FLORIDA

# Experience Physics®

## Printable Lab Worksheets

SAVVAS

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With *Florida Experience Physics* you have access to amazing online activities, games, interactives, and more. This is a sampler of printable lab worksheets, which are housed in the digital learning platform Savvas Realize®.



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# Lab Safety

When it comes to laboratory physics, the safety of students and teachers is the primary concern of Savvas. To that end, all versions of the lab investigations give detailed safety information for the student and the teacher at the beginning of each lab.

## Safety in the Physics Laboratory

The following information is intended to help the teacher plan demonstrations and prepare labs. The material included here is not comprehensive. Savvas takes no responsibility for the completeness of this information or for the implementation of these suggestions. It is meant to help you establish safety awareness for staff and students. The teacher is responsible for teaching safety awareness by holding each student accountable for the safety of all participants in the lab. The most effective way of teaching laboratory safety is by always modeling safe practices and by making a discussion of safety concerns a top priority for all lab activities.

## Education

- Have a safety committee that includes school faculty, administrators, and students.
- Schedule regular meetings of the safety committee to discuss issues, accident reports, and the results of lab inspections.
- Implement a safety education program for staff and students.
- Encourage school staff to become certified in CPR and first aid.
- Require that science staff read any of several publications on safety in the high school science classroom.
- Require students to know the lab safety rules:
    - Assess students safety knowledge by giving them a safety quiz.
    - Write a safety contract and have students sign it.
    - Send the contract home with a set of rules and require that one parent or guardian sign the contract, having read the rules.
- In pre-lab discussions, stress safety issues relevant to each specific lab.
- Give a safety grade with each lab, based on each student's behavior during the lab.
- Penalize unsafe behavior by removing students from the lab.

## Lab Management

- Report all accidents to the safety committee.
- Keep phone numbers for the fire and police departments, and poison control center next to every phone.
- Keep a first-aid kit stocked and available.
- All laboratories should have: a fire extinguisher, a smoke alarm, a safety shower, an eye-wash faucet, a fume hood.
- Maintain and check all safety equipment regularly and report findings to the safety committee.
- Require students to read each lab before doing it.
- Tie back hair and do not wear loose jewelry or clothing. If using chemicals wear closed-toe shoes and long pants.
- Keep the aisles clear. Backpacks and books should be kept away from aisles and lab stations so that they do not pose tripping hazards.
- Display safety warning signs and posters.
- Prohibit students access to stock rooms.
- Provide enough space between groups and encourage students to be aware of where other students are in the physics lab.

## Lab Techniques

- Do not allow any student to work alone in the laboratory.
- Do not leave any experiment unattended.
- When pipetting, use a suction bulb. Never use your mouth.
- Use caution when heating:
    - Use caution when using hot plates as they may be hot even when they appear to be off.
    - When heating the contents of a test tube, direct the mouth of the test tube away from yourself and away from others.
    - Always use borosilicate glassware when heating items in the lab.
    - Never heat an empty container. It could shatter and break.
    - When using glassware, avoid extreme temperature changes as it could cause glassware to break and shatter.

# APPENDIX B SAFETY IN THE LAB

The experiments in this program have been carefully designed to minimize the risk of injury. However, safety is also your responsibility. The following rules are essential for keeping you safe in the laboratory. The rules address pre-lab preparation, proper laboratory practices, and post-lab procedures.

## Pre-Lab Preparation

1. Read the entire procedure before you begin. Listen to all of your teacher's instructions. When in doubt about a procedure, ask your teacher.
2. Do only the assigned experiments. Only do experiments when your teacher is present and has given you permission to work.
3. Know the location and operation of the following safety equipment: fire extinguisher, fire blanket, emergency shower, and eye wash station.
4. Know the location of emergency exits and escape routes. To make it easy to exit quickly, do not block walkways with furniture. Keep your work area orderly and free of personal belongings, such as coats and backpacks.
5. Protect your clothing and hair from chemicals and sources of heat. Tie back long hair and roll up loose sleeves when working in the laboratory. Avoid wearing bulky or loose-fitting clothing. Remove dangling jewelry. Wear closed-toe shoes at all times in the laboratory.

## Proper Laboratory Practices

6. Even with well-designed and tested laboratory procedures, an accident may occur while you are working in the lab. Report any accident, no matter how minor, to your teacher.
7. Wear chemical splash goggles at all times when working in the laboratory. These goggles are designed to protect your eyes from injury. While working in the lab, do not rub your eyes, because chemicals are easily transferred from your hands to your eyes.

⚠ If, despite these precautions, a chemical gets in your eye, remove any contact lenses and immediately wash your eye with a continuous stream of lukewarm water for at least 15 minutes.

8. Always use the minimal amounts of chemicals specified for an experiment to reduce danger, waste, and cleanup.
9. Never taste any chemical used in the laboratory, including food products that are the subject of an investigation. Treat all items as though they are contaminated with unknown chemicals that may be toxic. Keep all food and drink that is not part of an experiment out of the laboratory. Do not eat, drink, or chew gum in the laboratory.

⚠ If you accidentally ingest a substance, notify your teacher immediately.

10. Don't use chipped or cracked glassware. Don't handle broken glass. If glassware breaks, tell your teacher and nearby classmates. Discard broken glass as instructed by your teacher.

⚠ If, despite these precautions, you receive a minor cut, allow it to bleed for a short time. Wash the injured area under cold, running water and notify your teacher. More serious cuts or puncture wounds require immediate medical attention.

11. Do not handle hot glassware or equipment. You can prevent burns by being aware that hot and cold equipment can look exactly the same.

⚠ If you are burned, immediately run cold water over the burned area for several minutes until the pain is reduced. Cooling helps the burn heal. Ask a classmate to notify your teacher.

12. Recognize that the danger of an electrical shock is greater in the presence of water. Keep electrical appliances away from sinks and faucets to minimize the risk of electrical shock. Be careful not to spill water or other liquids in the vicinity of an electrical appliance.

⚠ If, despite these precautions, you spill water near an electrical appliance, stand back, notify your teacher, and warn other students in the area.

**13.** Report any chemical spills immediately to your teacher. Follow your teacher's instructions for cleaning up spills. Warn other students about the identity and location of spilled chemicals.

⚠ If, despite these precautions, a corrosive chemical gets on your skin or clothing, notify your teacher. Then wash the affected area with cold running water for several minutes.

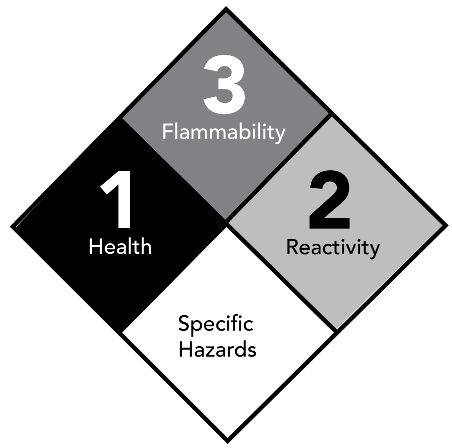
## Post-Lab Procedures

**14.** Dispose of chemicals in a way that protects you, your classmates, and the environment. Always follow your teacher's directions for cleanup and disposal. Clean your small-scale reaction surface by draining the contents onto a paper towel. Then wipe the surface with a damp paper towel and dry the surface completely. Dispose of the paper towels in the waste bin.

**15.** Wash your hands thoroughly with soap and water before leaving the laboratory.

A Materials Safety Data Sheet (MSDS) for a chemical describes any safety issues. A diagram summarizes risks related to flammability, health, and reactivity. A number scale indicates the level of risk.

0 Low
1 Slight
2 Moderate
3 High
4 Extreme




## Safety Procedures

Take appropriate precautions when any of the following safety symbols appears in an experiment.

