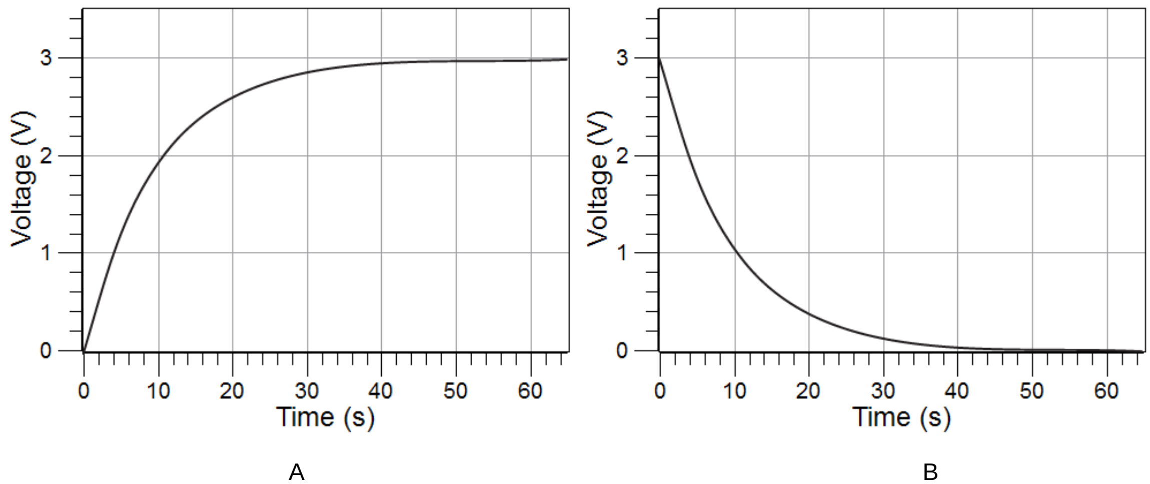
RC circuit using a the 10 Ω resistor measuring resistor voltage

21. ☐ Why do we have to move the voltage sensor but not the current sensor when investigating the resistor?

This is a series circuit. So, the current is the same at any point in the loop, and it can be measured anywhere in the circuit.

Collect Data

22. ☐ Graph A below indicates the voltage across the capacitor versus time as it charges. In graph B, sketch a prediction of what you would expect the voltage across the resistor to be versus time as the capacitor charges.



Most students will understand that the current in the circuit decreases as the capacitor charges-up, thus decreasing the voltage across the resistor according to Ohm's Law:

23. ☐ Start data recording. �(6.2)

24. ☐ Close the switch in the "Charge" position, thus closing the circuit and allowing current to flow.

25. ☐ Wait until the readings stabilize, and then proceed to the next step.

26. ☐ Move the switch from the "Charge" position to the "Discharge" position.

27. ☐ Given the shape of the capacitor's Voltage versus Time curve when charging, does the resistor's Voltage versus Time curve make sense? Why?

Yes, the total potential drop across the circuit is equal to the potential of the batteries. There are only two components in the series circuit, so the sum of the voltages must equal the total voltage.

28. ☐ Wait until the readings stabilize, and then proceed to the next step.

29. ☐ Stop data recording. �(6.2)

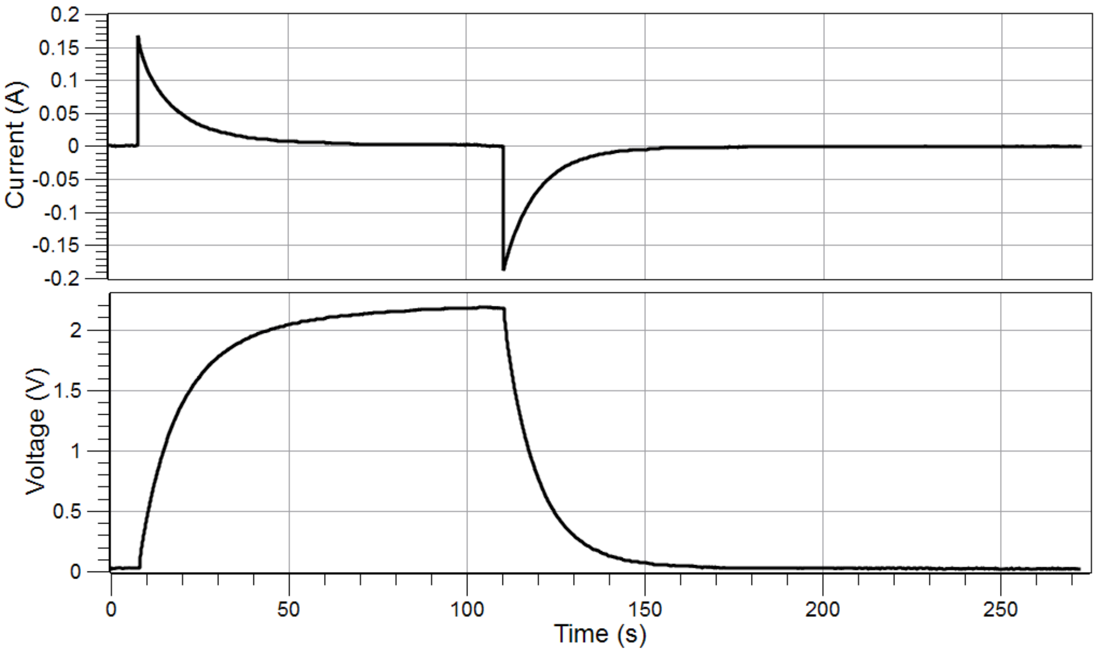
Analyze Data

30. ☐ Sketch your graphs of Voltage versus Time and Current versus Time in the space provided in the Data Analysis section.

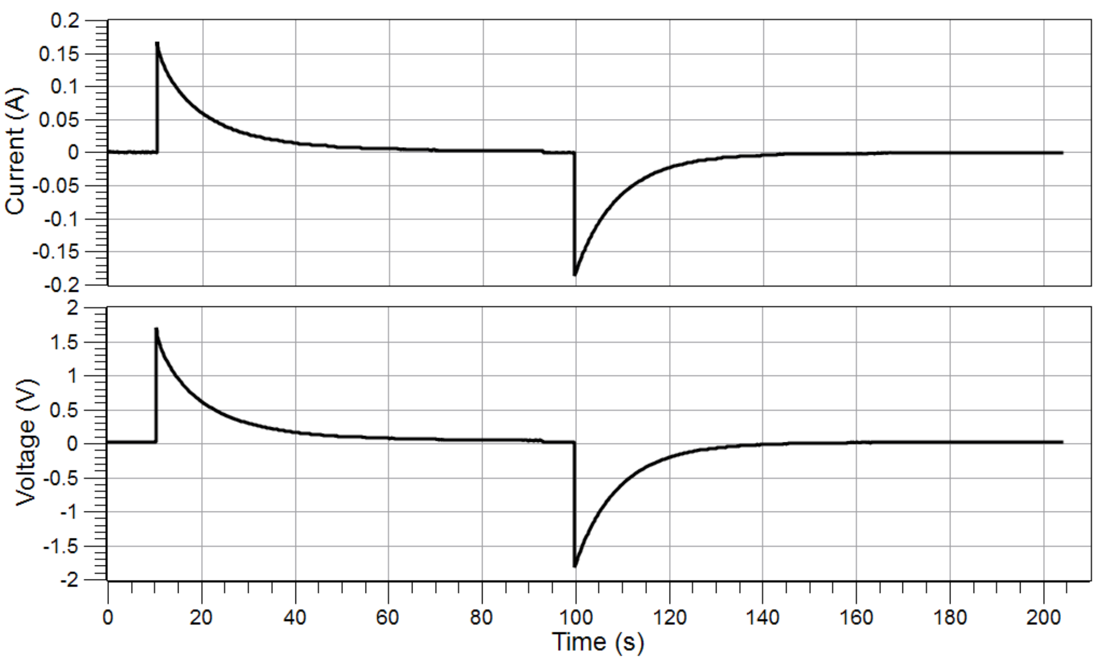
31. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Graph 1: Current versus time and voltage versus time for the capacitor



Graph 2: Current versus time and voltage versus time for the resistor



Analysis Questions

1. How did your graph of Voltage versus Time for the resistor compare to your prediction?

Answers may vary: They looked very similar. Or, our prediction was upside-down compared to the actual graph.

2. How does your Voltage versus Time graph for the capacitor and Voltage versus Time graph for the resistor compare to each other? What are some of the similarities and differences?

They are similar shapes, but the V_R graph is upside-down compared to the V_C graph. V_R starts at 3 and decreases to 0, while V_C starts at 0 and increases to 3.

3. Display your Voltage versus Time graph for the capacitor and Voltage versus Time graph for the resistor. �(7.1.10) If the function describing the Voltage versus Time graph for the capacitor is $V_C(t)$, what would be the function for your Voltage versus Time graph for the resistor in terms of $V_C(t)$? *Hint: $f_2(t) = -f_1(t)$ indicates that f_2 is the same graph as f_1, just inverted about the x-axis with no shift.*

*V*R*(t)* is the same function as *V*C*(t)* except it is inverted and shifted up 3:

*V*R*(t) = 3 - V*C*(t)*

4. How does your graph of V_R versus Time compare to the Current versus Time graph for the same charge and discharge cycle? Using Ohm's law, show how the two are mathematically related.

The two graphs have the same shape with different *y*-axis values. According to Ohm's Law, $V = IR$, therefore:

$$V_R(t) = I_0 R\, e^{-t/RC}$$

5. On your V_R versus Time graph, find the time at which the voltage decreases to only 36% of its original starting voltage after the switch was closed and the capacitor began to charge. Compare that value for time to the actual time constant τ for your circuit. What is the percent error? �(9.1)(9.2)

$$\tau_{\text{measured}} = 10.2\text{ s}$$

$$\tau_{\text{actual}} = R \times C = 10.0\text{ s}$$

$$\%\,\text{Error} = \frac{|10.0\text{ s} - 10.2\text{ s}|}{10.0\text{ s}} \times 100 = 2\%$$

6. What are some of the factors that may have caused your measured time constant value to have error? How might these factors have been prevented?

Some possible factors:

The capacitor had residual charge before changing discharging.

The capacitor may have leaked charge into the atmosphere.

Batteries may not have been an ideal voltage source.

Wire leads introduce more resistance into the circuit causing R × C to be greater.

Poor connections.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What is the maximum positive current through a resistor that is part of a simple RC circuit powered by 15 VDC with R = 1 MΩ and C = 485 pF? At what point in the charge and discharge cycle does it occur? Justify your answer.

The maximum positive current occurs when the capacitor is just beginning to charge, at which point the capacitor is basically not part of the circuit, and current is equal to V/R:

I = V/R = (15 V)/(1 × 10^6 Ω) = 15 μA

2. Calculate the amount of charge stored in a fully charged capacitor that is part of a simple RC circuit powered by 3 VDC with R = 330 kΩ and $\tau = 4.25 \times 10^{-4}$ s. Show your work.

$$\tau = RC$$

$$Q = CV$$

$$Q = \frac{\tau}{R}V = \frac{4.25 \times 10^{-4}\ \text{s}}{330 \times 10^{3}\ \Omega}(3\ \text{V})$$

$$Q = 3.86 \times 10^{-9}\ \text{C}$$

3. If you were measuring the voltage across a charging capacitor in a simple RC circuit powered by 5 VDC with R = 220 kΩ and C = 47 μF, how long will it take for the voltage across the capacitor to reach 3.15 V? Show your work. *Hint: you will not need to use Equation 2 or Equation 3*

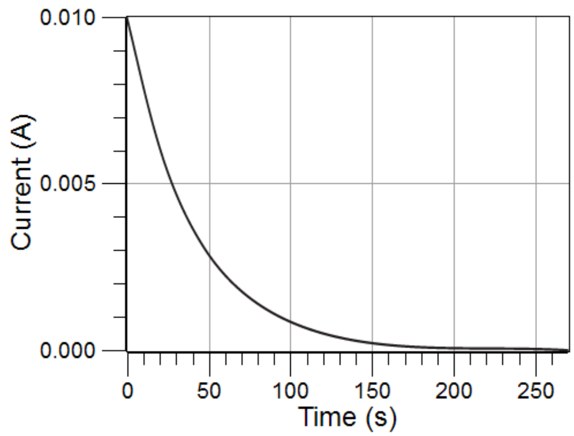
3.15/5 = 63%

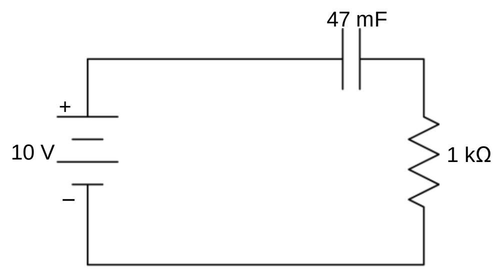
Therefore time will equal the time constant $RC = (220 \times 10^{3}\ \Omega)(47 \times 10^{-6}\ \text{F}) = 10.34$ s

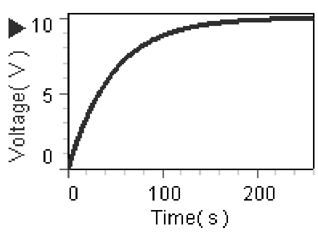
Multiple Choice Questions

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

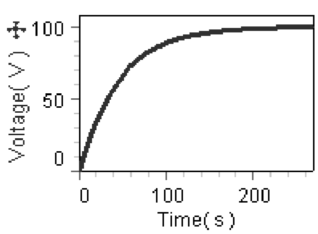
1. The graph below describes the current through the resistor in the accompanying circuit as the capacitor is being charged. Which of the graphs A through D describes the voltage across the capacitor in the circuit?

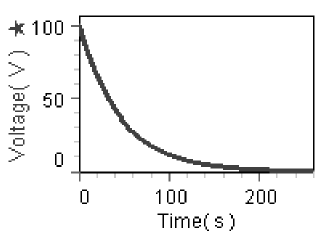


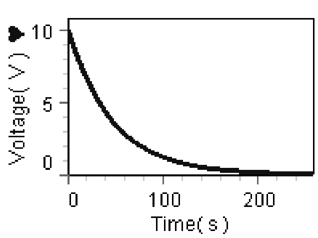


A. 

[correct]

B. 

C. 

D. 

2. We used two AA-cell batteries that produced a constant 3 VDC. If we had instead used a power supply the provided the circuit with 25 VDC, how would our time constant be different:

- **A.** τ would increase.
- **B.** τ would decrease.
- **C.** **τ would stay the same.**
- **D.** There is not enough information.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. When a DC voltage source is connected across an uncharged capacitor, the rate at which the capacitor charges up **decreases** as time passes. At first, the capacitor is easy to charge because there is very little **charge** in the capacitor. But as charge **accumulates** in the capacitor, the voltage source must "do more work" to move additional charge onto the plates because the plates already have charge of the **same** sign on them. As a result, the capacitor charges **exponentially**: quickly at the beginning, and more slowly as the capacitor becomes **fully charged**.

2. The shape of the voltage versus time graph for the resistor in a simple RC circuit is **different** from the voltage versus time graph for the capacitor in the same circuit while the capacitor charges and discharges. As the charge in the capacitor **increases**, the voltage across the capacitor increases. However, as the capacitor charges-up, the voltage across the resistor **decreases** because the current in the circuit decreases. When the capacitor discharges through the **resistor**, current flows through the resistor in the **opposite** direction it was flowing when the **capacitor** was charging.

Extended Inquiry Suggestions

It may be beneficial to your students to incorporate more series and parallel resistor and capacitor combinations into the discussion of RC circuits. Explore with your students how the time constant changes with the addition and subtraction of capacitance and resistance, and how this can be accomplished using additional components connected in series or parallel.

Ask your students: "We have a circuit that has a time constant equal to t, but we must decrease this value to $t - x$ for our application. Considering that we only have access to more of the same resistor and capacitor in our circuit, how could you reconfigure the circuit to accomplish this?"

33. Magnetic Field: Permanent Magnet

Objectives

Although we cannot directly see the presence of magnetic fields, we can detect their existence. For example, we can use compasses positioned around the perimeter of a bar magnet. The needles in the compasses will align themselves with the magnetic field surrounding the magnet, indicating the direction of the field lines. In this lesson, students investigate the strength of the magnetic field of a permanent magnet as a function of distance from the magnet.

Procedural Overview

Students gain experience conducting the following procedures:

- Aligning a magnetic field sensor with the magnetic field from a permanent magnet.
- Measuring and recording the magnetic field strength from a permanent magnet as a function of distance from the magnet
- Determining the relationship between the magnetic field strength and distance from a permanent magnet

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	30 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Magnetic field sensor
- Sensor extension cable (optional)
- Neodymium magnet (1/2" or 3/4")
- Meter stick (non-metallic)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Gravitational and electric fields

Related Labs in This Guide

Labs conceptually related to this one include:

♦ Magnetic Field: Coil

Using Your Data Collection System

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

♦ Starting a new experiment on the data collection system �(1.2)

♦ Connecting a sensor to the data collection system �(2.1)

♦ Putting the data collection system into manual sampling mode with manually entered data �(5.2.1)

♦ Starting a manually sampled data set �(6.3.1)

♦ Recording a manually sampled data point �(6.3.2)

♦ Stopping a manually sampled data set �(6.3.3)

♦ Displaying data in a graph �(7.1.1)

♦ Adjusting the scale of a graph �(7.1.2)

♦ Changing the variable on the *x*- or *y*-axis of a graph �(7.1.9)

♦ Drawing a prediction �(7.1.12)

♦ Applying a curve fit �(9.5)

♦ Saving your experiment �(11.1)

Background

The presence of magnetic fields permeates everyday life in many ways. A microwave oven contains a magnet that aides in directing radiation towards the center of the oven. Stereo speakers contain magnets that control the coils that accept the audio signals. Basic electric motors consist of magnets.

The strength of a magnetic field varies with distance from a magnet. Students familiar with concepts such as light intensity from a point source, or gravitational field strength, might guess that magnetic field strength varies inversely as the square of the distance. Unlike gravitational or electric fields which are radial, a magnetic field from a permanent magnet consists of complete loops that surround and go through the magnet forming two distinct poles (north and south). As a result, the magnetic field strength varies inversely as the cube of distance.

$$\vec{B} \propto \frac{1}{d^3}$$

Pre-Lab Discussion and Activity

Engage your students by considering the following questions:

1. What makes a material magnetic? Are there any naturally occurring minerals in the earth that are magnetic?

The phenomena called magnetism consists of materials that can either attract or repel other magnetic materials. Some materials such as iron, nickel, cobalt, steel, and magnetite have easily detectable magnetic properties. Magnetite is the only naturally occurring magnetic material.

2. How would you magnetize a pair of scissors?

Simply rubbing a bar magnet on a pair of scissors or a long knitting needle will cause the surface electrons (electronic) domains to become aligned, thus becoming magnetic.

3. What may happen when you place small paper clips in and around a bar magnet?

Ask students to place a bar magnet on their desk and position several paper clips around the magnet at varying distances. What happens? Ask the students why some paper clips react quickly and cling to the magnet (more so at the poles) and others do not move at all.

Materials such as the clips that are closest to the magnet are in the strongest area of the field and will react by being drawn toward the magnet. Clips that do not move, are located in a region of the magnetic field that is very weak.

4. What happens when we place a small compass around the outside of a bar magnet?

Assuming the colored tip is marked as North students should find that the colored tip of the needle is directed into the south pole, or away from the north pole. As students move the compass to varying positions, instruct them to mark the position of the colored tip to show the direction of the magnetic field at that point.

If you have enough compasses available, have students try this for themselves, otherwise demonstrate for the class.

Lab Preparation

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

1. Lay out supplies as listed in the materials and equipment section.
2. If the magnetic field sensor you are using has both radial and axial measurements built in, be sure your students are measuring the axial field.

3. Do not use lab benches or tables made of metal.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ Keep magnets away from computers.

♦ Keep the magnet away from the magnet field sensor when you zero the sensor.