**Eye Safety** Wear safety goggles.

**Clothing Protection** Wear a lab coat or apron when using corrosive chemicals or chemicals that can stain clothing.

**Skin Protection** Wear plastic gloves when using chemicals that can irritate or stain your skin.

**Broken Glass** Do not use chipped or cracked glassware. Do not heat the bottom of a test tube.

**Open Flame** Tie back hair and loose clothing. Never reach across a lit burner.

**Flammable Substance** Do not have a flame near flammable materials.

**Corrosive Substance** Wear safety goggles, an apron, and gloves when working with corrosive chemicals.

**Poison** Don't chew gum, drink, or eat in the laboratory. Never taste a chemical in the laboratory.

**Fume** Avoid inhaling substances that can irritate your respiratory system. Use a fume hood whenever possible.

**Thermal Burn** Do not touch hot glassware or equipment.

**Electrical Equipment** Keep electrical equipment away from water or other liquids.

**Sharp Object** To avoid a puncture wound, use scissors or other sharp objects only as intended.

**Disposal** Dispose of chemicals only as directed.

**Hand Washing** Wash your hands thoroughly with soap and water.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Motion Plots

**What would a plot of your motion look like?**

When you walk through a park or inside your home, your position and speed are changing constantly as you follow your path and avoid obstacles. In this investigation, you will examine your own motion and use graphs to keep track of your position and speed as a function of time. Likewise, you will explore the differences between position and displacement and between speed and velocity.

## Focus on Science Practices

**SEP 4** Analyze Data and Interpret Data
**SEP 5** Use Math and Computational Thinking

## Materials Per Group

- Graphing paper
- Masking tape
- Metric tape or meter stick
- Motion detector
- Motion detector, data collection interface, and software
- Pencil (optional)
- Timer (optional)

## Safety

*The materials in this lab are considered nonhazardous. Follow all laboratory safety guidelines. Wear safety glasses when performing this experiment.*

## Procedure

*How can you obtain plots of your position and speed as a function of time?*

1. Place a motion detector on the edge of a tabletop or flat surface, slightly above waist height. Remove potential sources of interference, such as chairs and desks, from the motion detector's path of emitted sound waves.

2. Use a ruler or meter stick to mark distance in one-meter increments from the edge of the table or motion detector. Place masking tape at each 1 m interval, up to 4 m.

NAME ________________ DATE ________ CLASS ________

3. Connect the motion detector to a computer interface. Select graph mode.

4. Stand in the path of the motion detector at the 1 m mark. Hold a book or other flat surface steady in front of your body to serve as a uniform deflector for the emitted sound waves. This will reduce noise in the motion graphs.

5. Begin collecting data.

6. Collect position vs. time (*d*–*t*) and speed vs. time (*v*–*t*) data for the following types of motion.

   a. Stand motionless at the 2 m mark for 10 seconds.

   b. Quickly walk away from the motion detector at a constant speed for 4 seconds.

   c. Quickly walk towards the motion detector at a constant speed for 2 seconds.

   d. Slowly walk towards the motion detector at a constant speed for 10 seconds.

7. Construct position vs. time (*d*–*t*) and speed vs. time (*v*–*t*) plots for the motions performed in step 6. Draw or insert a picture of all the plots.

NAME ______________________________ DATE __________ CLASS ____________

**8. SEP Plan Your Investigation** Design an experimental procedure to examine motion such that you start at a given position, change your position a few times in intervals, and then return to the original position. Your speed must be different for every interval but constant during a given motion interval. Describe in detail the type of motion you will perform that meets these requirements, and then conduct the appropriate lab measurements.

**9.** Draw or insert pictures of the *d–t* and *v–t* plots obtained when you conducted your measurements in step 8.

## Analyze and Interpret Data

**1. SEP Analyze Data** What information can be found from the slopes of *d–t* and *v–t* graphs? How does the slope of a *d–t* graph relate to speed? Explain.

**2. SEP Construct an Explanation** Does the origin of a *d–t* graph always have to be at (0,0)?

3. **SEP Use Graphs** Displacement can be represented as a vector arrow that extends from the initial position to the final position reached by an object in motion. The arrowhead of the displacement vector points in the direction of the motion. Velocity is also a vector and speed is velocity's magnitude. The magnitude of the velocity vector is proportional to its length. The vector's arrowhead points in the direction of the motion at any given time. Draw a diagram using vectors that indicates the displacement and velocity for each motion performed in step 6.

4. **SEP Construct an Explanation** Describe why choosing an appropriate data collection window, or amount of time over which data is collected, is important when using a motion detector to monitor walking in a finite space.

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INQUIRY LAB – OPEN

# Free Fall Acceleration

**Do objects in free fall move at a constant speed, or do they experience acceleration?**

When an object is dropped from a certain height above Earth's surface, it will invariably reach the ground after some time. Do objects of different sizes or masses fall at the same rate? In this laboratory, you will study the free fall of various objects to determine their acceleration, and how this variable relates to their sizes or masses.

## Focus on Science Practices

**SEP 4** Analyze Data and Interpret Data
**SEP 5** Use Math and Computational Thinking

## Materials Per Group

- Balance, 0.01 g precision
- Ball, steel, 1⅓ ″-diameter
- Ball, steel, ⅝ ″-diameter
- Basket or box
- Foam pad
- Masking tape
- Metric measuring tape or meter stick
- Stopwatch or timer

## Safety

*Wear safety glasses. Please follow all laboratory safety guidelines.*

NAME ______________________ DATE ____________ CLASS ____________

## Procedure

*How can you measure the acceleration of an object in free fall?*

1. **SEP Plan Your Investigation** Using the items available to you for this lab, design an investigation to determine the time it takes for steel balls of different size or mass to hit the ground, after being dropped from a certain height. Use the data tables provided to guide your design, and write a detailed procedure. Note: You may want to choose one partner to drop the ball, one partner to time the drop, and one partner to retrieve the ball and record the data; in addition, practice dropping the ball from the marked height a few times while the partner dropping the ball and the one measuring time discuss and coordinate when to start timing.

NAME ______________________ DATE __________ CLASS __________

**Table 1**

| Smaller Ball | | | |
|---|---|---|---|
| **Ball's Mass (g)** | | | |
| **Drop Height (m)** | | | |
| **Trial** | **Drop Time (s)** | **Gravitational Acceleration, g ($m/s^2$)** | **Percent Error (%)** |
| **1** | | | |
| **2** | | | |
| **3** | | | |
| **4** | | | |
| **5** | | | |
| **6** | | | |
| **7** | | | |
| **8** | | | |
| **9** | | | |
| **10** | | | |
| **Average** | | | |

NAME ______________________ DATE __________ CLASS __________

**Table 2**

| Larger Ball | | | |
|---|---|---|---|
| **Ball's Mass (g)** | | | |
| **Drop Height (m)** | | | |
| **Trial** | **Drop Time (s)** | **Gravitational Acceleration, g ($m/s^2$)** | **Percent Error (%)** |
| **1** | | | |
| **2** | | | |
| **3** | | | |
| **4** | | | |
| **5** | | | |
| **6** | | | |
| **7** | | | |
| **8** | | | |
| **9** | | | |
| **10** | | | |
| **Average** | | | |

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Use Mathematics** Use Equation 1 to figure out how to calculate the acceleration, *a*, of each drop. In Equation 1, *y* is the distance traveled by the ball during free fall (or its initial height), $y_0$ is the starting point on its trajectory (which can be set to be zero), $v_0$ its initial velocity, *g* is the gravitational acceleration, and *t* is time. Show a sample calculation and fill in the data table for each size ball.

   **Equation 1:** $y = y_0 + v_0 t + \frac{1}{2}at^2$

2. **SEP Use Mathematics** Use Equation 2 to calculate the percent error between the measured and accepted values of the acceleration due to gravity for each drop. Use 9.8 m/$s^2$ for the accepted value. Show a sample calculation and fill in the data tables.

   **Equation 2:** $Percent\ Error = \frac{|measured\ value - accepted\ value|}{accepted\ value} \times 100$

3. **SEP Analyze Data** Compare the average acceleration of the steel balls to the accepted value of 9.8 m/$s^2$. What are some of the sources of experimental error in this investigation? Explain.

4. **SEP Interpret Data** Compare the average acceleration of the smaller ball to the average acceleration of the larger ball. What conclusion can be drawn about the relationship between gravitational acceleration on Earth and mass?

5. **SEP Construct an Explanation** What does the value of the gravitational acceleration on Earth, *g*, tell you about the speed of the steel balls during free fall?

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INQUIRY LAB – OPEN

# Model Projectile Motion

**What does the trajectory of a launched round shot look like from the point of view of an observer?**

When objects are thrown forward, horizontally, or at an angle, they follow a curved trajectory until they hit the ground. This trajectory is commonly known as projectile motion and can be modeled using the mathematical equations that describe a parabola. In this laboratory, you will apply the physics of projectile motion and the law of conservation of energy to determine the launch speed of a steel ball after rolling down an inclined plane.