Sequencing Challenge

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

3	2	4	1
Place a magnet next to the 5 cm mark on the meter stick with the north pole of the magnet facing the sensor.	Place the magnetic field sensor so the end of the probe is even with the zero end of the meter stick.	Record a manually sampled data point for every 1cm increase in the magnet's position.	Place a meter stick on a flat surface.

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. ☐ What two quantities will you measure?

Magnetic field strength and distance to the magnet.

2. ☐ What tools will you use to help you make these measurements?

A magnetic field sensor and metric ruler.

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

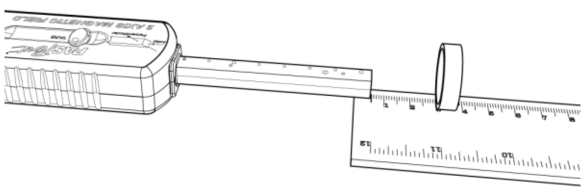
4. ☐ Connect the magnetic field sensor to the data collection system. �(2.1)

5. ☐ Put your data collection system into manual sampling mode with manually entered data. Name the manually entered data "Distance" and give it units of meters. �(5.2.1)

6. ☐ Display Magnetic Field on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

7. ☐ Change the variable on the *x*-axis to Distance. �(7.1.9)

8. ☐ How do you think the magnetic field will change with distance? Draw a prediction in the Magnetic Field versus Distance Prediction blank graph axes in the Data Analysis section. Be sure to label the graph axes.



9. ☐ Set the meter stick flat on a table.

10. ☐ Set the magnetic field sensor on the table so that the tip of the sensor is aligned with the "0 cm" marker on the meter stick.

11. ☐ If the sensor you are using has a Tare button, press it before bringing the magnet near the sensor.

12. ☐ Set the magnet on the table against the meter stick with the end of the north pole pointed towards the tip of the magnetic field sensor.

13. ☐ Slide the magnet along the meter stick until it is aligned with the 5 cm marker on the meter stick (0.05 m away from the tip of the sensor).

Collect Data

14. ☐ Go to the data table you created on the data collection system.

15. ☐ Make sure the north end of the magnet points toward the magnetic field sensor. If the magnetic field reading is negative, turn the magnet around.

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

17. ☐ Starting at 0.05 m (5 cm) and ending at 0.15 m (15 cm), record a magnetic field value for each centimeter of distance, moving the magnet 1 cm at a time between each recorded value. �(6.3.2)

18. ☐ Stop the manually collected data set. �(6.3.3)

Analyze Data

19. ☐ Go to the Magnetic Field versus Distance graph you created on the data collection system.

20. ☐ Sketch the graph of Magnetic Field versus Distance in the Magnetic Field versus Distance blank graph axes in the Data Analysis section.

21. ☐ Based on this graph, what do you think the mathematical relationship is between the strength of the magnetic field and the distance from the magnet?

Student answers will vary, but will likely center around an inverse square relationship: $\vec{B} \propto \frac{1}{d^3}$

22. ☐ Apply a "Power" curve fit to the graph on your data collection system. �(9.5)

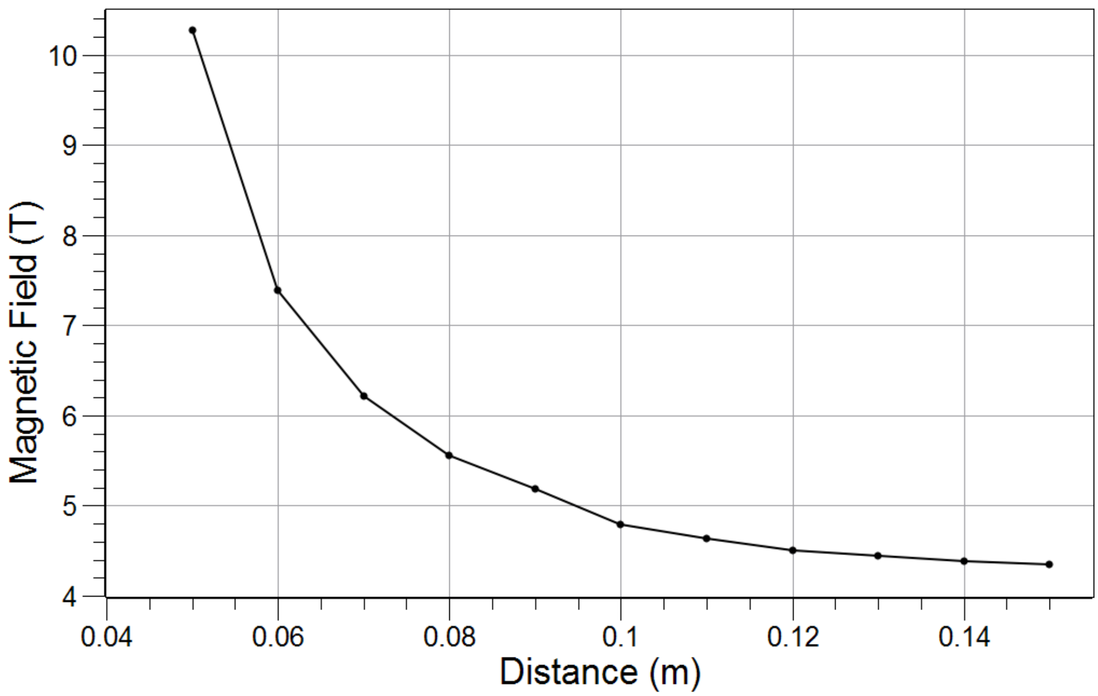
Note: If your data collection system does not support curve fits other than linear, try linearizing your data by building a calculation on the data and then applying the linear curve fit. If the linear curve fit is successful then the calculation describes the relationship between the variables.

23. ☐ Add the curve fit to your sketch in the Magnetic Field versus Distance graph in the Data Analysis section.

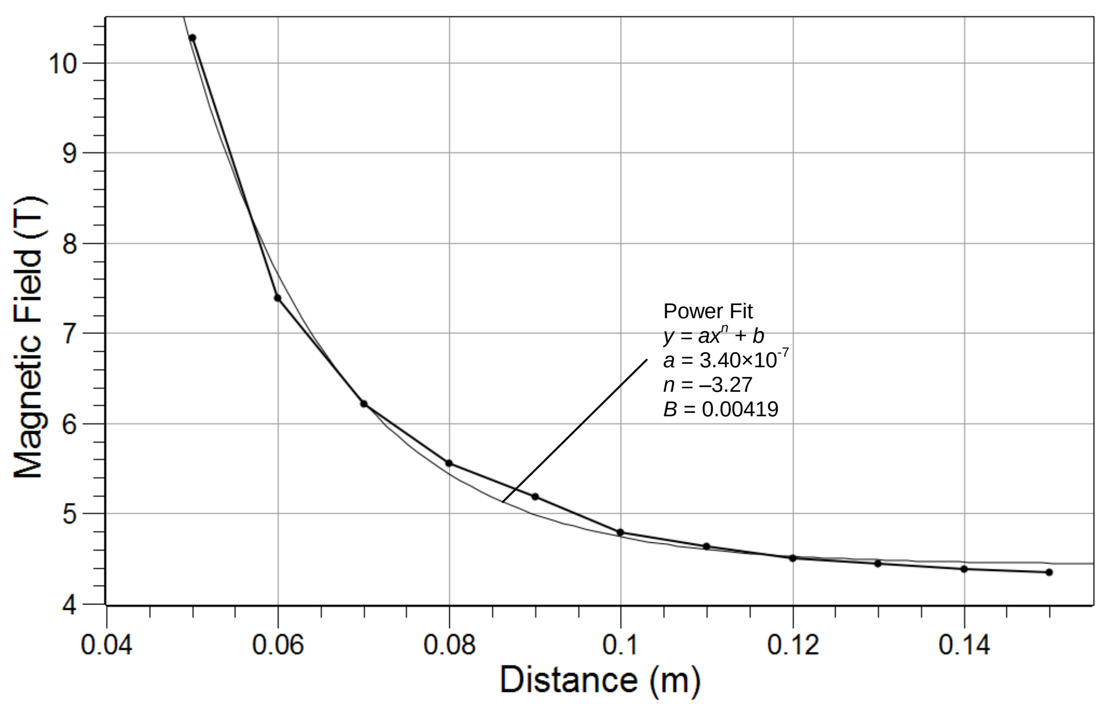
24. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Magnetic Field versus Distance Prediction



Magnetic Field versus Distance



Analysis Questions

1. How does the actual graph compare to your prediction?

Student answers will vary.

2. How well did your curve fit match your data?

Student answers will vary, but the “power” fit should be a good fit for their data.

3. Was the mathematical relationship you chose in the Analyze Data Section representative of the theoretical relationship?

Student answers will vary, but they should make some direct comparison between their predicted relationship and the actual relationship illustrated by the curve fit.

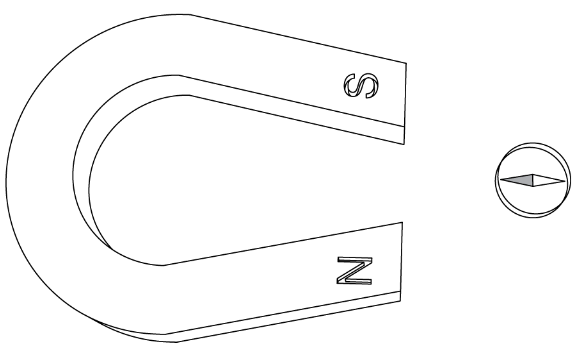
4. From the result of your curve fit, what do you conclude is the mathematical relationship between the magnetic field strength and distance?

$$\vec{B} \propto \frac{1}{d^3}$$

Synthesis Questions

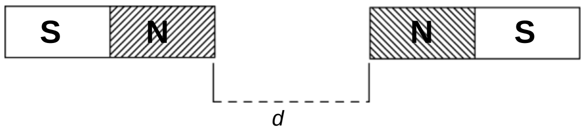
Use available resources to help you answer the following questions.

1. The needle in a compass acts like a tiny bar magnet. When the needle is in the presence of a strong magnetic field, it will align itself with that field. If the red end of the needle represents the south pole of the "magnet," which direction would the red end point if the compass were placed between the poles of the magnet?



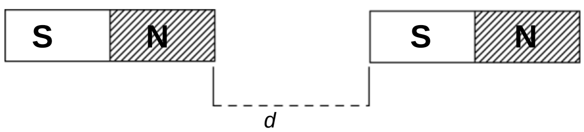
The red end of the needle would point to the south pole of the magnet.

2. **If you had two identical bar magnets separated by distance *d* with the north pole of each magnet facing the other, what value would your magnetic field sensor read at distance *d*/2 (exactly half way between the magnets)?**



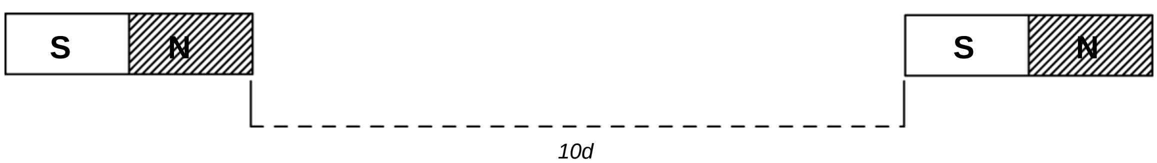
0

3. **If each magnet alone produces an axial magnetic field strength of 0.25 T at a distance *d*/2, what value would your magnetic field sensor read at distance *d*/2 if the north and south poles were facing each other a distance *d* apart?**



0.5 T

4. **How will the magnetic field strength measured half way between the magnets change (increase, decrease, or stay the same) if the distance between the magnets in increased from *d* to 10*d*?**



Decrease.

Multiple Choice Questions

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

1. **A compass is positioned at a location near the north pole of a bar magnet with the white end of the needle pointing towards the north pole. How does the compass needle orient itself when placed near the south pole?**

- **A.** The white end of the needle remains pointing towards the north pole
- **B.** The white end of the needle points perpendicular to the north pole
- **C.** **The white end of the needle points away from the south pole**
- **D.** The white end of the needle points inward towards the south pole.

2. As the magnitude of the magnetic field of a permanent (disc) magnet increases, the position of the sensor from the magnet will ____________.

- **A.** Increase
- **B.** **Decrease**
- **C.** Remain the same
- **D.** Decrease to zero

Key Term Challenge

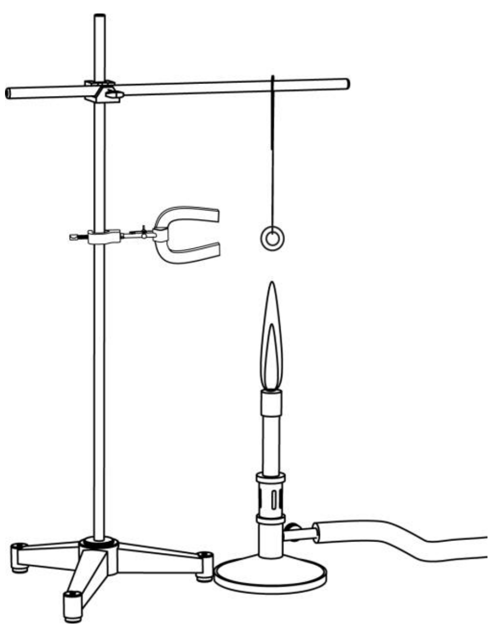
Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. Magnets come in many shapes and sizes, but all of them have two poles. We identify the poles as **North** and South. An example of a strong **permanent** magnet is called a neodymium magnet. A simple device, such as a **compass,** is an example of a weak permanent **magnet**. The units for magnetic field strength are named after their founding fathers; such as **Tesla** and Gauss.

Extended Inquiry Suggestions

Curie Point

A ferromagnetic material can be demagnetized by heating it beyond its Curie Point. The Curie point is the temperature at which it loses its ferromagnetic ability. The demonstration below shows a magnet attracting a small iron object. If the object is heated by a flame, the object loses it attraction to the magnet and hangs straight down.



34. Magnetic Field: Coil

Objectives

This activity is designed to provide students with an understanding of some of the factors affecting the electromagnetic field strength within a solenoid. Throughout the activity students will:

- Build foundational understanding of how magnetic field strength inside a coil is related to the magnitude of current carried through the coil wire
- Explore the relationship between and the number of turns of wire in a coil and the magnetic field strength within the solenoid

Procedural Overview

Students gain experience conducting the following procedures:

- Measuring and recording the magnitude of the magnetic field within a coil
- Plotting a graph of Magnetic Field versus Turns in a coil to determine the relationship between the magnetic field strength and the number of turns in a coil,
- Plotting a graph of Magnetic Field versus Current in the wire of a coil to determine the relationship between magnetic field strength and the current flowing through a coil.

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Current sensor
- Magnetic field sensor
- Sensor extension cable (optional)
- Coils of varying turns but the same radius (3)
- Meter stick
- DC power supply, 10-V 1-A minimum
- Patch cord, 4-mm banana plug (3)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Forces and motion
- ♦ Electric and magnetic fields
- ♦ Magnetic fields induced by current-carrying wire

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Magnetic Field: Permanent Magnet
- ♦ Charges and Electric Fields
- ♦ Ohm's Law
- ♦ Faraday's Law of Induction

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data collection system �(2.2)
- ♦ Putting the data collection system into manual sampling mode �(5.2.2)
- ♦ Monitoring live data without recording �(6.1)
- ♦ Starting a new data set in manual sampling mode, recording data points, and stopping the data set �(6.3)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Changing the variable on the *x*-or *y*-axis of a graph �(7.1.9)
- ♦ Adding a measurement to a digits display �(7.3.2)
- ♦ Applying a curve fit �(9.5)
- ♦ Saving your experiment �(11.1)

Background

The use of coils as electromagnetic devices is varied. The following is a list of applications of the coil:

- ♦ Transformers that allow electricity to be delivered long distances
- ♦ Pickup coils that convert the movement of metal guitar strings into electrical currents that are amplified through speakers.
- ♦ Voice coils within loudspeakers
- ♦ Poly phase coils within electric motors that convert electrical energy to mechanical energy
- ♦ Coils within a generator that convert mechanical energy into electrical energy

The proliferation of applications for coils make it important to understand how they behave. The strength of the magnetic field inside a coil depends upon the number of turns of the wire, the magnitude of the current in the wire, and the radius of the coil:

$$B = N\left(\frac{\mu_0 I}{2R}\right)$$

Where B is the magnetic field strength, N is the number of turns, μ_0 is a constant ($\mu_0 = 4\pi \times 10^{-7}\ \text{N}\cdot\text{A}^{-2}$), I is the current in amperes, and R is the radius of the coil in meters.

The direction of the magnetic field depends upon the direction of the current. One way to determine the direction of the magnetic field is called Right Hand Rule 2: Grasp the wire (do not touch a live wire) with your right hand and point your thumb in the direction of the current. Your fingers show the direction of the magnetic field around the wire.

Pre-Lab Discussion and Activity

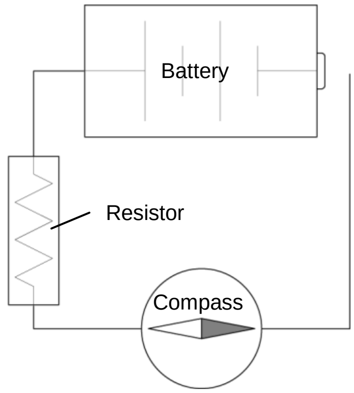
Engage your students by considering the following questions:

1. What are the different sources of magnetic fields?

Some materials like iron, nickel, cobalt, steel, and magnetite (also known as ferromagnetic materials or permanent magnets) remain magnetic and produce magnetic fields. An electromagnet is a device that uses an electric current to induce a magnetic field.

As a refresher, use a battery (1.5 V), wire, resistor (10 Ω), and a compass with a non-metallic body to show that a current carrying wire does indeed generate a magnetic field.

On a non-metallic table, connect one end of the resistor to the negative end of the battery, and the wire to the other end of the resistor. Lay the compass over the wire and arrange everything so that the needle of the compass is in line with the wire.



Touch the loose end of the wire to the positive side of the battery, and observe the deflection of the needle. A document camera and projector is a great way to convey this demonstration to a larger group.

2. Does the deflection of the needle agree with your understanding of the right hand rule?

Yes. Using Right-Hand-Rule 2: Grasp the wire (do not touch a live wire) with your right hand, point your thumb in the direction of the current. Your fingers show the direction of the magnetic field around the wire. The needle of the compass deflected to be parallel with the finger of the right hand.

3. If you have a compass, how would you determine the polarity of an electromagnet?

Place the compass along the axis of the electromagnet. The north end of the compass will align with the south end of the electromagnet.

4. How do you determine the direction of the magnetic field inside a coil?

Using Right Hand Rule 2: Imagine grasping the wire of the coil (do not touch a live wire) with your right hand, point your thumb in the direction of the current. Your fingers show the direction of the magnetic field inside the coil.

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:

- Keep the coil away from any sensitive electronic equipment.
- Keep liquids away from the power supply.

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	4	3
Measure and record the magnetic field at the center of the coil.	Attach the magnetic field sensor to the data collection system. Connect the power supply to the coil.	Repeat previous steps for all other coils.	Record the current within the coil and the radius of the coil.

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 - Number of turns in a coil versus magnetic field

Set Up

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

2. ☐ In this activity, what quantities will you measure, and in what units?

Magnetic field strength or magnetic flux density in tesla, current in amperes and the radius of the coil in meters.

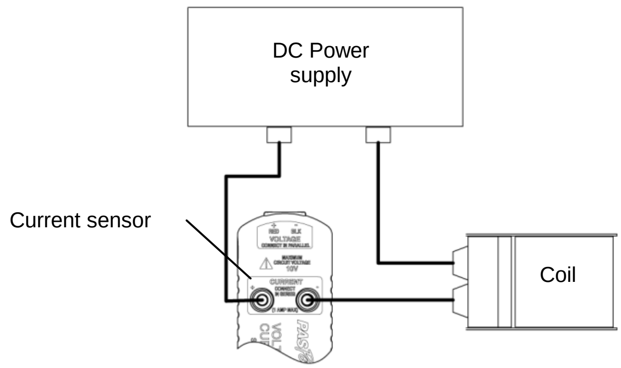
3. ☐ What tools will you use to help you make these measurements?

Magnetic field sensor, metric ruler, current sensor.

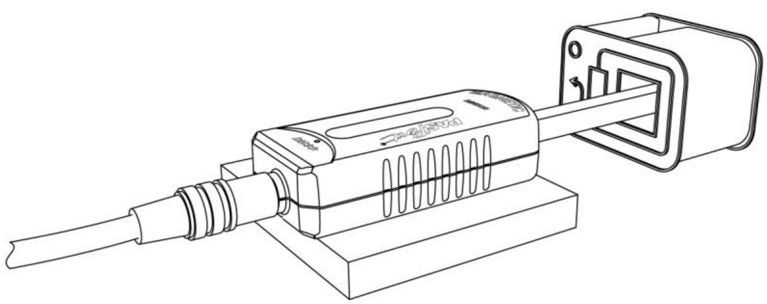
4. ☐ Connect the magnetic field sensor and the current sensor to the data collection system. �(2.2)

5. ☐ Measure the radius of the coils you will be using and record this value in the Data Analysis section.

6. ☐ Using patch cords, connect the negative terminal from the power supply directly to one of the terminals on the first coil. Connect the positive terminal from the power supply to the positive terminal on the current sensor, and then connect the negative terminal on the current sensor to the second terminal on the coil.



7. ☐ Position the tip of the magnetic field sensor inside the coil at the center such that the probe of the sensor is perpendicular to the plane of the coil.



8. ☐ Set up the data collection system to monitor current and magnetic field in a digits display. �(7.3.2) (6.1)

9. ☐ Turn on the power supply, and adjust the voltage until the current measured by the current sensor is approximately 0.5 A.

Collect Data

10. ☐ Record the current value in the Data Analysis section.

11. ☐ Record the number of turns in the coil and magnetic field strength in Table 1 in the Data Analysis section.

12. ☐ Turn off the power supply, disconnect the coil, and replace it with the next coil.

13. ☐ Reposition the coil and magnetic field sensor, and then turn the power supply back on. Adjust the voltage until the current is the same magnitude as was used with the previous coil.

14. ☐ Record the number of turns in the coil and the magnetic field strength in Table 1 in the Data Analysis section.

15. ☐ Turn off the power, disconnect the coil, and replace it with the last coil.

16. ☐ Reposition the coil and magnetic field sensor, and then turn the power supply back on. Adjust the voltage until the current is the same magnitude as was used with the previous coils.

17. ☐ Record the number of turns in the coil and the magnetic field strength in Table 1 in the Data Analysis section.

Analyze Data

18. ☐ Sketch a graph of Magnetic Field versus Turns of the Coil in the space provided in the Data Analysis section.

19. ☐ What type of mathematical relationship does the data appear to be in the first approximation?

Linear

20. ☐ How would you verify this relationship?

Repeat the data collection steps with additional coils that have the same shape and radius.

Part 2 - Current versus magnetic field

Set Up

21. ☐ Using the same set up as in Part 1, turn the voltage all the way down on the power supply.

22. ☐ Put the data collection system into manual sampling mode without manually entered data. �(5.2.2)

23. ☐ Display Magnetic Field on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

24. ☐ Change the variable on the *x*-axis from Time to Current. �(7.1.9)

25. ☐ How do you think the magnetic field will change with respect to current? Use the data collection system to draw a prediction, and then copy the prediction to the Magnetic Field versus Current graph in the Data Analysis Section. Be sure to label the graph axis. �(7.1.12)

Collect Data

26. ☐ Start recording a set of manually sampled data. �(6.3)

27. ☐ Increase the voltage slightly until the current increases about 0.1 A.

28. ☐ Record the data point, and then adjust the voltage until the current increases approximately another 0.1 A. �(6.3)

29. ☐ Continue collecting data points every 0.1 A until you have data points that range from 0 to 1.0 A, and then stop Data Collection. �(6.3)

Note: your teacher may choose a different current range to measure based on the coils you are using. Do not exceed the current rating of the coil you are using.

Analyze Data

30. ☐ Sketch the Magnetic Field versus Current graph from the data collection system to the space provided in the Data Analysis section.

31. ☐ Based on this graph, what do you think the relationship is between the strength of the magnetic field and the current through the coil?

The relationship is linear or directly proportional.

32. ☐ Apply a linear curve fit to the graph on the data collection system. �(9.5)

33. ☐ Add the curve fit to the Magnetic Field versus Current sketch in the Data Analysis section.

34. ☐ Save your experiment as instructed by your teacher. �(11.1)

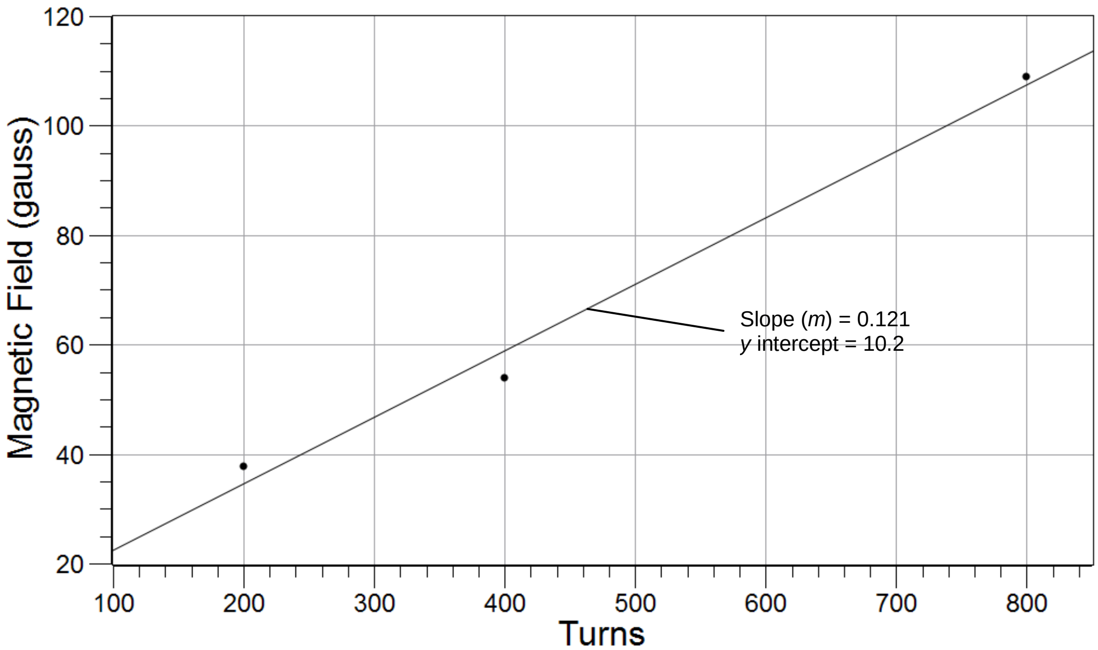
Data Analysis

Current in the coils: 0.612 A Radius of the coils: .023 m

Table 1: Number of Turns in the Coil and Magnetic Field

Number of Turns in the Coil	Magnetic Field (T) Measured	Magnetic Field (T) Calculated	Percent Difference
200	0.0032	.0033	3.1%
400	0.0059	.0067	12%
800	0.011	0.013	15%

Magnetic Field versus Number of Turns in the Coil



1. ☐ The theoretical strength of the magnetic field inside a circular coil depends upon the number of turns of wire N, the magnitude of the current in the wire I, and the radius of the coil R:

$$B = N(\frac{\mu_0 I}{2R})$$

Where μ_0 is a constant ($\mu_0 = 4\pi \times 10^{-7}$ N·A^{-2}).

Calculate the Theoretical value for the coils you used and add these values to the data table.

$$B = N(\frac{\mu_0 I}{2R})$$

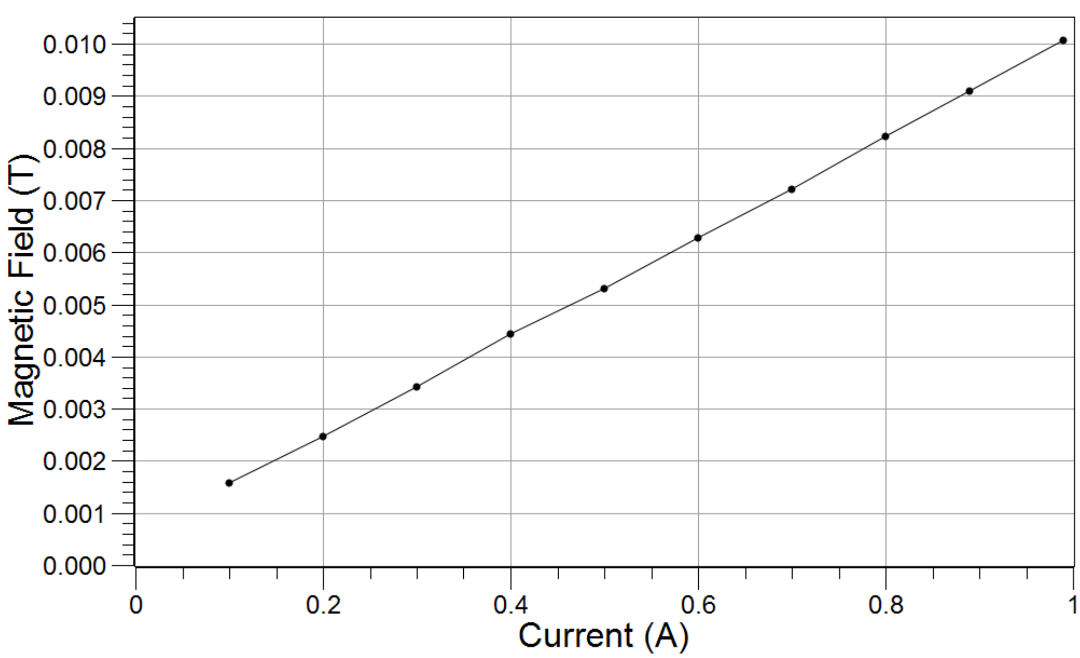
$$B = 800\left(\frac{(4\pi \times 10^{-7}) \times 0.612\text{A}}{2 \times 0.023\text{m}}\right)$$

$$B = 0.013\ \text{T}$$

2. ☐ Compare your measured values to your calculated values for the magnetic field strength within each coil. Find the percent difference and add these values to the data table.

$$\frac{(B_{\text{measured}} - B_{\text{calculated}})}{\left(\frac{B_{\text{measured}} - B_{\text{calculated}}}{2}\right)} \times 100 = \frac{(0.0032\ \text{T} - 0.0033\ \text{T})}{\left(\frac{0.0032\ \text{T} + 0.0033\ \text{T}}{2}\right)} \times 100 = 3.1\%$$

Magnetic Field versus Current



Analysis Questions

1. How do you account for the differences in your calculated values versus your measured values?

The equation used in this experiment assumes a completely circular coil. If the coil is not completely circular, then a systematic error will appear.

2. Is there a pattern in your results? If so, explain.

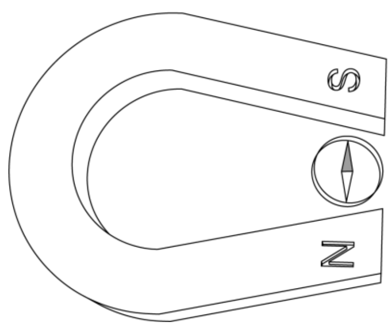
The magnetic field strength appears to be proportional to the current and the number of turns in a coil.

Synthesis Questions

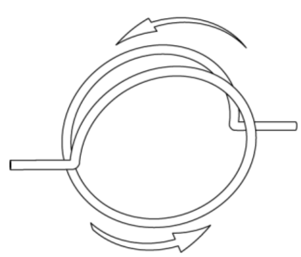
Use available resources to help you answer the following questions.

1. The needle in a compass acts like a tiny bar magnet. When the needle is placed between the poles of the magnet the red end of the compass needle points toward the south pole of the magnet. It is hypothesized that the earth acts as a large electromagnet because of the flow of molten material within it. When the same compass is used on earth, the red end of the compass needle points toward the Earth's north pole. Account for this apparent disparity.

What we call the "north" pole is actually a magnetic south pole.

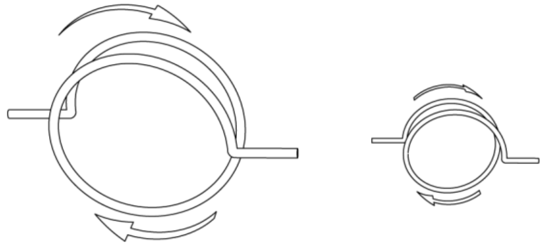


2. In the loop below, current flows counter clockwise. In what direction is the magnetic field inside the loop?



Outward.

3. In the figure below, the loop to the right has a radius half that of the loop to the left. What must happen to the current in the loop on the right in order to maintain the same magnetic field strength in the center of the coil, as the loop to the left?

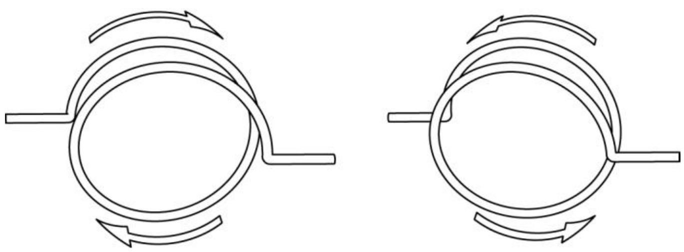


The current in the loop on the right must become half of the current of the loop on the left.

Multiple Choice Questions

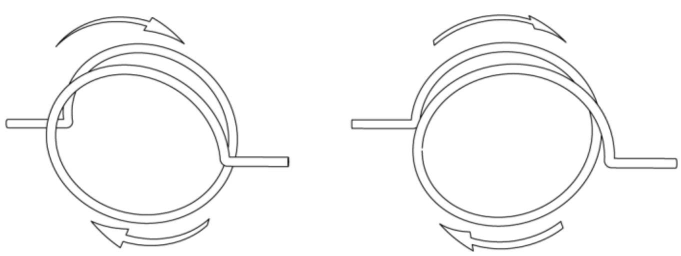
Select the best answer or completion to each of the questions or incomplete statements below.

1. The two loops below have the same current and the same radii. The current in the loop on the left is clockwise; whereas, the current in the loop on the right is counterclockwise. In what direction is the magnetic field at the point between them?



- **A.** Out of the paper.
- **B.** Into the paper.
- **C.** **The magnetic fields of the coils at the point between them cancel.**
- **D.** Upward.

2. The two loops below have the same current and the same radii. Both currents are clockwise. In what direction is the magnetic field at the point between them?



- **A.** **Out of the paper.**
- **B.** Into the paper.
- **C.** There is no magnetic field at the point between them.
- **D.** Upward.

Key Term Challenge

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

1. Two main types of magnets are **permanent** magnets and electromagnets. A wire carrying a **current** induces a magnetic field around it. When the wire is wound into a circle, it is called a coil. The magnetic field strength at the center of a coil depends upon the current and **radius** of the coil. If the coil contains many different turns, the magnetic field strength will **increase**. The current is **directly** proportional to the magnetic field strength. The **radius** is inversely proportional to the magnetic field strength.

Extended Inquiry Suggestions

The logical next step in the study of electromagnetism after the coil is the study of the solenoid. A current within a solenoid also produces a magnetic field. Theoretically, the magnetic field strength within a long solenoid is not radius dependent. Comparing and contrasting these different geometries and their subsequent derivations allow students to explore more advanced physics and mathematical constructs.

Another logical extension of this activity is to repeat the procedure for the Magnetic Field: Permanent Magnet lab by observing how the magnetic field from a coil falls off with distance from the coil.

A third variation of the experiment (radius) is to use multiple coils with the same number of turns but different radii. However, this is more difficult to quantify. If you have coils available, repeat Part 1 with radius as one of the variables.

35. Faraday's Law of Induction

Objectives

In this experiment, students observe the electromotive force generated by passing a magnet through a coil. Students will explore the relationship between:

- The number of turns in the coil and the magnitude of the electromotive force
- The rate of change of the magnetic flux by virtue of the size of the magnetic field in motion and the magnitude of the electromotive force
- The rate of change of the magnetic flux by virtue of the speed of the magnet field in motion and the magnitude of the electromotive force

Procedural Overview

Students gain experience measuring a continuously changing voltage for a very short duration. This lab pays particular attention to the scientific method of isolating a variable. In each of three parts, students isolate and change a single variable to determine the effect it has on the outcome.

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Voltage sensor
- 200, 400, and 800 turn coils
- Magnets of different strengths (3)
- Rod stand
- Three-finger clamp
- Paper
- Tape
- Pen or pencil
- No-bounce pad (Optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Voltage or electromotive force
- ♦ Current
- ♦ Magnetic fields
- ♦ Acceleration due to gravity

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Voltage: Fruit Battery/Generator
- ♦ Ohm's Law
- ♦ Magnetic Field: Permanent Magnet
- ♦ Magnetic Field: Coil

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to your data collection system �(2.1)
- ♦ Changing the sample rate �(5.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Displaying multiple data runs in a graph �(7.1.3)

- ♦ Adding a note to a graph �(7.1.5)
- ♦ Drawing a prediction �(7.1.12)
- ♦ Saving your experiment �(11.1)

Background

Michael Faraday (1791–1867) discovered a relationship between a changing magnetic flux Φ, and the potential within a conductor *ε*:

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} \qquad \textbf{Eq.1}$$

Known as Faraday's Law, this relationship is defined by two key elements: the number of turns in a coil *N*, and the change in magnetic flux Φ. The negative sign indicates that the induced electromotive force (emf) always opposes the change in magnetic flux. Magnetic flux is related to the strength of the magnetic field *B*, the area enclosed by the wire loop *A*, and the angle between them *θ*.

$$\Phi = BA\cos\theta \qquad \textbf{Eq.2}$$

Because the size of the coil we will be using is fixed, and we are dropping the magnet through the coil perpendicular to the plane of the wire loops in the coil (cosine θ term equals 1) we can say that the flux is proportional to the strength of the magnetic field.

We will investigate the rate of change of flux by using magnets of different strength and increasing the rate at which the magnet passes through the coil. We will use three different coils to see what effect different number of turns in a coil has on the induced electromotive force.

Pre-Lab Discussion and Activity

For the demonstration station:

- ♦ Data collection system
- ♦ Voltage sensor
- ♦ 800 turn coil
- ♦ Projection system recommended
- ♦ Magnet
- ♦ DC voltage supply
- ♦ Magnetic field sensor
- ♦ Patch cord, 4-mm banana plug (2)

Connect the DC power supply directly to the coil using the banana plug patch cords. Demonstrate with a magnetic field sensor that, when the power is "off," the magnetic field strength is zero, and when the power is "on," a field is present and stable. Use the magnetic field sensor to show that a stable field is also present around your magnet.

Connect the voltage sensor directly to the coil. Place the magnet in the center of the coil and hold it in place. Begin collecting or monitoring voltage data and show that the voltage produced by the static magnetic field is zero. This can also be accomplished with a demonstration multi-meter or voltmeter.

Challenge your students to predict what will happen when you pull the magnet out of the coil.

Teacher Tip: Accept all answers, and write ideas on the board or overhead projector, keeping them displayed during the activity.

Quickly pull the Magnet out of the coil, and discuss the result relative to the student predictions.

Lab Preparation

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

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

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Be careful with magnets. Strong magnets can disrupt electronic devices and severely pinch any skin that comes between them.
- ♦ Especially keep magnets away from computer hard drives, USB drives, or videotapes.

Sequencing Challenge

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

1	3	5	4	2
Connect the Voltage Sensor to the Data Collection System.	Drop the magnet through the coil, and then stop data collection.	Compare the voltage produced by the 200-turn coil to that produced by the 400 turn coil on the graph.	Remove the 200-turn coil and replace it with the 400 turn coil.	Begin collecting data with your Data Collection System.