## Focus on Science Practices

**SEP 4** Analyze Data and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Ball, steel, ¾ ″-diameter
- Clamp holder
- Inclined plane, wood
- Metal sheet, 4 ″ × 4 ″
- Meterstick
- Pencil or chalk
- Printer paper, white, 3–4 sheets
- Protractor
- Scissors
- Support rod
- Support stand
- Support stand clamp
- Textbooks, 3–4 (optional)
- Transparent tape
- Washer and fishing line (about 1.5–2 m, for plumb bob)

## Safety

*Be sure to quickly retrieve the ball once it hits the floor. Wear safety glasses when performing this experiment.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

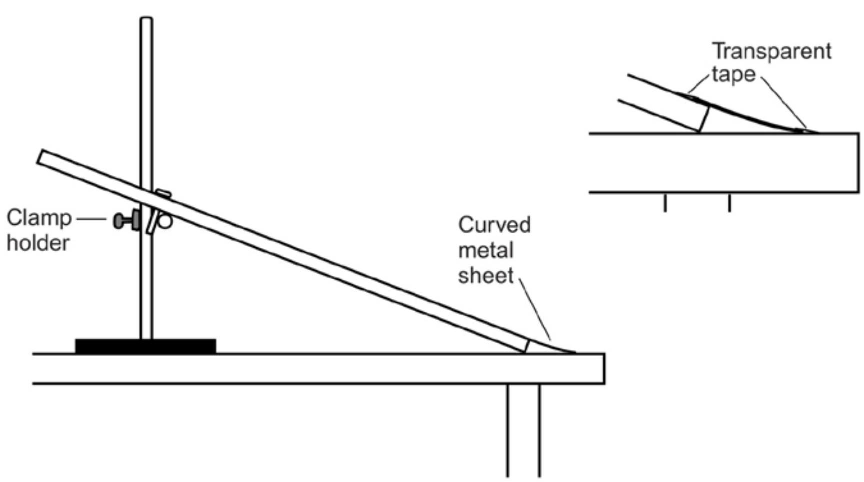
*What is the trajectory and speed of a projectile launched horizontally?*

1. Set up the inclined plane as shown in Figure 1. The angle of the inclined plane should be between 15° and 45°. Position the bottom of the inclined plane approximately 10 cm from the edge of the table. Make sure there is at least 2–3 meters of open space on the floor around the edge of the tabletop so the steel ball will have enough space to launch off the end of the table.

2. Obtain the 4 ″ × 4 ″ metal sheet. Use transparent tape to tape the edge of the 4 ″ × 4 ″ metal sheet to the bottom end of the inclined plane.

3. Bend the metal sheet slightly to form a smooth transition curve between the end of the inclined plane and the tabletop surface. The free end of this sheet should be within a centimeter or two from the edge of the tabletop. When the metal sheet forms a smooth curve, tape the other end of the sheet to the tabletop using transparent tape. Make sure the tape is flat and smooth at both ends of the metal sheet. See Figure 1.

**Figure 1**




4. Practice rolling the ball down the inclined plane and off the edge of the tabletop. Make sure the ball does not hit the tabletop hard, causing the ball to bounce upward. Adjust the curve in the metal sheet until the ball makes a smooth transition between the inclined plane and the tabletop. If the metal appears to

bend down when the ball rolls over it, small amounts of crumpled paper can be used under the sheet to help support it.

5. Cut 1.5–2 m of fishing line (depending on the height of the table). Tie one end of the fishing line to a washer to create a plumb-bob.

6. Hang the plumb-bob from the end of the tabletop where the inclined plane will launch the steel ball. The fishing line only needs to be held in place with a hand. It does not need to be tied. Make sure the plumb-bob hangs close to the floor without touching.

7. Place a strip of transparent tape, or use erasable chalk or pencil, to mark the spot on the floor directly below the hanging plumb-bob. If tape is used, make sure one edge of the tape signifies the location directly below the plumb-bob.

8. Use a meterstick to measure the height of the top edge of the tabletop from the floor, $y$. Make sure to measure from the mark made below the hanging plumb-bob. Record this height in the data table.

9. Mark on the inclined plane a point that will be the release position of the ball, $h$. Use a ruler or meterstick to measure the height of this release point above the tabletop.

10. Place the center of the steel ball at the release line. (One person should be ready to catch the ball after the first bounce.) Gently release the ball, making sure not to give it any additional push. The ball should roll straight down the inclined plane. Take note of the general area on the floor where the ball lands.

11. Use white printer paper along the horizontal path that the launched ball followed during the test run in step 10 to mark the point where the ball hit during the practice run.

12. Repeat step 10 six times. Release the ball from the same release height for each trial. The ball should leave a dark mark on the white paper where it lands.

13. Measure the horizontal distance, $x$, between the plumb-bob mark and the initial ball marks on the paper for each trial. Record all the appropriate data in the data table.

**14. SEP Plan Your Investigation** Describe how you would investigate the potential effect of changing the release point of the ball (*h*) and the angle of inclination of the ramp. Perform the required measurements and record your data in the data table.

NAME ______________________ DATE __________ CLASS __________

## Table 1

| Steel Ball Projectile Motion | | | | |
|---|---|---|---|---|
| **Table Height, *y* (cm)** | | | | |
| **Experiment Number** | **Trial** | **Release Height, *h* (m)** | **Angle of Inclined Plane** | **Ball Mark Distance, *x* (cm)** |
| **1** | **1** | | | |
| | **2** | | | |
| | **3** | | | |
| | **4** | | | |
| | **5** | | | |
| | **Average** | | | |
| **2** | **1** | | | |
| | **2** | | | |
| | **3** | | | |
| | **4** | | | |
| | **5** | | | |
| | **Average** | | | |
| **3** | **1** | | | |
| | **2** | | | |
| | **3** | | | |
| | **4** | | | |
| | **5** | | | |
| | **Average** | | | |

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Use Mathematics** Calculate the average launch distance (*x*) for each experiment. Enter the results in the data table.

2. **SEP Use Mathematics** Substitute the average launch distance calculated into Equation 1 to determine the launch speed of the ball ($v_x$) for each experiment. Show all your calculations.

   **Equation 1:** $v_x = \frac{x}{\sqrt{2y/g}}$

3. **SEP Use Mathematics** Use Equation 2 to calculate the theoretical launch speed the ball should have for each experiment. Show all your calculations.

   **Equation 2:** $v_x^2 = \frac{10}{7}gh$

4. **SEP Construct an Explanation** How does the speed of the launched ball depend on the angle of inclination of the ramp and the release height? Explain.

5. **SEP Construct an Explanation** In some trials, the ball may bounce slightly on the table before it leaves the tabletop. How would this affect the horizontal speed of the ball as it leaves the tabletop? Would the experimentally determined launch speed of the ball be higher or lower than the theoretical value as a result of this error? Explain.

NAME ______________________ DATE __________ CLASS __________

SCIENCE PERFORMANCE-BASED ASSESSMENT

# Speed, Acceleration, and Trajectory

**What factors determine the speed, acceleration, and trajectory of a moving object?**

**Phenomenon** Speed is a measure of how fast a moving object travels in a given time period. Speed is calculated by dividing the distance travelled by time elapsed in seconds. When the speed of a moving object changes over time, the object experiences acceleration. The magnitude of the object's acceleration determines how the speed changes with time.

Your task is to design an experiment to determine the average speed and acceleration of a cart–hanging mass system, and predict its trajectory.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Balance, 0.1 g precision
- Cart
- Meter stick
- Pencil
- Pine board (car stopper)
- Plastic bag
- Scissors
- String, 130 cm
- Table pulley
- Timer or stopwatch
- Washers

## Safety

*Please follow normal laboratory safety guidelines. Use care when handling scissors.*

## Procedure

### Part I: Average Speed and Acceleration

*What is the relationship between speed and acceleration?*

1. Measure and mark distances of 0.1 m and 1.1 m from the edge of a tabletop with a meter stick or ruler and masking tape. The cart will traverse this distance. The distance may be varied to accommodate the height of available tables. Low tables will require shorter distances.

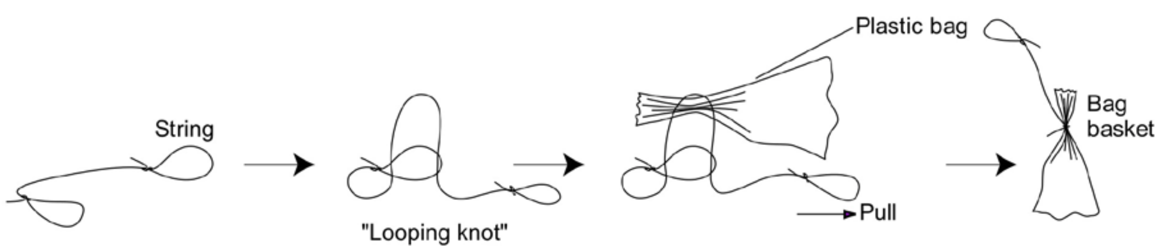
2. Secure a table pulley to the table's edge.

3. Measure the mass of a single washer. Record this value.

4. Place one washer inside of the plastic bag. Record the combined mass of the washer and bag, and record this value as the hanging mass, $m_H$.

5. Attach the plastic bag containing the washer to one end of a string, approximately 130 cm long, using a looping knot as shown in Figure 1. Attach the other end of the string to the cart.

**Figure 1**




6. Add four washers to the cart and weigh. Measure the mass of the cart with the washers. Record in the data table the combined mass of the cart with the washers plus the bag with one washer as the system's total mass, $m_T$.

7. Place the cart at the 1.1 m tape mark, farthest from the table pulley. Hold the cart in place and lay the string over the top of the pulley.

8. Release the cart and use a stopwatch to time its travel between the tape marks.

**9. SEP Plan Your Investigation** Using the procedure described in steps 1–8, and the data table provided, design an experiment to determine the average speed, *v*, of the cart as a function of the hanging mass, $m_H$. Identify what variables will vary and which will remain constant, and write a detailed procedure. Run up to three trials for each measurement, and record all the data in the data table. Note: Remember that average speed is determined by dividing distance traveled by the time elapsed.

NAME ______________________ DATE __________ CLASS __________

**Table 1**

| Average Speed and Acceleration | | | | | | |
|---|---|---|---|---|---|---|
| System's Total Mass, $m_T$ (kg) | | | | | | |
| Distance, $d$ (m) | | | | | | |
| Hanging Mass, $m_H$ (kg) | Trial | Time (s) | Average Time (s) | Average Speed, $v$ (m/s) | Acceleration, $a$ ($m/s^2$) | Landing Distance, $x$ (m) |
| | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |
| | 1 | | | | | |
| | 2 | | | | | |
| | 3 | | | | | |

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Use Mathematics** Calculate the average time for each trial. Record this information in the data table.
2. **SEP Use Graphs** Construct position (*p*) versus average time (*t*) plots that describe the motion of the cart on the tabletop, for each value of hanging mass used. Plot position in meters and time in seconds. Explain the meaning of the slope of these plots of position versus time.
3. **SEP Use Mathematics** Calculate the average cart speed, *v*, for each value of hanging mass, $m_H$. Show a sample calculation and record this information in the data table.

4. **SEP Use Models** Assume that the initial speed of the cart is zero. How could you calculate the acceleration of the cart, $a$, using its average speed, $v$? Write an equation that expresses the relationship between $a$, $v$, and time, $t$.

5. **SEP Use Mathematics** Using the equation you wrote in item 4, calculate the acceleration of the cart, $a$, for each value of hanging mass, $m_H$. Record these values in the data table and show a sample calculation.

6. **SEP Use Graphs** Construct a plot of acceleration, $a$, versus hanging mass, $m_H$. Draw a best fit line to connect the data points.

7. **SEP Construct an Explanation** How does the acceleration of the cart relate to the hanging mass values? What does this mean? Explain.

8. **SEP Use Models** Assume that the cart is horizontally ejected off the edge of the tabletop due to the falling hanging mass, and that it drops to the ground following a projectile trajectory (if the pulley were somehow not in the way). Write an equation that represents the cart's position along the horizontal direction, $x$, as a function of horizontal speed, $v_x$, and time, $t$.

9. **SEP Use Mathematics** Use the equation you wrote in item 8 to predict the landing distance of the cart, $x$, for each value of hanging mass used. Show a sample calculation and record all your data in the appropriate data table. Note: Use the average speed values determined in item 3 to estimate the final speed of the cart as it is launched horizontally off the tabletop; use Equation 1 for displacement on the $y$-axis for an object following projectile motion, where $g$ is the acceleration due to gravity (9.8 m/s$^2$), and $y$ is the height from which the cart drops.

**Equation 1:** $y = \frac{1}{2}gt^2$

# Investigation 2

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Forces and Motion

**What is the relationship between force, mass, and acceleration of a moving vehicle?**

An engine generates the mechanical force or push, required for a vehicle to move at a certain speed and acceleration. The larger the mass of a vehicle, the larger the magnitude of the mechanical force needed to set it in motion. Newton's second law describes and predicts the relationship between force, mass, and acceleration of moving objects. The larger the mass of an object, the larger the force required to set it in motion or increase its acceleration. In this laboratory, you will apply this physical law to analyze the motion of a cart on a tabletop.

## Focus on Science Practices

**SEP 4** Analyze Data
**SEP 5** Use Math and Computational Thinking

## Materials Per Group

- Balance, 0.1 g precision
- Cart
- Meterstick or ruler
- Pencil
- Pine board (car stopper)
- Plastic bag
- Scissors
- String, 130 cm
- Table pulley
- Timer or stopwatch
- Washers

## Safety

*Projectiles may be inadvertently launched during this activity. Wear safety glasses when performing this experiment. Follow all laboratory safety guidelines.*

## Procedure

### Part I: Acceleration

*What is the acceleration of the moving cart?*

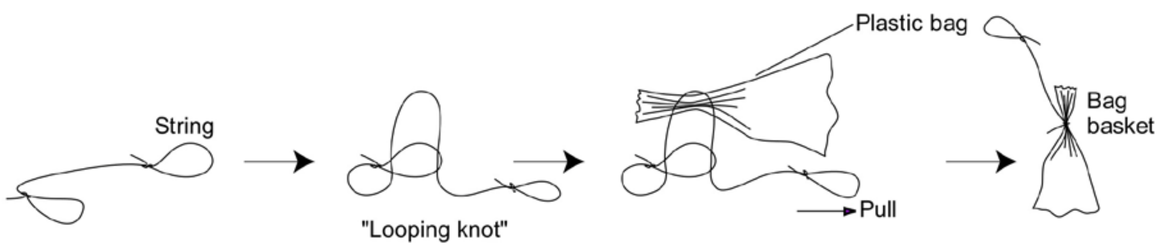
1. Measure and mark distances of 0.1 m and 1.1 m from the edge of a tabletop with a meter stick or ruler and masking tape. The cart will traverse this distance. The distance may be varied to accommodate the height of available tables. Low tables will require shorter distances.

2. Secure a table pulley to the table's edge.

3. Place one washer inside of the plastic bag and measure their combined mass. Record this as the hanging mass ($m_H$) value in the data table.

4. Attach a plastic bag to one end of a string, approximately 130 cm long, using a looping knot as shown in Figure 1. Attach the other end of the string to the cart.

**Figure 1**




5. Add four washers to the cart. Measure the combined mass of the carth with the washers, the bag (with its contents and string). Record in the data table the mass of the system's total mass, $m_T$.

6. Place the cart at the 1.1 m tape mark, farthest from the table pulley. Hold the cart in place and lay the string over the top of the pulley.

7. Release the cart and use a stopwatch to time its travel between the tape marks. Record this time in the data table.

8. Perform steps 6–7 three times and calculate the cart's average acceleration. Record these values in the data table.

NAME ______________________ DATE ____________ CLASS ____________

**Table 1**

<table>
<tr><th colspan="5">Acceleration</th></tr>
<tr><td colspan="3">Hanging Mass, $m_H$ (kg)</td><td colspan="2"></td></tr>
<tr><td colspan="3">System's Total Mass, $m_T$ (kg)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Distance, $d$ (m)</td><td colspan="2"></td></tr>
<tr><td>Time (s)</td><td>Acceleration ($m/s^2$)</td><td>Theoretical Acceleration ($m/s^2$)</td><td>Force (N)</td><td>Theoretical Force (N)</td></tr>
<tr><td></td><td></td><td rowspan="3"></td><td></td><td rowspan="3"></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Average Acceleration, $a$ ($m/s^2$)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Average Acceleration Percent Error (%)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Average Force, $F$ (N)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Average Force Percent Error (%)</td><td colspan="2"></td></tr>
</table>

## Part II: Relationship between Force and Acceleration

*What is the relationship between the force acting upon a moving cart and its acceleration?*

7. **SEP Plan Your Investigation** Write a detailed, step-by-step procedure to determine the relationship between the applied force and acceleration of the cart–hanging mass system. Use the provided data tables to guide your experimental design. Identify the independent and dependent variables, and any variables that should remain constant.