Procedure with Inquiry

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

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

Part 1 – As the Coil Turns: Same Magnet, Different Coils

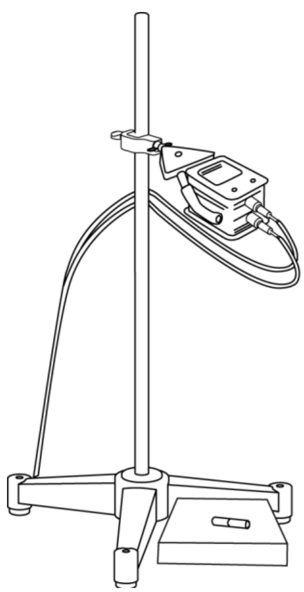
In the first part of this lab, we determine if passing a magnet through a coil of wire gives rise to a voltage (or electromotive force), and whether the number of turns in the coil *N* has any effect on the amount of voltage as predicted in Faraday's equation.

Note: For the best comparison, always be sure to use the same orientation of the magnet when dropping it through the coil.

Set Up

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

2. ☐ Mount the 200-turn coil to the rod stand using the three-finger clamp, approximately 40 cm above the lab table.



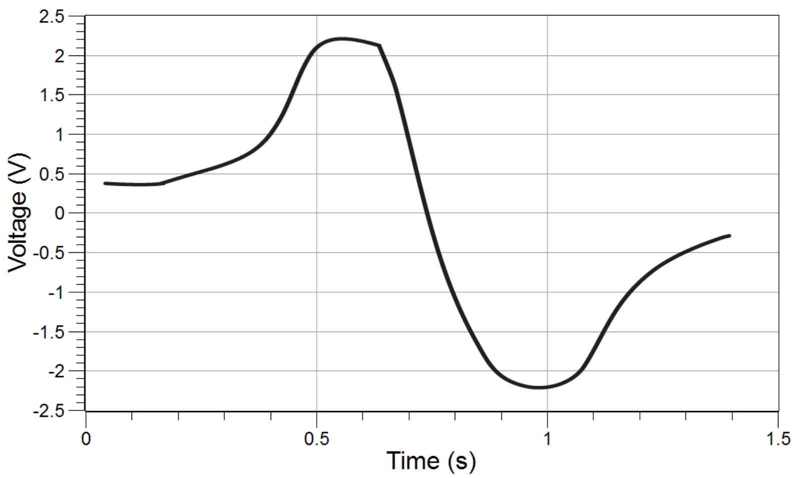
3. ☐ Connect the voltage sensor to the coil. If you are using a no-bounce pad, place it below the coil.

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

5. ☐ Display a graph of Voltage versus Time data on your data collection system. �(7.1)

6. ☐ Set the sampling rate of your data collection system for at least 1000 samples per second. �(5.1)

7. ☐ Given the bipolar nature of a magnet, try to predict the shape of the Voltage versus Time curve using the data collection system, and sketch your prediction on the set axis below. �(7.1.12)



8. ☐ If a changing magnetic field causes charges to move in a conductor, and charges moving in a conductor give rise to a magnetic field, what do you think the orientation of the induced magnetic field would be relative to the original changing magnet field?

The new field should have the opposite orientation of the changing magnetic field.

Teacher Tip: This could also be expressed as resisting or opposing the change of the original field.

Collect Data

9. ☐ Hold the magnet just above the coil opening.

10. ☐ Start collecting data with the data collection system. �(6.2)

11. ☐ Drop the magnet through the coil, and then quickly stop collecting data. �(6.2)

12. ☐ Annotate your data run with the number of turns in the coil you used. �(7.1.5)

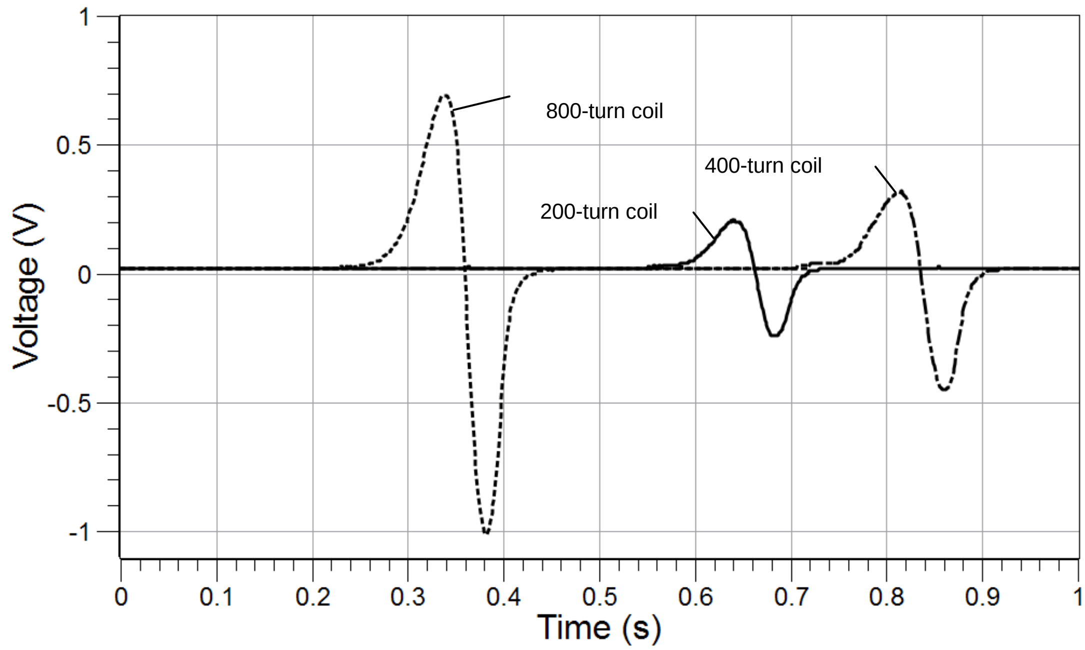
13. ☐ Replace the coil with the next in the series, and repeat the data collection steps for each coil.

Analyze Data

14. ☐ Display all three data runs on the graph on your data collection system. �(7.1.3)

15. ☐ Adjust the axis of your graph to focus on the portions of the graph where the greatest change in voltage takes place. �(7.1.2)

16. ☐ Sketch your graph below, and be sure to indicate which run corresponds to which coil.



17. ☐ Describe one of the major differences between the data runs.

The peak voltage increases as the number of turns in the coil increases

18. ☐ Describe the relationship between the number of turns in the coils and the peak voltages you observed.

The peak voltage appears to be proportional to the number of turns in the coil.

Part 2 – More Magnets: Same Coil, Different Magnets

The second part of Faraday's equation refers to the rate of change in magnetic flux. From our observations of magnets, different types of material produce different strengths of magnetic field. Try at least three magnets of different strengths to see if the strength of the magnet makes a difference. Use only one of the coils, and drop the magnets from the same height each time.

Set Up

19. ☐ Use the same set up for this part as in Part 1, but use only the 200-turn coil.

Collect Data

20. ☐ Hold the first magnet just above the coil opening.

21. ☐ Start collecting data with the data collection system. �(6.2)

22. ☐ Drop the first magnet through the coil, and then quickly stop collecting data. �(6.2)

23. ☐ Annotate your data run with the identifier for the magnet you used. �(7.1.5)

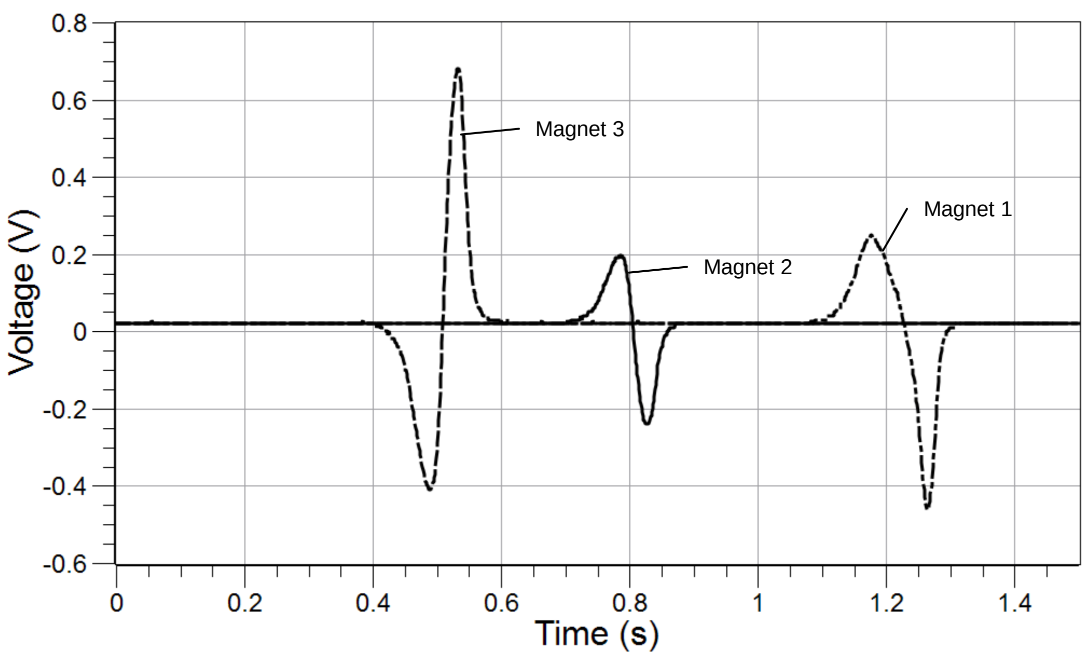
24. ☐ Repeat the data collection steps for each of the magnets, dropping the magnets from the same height each time.

Analyze Data

25. ☐ Display all the data runs on the graph on your data collection system. �(7.1.3)

26. ☐ Adjust the axis of your graph to focus on the portions of the graph where the greatest change in voltage takes place. �(7.1.2)

27. ☐ Sketch your graph below, and be sure to indicate which run corresponds to which magnet.



28. ☐ Describe one of the major differences between the data runs.

The peak voltage increases with stronger magnets.

29. ☐ Describe the relationship between the strength of the magnets used and the peak voltages you observed. What would you measure to better understand the relationship?

The peak voltage appears to be proportional to the strength of the magnet used, but measuring the strength of the magnets would give a better understanding of the relationship.

Part 3 – The Faster the Flux: One magnet, one coil, and different speeds

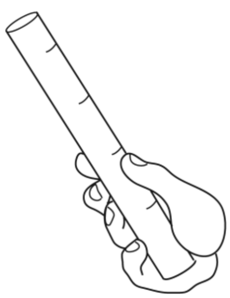
If the strength of the magnet affects the change in flux, how about the speed at which the magnet passes through the coil? The farther an object falls in a gravitational field, the faster it travels. If the magnet passes through the coil faster, it is reasonable that the magnetic flux in the coil is changing faster. Use one of your coils to find out.

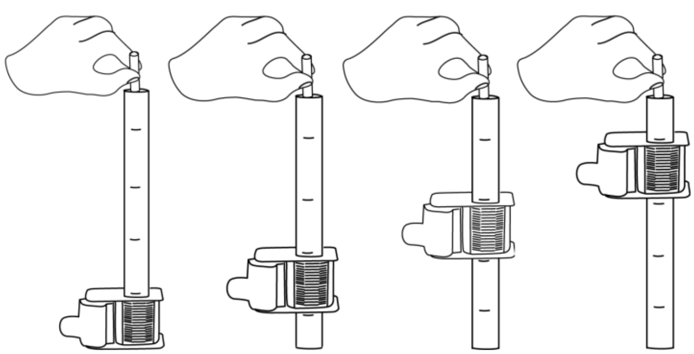
Set Up

30. ☐ Use the same set up for this part as Part 1, but using only the 200-turn coil and a single magnet.

31. ☐ Roll up a piece of paper into a tube, and tape it securely. The tube should be wide enough to allow your magnet to pass through freely, but narrow enough to fit inside the coil.

32. ☐ Mark four equally spaced positions on the tube and slide the tube into the coil so that the first mark is showing just above the coil opening.





Collect Data

33. ☐ Hold the magnet just above the tube opening.

34. ☐ Start collecting data with the data collection system. �(6.2)

35. ☐ Drop the magnet through the tube/coil, and then quickly stop collecting data. �(6.2)

36. ☐ Annotate your data run indicating the height from which the magnet was dropped (for example '1st Mark')

37. ☐ Slide the tube down into the coil until the next mark on the tube is just above the opening of the coil.

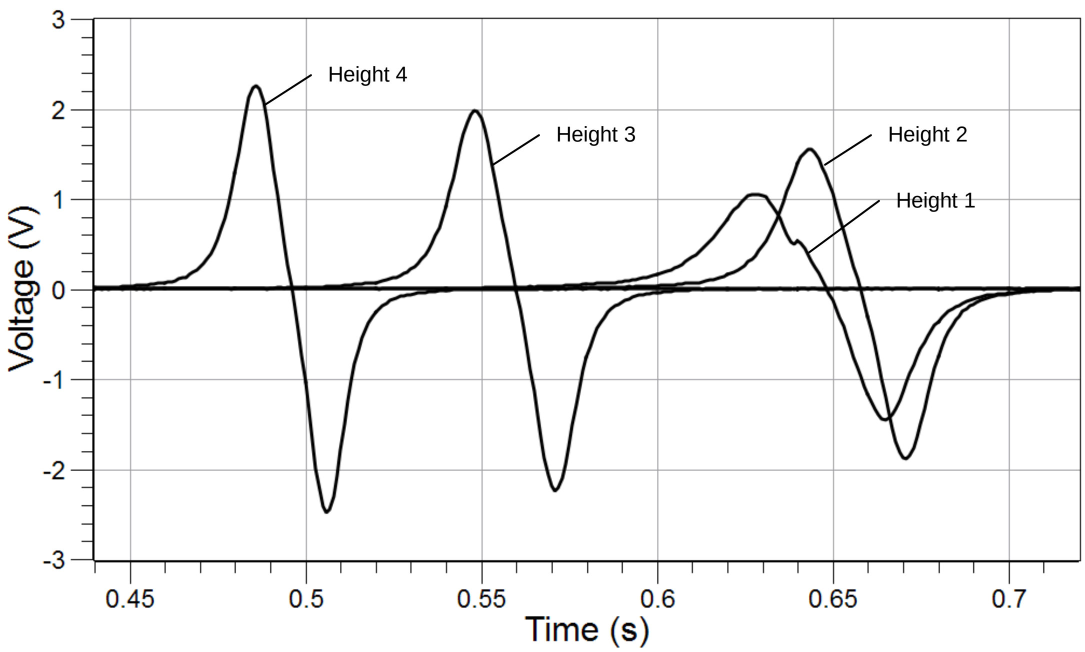
38. ☐ Repeat the data collection steps for each mark on the side of the tube.

Analyze Data

39. ☐ Display all the data runs on the graph on your data collection system. �(7.1.3)

40. ☐ Adjust the axis of your graph to focus on the portions of the graph where the greatest change in voltage takes place. �(7.1.2)

41. ☐ Sketch your graph below, and be sure to indicate which run corresponds to which height.



42. ☐ Describe one of the major differences between the data runs.

The peak voltage appears to increase with the speed of the magnet through the coil

43. ☐ Describe the relationship between the height at which the magnet fell above the coil and the peak voltages you observed. What would you measure to better understand the relationship?

The peak voltage appears to be proportional to the speed the magnet travels through the coil, but measuring the speed of the magnet as it passes through the coil would give a better understanding of the relationship.

Analysis Question

1. How does your prediction compare to the actual Voltage versus Time graph?

Answers will vary.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Based on your observations in this lab, describe the characteristics of an electric coil generator that you would optimize to get the most electromotive force out?

To produce the largest electromotive force, the generator would need to have as many coil turns as possible, have the strongest magnets available, and move as fast as possible.

2. You may have noticed that the second peak of the voltage curve is always in the opposite direction of the first peak. However, you may not have noticed that it is also a slightly higher peak. Can you describe why that might be?

The peak was higher because the magnet is speeding up as it falls, making the top part of the magnet travel faster as it passes through the coil.

Multiple Choice Questions

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

1. The emf produced from dropping a magnet through a coil is a form of energy transformation. What kind of transformation is it?

- **A.** Thermal energy is transformed into electrical energy.
- **B.** Mechanical energy is transformed into thermal energy.
- **C. Kinetic energy is transformed into electrical energy.**
- **D.** Electrical energy is transformed into thermal energy.

2. If a generator with a 200-turn coil produced 120 V of electromotive force, how much would it produce if it was upgraded to an 800-turn coil?

- **A.** 40 V
- **B. 480 V**
- **C.** 220 V
- **D.** There is not enough information to draw a conclusion.

3. The equation for Faraday's Law includes a negative sign on one side. What does it represent?

- **A.** Magnetism is an inherently negative force.
- **B.** Opposites attract.
- **C.** The EMF generated seeks to reinforce the change in magnetic field.
- **D. The EMF generated seeks to oppose the change in magnetic field.**

Key Term Challenge

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

1. Faraday's Law defines the relationship between the number of turns in a **coil** N, and the rate of change in **magnetic flux** Φ. Magnetic flux is related to the strength of the magnetic field, the area enclosed by the wire loop, and the angle between them. Because of the geometry of the experiment, we can say that the flux is proportional to the strength of the magnetic **field**.

Extended Inquiry Suggestions

Project: Build a Generator

Provide your students with raw parts (such as magnets, wire, etc.), and have them build a small generator. In groups of 3 to 5 students, ask them design and build a generator. Ask them to present their work to the class and include a live demonstration of the device.

Introducing area under a curve

Ask your students to repeat the experiment using one magnet and one coil of their choosing. On the graph of Voltage versus Time, have them use their data collection system to explore the area under the curve. �(9.7)

What are the units for the area under the curve?

Volt-seconds (v•s)

What does this represent?

The volt-second is also known as the weber and is a unit of magnetic flux

Demonstration

Use a hand-cranked generator to show how physical motion can be used to produce an electromotive force, and induce current to power a circuit.

Also, a discussion of electrical transformers could help here. You can discuss the electrical grid and how voltages are adjusted for domestic use and long-distance transmission. A great demo to enhance this discussion would be a "Jacob's Ladder," which transforms voltage from 120 V AC up to 10,000 V AC which is then high enough to jump a small gap and form the infamous "rising spark" so common to old sci-fi movies.

Other relevant applications worth mentioning are:

How does a "hybrid" car save so much money on gas?

Induced current from mechanical braking sets up an induced current that recharges electrical batteries, which becomes usable energy.

Light

36. Inverse Square Law

Objectives

During the course of this lab, students have the opportunity to actually experience the concept of light intensity varying inversely as the square of the distance from a point source of light. All of the textbook illustrations that show how and why this law works will become a real-time experience for those who complete this experiment. The experiment will provide first-hand experience in the following areas:

- ♦ Using relevant technology (in this case a light sensor) to investigate the concept of the inverse square law of light intensity.
- ♦ Analyzing and drawing inferences from a graph of “Light Intensity versus Distance” that was collected with real data during the experiment.
- ♦ Comparing the theoretical model (the one taught in the textbooks) to the actual mathematical model (the one that they collect in the lab.) concerning this Inverse Square law.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Simultaneously measuring light intensity and distance from a point light source
- ♦ Collecting data using the “Manual Data Collection” mode
- ♦ Graphing one measured quantity against another (in this case, light intensity vs. distance.)
- ♦ Linearizing a graph
- ♦ Drawing conclusions from graphed data. (Making the actual graph fit a mathematical model.)

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	20 minutes
♦ Lab activity	35 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Light sensor
- ♦ Sensor extension cable
- ♦ Basic optics bench
- ♦ Basic optics light source
- ♦ Aperture bracket

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Light intensity
- ♦ Linearization of graphs

Related Labs in This Guide

- ♦ Polarization

Using Your Data Collection System

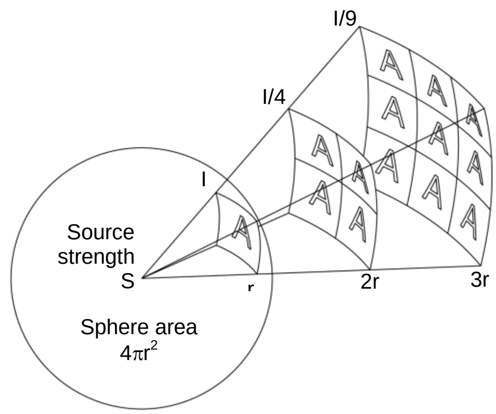
Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Putting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Monitoring live data �(6.1)
- ♦ Changing the variable on the x- or y-axis �(7.1.9)
- ♦ Starting a manually sampled data set �(6.3.1)
- ♦ Recording a manually sampled data point �(6.3.2)
- ♦ Stopping a manually sampled data set �(6.3.3)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Applying a curve fit �(9.5)
- ♦ Creating calculated data �(10.3)
- ♦ Saving data files �(11.1)

Teacher Tip: If you have not done it already, this lab requires that you take the time to teach students how to linearize a graph. The graph that will be produced here will not be linear. In order to get the actual mathematical relationship that exists between these variables, it will be necessary to determine the form of the equation and then (in this case) to plot the intensity vs. $1/r^2$. It is only when that relationship produces a straight line that we know it is correct. This is probably new to most of your students, so it is necessary that you take the time to show them how it works.