NAME ______________________ DATE __________ CLASS __________

**Table 2**

<table>
<tr><th colspan="5">Relationship between Force and Acceleration</th></tr>
<tr><td colspan="5">Hanging Mass, $m_H$: Two Washers</td></tr>
<tr><td colspan="3">System's Total Mass, $m_T$ (kg)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Distance, d (m)</td><td colspan="2"></td></tr>
<tr><td>Time (s)</td><td>Acceleration ($m/s^2$)</td><td>Theoretical Acceleration ($m/s^2$)</td><td>Force (N)</td><td>Theoretical Force (N)</td></tr>
<tr><td></td><td></td><td rowspan="3"></td><td></td><td rowspan="3"></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Average Acceleration, a ($m/s^2$)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Average Acceleration Percent Error (%)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Average Force, F (N)</td><td colspan="2"></td></tr>
<tr><td colspan="3">Average Force Percent Error (%)</td><td colspan="2"></td></tr>
</table>

NAME ______________________ DATE __________ CLASS __________

## Table 3

| Relationship between Force and Acceleration | | | | |
|---|---|---|---|---|
| **Hanging Mass, $m_H$: Three Washers** | | | | |
| **System's Total Mass, $m_T$ (kg)** | | | | |
| **Distance, *d* (m)** | | | | |
| **Time (s)** | **Acceleration ($m/s^2$)** | **Theoretical Acceleration ($m/s^2$)** | **Force (N)** | **Theoretical Force (N)** |
| | | | | |
| | | | | |
| | | | | |
| **Average Acceleration, *a* ($m/s^2$)** | | | | |
| **Average Acceleration Percent Error (%)** | | | | |
| **Average Force, *F* (N)** | | | | |
| **Average Force Percent Error (%)** | | | | |

NAME ______________________ DATE ____________ CLASS ____________

## Table 4

| Relationship between Force and Acceleration | | | | |
|---|---|---|---|---|
| Hanging Mass, $m_H$: Four Washers | | | | |
| System's Total Mass, $m_T$ (kg) | | | | |
| Distance, $d$ (m) | | | | |
| Time (s) | Acceleration (m/s$^2$) | Theoretical Acceleration (m/s$^2$) | Force (N) | Theoretical Force (N) |
| | | | | |
| | | | | |
| | | | | |
| Average Acceleration, $a$ (m/s$^2$) | | | | |
| Average Acceleration Percent Error (%) | | | | |
| Average Force, $F$ (N) | | | | |
| Average Force Percent Error (%) | | | | |

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Use Graphs** Draw a diagram of the cart–hanging mass system. Indicate the gravitational (*W*) and normal (*N*) forces acting on the cart, the tension on the string suspended over the pulley (*T*), the force pulling on the cart (*F*), and the gravitational force acting on the hanging mass ($F_g$).

2. **SEP Use Math** Apply Equation 1, which describes the acceleration of the hanging mass in free fall, to calculate the acceleration of the cart in each trial (in $m/s^2$) and then calculate its average acceleration. Fill in the data tables and show an example of your calculations.

   **Equation 1:** $a = 2d/t^2$

3. **SEP Use Math** Apply Equation 2, which expresses Newton's second law of motion, to calculate the total force acting on the cart–hanging mass system in each trial, in newtons (N). In addition, calculate the average force acting on the cart. Fill in the data tables and show an example of your calculations.

   **Equation 2:** $F = m_T a$

4. **SEP Use Models** Combine Newton's second law (Equation 2) and the equation for the gravitational force acting on the hanging mass (Equation 3) and solve for the acceleration. This equation represents the theoretical acceleration of the cart in the cart–hanging mass system.

   **Equation 3:** $F_g = m_H g$

5. **SEP Use Math** Use the equation you wrote in step 4 to calculate the theoretical acceleration of the cart in the cart–hanging mass system. Fill in the data tables and show a sample calculation.

6. **SEP Use Math** Use Equation 3 to calculate the theoretical force (*F*) acting upon the cart in the cart–hanging mass system. Fill in the data tables and show a sample calculation.

7. **SEP Use Math** Calculate the percent error of the average acceleration and average force acting upon the cart in each trial. Use Equation 3 to determine the percent error of the experimentally determined values. Enter these values in the corresponding data table.

   **Equation 3:** $Percent\ Error = \frac{|Experimental\ Value - Theoretical\ Value|}{Theoretical\ Value} \times 100$

**8. SEP Construct an Explanation** What potential sources of error may have influenced the determination of average acceleration and average force in the cart–hanging mass system? Explain.

**9. SEP Use Graphs** Construct a plot of average acceleration versus average force for the cart–hanging mass system.

**10. SEP Analyze Data** Does your plot from step 9 agree with Newton's second law? Explain.

**11. SEP Analyze Data** What is the slope of the plot made in step 9? Based on Newton's second law, what does this slope value correspond to?

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INQUIRY LAB – OPEN

# The Buoyant Force

**Why do people and objects seem lighter or float when placed in water?**

The apparent "weight loss" of an object or person immersed in a fluid is known as buoyancy. In reality, this perception of weight loss is due to the lifting buoyant force that the fluid applies on any object immersed in it. The Greek mathematician and scientist Archimedes (287 BC–212/211 BC) discovered some interesting facts about buoyancy. In this investigation, you will design an experiment to make careful observations and measurements with objects submerged in water, to rediscover the law of buoyancy.

## Focus on Science Practices

**SEP 4** Analyze Data
**SEP 5** Use Math and Computational Thinking

## Materials Per Group

- Water, tap
- Beaker, 400 mL
- Metric ruler
- Paper towels
- Spring scale, 5 N, 1
- Vial, empty, 1
- Vial with cap and paper clip hanger, 4

## Safety

*The materials in this lab are considered nonhazardous. Follow all laboratory safety guidelines. Wear safety glasses when performing this experiment. Wipe up any spills immediately.*

## Procedure

### Part I: Determine the Volume of a Vial

*What is the volume of a cylindrical-shaped vial?*

1. Obtain an empty vial and determine its volume. Describe what measurements you need to make and show your calculations.

NAME ______________________ DATE __________ CLASS __________

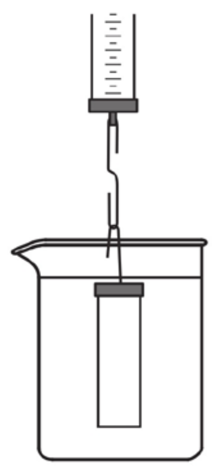
## Part II: The Weight of Filled Vials

*What is the weight of filled vials in and out of water?*

2. **SEP Plan Your Investigation** Design and write a detailed procedure to determine the weight of filled vials in and out of water, using the materials available to you. Obtain filled vials, previously numbered 2–5 by your instructor and record your data in the provided data table. Note: When conducting your measurements, the top of the vial's cap should be just below the surface of the water as seen in Figure 1.

NAME ______________________ DATE __________ CLASS ___________

**Figure 1**



NAME ____________________ DATE __________ CLASS __________

**Table 1**

| The Weight of Filled Vials | | | | |
|---|---|---|---|---|
| **Vial** | **Filling Material** | **Weight out of Water, *W* (N)** | **Weight in Water, *Net Force* (N)** | **Buoyant Force, $F_B = W - Net\ Force$ (N)** |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

## Analyze and Interpret Data

1. **SEP Use Math** Calculate the buoyant force, $F_B$, for each filled vial. Record these values in the data table. Show a sample calculation.

2. **SEP Identify Patterns** Examine the buoyant force for each vial.
   - **a.** How does the buoyant force compare from one vial to the next?
   - **b.** Does there seem to be a correlation between the weight of the vial out of water and the buoyant force?

**c.** Does there seem to be a correlation between the volume of the vial and the buoyant force?

3. **SEP Analyze Data** Consider the volume of the empty vial.
   **a.** When the vial is completely submerged, what is the volume of the displaced water?

   **b.** What is the mass of the displaced water in grams and kilograms? Show your calculation. Note: Remember that volume is related to mass through density; you may assume the density of water to be 1 g/cm$^3$.