Background

There are actually several measures of light intensity. The simplest of these measures is irradiance, which is defined as the rate at which energy is incident upon a given surface area (W/m^2). In order to understand how light intensity from a point source varies as a function of distance, consider a point light source located in space. The source emits energy at a certain rate S. If the energy is radiated in every direction equally, at a distance of r meters from the source, all of the energy generated would be passing through the surface of a sphere of radius r. The light intensity would be S divided by the surface area of the sphere (That surface area would be $4\pi r^2$). So the light intensity at a distance of r would then be:



$$I_1 = \frac{S}{4\pi r^2}\,\text{W/m}^2 \qquad \textbf{Eq.1}$$

At some greater distance R the intensity would be:

$$I_2 = \frac{S}{4\pi R^2}\,\text{W/m}^2 \qquad \textbf{Eq.2}$$

So the ratio of I_2 to I_1 would be:

$$\frac{I_2}{I_1} = \frac{\frac{S}{4\pi R^2}}{\frac{S}{4\pi r^2}} \qquad \textbf{Eq.3}$$

Note that the units cancel out. This expression simplifies to:

$$\frac{I_2}{I_1} = \frac{r^2}{R^2} \qquad \textbf{Eq.4}$$

It is often more useful to express the above as:

$$I_2 = \left(\frac{r^2}{R^2}\right) I_1 \quad \textbf{or} \quad I \propto \frac{1}{R^2} \qquad \textbf{Eq.5}$$

This is known as the Inverse Square Law because it shows that the light intensity is inversely proportional to the square of the distance from the light source R^2.

Pre-Lab Discussion and Activity

A good discussion to get students thinking about intensity versus distance might be to simply ask what they think happens to the light intensity as one gets farther and farther from the source. Most students will correctly conclude that light intensity falls off as we move away from the source. But then ask specifically what happens to the intensity if we double our distance from the source or triple our distance from the source. The most common responses are that the intensity would become one half and one third of the original.

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

1. Without doing any of the math, simply show the students a large sphere. Have them imagine a point source of light (perhaps a tiny light bulb) at the center.

2. Now explain to them that a given amount of energy is being emitted from the light source. And it is moving away in every direction.

3. All of the energy (we will not allow for losses to the atmosphere) is incident upon the entire area of the sphere. So the density of the energy would be the total amount of energy emitted divided by the surface area of the sphere.

4. Now have them imagine a larger sphere (for example, a circle with a radius twice as big as the first radius.) Just ask them about the density of the energy at that sphere's surface. (Again, do not perform the math here, just pose the questions.)

Teacher Tip: At this point, some of the students might get the answer right but our goal now is to actually find out how the light intensity varies as a function of the distance from the source. You might pose the mathematical derivation as an outside assignment. See if they can derive an equation to show mathematically what they are about to show experimentally.

Lab Preparation

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

1. Provide all of the equipment on the equipment list to each group, but do not make any of the connections.
2. Test all of the light sources to be sure they are working.
3. It is also a good idea to test each of the light sensors with the data collection system. Make sure that everything is working properly before the students arrive. Leave nothing connected so that students can learn how to make the actual connections so that the data collection system operates properly.

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
Set up the initial location at a point near the light source itself.	Set up the track, and determine the location of the filament inside the bulb, as well as the location of the surface of the light sensor.	Analyze graphs of Intensity versus Distance, Intensity versus reciprocal distance, and Intensity versus reciprocal of the square of the distance.	Measure light intensity at progressively larger and larger distances from the light source.	Tabulate the data & compare the results for each position with the calculated intensities by applying the inverse square law.

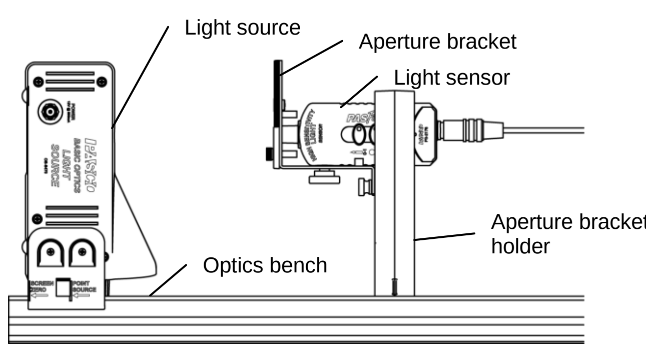
Procedure with Inquiry

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.

1. ☐ Set up your optics bench on a table. Mount the optics light source so that the line indicating the location of the "point source" (bulb filament) is aligned with the 0 cm mark on the optics bench.

2. ☐ Mount the light sensor on the aperture bracket using the small thumbscrew. Attach the aperture bracket to the aperture bracket holder. Mount the aperture bracket holder onto the optics bench.



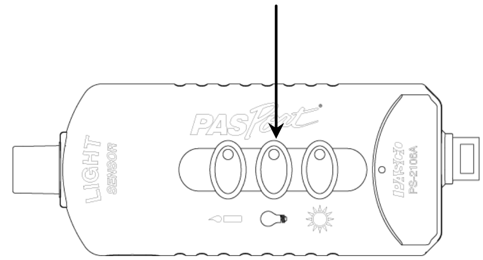
3. ☐ Start a new activity on the data collection system. �(1.2)

4. ☐ Connect the light sensor to the data collection system using the sensor extension cable. �(2.1)

5. ☐ Configure your data collection system to monitor live data. �(6.1)

6. ☐ Display light intensity in a digits display. �(7.3.1)

7. ☐ If your light sensor has different range settings, start with the middle range by pressing the center button on the front if the sensor. (See figure at the right)



8. ☐ Rotate the disk on the front of the aperture bracket so the open circular aperture is in line with the opening to the light sensor.

9. ☐ Turn on the light source.

10. ☐ Slide the sensor, in the holder, back and forth on the track to determine the point where the values of light intensity just begin to change. This will be the minimum distance the light sensor must be away from the light source. You may need to change the sensitivity of the sensor if this point is farther than 50 cm from the light source.

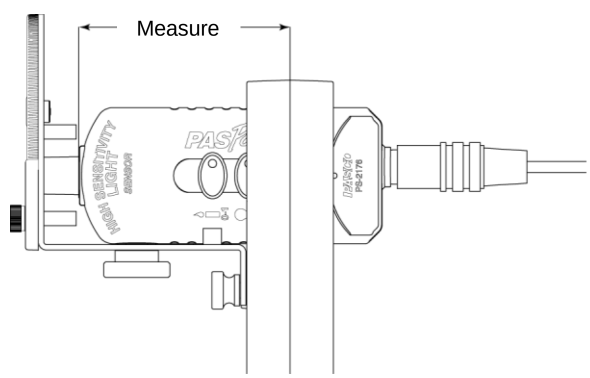
Teacher Tip: Since all measurements have some error associated with them, and since we want to keep errors at a minimum, a large initial separation of 20 cm or more is being used here. Assuming that there is an error of a few millimeters in that determination, it is easy to see the error associated with it will be a much smaller percentage of the measurement than if the original separation was 5 or 10 cm.

11. ☐ At this time, the data collection system will need to be put into manual sampling mode with manually entered data. Title the manually entered data set "Distance" with units of m. �(5.2.1)

Collect Data

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

13. ☐ Record the first manually sampled data point and then enter the corresponding distance, in meters, between the bulb filament in the light source and the sensing element on the light sensor. �(6.3.2)



Note: The actual light-sensing element in the light sensor is just beyond the lower end of the black tube on the front of the sensor. The distance between the bulb filament inside the light source and the sensing element inside the light sensor should be measured from the "point source" indicator on the bottom of the light source to the front edge of the case on the light sensor. One way to do this is measure the distance from the sensing element to the indicator on the lens holder. Then you can measure the distance from the filament indicator to the lens holder indicator and subtract the distance to the sensing element.

14. ☐ Slide the light sensor 2.0 cm further away from the light source and then record another manually sampled data point. Enter the corresponding distance, in meters, between the bulb filament in the light source and the sensing element on the light sensor. �(6.3.2)

15. ☐ Repeat the previous steps until you have collected at least 10 data points.

16. ☐ Stop data collection. �(6.3.3)

Analyze Data

17. ☐ Create a graph with Light Intensity on the *y*-axis and Time on the *x*-axis. �(7.1.1)

18. ☐ Change the measurement on the *x*-axis from Time to Distance. �(7.1.9)

19. ☐ Sketch your graph in the space provided in the Data Analysis section.

Sample Data

Table 1: Volume and Pressure

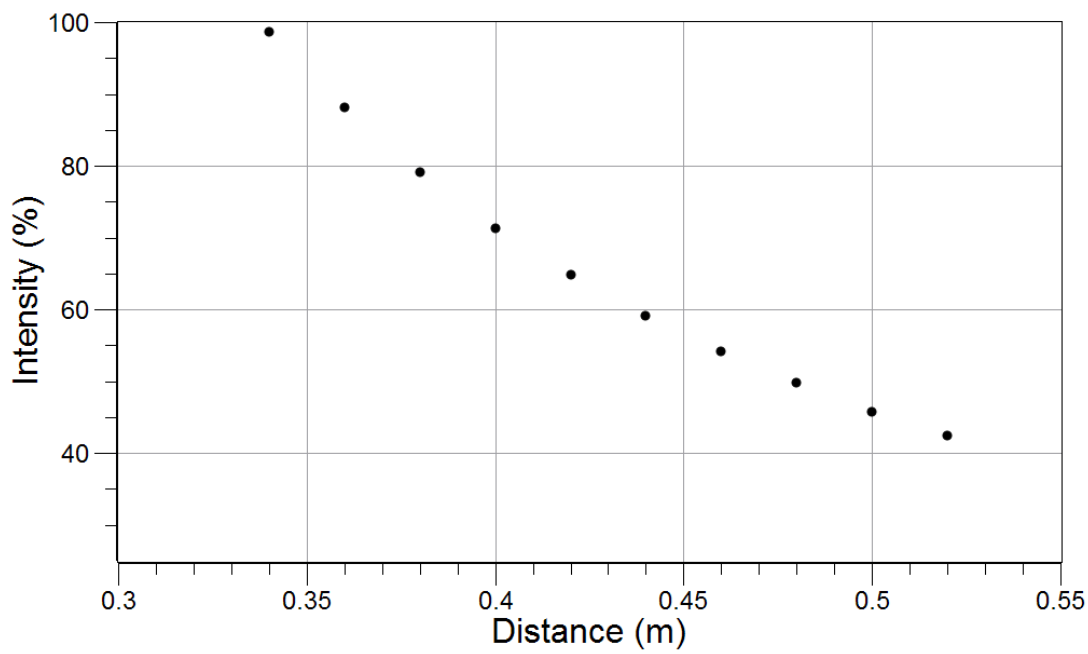
Distance (m)	1/Distance (m^{-1})	1/Distance^2 (m^{-2})	Intensity (%)
0.34	2.94	8.65	98.70
0.36	2.78	7.72	88.10
0.38	2.63	6.93	79.10
0.40	2.50	6.25	71.30
0.42	2.38	5.67	64.80
0.44	2.27	5.17	59.10
0.46	2.17	4.73	54.20
0.48	2.08	4.34	49.80
0.50	2.00	4.00	45.70
0.52	1.92	3.70	42.40

Teacher Tip: Sample data was collected with a High Sensitivity Light Sensor so the values are displayed as a percentage. The default unit for your light sensor may be different, but the unit of measure should not make a difference for this experiment.

Data Analysis

Answer each of the following questions, or complete the step in order to analyze the data that was just collected.

Graph 1: Light Intensity versus Distance



1. ☐ Describe the graph that you obtained from your data collection. Be as specific as possible. Include such observations as: did the intensity go up or down as you got further from the source, and was the graph linear or was it curved? If it was curved, what mathematical relationships produce graphs of this shape?

The graph shows that the intensity got smaller as the distance got greater. No, the graph is not linear. And it looks something like:

$Intensity = \frac{A}{R}$ or $Intensity = \frac{A}{R^2}$ where A is some constant.

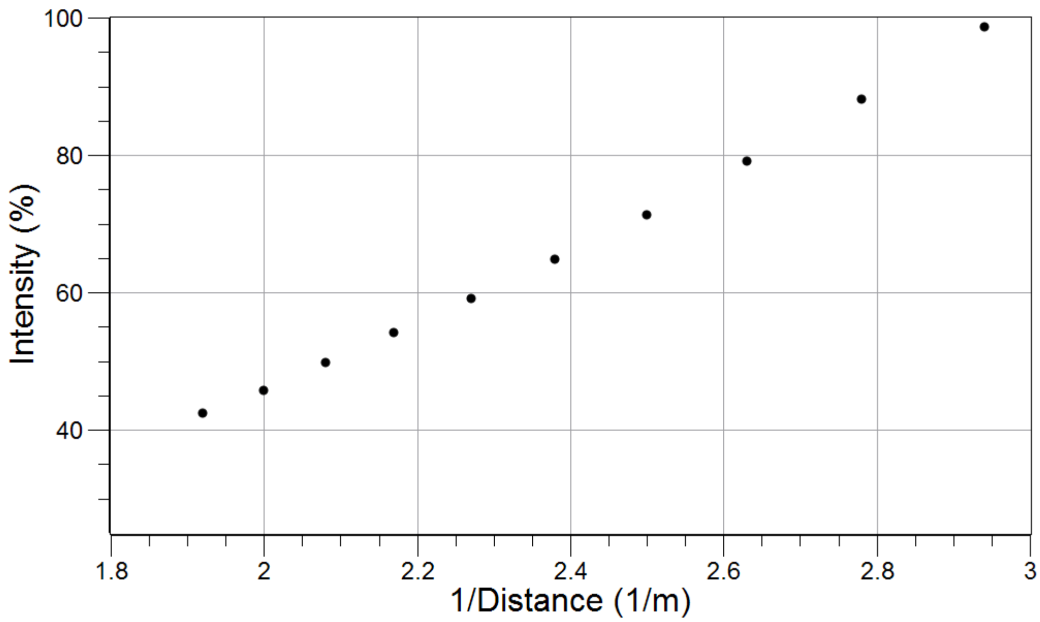
2. ☐ Using the data collection system, create the following calculations: �(10.3)

1/[Distance (m)] and 1/[Distance (m)]^2

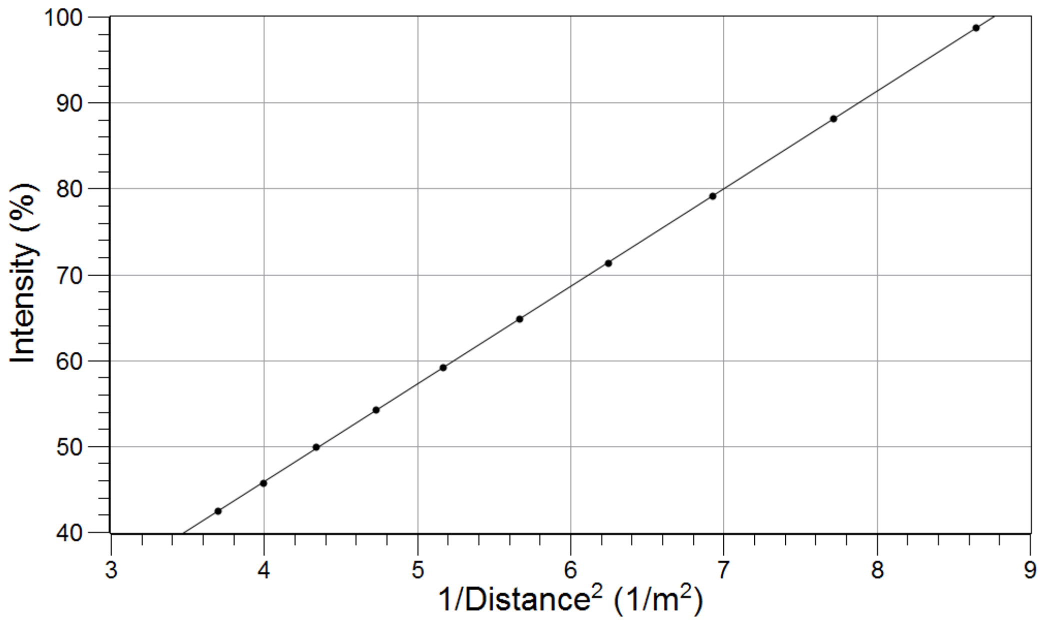
3. ☐ Create two new graph displays: one with Light Intensity on the y-axis and 1/[Distance (m)] on the x-axis, the other with Light Intensity on the y-axis and 1/[Distance (m)]^2 on the x-axis. �(7.1.9)

4. ☐ Sketch each graph on separate sets of axes.

Graph 2: Light Intensity versus 1/Distance



Graph 3: Light Intensity versus 1/Distance^2



5. ☐ Do either of the plots produce a straight line?

Yes. The graph of intensity vs. 1/R^2 produces a nearly perfectly straight line.

6. ☐ What is the significance of your answer to the previous question?

It means that the intensity is proportional to the reciprocal of R^2.

Analysis Questions

1. Using the data that you just collected, determine how far you would need to place the sensor so that the light intensity was less than ½ of one percent of the original intensity.

Answers will vary but the solution is a straightforward application of the inverse square law.

$$d_1 = 0.34\,\text{m}$$
$$I_1 = 98.7\%$$
$$I_2 = I_1(.005) = 0.49\%$$
$$I_2 = \left(\frac{r^2}{R^2}\right)I_1$$
$$0.49\% = \frac{(0.34\,\text{m})^2}{R^2}\cdot 98.7\%$$
$$R = \sqrt{\frac{(0.34\,\text{m})^2}{0.49\%}\cdot 98.7\%}$$
$$R = 4.82\,\text{m}$$

2. What differences do you suppose there would be if you had used a candle instead of the light source for this experiment?

The lower sensitivity switch would have been used and it might have been more difficult to establish exactly where the candle flame was relative to the light sensor. Aside from these two differences, however, the experiment would have been about the same.

Synthesis Questions

Use available resources to help you answer the following questions.

1. The sun could certainly be considered to be a point source of light for objects in our solar system. We can describe the amount of the Sun's energy reaching Earth as 1 solar constant. The average distance from the Sun to Earth is 149,597,870.66 kilometers (92,955,807.25 miles), which we can simplify to what astronomers call 1 Astronomical Unit or 1 AU. So, Earth is 1 AU from the Sun and receives 1 solar constant of light intensity. This will help keep the math easy for the following exercise:

The distance from the sun to each of the nine planets in our solar system is listed in the table below. Using what you have learned in this lab, calculate the light intensity (in solar constants) for all nine of the planets. State your answer in *percent*. In other words, what percentage of the light intensity on earth, does each planet receive?

$d_1 = 0.387$ au

$I_1 = 1$

$$I_2 = \left(\frac{r^2}{R^2}\right) I_1$$

$$100\% = \frac{(0.387)^2}{(1\text{au})^2} \cdot I_1$$

$$\frac{100\%}{0.149} = I_1$$

$I_1 = 667.69\%$

Planet	**Distance (AUs)**	**Light Intensity (% solar constants)**
Mercury	0.387	667.69%
Venus	0.723	191.30%
Earth	1.000	100.00%
Mars	1.523	43.11%
Jupiter	5.202	3.70%
Saturn	9.538	1.10%
Uranus	19.181	0.27%
Neptune	30.057	0.11%
Pluto (avg.)	39.440	0.06%

2. A classroom has individual incandescent lights (the lights can be considered to be point sources of light) that hang from the ceiling. The lights have 200-Watt bulbs inside. An inspector notifies the principle that the light intensity on the student desks must be doubled but the lamps have a warning sticker that says "no bulb larger than 200 Watts can be installed."

The science teacher says that she has measured the distance between the lights and the desks to be precisely 8.0 feet. She suggests lowering the lights until the light intensity is doubled. What will be the final height above the desks for the lamps if the goal of doubling light intensity at the desks is to be achieved?

$$I_2 = \frac{r^2}{R^2} I_1$$

$$2I_1 = \frac{(8\text{ m})^2}{R^2} I_1$$

$$R^2 = \frac{(8\text{ m})^2}{2}$$

$$R = \frac{8\text{ m}}{\sqrt{2}} = 5.7\text{ m}$$

Multiple Choice Questions

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

1. Which of the following transmissions of energy would obey the inverse square law?

- **A.** Waves on a pool of water
- **B. Electromagnetic waves from a radio antenna**
- **C.** Electricity in a wire
- **D.** Heat being conducted along a metal pipe

2. To increase the intensity of light at a surface which would be most effective?

- **A.** Doubling the energy emitted from the source
- **B. Halving the distance from the source to the receiver**
- **C.** Tripling the energy emitted from the source

3. If we double the distance between a point light source and a light sensor, by what factor would the light intensity be multiplied?

- **A.** 2
- **B.** 4
- **C.** 0.**25**
- **D.** 0.33

4. By what factor must we change the distance between a point source and receiver in order to make the light intensity one half of what it was originally?

- **A.** 2
- **B.** 0.5
- **C.** **1.414**
- **D.** 1.855

Key Term Challenge

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

1. The simplest measure of light intensity is **irradiance**. Light Intensity falls off with distance according to the **Inverse** Square Law, but the Inverse Square Law for electromagnetic energy transmission only works if the source of energy can be considered to be a **point source**, and we were cautioned to always state the distances in **meters**.

2. The device used to measure **distance** is the built in meter scale on the optics track. The device that measured the light **intensity** is known as a **light sensor**. The distance we measured was between the sensing element in the light sensor and the **filament** in the light source.

Extended Inquiry Suggestions

Try the same experiment with a candle as the light source. Perhaps you could also try a flashlight (if you do, be prepared for the results to look quite a bit different). Why do you suppose a flashlight or a laser will not work when you do this experiment?

A flashlight has a reflector to concentrate the beam. Consequently, it cannot be viewed as a point source of light (the energy does not go in all directions). The same would be true of a laser but even more so. The laser beam is highly concentrated to move in only one direction.

37. Polarization

Objectives

By passing light through two polarizing disks with their transmission axes oriented at various angles to each other students will study the effects of polarization on light intensity, and explore Malus' Law.

Procedural Overview

Students gain experience conducting the following procedures:

- Using a light sensor to measure the intensity of light passing through two polarizing discs oriented at varying angles between their transmission axes
- Measuring and recording the angle of one polarizing disk relative to a second polarizing disk (usually referred to as the analyzer)
- Plotting Light Intensity versus Angular Separation of Transmission axes for the polarizing disks
- Analyzing and drawing inferences from a graph of Light Intensity versus Angular Separation of Transmission Axes
- Plotting Light Intensity versus $\cos^2 \theta$ where θ is the angle between transmission axes of the two polarizing disks
- Analyzing and drawing inferences from a graph of Light Intensity versus $\cos^2 \theta$ for the angle between the transmission axes.

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and activity	35 minutes
♦ Lab activity	40 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Light sensor
- Sensor extension cable
- Basic optics diode laser
- Basic optics aperture bracket
- Basic optics bench
- Polarizing disk (2)[1]
- Polarizing disk accessory holder[1]

[1]Included with the Basic Optics Polarizer Set

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Transverse waves
- ♦ The wave nature of light

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Inverse Square Law

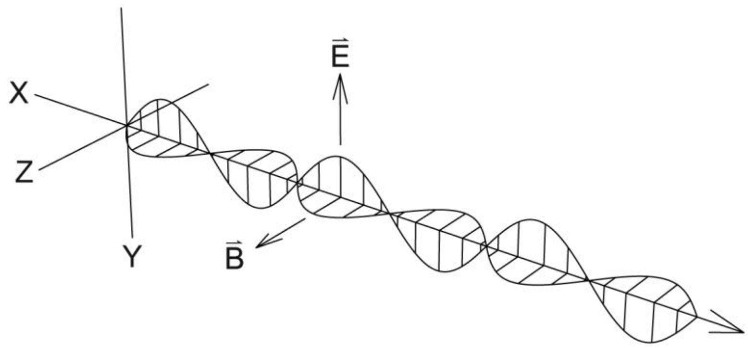
Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Putting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- ♦ Starting a set of manually sampled data �(6.3.1)
- ♦ Recording a manually sampled data point �(6.3.2)
- ♦ Stopping a set of manually sampled data �(6.3.3)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Adding a measurement to a table �(7.2.2)
- ♦ Creating calculated data �(10.3)
- ♦ Saving your experiment �(11.1)

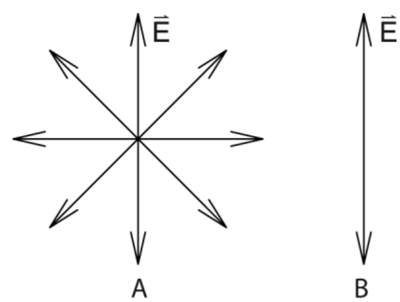
Background

A photon of light consists of two wave components: an electric field wave component, and a magnetic field wave component. Together they are referred to as a single electromagnetic wave.



The diagram above is a 3-dimensional representation of such a wave traveling along the *x*-axis. Notice the electric field and magnetic field are both at right angles to the direction of propagation, as well orthogonal to each other.

Electromagnetic energy such as light is generally emitted from sources that produce unpolarized light, in which the electric field is oscillating in a disorganized manner. The figure A below shows an unpolarized ray coming out of the page toward the reader.
For simplicity, only the electric field vectors are shown.



Polarization of light occurs when the electric field component of the electromagnetic wave is constrained to oscillate in a consistent plane. A wave is linearly polarized if the resultant electric field is constrained to oscillate in only one plane at a particular location. The electric field for such polarized light would look like B in the figure at the left. The plane formed by ***E*** and the direction of propagation is called the plane of polarization. Because the wave is traveling along the *x*-axis (coming out of the page) in the illustration, the plane of polarization would be the *x*-*y* plane

The most common way to produce a polarized beam of light is to remove all waves from the beam except those that have their electric fields that oscillate in the appropriate plane. There are three processes that can be used to do this: selective absorption, reflection, and scattering. Although you will most likely study all three processes, the method by which we will polarize the light is selective absorption.

This experiment requires a material that transmits light waves having electric field vectors that oscillate in a particular direction while absorbing waves having electric field vectors that oscillate outside that direction. Such a material was invented by Dr. Edwin Land in 1932. He called the material Polaroid. The material is a kind of plastic made of long-chain hydrocarbons. As the sheets cool in the manufacturing process, they are stretched in such a manner as to align the hydrocarbon chains in one direction. Each sheet is dipped into a solution that contains iodine making the molecules good electrical conductors.

The result was a material that absorbs light waves having electric fields parallel to the hydrocarbon chains, while waves with electric fields perpendicular to the hydrocarbon chains are transmitted. Consequently, we normally refer to the direction that is perpendicular to the molecular chains as being the transmission axis of the polarizing material.

An unpolarized beam of light incident upon a linear polarizer will result in a beam of light, linearly polarized in the same direction as the polarizer's transmission axis. However, the intensity of the resultant beam will now be less due to the absorption of all other light in the beam with polarization not matching that of the polarizer. If a second polarizer (usually called an analyzer) is placed in the beam's path after the location of the original polarizer, the intensity of the light that is transmitted through it will decrease, again do to absorption. As the angle between transmission axes on both the analyzer and polarizer gets closer to 90°, the intensity of light transmitted through the analyzer will approach zero. Malus' law states:

$$I = I_o \cos^2 \theta$$

where I_0 is the intensity of a polarized beam of light incident on an analyzer, θ is the angle between the light's polarization direction and the transmission axis of the analyzer, and I is the intensity of the light after passing through the analyzer.

Pre-Lab Discussion and Activity

Obtain two pairs of polarizing sunglasses. Show them to the students, and ask how these glasses differ from ordinary sunglasses. Undoubtedly some students will tell you that it is possible to see fish and underwater objects on a bright sunny day if you are wearing glasses like these. Engage students into a discussion of what is meant by the term "polarized light." It will be necessary to discuss the transverse wave nature of the light wave and how it can be polarized. This can be followed up with discussion of Malus' Law.

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:

- Do not look directly into the laser.
- Avoid laser beam reflections that may cause eye damage. Be aware of the laser beam at all times; you may be producing unknown stray reflections.

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
Rotate one polarizing disk 10° at a time, and determine the intensity of transmitted light at each angle.	Set up the polarizing disks such that their transmission axes are parallel to each other.	Verify Malus' law by comparing measured intensity values to calculated intensity values.	Plot intensity versus the angle between the transmission axes for the two polarizing disks.	Draw conclusions about the amount of light transmitted and the angle between the transmission axes.

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.

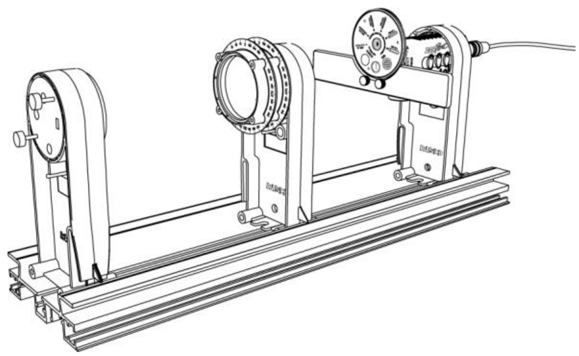
Set Up

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

2. ☐ Mount the light sensor to the aperture bracket, and rotate the aperture disk until the large circular aperture in front of the light sensor.

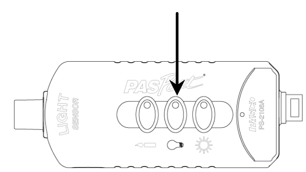
3. ☐ Use the sensor extension cable to connect the light sensor to the data collection system. �(2.1)

4. ☐ Mount the laser, polarizing disk mount, and light sensor with aperture bracket to the optics bench. Align the laser with the beam pointed toward the light sensor.



5. ☐ Plug in and turn on the laser.

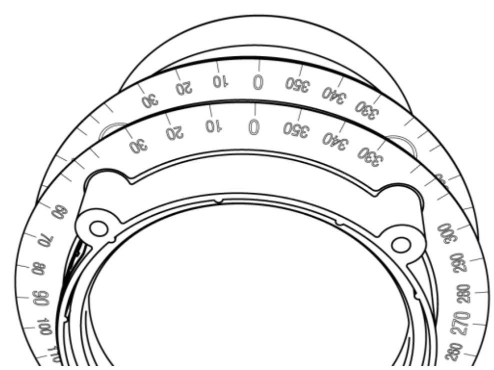
6. ☐ Adjust the horizontal and vertical alignment thumbscrews on the laser until the laser beam passes directly through the round aperture hole and strikes the light sensor directly.



7. ☐ Press the center button on the light sensor to select the middle intensity range setting. A green light will illuminate at the top of that button.

8. ☐ Monitor light intensity in a digits display with your data collection system. �(6.1)

9. ☐ Mount the two polarizing disks to the accessory holder (the first serves as the polarizer and the second serves as the analyzer).



10. ☐ Rotate both polarizing disks independently until the scales on the outside of the disks are aligned.

11. ☐ Rotate the two disks together, observing the light intensity on your data collection system simultaneously, until the transmitted intensity through both disks is greatest.

Note: If the light intensity does not change, try the next higher intensity range setting on your light sensor.

12. ☐ Stop monitoring data.

13. ☐ Put the data collection system into manual sampling mode with manually entered data. Name the manually entered data set “Angle” with units of degrees. �(5.2.1)

Collect Data

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

15. ☐ Begin with the angle between the polarizing disks set to zero. Record your first point, and enter "0" for the angle between the axes. �(6.3.2)

16. ☐ Rotate the polarizing disk closest to the light sensor 10°.

17. ☐ Record your second data point, and enter "10" as the angle between the two disks.

18. ☐ Continue this procedure, incrementing the angle 10° each time until you have completed a full revolution (360°) for the polarizing disk.

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

Analyze Data

20. ☐ Display Intensity on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

21. ☐ Change the measurement on the *x*-axis from Time to Angle. �(7.1.9)

22. ☐ Sketch your graph of Light Intensity versus Angle in the Data Analysis section.

23. ☐ Describe, in words, what you have discovered about the intensity of the light, as the angle between the transmission axes of two polarizing disks is changed. Can you draw any conclusions about when the axes are parallel? When they are perpendicular? When they move from parallel to perpendicular? When they move from perpendicular back to parallel (from 90° to 180°)?

The transmission of light appears to be at a maximum when the angle between the polarizers is 0°and 180°, and the transmission of light is at a minimum when the angle between the polarizers is 90° or 270°. The intensity of the light changes in a repeating, non-linear, pattern.

Sample Data

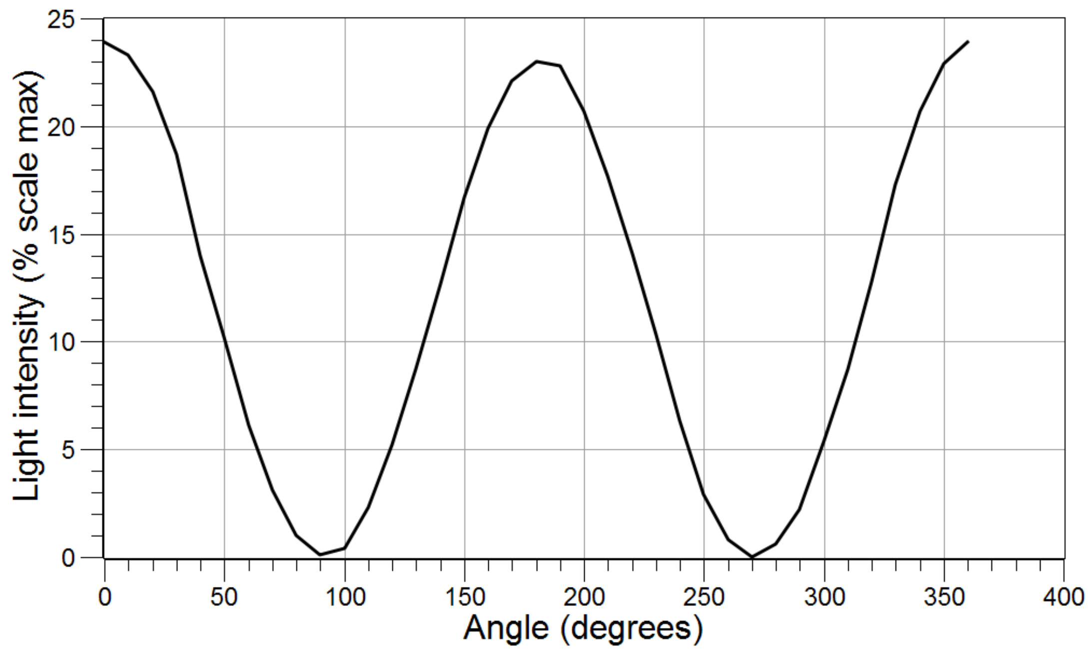
Table 1: Angle versus Intensity

Degrees	Reading	Ideal	% Error
0	23.9	23.9	0.00%
10	23.3	23.2	0.50%
20	21.6	21.1	2.07%
30	18.7	17.9	3.24%
40	14.0	14.0	-0.11%
50	10.2	9.9	1.36%
60	6.1	6.0	0.52%
70	3.1	2.8	1.27%
80	1.0	0.7	1.17%
90	0.1	0.0	0.42%
100	0.4	0.7	-1.34%
110	2.3	2.8	-2.07%
120	5.2	6.0	-3.24%
130	8.7	9.9	-4.92%
140	12.7	14.0	-5.54%
150	16.7	17.9	-5.13%
160	19.9	21.1	-5.04%
170	22.1	23.2	-4.52%
180	23.0	23.9	-3.77%
190	22.8	23.2	-1.59%
200	20.7	21.1	-1.69%

210	17.7	17.9	-0.94%
220	14.1	14.0	0.31%
230	10.3	9.9	1.78%
240	6.3	6.0	1.36%
250	2.9	2.8	0.44%
260	0.8	0.7	0.33%
270	0.0	0.0	0.00%
280	0.6	0.7	-0.50%
290	2.2	2.8	-2.49%
300	5.4	6.0	-2.41%
310	8.7	9.9	-4.92%
320	12.8	14.0	-5.13%
330	17.3	17.9	-2.62%
340	20.7	21.1	-1.69%
350	22.9	23.2	-1.17%
360	23.9	23.9	0.00%

Data Analysis

Light intensity versus Angle



1. ☐ On your data collection system, build the following calculation: �[10.3]

Intensity = *I**(cos([Angle])^2)

where I is the maximum light intensity value you measured at angle zero.

Note: ensure that your data collection system calculator is set to calculate angles in degrees.

2. ☐ Return to the table on your data collection system, and add a new column containing the Intensity calculation. �[7.2.2]

3. ☐ Compare the Intensity calculations to the actual intensities that you measured. To make a quantitative comparison create a new calculation: �[10.3]

PercentDifference = 100*((Intensity-[Light Intensity])/Intensity)

4. ☐ Return to your table, and add a new column containing the PercentDifference calculation. �[7.2.2]

5. ☐ Save your work as instructed by your teacher. �[11.1]

Analysis Questions

1. Polarizing disks, such as the ones used in this experiment, were invented by Dr. Edwin Land. You will recall that the long-chain hydrocarbon molecules in the disk material are made to be electrically conducting. In what direction is the transmission axis for such a disk, relative to the long molecules?

The molecules are lined up in the manufacturing process, and because currents can flow easily along the chains, waves with their electric field parallel to the chains are absorbed (*not* transmitted). As a result, the axis of transmission is perpendicular to the molecular chains in the Polaroid material.

2. Can a sound wave be polarized? Explain.

Sound waves are longitudinal. Only transverse waves can be polarized. So, no, sound waves cannot be polarized.

Synthesis Question

Use available resources to help you answer the following questions.

1. In everyday life, radio waves are typically polarized, but light waves are not. Why is this the case?

Radio waves are typically broadcast from electrical currents oscillating in tall vertical towers. The waves have vertical planes of polarization. Light, on the other hand, originates from the vibrations of atoms, which represent oscillations in all possible directions. Therefore, light, is not normally polarized.

2. The glare of headlights of oncoming traffic causes many automobile accidents every year. Would it be possible to design a "non-glare" headlight system for cars?

Yes. If all cars had a polarizing sheet in front of the headlights with the axis of transmission, say vertical. Then, if windshields were made of Polaroid material with the axis of transmission at, say 45° to the vertical, glare would be drastically reduced. This was actually proposed by Edwin Land when he invented Polaroid material. It was dismissed by car makers because it would be expensive and would have to be on *all* cars. Thus, no one manufacturer could gain market share by incorporating it first.

Multiple Choice Questions

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

1. Polarizing disks, like the ones used in this experiment, polarize light by what method?

- **A.** Reflection
- **B.** Scattering
- **C.** **Selective absorption**

2. When light reflects off a horizontal surface, such as water, the light waves are much more pronounced in the horizontal plane. So, in order to reduce glare most effectively, what should be the axis of transmission for a pair of polarized sunglasses?

- **A.** Horizontal
- **B.** **Vertical**
- **C.** 45° to the horizontal plane

Key Term Challenge

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

1. Polarized sunglasses polarize light by the **selective absorption** process. Light waves are made up of two types of fields: electric and **magnetic** fields. The hydrocarbon chains in Polaroid material absorb the **electric** field component of an electromagnetic wave, so the direction of vibration of the electric field that can be transmitted is **perpendicular** to the hydrocarbon chains. The orientation or direction of the oscillating electric field that can be transmitted is called the **transmission axis** for the Polaroid material. The law that can be used to determine the intensity of the light that passes through two polarizing sheets with their transmission axes at a particular angle to each other is known as **Malus' Law**.