4. **SEP Use Math** Newton's second law states that force (*F*) is equal to mass (*m*) multiplied by acceleration (*a*), as shown in Equation 1. By multiplying the mass of the displaced water in kg by the acceleration due to gravity (9.8 m/s$^2$), one can find the weight (*W*) of the displaced water in newtons. Calculate and record the weight of the displaced water.

   **Equation 1:** $F = ma$

5. **SEP Analyze Data** How does the weight of the displaced water compare to the buoyant force acting on the vial?

6. **SEP Construct an Explanation** Archimedes described the relationship between the weight of water displaced by an object ($W$) and the buoyant force acting on the object ($F_B$). Write Archimedes' Principle in your own words.

7. **SEP Use Models** Write an equation for the buoyant force ($F_B$) as a function of the weight of the water displaced by the submerged object ($W$). Use your answers to questions 4–6 to derive the equation.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Friction

**Why is it easier to slide on ice than on asphalt?**

Walking, riding a bike or any type of vehicle are everyday activities that are possible because of friction. If the ground were perfectly smooth and slippery, it would be nearly impossible to move from one place to another. Friction affects motion and, in some cases, it is desirable to have such forces in opposition to motion. For example, when roads are covered with a thin layer of ice, drivers have to be especially careful to avoid skidding; to solve this problem, special tires and road deicers are used to restore friction between the vehicle and the road. The hazard presented by slippery wet floors is another example that illustrates the effect of low friction on motion. In this investigation, you will explore the physical factors that affect the force of friction between two objects, and you will use physical models to quantify friction between different surfaces.

## Focus on Science Practices

**SEP 4** Analyze Data
**SEP 5** Use Math and Computational Thinking

## Materials Per Group

- Balance, 0.1 g precision (optional)
- Masking tape
- Masses, 100 g, 5
- Sandpaper, 3” × 12”
- Spring scale, pull type, 2.5 N
- Tabletop, smooth and clean
- Tape
- Wood block with attached mirror and eyebolt
- Wood block with eyebolt

## Safety

*The materials in this lab are considered nonhazardous. Follow all laboratory safety guidelines. Wear safety glasses when performing this experiment.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

### Part I: Friction and Surface Area

*What is the relationship between friction (static and kinetic) and surface area?*

1. Place the wood block, without the mirror, flat on a tabletop.
2. Attach a spring scale to the eyebolt.
3. The static friction ($F_s$) is the force that is measured on the spring scale just before the block begins to slide. This is best measured by slowly and evenly pulling the block horizontally with the spring scale, while closely observing the spring scale needle. Record the maximum force measured by the spring scale immediately before the block begins to move. Once the block begins to move, the force registered by the spring scale will decrease slightly. With a spring scale, practice measuring the maximum static friction between the tabletop and the wood block until confident results are obtained.
4. Measure the static friction ($F_s$) between the block and the tabletop. Record the results in the appropriate data table.
5. The sliding or kinetic friction ($F_k$) is measured when the block is moving with constant speed. Use the spring scale to pull the wood block horizontally. As the block slides, adjust the amount of force needed to keep the block moving until the spring scale reading is balanced. When the spring scale is balanced, the block will be moving at a constant speed because the pulling force and the kinetic friction are balanced (no net force acting on the block means no acceleration). The measurement on the spring scale at this point will be equal to the kinetic. Again, practice this technique until consistent results are obtained. The speed of the object will not influence the kinetic friction, but it is generally easier to read the moving spring scale when it is traveling slowly. Pulling the block a meter or two along the tabletop may be required in order to adjust the pulling force appropriately to obtain a constant speed (and therefore balanced forces).
6. Measure the kinetic friction ($F_k$) between the block and the tabletop. Record the results in the data table.
7. Place the same wood block on its edge (thin side) and again attach a spring scale to the eyebolt.

8. Measure the static friction between the block on its edge and the tabletop. Record the results in the data table.

9. Measure the kinetic friction between the block on its edge and the tabletop. Record the results in the data table.

**Table 1**

| Friction and Surface Area | | | | |
|---|---|---|---|---|
| **Object** | **Tested Block Surface** | **Tested Surface** | **Static Friction, $f_s$ (N)** | **Kinetic Friction, $f_k$ (N)** |
| **Wood Block, without Mirror** | **Flat** | **Tabletop** | | |
| **Wood Block, without Mirror** | **Edge** | **Tabletop** | | |

## Part II: Friction with Different Surfaces

*What is the relationship between friction (static and kinetic) and the type of surface?*

10. **SEP Plan Your Investigation** Design an experimental procedure to determine whether friction (static and kinetic) depend on the type of surfaces in contact. Write a detailed procedure and use the materials available to you to conduct measurements. Indicate what variables will change and which will remain constant throughout the experiment.

NAME ______________________________ DATE ____________ CLASS ____________

**Table 2**

| Friction with Different Surfaces | | | | |
|---|---|---|---|---|
| **Object** | **Tested Block Surface** | **Tested Surface** | **Static Friction, $f_s$ (N)** | **Kinetic Friction, $f_k$ (N)** |
| **Wood Block, with Mirror** | | | | |
| **Wood Block, with Mirror** | | | | |
| **Wood Block, with Mirror** | | | | |
| **Wood Block, with Mirror** | | | | |

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Use Graphs** Draw a diagram for a wooden block on a tabletop right before it begins to move (static) and when it is sliding due to a horizontal force (*F*) pulling on it. Indicate in your diagram the various forces acting on the block, i.e. the weight (*W*), the normal (*N*), the static and kinetic friction ($f_s$ and $f_k$), and the pulling force acting on the block (*F*).

2. **SEP Analyze Data** Based on your results from Part I, does it take more force to start an object sliding over a surface or to keep it sliding at a constant speed? Explain.

3. **SEP Construct an Explanation** In Part I, how does the static and kinetic friction between the two different experiments compare? What influence does the surface area have on the friction? Explain.

4. **SEP Analyze Data** Based on your results from Part II, which surfaces in contact with each other produced the largest friction? Explain.

NAME ______________________ DATE __________ CLASS __________

5. **SEP Construct an Explanation** In Part II, what influences the friction between the sliding objects? Explain.

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INQUIRY LAB – OPEN

# Weathering of Rock

**What type of forces shape the landscape of our planet?**

Two general processes contribute to the breakdown of rock—mechanical weathering and chemical weathering. Examples of mechanical or physical weathering include glacial activity, water erosion, wind erosion, the growth of plant roots, and ice expansion. Examples of chemical weathering include dissolution, oxidation, and hydrolysis. In this investigation, you will use models to simulate and gain a better understanding of some of the mechanical processes that contribute to the weathering of Earth's surface.

## Focus on Science Practices

**SEP 2** Develop and Use Models

## Materials Per Group

- Granite chips, 20 g
- Halite chips, 15 g
- Ice cubes, 2
- Local rock samples, 2
- Marble chips, 25 g
- Sand, 6 spoonfuls
- Balance, 0.1 g precision
- Magnifying glass
- Paper towels
- Sample containers and lids, 3
- Sheet of white paper, letter size, unlined, 1
- Spoon, 1
- Polystyrene tray, 1
- Timer or stopwatch
- Water, tap
- Weighing dish

## Safety

*Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the classroom. Please follow all laboratory safety guidelines. Follow all laboratory safety guidelines.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

### Part I: Breakdown and Dissolution of Rock

*How do different types of rocks interact with water?*

1. Obtain different types of rock chips. Measure the mass of a given amount of each type of chips and record their masses in the data table.
2. Place the chips into separate sample containers and add water to the sample container until the chips are completely covered with water. Record all observations in the data table.
3. Screw on the lids and shake the sample containers for a few minutes. Measure and record the time you shake each container. Record all observations in the data table.
4. Unscrew the lid and carefully pour off the water so that none of the chips are poured out of the container. Use a paper towel to dry the chips.
5. Using a balance and a weighing dish, mass the chips left in each sample container. Record the mass of the chips in the data table.
6. Using a magnifying glass, observe the condition of the rock chips. Look closely at the edges and the surface of the rock ships.
7. Place the rock chips back into the sample container and repeat steps 2–6 several times for a total of about 12 minutes of shaking. Record all observations in the data table.