Extended Inquiry Suggestions

Using the same polarizing disks that were used in this experiment and a bright penlight, make a prototype of the "non glare" automobile headlight system discussed in an earlier question, and see how effective it is. Take photographs of the "headlight" with and without the "non-glare" system. As a class, discuss the benefits and challenges of implementing such a system.

Sound

38. Sound Intensity

Objectives

In this experiment, students investigate the sound intensity from devices such as tuning forks, musical instruments, and the human voice. Students:

- Compare the sound level produced by different sources
- Explore the intensity of sound as a function of distance from the sound source
- Develop an understanding of the decibel scale versus the intensity of sound waves

Procedural Overview

Students will gain experience conducting the following procedures:

- Observing the intensity of sound emitted from different sound sources
- Measuring the intensity of a sound as a function of the distance from the source, and investigating the relationship
- Comparing the decibel scale to raw intensity

Time Requirement

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

Materials and Equipment

For each student or group:

- Data collection system
- Sound level sensor[1]
- Tuning fork
- Meter stick
- Patch cord, 4 mm banana plug (2)
- Power amplifier/function generator
- Musical instrument
- Speaker
- Sensor extension cable (optional)

[1]This lab requires the PS-2109 Sound Level Sensor because it has both dB and W/m^2 measurements available.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Mechanical waves

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Inverse Square Law

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Putting the data collection system into manual sampling mode with manually entered data �(5.2.1)
- ♦ Displaying data in a digits display �(7.3.1)
- ♦ Monitoring live data without recording �(6.1)
- ♦ Starting a manually sampled data set �(6.3.1)
- ♦ Recording a manually sampled data point �(6.3.2)
- ♦ Stopping a manually sampled data set �(6.3.3)
- ♦ Displaying data in a graph display �(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)
- ♦ Drawing a prediction �7.1.12
- ♦ Applying a curve fit �(9.5)
- ♦ Creating calculated data �(10.3)
- ♦ Saving your experiment �(11.1)

Background

Sounds from vibrations can come from irregular or regular sources. Noise corresponds to an irregular vibration of the eardrum produced by some irregular source. Sounds from traffic and clapping hands are examples of irregular vibrations. Musical sounds have basically periodic tones produced by regularly vibrating sources. Sound waves impact our inner ear, which sends a signal to our brain to indicate whether something is loud or not.

When the human ear is exposed to excessively loud sound over time, the ear can become less sensitive to them. So, it is useful to have a scale to measure sound more objectively. Just like the human ear, this scale needs to represent both the quietest whisper and the overwhelming din of an airplane taking off. In this experiment, you use a sound level sensor to measure sound intensities from different sources and to investigate how distance from the source affects sound level.

The sound level sensor measures both decibels and watts per square meter. The decibel is a commonly used unit that compares the intensity of a sound to the threshold of human hearing. The SI unit for sound intensity is the watt per square meter. The lower limit of human hearing is defined as 1.0×10^{-12} W/m^2. For a sound that is approximately the level of human conversation 1 meter away (3.2×10^{-6} W/m^2) you would get:

$$\beta = (10\,\text{dB}) \times \log\left(\frac{I_{\text{sound)}}}{I_0}\right)$$

$$\beta = (10\,\text{dB}) \times \log\left(\frac{3.2 \times 10^{-6}\ \text{W/m}^2}{1.0 \times 10^{-12}\ \text{W/m}^2}\right)$$

$$\beta = (10\,\text{dB}) \times \text{Log}\left(3.2 \times 10^{6}\right)$$

$$\beta = (10\,\text{dB}) \times 6.5$$

$$\beta = 65\,\text{dB}$$

The decibel scale, named in honor of Alexander Graham Bell, is still commonly used today to describe environmental sound levels because of its strong relationship to the way humans hear sound. The sound sensor used in this experiment displays two variations of this scale: dBA and dBC. The dBC scale is a straight forward representation of the mathematical model described above. The dBA scale is modified (filtered) to even more closely represent the sensitivity of the human ear.

Pre-Lab Discussion and Activity

Engage your students by considering the following questions.

1. What is a wave? Do all waves require a medium in order to travel?

A wave is a disturbance in a medium. For example, dropping a stone in a pond produces waves. Sound waves require molecules in order to propagate, or travel. Light waves do not require a medium because light consists of dually vibrating electric and magnetic fields.

2. What are some other waves in everyday life?

Tidal waves in the ocean, seismic waves in the earth, gamma waves from distant stars, and even people waves in a large stadium!

Students can perform a simple demonstration of amplified sound. Find several inexpensive polystyrene combs of varying lengths. Have the students hold the combs against different materials (for example, wood, wooden boxes, paper, metal, or plastic), and pluck the teeth with their fingernails. Then ask your students to consider the following questions:

3. How did the sound get amplified?

The sound was transferred though contact with the material and had resonance within the material.

4. Why are the sounds louder or softer when held and vibrated against different materials?

Different materials have different abilities to transfer vibration, and resonance occurs under very specific conditions.

5. What factors influence the loudness or intensity of a sound?

The amplitude of vibration and frequency influence loudness, but the frequency only becomes a factor in resonance conditions.

6. What materials best amplify the sound?

Rigid and hollow materials. This is why many musical instruments are made of metal or wood, and some part of them is hollow.

7. What causes different pitches to result?

Vibrations at different frequencies.

Lab Preparation

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

1. When using the tuning forks, avoid striking them on very hard surfaces, such as tables, as this can permanently damage the fork. To establish a normal mode of vibration, use a rubber mallet to strike the tuning fork. Or, use your upper leg, and tap your leg with the fork. You can make a simple mallet by attaching a rubber stopper to the end of a wooden stick.

Safety

Add this important safety precaution to your normal laboratory procedures:

- When using any sound producing device, start from a low amplitude (volume), and increase the volume to a comfortable level to avoid damage to hearing.

Sequencing Challenge

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

4	2	3	1
Compare the graphs of Intensity versus Distance in dB to the graph of W/m^2.	Observe the sound level from a tuning fork, an instrument, and your voice before setting up a continuous sound source.	Move the sound level sensor another 5 cm away from the sound source, and collect another data point.	Set up the data collection system to monitor sound with the sound level sensor.

Procedure with Inquiry

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

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

Part 1 - Sound Levels

Set Up

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

2. ☐ Connect the sound level sensor to the data collection system. �(2.1)

3. ☐ Collect the sound producing items you will need, such as the tuning fork and musical instrument.

4. ☐ Display sound level (dBA) in a digits display. �(7.3.1)

5. ☐ The "A" in dBA means that this scale has been weighted to represent a response to sound that is similar to the human ear. What does the dB stand for in dBA?

Decibels.

Collect Data

6. ☐ Begin monitoring sound level (dBA). �(6.1)

7. ☐ Observe the ambient sound level in your room for a few seconds, and then record an approximate value in Table 1 in the Data Analysis section.

Note: For the following steps, hold each sound making device a few centimeters from the sound level sensor at approximately the same distance.

8. ☐ Observe the sound level from a vibrating tuning fork for a few seconds, and then record an approximate value in Table 1 in the Data Analysis section.

9. ☐ Observe the sound level from a musical instrument for a few seconds, and then record an approximate value in Table 1 in the Data Analysis section.

10. ☐ Observe the sound level from your voice singing a musical note for a few seconds, and then record an approximate value in Table 1 in the Data Analysis section.

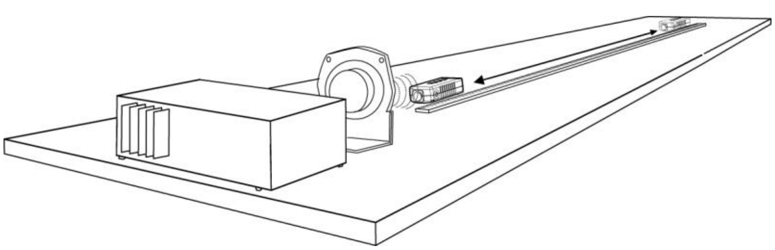
Part 2 - Sound Level and Sound Intensity versus Distance

Set Up

11. ☐ Place the speaker on a table, and connect it to the power amplifier/function generator using the patch cords.

Note: Orient your experimental set up to minimize the amount of sound coming from other lab groups.

12. ☐ Position a meter stick in front of the speaker so that the 0 cm line is almost touching the speaker.



13. ☐ If you are using a sensor extension cable, connect it between the data collection system and the sound level sensor.

14. ☐ Place the end of the sound level sensor at the 5 cm (0.05 m) mark facing the speaker.

Note: At this point, it is a good idea to use the sound monitoring technique from Part 1 to ensure the tone from the speaker is at a reasonable amplitude (volume). Monitor the sound at the 5 cm and 50 cm marks to ensure the sound level sensor still shows fluctuations (is not at the end of its scale).

15. ☐ Put your data collection system into manual sampling mode with manually entered data. Name the manually entered data “Distance” and give it units of meters. �(5.2.1)

16. ☐ Display Sound Level (dBC) on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

17. ☐ Change the variable on the *x*-axis to Distance. �(7.1.9)

18. ☐ What do you think the graph of Sound Level versus Distance will look like? Draw your prediction using the prediction tool on the graph. �(7.1.12)

19. ☐ Turn on your power amplifier/function generator, and adjust the frequency and amplitude to an audible tone that does not interfere with other student lab groups.

Collect Data

20. ☐ Go to the table display you created on the data collection system.

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

22. ☐ Starting at 0.05 m (5 cm) and ending at 0.50 m, record a sound level data point for every 0.05 m of user-entered Distance (moving the sound level sensor 5 cm at a time between each value you keep). �(6.3.2)

23. ☐ Stop the data set. �(6.3.3)

Analyze Data

24. ☐ Copy the values from the table of Distance and Sound Level data on your data collection system to Table 2 in the Data Analysis section.

25. ☐ Return to the Sound Level (dBC) versus Distance graph that you created on the data collection system.

26. ☐ Sketch the graph of Sound Level versus Distance in the Data Analysis section.

27. ☐ Is the relationship linear between the sound level and distance from the source?

No, it is a curve.

28. ☐ Apply different curve fits to the graph on the data collection system. �(9.5)

Note: If you do not have sufficient curve fits available, try linearizing your data by building a calculation with the data to see if the resulting graph is linear. �(10.3) You may need to adjust the scale of your graph to see the relationship. �(7.1.2)

29. ☐ Do any of these curve fits seem to match your data?

Answers will vary. Generally, most fits will not be very good.

30. ☐ Display Sound Intensity on the *y*-axis of a graph with Time on the *x*-axis. �(7.1.1)

31. ☐ Change the variable on the *x*-axis from time to distance. �(7.1.9)

32. ☐ Sketch the graph of Sound Intensity versus Distance in the Data Analysis section.

33. ☐ Change the variable on the *x*-axis to sound level (dBC).

34. ☐ Sketch the graph of Sound Intensity versus Sound Level(dBC) in the Data Analysis section.

35. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

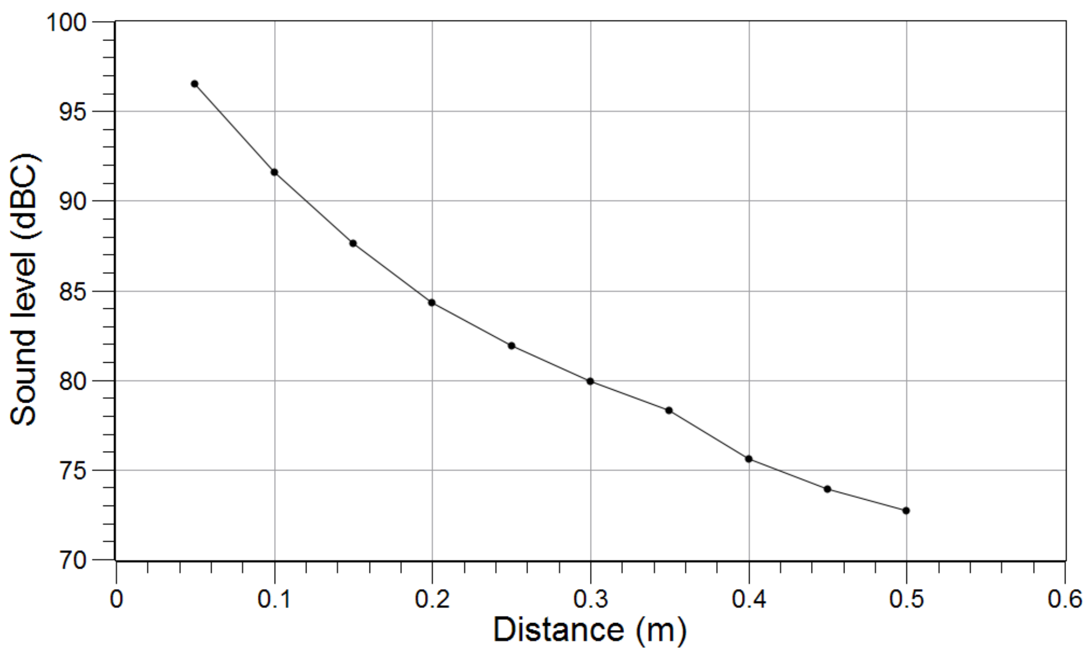
Table 1: Sound levels

Sound Source	Sound level (dBA)
Room	42
Tuning Fork	55
Musical Instrument	81
Voice	98

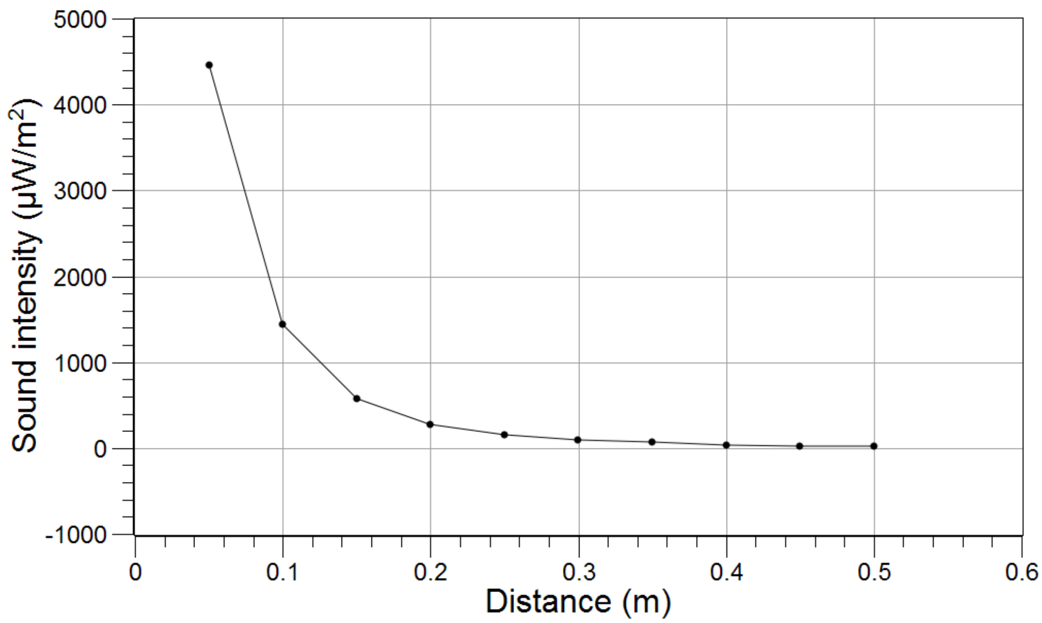
Table 2: Sound levels and distance

Distance (m)	Sound level (dBC)
0.05	96.5
0.10	91.6
0.15	87.6
0.20	84.3
0.25	81.9
0.30	79.9
0.35	78.3
0.40	75.6
0.45	73.9
0.50	72.7

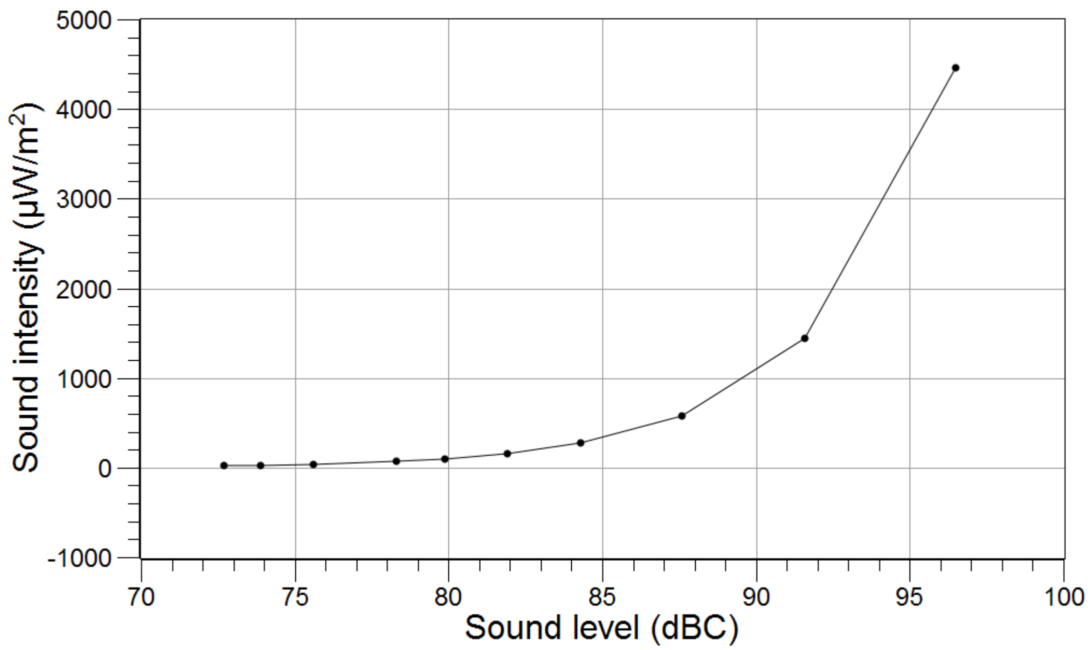
Sound level versus distance



Sound intensity versus distance



Sound intensity versus Sound level



Analysis Questions

1. Describe the difference in volume between the different sound producing devices according to your ear as compared to the values you recorded in Table 1.

Answers will vary. Generally the tuning fork will sound the quietest, and the musical instrument or voice will sound the loudest. The sources should be arranged according to the values in Table 1. The spread of values will generally seem small compared to the perceived sound.

2. What curve fit was closest to the trend of your data?

Answers will vary. It is likely to be an inverse fit or negative power fit.

3. What frequency (pitch) did you use for the Intensity versus Distance part of the lab? Do you think it made a difference? How would you test this?

200 Hz. Students will general state that the frequency did not made a difference. To test this, keep the sound sensor at the same distance, and change the frequency.

Synthesis Questions

Use available resources to help you answer the following questions.

1. The dBA scale is weighted to represent the response of the human ear, based on your experience with different sounds, and likely non-linear. Why do you think that human hearing might follow such an unusual response curve?

Humans need the ability to hear a wide range of sounds. Historically, humans had to distinguish the subtle sounds of a predator sneaking up on them, but also need the ability to lay-in-wait near a thundering herd of water buffalo without damaging their hearing.

2. The dBA scale is weighted to represent the response of the human ear. However, intensity is related to the power incident on a surface. If your sound source were ideal, how do you think intensity would change with distance? (Hint: surface area of a sphere increases as a function of r^2)

The intensity should drop off as a function of $1/r^2$.

3. If a sound that is 50 dB is 10 times the intensity of a sound that is 40 dB, and a 70 dB sound is 10 times the intensity of a 60 dB sound, How much more intense is a 70 dB sound than a 40 dB sound? What kind of scale is this?

A 70 dB sound is 1000 times louder than a 40 dB sound. This is a logarithmic scale.