NAME ______________________________ DATE ____________ CLASS ____________

**Table 1**

| Breakdown and Dissolution of Rock | | | | |
|---|---|---|---|---|
| **Marble Chips** | | | | |
| **Original Mass (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** |
| | | | | |
| **Original Observations** | **Observations at __ min** | **Observations at __ min** | **Observations at __ min** | **Observations at __ min** |
| | | | | |
| **Halite Chips** | | | | |
| **Original Mass (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** |
| | | | | |
| **Original Observations** | **Observations at __ min** | **Observations at __ min** | **Observations at __ min** | **Observations at __ min** |
| | | | | |
| **Granite Chips** | | | | |
| **Original Mass (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** | **Mass After __ min (g)** |
| | | | | |
| **Original Observations** | **Observations at __ min** | **Observations at __ min** | **Observations at __ min** | **Observations at __ min** |
| | | | | |

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## Part II: Glacial Changes

*How does glacier motion affect the surface of the land?*

8. **SEP Plan Your Investigation** Using ice cubes, sand, a paper towel, and a polystyrene tray, develop a model to simulate the effects of glaciers moving over land. Write a brief description of how you will conduct this simulation. Record all observations in the corresponding data table and describe the appearance of the various elements used after the demonstration is done.

**Table 2**

| Glacial Changes |
|---|
| **Observations** |
| |

NAME ________________ DATE ________ CLASS ________

## Analyze and Interpret Data

1. **SEP Construct an Explanation** What was the effect of the amount of time and the amount of weathering?

2. **SEP Analyze Data** How did the mass of the different types of rock chips change with the amount of time?

3. **SEP Use a Model to Evaluate** What do you think would happen to the various rock chips if they were shaken for a day or longer?

4. **SEP Use a Model to Evaluate** What rock used in this activity is the most resistant to these types of weathering? What do you think makes this type of rock more resistant to mechanical weathering? Explain.

5. **SEP Analyze Data** In Part II, what happened to the surface of the ice cube? And what happened to the surface of the polystyrene tray?

6. **SEP Use a Model to Evaluate** Use your observations from Part II to predict what would happen if a glacier moved across the surface of land.

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SCIENCE PERFORMANCE-BASED ASSESSMENT

# Force, Mass, and Acceleration

**What variables control the acceleration of a moving object?**

**Phenomenon** Intuitively, you may recognize that moving an object up a hill will require a larger amount of force than moving the same vehicle in a valley (assuming friction remains constant). If the same force were applied on the object to move it uphill or on a flat surface, what would its acceleration be?

In this lab, you will design a procedure to determine the relationship between force, mass and acceleration for a cart moving up on an inclined ramp.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Assembled inclined plane setup
- Balance, 0.1 g precision
- Cart
- Masses, hooked, 100 g, 2
- Meter stick or ruler
- Pencil
- Protractor
- String, thin
- Scissors
- Stopwatch or timer
- Support stand
- Support stand clamp
- Support stand rod
- Textbooks, 3–4 (optional)

## Safety 

*Please follow normal laboratory safety guidelines. Use care when handling scissors.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

*What is the relationship between the acceleration of a cart moving on an inclined plane and the force acting on it?*

1. Measure the mass of the cart to the nearest gram using the balance. Record the mass in the data table.
2. Measure and cut between 60 and 80 cm of string.
3. Tie one end of the string to the front of the cart.
4. Tie a loop in the other end of the string as shown in Figure 1.

**Figure 1**

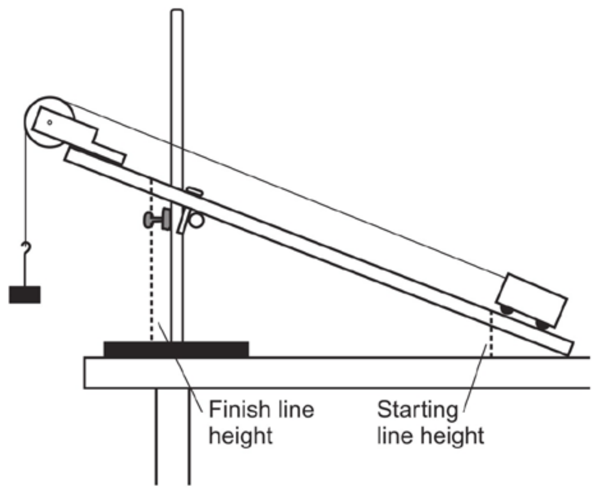

5. At the end that is opposite from the pulley, measure approximately 12 cm from the edge of the board. Lightly mark this point with a pencil. The mark should be far enough from the end of the inclined plane so that all four wheels of the cart are on the inclined plane when the front of the cart lines up with this mark.
6. Use a ruler to make a light pencil line through this 12 cm mark so the line is parallel to the end of the board. This line represents the "start line."
7. Measure the distance between the "start" line and the "finish" line pencil marks on the inclined plane. Record this distance in the data table.
8. Place the inclined plane flat on the tabletop with the end of the pulley hanging over the edge of the table. Remove the wide screw and nut from the inclined plane, if necessary.
9. Place the front wheels of the cart at the starting line. Hang the string over the pulley so that it hangs down.
10. Obtain a stopwatch and two 100 g masses.

11. Add one mass to the compartment in the cart. Add the second mass to the loop in the string hanging over the pulley. Do not release the hanging mass yet.

12. Check that the string runs over the pulley and that there is not much slack in the string between the cart and the mass. Also, check that the front wheels are on the starting line. Prepare the stopwatch for timing.

13. Set up the support stand, support stand clamp, support rod, inclined plane, and cart as shown in Figure 2.

**Figure 2**



**14. SEP Plan Your Investigation** Design an experimental procedure to measure the time it takes for the cart to travel between the "start" and "finish" lines on the inclined plane. Explore in your experiment how to change the net force acting on the cart (*F*) varying the inclination of the ramp, and the effect of this force on the acceleration of the cart (*a*).

NAME ______________________ DATE ____________ CLASS ____________

**Table 1**

| Plane Inclination and Cart Timing | | | | | |
|---|---|---|---|---|---|
| Distance between "Start" and "Finish" Lines, *d* (cm) | | | | | |
| Mass of Cart plus Added Mass, $m_C$ (g) | | | | | |
| Hanging mass, $m_H$ (g) | | | | | |
| | | | | | |
| Inclined Plane Angle ($\theta$) | Time (s) | | | | |
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Average |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Table 2**

| Force and Acceleration | | | | |
|---|---|---|---|---|
| Inclined Plane Angle ($\theta$) | Theoretical Net Force, *F* (N) | Theoretical Acceleration, *a* ($m/s^2$) | Experimental Acceleration, *a* ($m/s^2$) | Experimental Net Force, *F* (N) |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

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## Analyze and Interpret Data

1. **SEP Use Mathematics** Calculate the average time for each trial. Record this information in the data table.
2. **SEP Use a Model** Draw a free body diagram of the cart–hanging mass system on an inclined plane. Indicate in the diagram the force of gravity on the cart (*W*) and hanging mass ($F_g$), the normal force acting on the cart (*N*), and the net force driving the system's motion (*F*.)
3. **SEP Use a Model** Based on the free body diagram sketched for the cart–hanging mass system in question 2, write an equation that represents the net force driving the system's motion (*F*) as a function of the force of gravity on the cart (*W*) and hanging mass ($F_g$), and the angle of inclination of the ramp ($\theta$.)
4. **SEP Use Mathematics** Use the equation derived in question 3 to calculate the theoretical value of the net force acting on the cart for each inclined plane angle. Record this information in the data table and show a sample calculation.

5. **SEP Use Mathematics** Apply Newton's second law of motion to determine the theoretical acceleration of the cart–hanging mass system at each angle of inclination of the plane. Record this information in the data table and show a sample calculation.

6. **SEP Use a Model** Assume that the hanging mass in the cart–hanging mass system follows a free fall trajectory when released and that its initial velocity is zero. If that is the case, Equation 1 would represent the acceleration of the system. In this equation, *d* represents distance traveled by the cart on the ramp (or distance traveled by the falling hanging mass) and *t* is time. Use this equation to calculate the experimental acceleration of the system at every angle of plane inclination. Record these values in the data table and show a sample calculation.

   **Equation 1:** $a = 2d/t^2$

7. **SEP Use Mathematics** Apply Newton's second law of motion to determine the experimental net force (*F*) acting on the cart–hanging mass system at each angle of inclination of the plane. Record this information in the data table and show a sample calculation.

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8. **SEP Use Graphs** Plot the values of experimental force (*F*) versus experimental acceleration (*a*). Plot force on the y-axis and acceleration in the x-axis.

9. **SEP Analyze Data** How does the net force (*F*) and the acceleration (*a*) of the cart–hanging mass system change as a function of the angle of inclination of the plane? Explain the relationship between *F* and *a*.