Multiple Choice Questions

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

1. What do sound waves require to travel?

- **A. Medium**
- **B.** Tuning fork
- **C.** Wavelength
- **D.** Instruments

2. Which unit describes the frequency of a sound?

- **A.** Vibe
- **B. Hertz**
- **C.** Meter
- **D.** Meter per second

3. Which unit describes the intensity of a sound?

- **A.** Wavelength
- **B.** Meter
- **C.** Hertz
- **D. Decibel**

4. The intensity of a sound wave is related to the ____________ of a wave.

- **A.** Pitch
- **B.** Frequency
- **C.** Wavelength
- **D. Amplitude**

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. A wave is a disturbance in a **medium**. Sounds consist of **vibrations** of air molecules that are modeled as **longitudinal** waveforms. Every tuning fork has a specific **pitch** that relates to the frequency of the vibrations. The **frequency** of vibration is represented in units of hertz. The loudness or softness of a tone is described as the **intensity**. A sound level sensor measures the intensity of sound waves.

Extended Inquiry Suggestions

Find a glass (or plastic) hollow tube (a resonance tube). Find a cork or stopper slightly smaller than the diameter of the tube. Attach a string to one end, and glue a piece of felt to the other end. Lower the cork about an inch into the top of the tube. Strike a tuning fork, and hold the vibrating tines under the open end of tube. Do not allow the vibrating fork to touch the open end of the tube. Lower the cork until you observe a change in the intensity of the sound. Measure the corresponding length for each intensity (an enhanced loudness) point. These distinct points are called resonance points.

Ask students how many resonance points were present.

Ask students if they can calculate the speed of sound based upon the resonance length of the tube and the frequency of the tone? (You will need to provide the correction factor for the resonance length; this takes into consideration the diameter of the tube and the fact that the air molecules are vibrating just beyond the edge of the open tube.)

Nuclear Physics

39. Radiation

Objectives

Students gain a new understanding of how to handle radioactive sources, how to measure radiation intensity, and how radioactive particles react with various materials. Students will:

- Understand the relationship between the distance from a radioactive source and the measured activity of the source
- Observe the penetrating ability of three common types of nuclear radiation
- Investigate the ability of different materials to absorb energy associated with nuclear radiation

Procedural Overview

Students gain experience conducting the following procedures:

- Using a Geiger-Müller tube to measure the activity of different radiation sources
- Measuring the change in counts for a given time interval as a function of distance from the source
- Measuring the effectiveness of different types of shielding for different types of radioactive sources

Time Requirement

♦ Preparation time	5 minutes
♦ Pre-lab discussion and activity	10 minutes
♦ Lab activity	55 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Geiger-Müller tube with power supply
- Digital adapter
- Radioactive sources (alpha, beta, gamma)
- Three-finger clamp
- Shielding materials (paper, plastic, lead)
- Rod stand
- Meter stick

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Types of radiation and their associated particles
- ♦ Stability and instability of the nucleus of atoms
- ♦ Inverse square law as it relates to gravitation, electric, and magnetic forces

Related Labs in this Guide

Labs conceptually related to this one include:

- ♦ Inverse Square Law

Using Your Data Collection System

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

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Recording a run of data �(6.2)
- ♦ Displaying data in a table �(7.2.1)
- ♦ Viewing statistics of data �(9.4)

Background

Nuclear science is an important aspect of our physical world. We use x-rays to inspect our bones, we use radiation therapy to battle cancer, and we use radioactive decay to generate power. Scientists such as Henri Becquerel and Pierre and Marie Curie spent most of their careers searching for understanding of the nucleus, radioactive materials, and nuclear chain reactions.

Ionizing radiation is radiation with enough energy to eject electrons from atoms or molecules. This can have a profound effect on biological systems like us, so we have a vested interest in how it behaves. For example, what happens to the intensity of radiation as you get farther from the source? Or what kinds of materials can protect you from different types of radiation?

Radiation can be particles or the entire spectrum of electromagnetic waves, but ionizing radiation tends to be in the higher energy region of the spectrum. We will be investigating three types of radiation: alpha particles, beta particles, and gamma rays. Alpha particles are helium nuclei, beta particles are electrons, and gamma rays are photons.

A natural source of ionizing radiation is radioactive decay. Radioactive decay is a spontaneous change to the nucleus of an atom, and only observable using special detection devices, such as a Geiger-Müller tube. Because we are interested in ionizing radiation it makes sense that the Geiger-Müller tube uses an ionic cascade to register a count. Some particles readily pass through materials and others are easily blocked. The Geiger-Müller Tube enables you to count the number of emitted particles or photons that reach the tube over a fixed interval of time.

Pre-Lab Discussion and Activity

Engage your students by considering the following questions:

1. What is radiation? What evidence is there in the physical world that radiation exists? Give some examples.

Student responses will vary here. The sun is a source of electromagnetic radiation. A microwave oven emits microwave radiation. A patient in the dentist's office may have an x-ray of the teeth recorded.

2. What is an atom? How do we envision the structure of an atom in our minds? What does the nucleus of an atom consist of?

Have students (either individually or in a team) draw their representation of what an atom looks like.

All elements consist of atoms. Atoms are incredibly small. Their model is spherical in shape and consists of a central nucleus and orbiting electrons. The nucleus of the atom consists of protons and neutrons. Depending upon the age level of students, the reference to electron orbits, or electron clouds according to the Bohr model may be discussed and the new modern view of the quantum mechanical wave model.

3. Which elements of the periodic table are stable atoms and which are unstable atoms? What are isotopes?

Have students cutout squares or circles from brightly colored paper and tape them to a periodic table to highlight their responses.

Elements with atomic numbers less than 20 are considered stable; in general (there are exceptions). Isotopes of an element have the same number of protons but differing numbers of neutrons in each nucleus. Isotopes of hydrogen are hydrogen –1, deuterium –2, and tritium –3. This means that there is increase in the number of neutrons by one for the total number of nuclei of each isotope.

4. Do you know a device that could be used to detect or measure nuclear radiation?

Some students may respond with a counter of some sort. If available, you may want to demonstrate with a cloud chamber so the students can observe the vapor trails left by the particles as they spew out from the radioactive source.

5. Do you think nuclear radiation can pass through materials? What kinds of materials?

You may want to first describe the physical characteristics of specific particles such as for the alpha, beta, and photon. Beta particles are electrons that move fast due to their low mass whereas alpha particles of high mass (helium nuclei) move slow. Gamma radiation is electromagnetic in origin.

Lab Preparation

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

Safety

Add these important safety precautions to your normal laboratory procedures:

- Radioactive materials are harmful. Instruct students not to tamper with the plastic discs which contain a small (microgram) of radioactive material.
- Although the dose rate of most radioactive sources used for educational purposes is far too small to pose any health threat, students should not handle radioactive materials with their hands; however, if contact occurs, have students thoroughly wash the contact site with soap and water.
- The front surface of the Geiger-Müller tube/power supply is very sensitive. Instruct students not to touch it. In addition when removing and replacing the protective cap, do not cover the small vent hole on the cap.

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
Display counts in a table.	Connect the Geiger-Müller tube/power supply to the digital adapter.	Turn on the statistics in your table and record the mean or average counts as well as distance.	Create a graph of average counts versus distance.	Apply different curve fits to your plot of average counts versus distance to determine the relationship.

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.

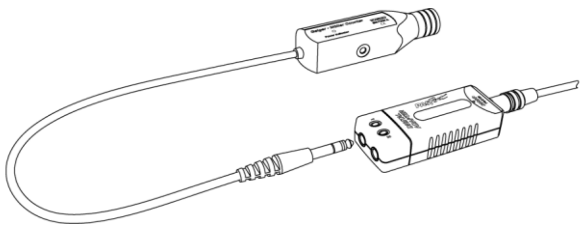
Part 1 – Background Radiation

Set Up

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

2. ◻ Connect the digital adapter to the data collection system. �(2.1)

3. ◻ Connect the Geiger-Müller tube/power supply to the digital adapter.



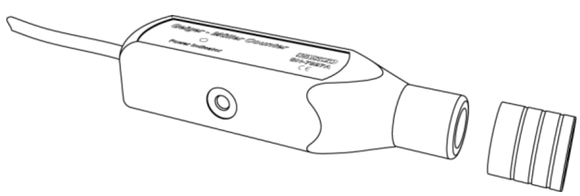
4. ◻ Select "General Counting" from the list of available measurements.

5. ◻ Set the "Count Time Interval" to five seconds in the counter's properties.

6. ◻ Display Pulse Count in a table display. �(7.2.1)

7. ◻ Use the three-finger clamp to attach the Geiger-Müller tube/power supply to the rod stand with the sensing element pointed down at the table. Ensure that your sources are as far away from the tube as possible.

8. ◻ Carefully remove the cap from the Geiger-Müller tube/power supply.



9. ◻ Do you think there will be radiation detected even when the sources are not present? Why?

Yes, radiation is a naturally occurring phenomenon, so it stands to reason that it is all around us—from the radioactive decay of elements in the environment to cosmic rays.

Collect Data

10. ◻ Start data recording. �(6.2)

11. ◻ Record at least 4 time intervals of data (approximately 20 s).

12. ◻ Stop data recording. �(6.2)

Analyze Data

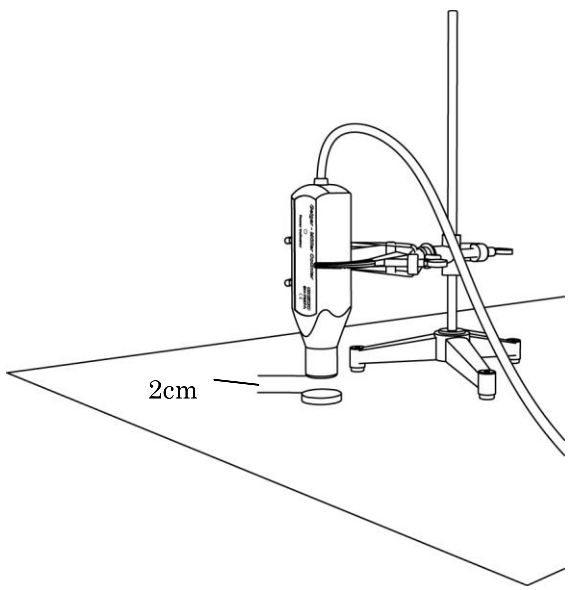
13. ☐ View the mean or average counts. �(7.1.4)

14. ☐ Record this value as the background radiation in the Data Analysis section.

Part 2 – Radiation versus Distance

Set Up

15. ☐ Place a radioactive source on the table directly under the Geiger-Müller tube/power supply.



16. ☐ Lower the Geiger-Müller tube/power supply until the sensing element is 2 cm above the source.

Collect Data

17. ☐ Start data recording. �(6.2)

18. ☐ Record at least 4 time intervals of data (approximately 20 s).

19. ☐ Stop data recording. �(6.2)

20. ☐ View the mean or average counts. �(7.1.4)

21. ☐ Record this value next to the appropriate distance in Table 1 of the Data Analysis section.

22. ☐ Move the Geiger-Müller tube/power supply sensor 2 cm further away from the source and repeat the data recording steps until you have reached a distance of 12 cm.

23. ☐ Repeat the data collection steps for each of the three sources.

Part 3 – Radiation versus Shielding

Set Up

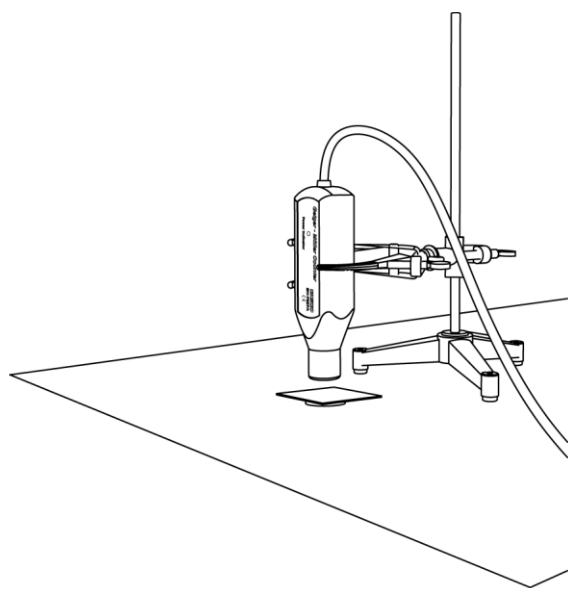
24. ☐ Set the Geiger-Müller tube/power supply 4 cm above the table.

25. ☐ Place a source under the Geiger-Müller tube/power supply.

26. ☐ Record the type of materials you will be using as shielding in Table 2 in the Data Analysis section. If you are using different thicknesses of the same material be sure to include that information too.

Collect Data

27. ☐ Place a shield material between the source and the Geiger-Müller tube/power supply



28. ☐ Start data recording. �(6.2)

29. ☐ Record at least 4 time intervals of data (approximately 20 s).

30. ☐ Stop data recording. �(6.2)

31. ☐ View the mean or average counts. �(7.1.4)

32. ☐ Record this value next to the appropriate material in Table 2 of the Data Analysis section.

33. ☐ Repeat the data collection steps for each of the shield materials using all three sources and record the mean or average counts in Table 2.

Data Analysis

Average background count: 2

Table 1: Distance and average count

Distance (m)	Average Alpha Count	Average Beta Count	Average Gamma Count
0.02	22	36	20
0.04	10	11	8
0.06	4	5	5
0.08	4	4	4
0.10	2	2	2
0.12	1	2	2

1. ☐ Plot a graph of Average Count versus Distance for the gamma source in the associated blank graph axes below.

Graph 1: Average Count versus Distance (gamma source)

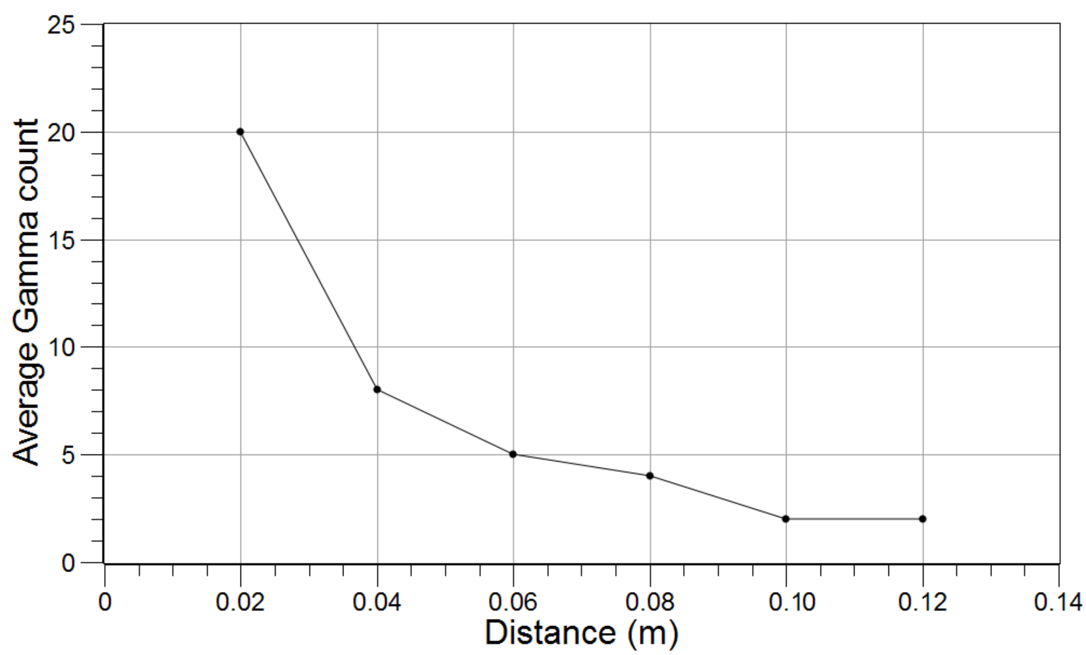


Table 2: Shield material and average count

Shield Material	Average Alpha Count	Average Beta Count	Average Gamma Count
One Sheet of Paper	5	9	7
Two Sheets of Paper	2	8	7
Plastic (thin)	2	7	9
Plastic (thick)	1	1	8
Lead (thin)	1	1	7
Lead (thick)	0	1	5

Analysis Questions

1. Does nuclear radiation follow the inverse square law?

Yes. As the source is moved away from the sensor, the amount of radiation decreases. Answers could vary depending upon how the mathematical fit is carried out.

2. What first action would be important to protect yourself from the radiation released from a broken container of radioactive material?

Answers will vary. When radiation is released from a broken container, an obvious reaction would be to increase your distance from the container as quickly as possible. In accordance with the inverse square law, if you double your distance from the source, the amount of radiation decreases to one-fourth or 25%.

3. What generalizations can you make about the effect of the thickness of the shielding material on the count rate?

Answers will vary. Generally, as the thickness of the shielding material increases, the amount of radiation that penetrates the shielding material will decrease.

4. What generalizations can you make about the effect of density of the shielding material on the count rate?

Answers will vary. Generally, the more dense the shielding material, the less radiation will penetrate it.

Synthesis Questions

1. How would the risk of exposure to radioactive substances be different if nuclear radiation followed an inverse cube law?

If nuclear radiation followed an inverse cube relationship to distance, the danger from nuclear radiation would be much less as the distance from the source increases. If you double the distance from the source, the radiation decreases to two cubed, or one-eighth of the original amount.

2. Because the energy of the radiation is absorbed by the shield (such as paper, plastic, lead), what effect does the absorbed energy have on the shield?

Answers will vary. One possibility is that as the energy of radiation is absorbed by the shield, the shielding material will heat up.

3. Why is there a difference in the penetrating ability of the three basic radiation types?

Answers will vary. The alpha particles are helium nuclei so they are larger and have less speed than the low mass beta particles (electrons). Alpha particles have a net positive charge and will be repelled by the nucleus of the atoms. Beta particles have a negative charge and will be repelled by the electron cloud that surrounds the nucleus of an atom. Gamma radiation is electromagnetic radiation and is not repelled by charged particles.

4. How effective would other shielding materials such as air or water be at stopping radiation?

Answers will vary. Water is more effective as a shielding material than air because it is much denser. There are more water molecules per volume than air molecules.

5. What material is the most effective in absorbing the energy of nuclear radiation?

For this exercise, lead is the most effective in absorbing the energy of nuclear radiation.

Multiple Choice Questions

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

1. The graph of Average Counts versus Distance demonstrates a trend that is:

- **A.** An exponential relationship
- **B.** An inverse relationship
- **C.** A direct relationship
- **D.** **An inverse squared relationship**

2. Which particle penetrates materials the least?

- **A.** Gamma
- **B.** Beta
- **C.** **Alpha**
- **D.** They are all the same

3. Rank the materials (paper, plastic, lead) in order of their effectiveness in absorbing radiation. Start with greatest first.

- **A.** Plastic, lead, paper
- **B.** Lead, paper, plastic
- **C.** Plastic, paper, lead
- **D.** **Lead, plastic, paper**

4. Which of the types of radiation is known as electromagnetic radiation?

- **A.** Alpha
- **B.** Beta
- **C.** **Gamma**
- **D.** Electron

Key Term Challenge

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

1. A **Geiger-Müller** tube is a device used to detect radioactive emissions from a radioactive source. The closer the radioactive source is positioned to the sensor, the **greater** the amount of counts per second. Helium nuclei known as **alpha** particles, electrons known as **beta** particles, and photons known as **gamma** are types of radiation. The amount of penetration, or absorbance, of radioactive particles in a material is based upon the **density** of the material and the **nature** of the particle. Substances or **materials**, like **lead** are excellent shields.

Extended Inquiry Suggestions

The optional setup utilizes the linear motion accessory and the rotary motion sensor for precise position data.

Back in the 1950's dinnerware like Fiestaware contained a radioactive isotope of lead in the paint. Ask around to see if you can find a dish or cup. Flea markets are a good source to locate Fiestaware. Measure the radiation for the dish or cup as you carried out in Part 2. Another source of radiation (thorium) are the mantels in old camping latterns.

Conduct an internet search of synthetic (man-made) radioactive materials that are used in medicine. Consider the following questions:

a) What are they?

b) How are they used?

c) What type of radiation scans exist?

d) How long does the synthetic compound remain in the body?

e) What does a radioactive scan look like on film?

f) In the medical field, what are the qualifications to be a nuclear lab technician?