10. **SEP Analyze Data** What is the meaning of the slope of the plot made in step 8? What is this value equal to?

11. **SEP Analyze Data** How do the theoretical values of net force and acceleration of the cart–hanging mass system compare? Explain.

# Investigation 3

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INQUIRY LAB – OPEN

# Investigate Gravity Using Pendulums

**How does gravity affect the motion of objects on Earth?**

The period of an ideal pendulum at a given location on Earth is related to the acceleration due to gravity at that location. In this lab, you will examine the factors that affect the period of a pendulum, and you will use this information to determine the value of the acceleration due to gravity (*g*) and the universal gravitational constant (*G*.)

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Clothespin
- Meterstick
- Protractor
- Scissors
- Spreadsheet computer program or graph paper
- Steel bobs, drilled, large and small
- Stopwatch or timer
- String, 75 cm
- Support stand and ring clamp

## Safety

*Wash hands thoroughly with soap and water before leaving the laboratory. Please follow normal laboratory safety guidelines.*

## Procedure

### Part I: Pendulum Length and Period

*Is there a relationship between the period of a pendulum and its length?*

1. Set up a support stand and ring clamp.
2. Cut a length of string 75 cm long.

3. Thread one end of the string through the larger steel bob. Make a knot at the end of the string to hold the steel ball in place. Cut off any extra string from the knot to keep excess string to a minimum.
4. Clamp the string to the side of the ring with the clothespin.
5. Position the support stand so that the steel bob can dangle over the edge of the table and swing freely.
6. Use a meterstick to adjust the length of the pendulum so that it is 20 cm. Measure the length from the center of the steel bob.
7. Use a protractor to measure the angle between the string and the equilibrium position (vertical). Pull the steel bob along its swing arc to an angle $\theta$ of 5° from equilibrium.
8. Simultaneously release the steel bob and begin timing. Count the number of times the steel bob swings through one complete oscillation within a total time of 30 seconds. Record the times in Table 1.
9. Repeat the measurement at least twice to determine the reproducibility. Record the times in Table 1.
10. Repeat steps 6–9 with 30 cm, 40 cm, and 50 cm-long pendulums.
11. Calculate the average number of oscillations in 30 seconds for each pendulum length. Record these values in Table 1.

**Table 1**

| **Pendulum Length and Period** | | | | | | |
|---|---|---|---|---|---|---|
| | **Number of Complete Oscillations in 30 Seconds** | | | | **Period, *T* (s)** | ***g* (m/s$^2$)** |
| **Pendulum Length, *L* (cm)** | **Trial 1** | **Trial 2** | **Trial 3** | **Average** | | |
| **20** | | | | | | |
| **30** | | | | | | |
| **40** | | | | | | |
| **50** | | | | | | |

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## Part II: Pendulum Mass and Period

*Is the period of a pendulum affected by its mass?*

12. **SEP Plan Your Investigation** Design an experimental procedure to investigate whether the period of a pendulum is affected by the mass of the pendulum bob. Use the provided data table to collect your data, and write a detailed procedure to describe your measurements.

**Table 2**

| Pendulum Mass and Period | | | | | |
|---|---|---|---|---|---|
| | Number of Complete Oscillations in 30 Seconds | | | | Period, *T* (s) |
| Pendulum Size | Trial 1 | Trial 2 | Trial 3 | Average | |
| Larger | | | | | |
| Smaller | | | | | |

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## Analyze and Interpret Data

1. **SEP Use Mathematics** Calculate the oscillation period (*T* in seconds) for each experiment and record the values in the respective data table. Show a sample calculation. Note: Remember that period, *T*, is the time required per oscillation.

2. **SEP Analyze and Interpret Data** Compare the oscillation periods in Part I. How does the length of the pendulum affect the oscillation period?

3. **SEP Analyze and Interpret Data** Compare the oscillation periods in Part II. How does the pendulum's size and mass affect the oscillation period?

4. **SEP Use Mathematics** Equation 1 represents the period (*T*) of an ideal pendulum as a function of its length (*L*), and the acceleration due to gravity on Earth (*g*). Solve for *g* and write the resulting equation.

   **Equation 1:** $T = 2\pi\sqrt{\frac{L}{g}}$

5. **SEP Use Mathematics** Using the data from Part I and the equation you wrote in question 4, calculate the value of the gravitational acceleration on Earth, *g*, for each pendulum length. Record the values in Table 1, and show a sample calculation.

6. **SEP Use Mathematics** Equation 2 represents Newton's law of gravity, where $F_g$ is the force of gravity between two objects of masses *m* and *M*, *r* is the distance between the centers of these objects, and *G* is the universal gravitation constant. Assume the objects are Earth and the larger bob pendulum. Given that $F_g$ is the force of gravity exerted by Earth on the pendulum or the pendulum's weight, solve for *G* and write the resulting equation where *G* is a function of *m*, *M*, *r*, and *g*.

   **Equation 2:** $F_g = G\frac{mM}{r^2}$

7. **SEP Use Mathematics** Using the data from Part I, calculate an average value for the gravitational acceleration *g*, and then use the equation you wrote in question 6 to calculate the value of the universal gravitational constant *G*. Show all your calculations. Note: *r* is the distance between the center of Earth and the center of the pendulum bob. Because the radius of Earth is much larger than the distance between Earth's surface and the pendulum bob, assume *r* is the radius of Earth.

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INQUIRY LAB – OPEN

# Model the Orbital Motion of Planets

**What determines the orbital trajectory of the planets around the sun?**

Newton's law of gravity establishes that the attractive force between two particles of matter is proportional to the product of their respective masses, and inversely proportional to the square of the distance between their centers. The forces between the planets and the sun are gravitational forces. Because the planets orbit the sun following trajectories that are roughly circular, these forces are also known as centripetal—(centripetal forces keep objects moving in circular paths around a central point.) In this lab, you will use models to explore the forces that keep the planets in orbit, and why some revolve closer or farther away from the sun.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Balance, 0.1 g precision
- Handle tube
- Meterstick
- Paper clips, 2
- Rubber stopper, two-hole
- Scissors
- String, 1.5 m
- Timer or stopwatch
- Washers, 18

## Safety

*The very nature of the motion in this activity makes it potentially dangerous. Use caution when twirling the rubber stopper. This demonstration is best conducted in a large open area. Wear safety glasses or goggles. Please follow all laboratory safety guidelines.*

## Procedure

### Part I: Orbital Speed, Period, and Radius

*What is the relationship between the speed, period, and radius of orbital motion?*

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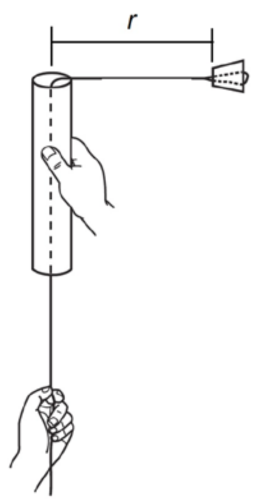
1. Thread the string through one hole in the rubber stopper and then back through the other hole. Tie the stopper securely to the end of the string. Tie a few knots to make sure the stopper is secure.

2. Thread the free end of the string through the handle tube. Leave about 1 meter of string between the top of the handle and the rubber stopper. Figure 1 illustrates the basic setup.

**Figure 1**




3. Tie a loop in the free end of the string 25 cm below the handle tube.

4. Slip the loop through the center of six washers and hold the washers in place by inserting a bent paper clip through the loop, as shown in Figure 2. Slip a paper clip over the string just below the handle tube as shown in Figure 2. This will be the “marker” clip

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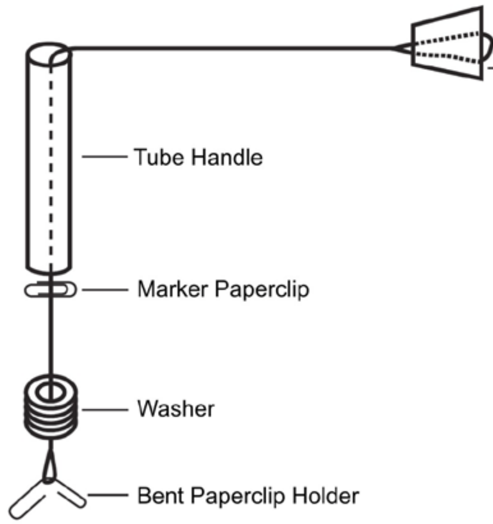
**Figure 2**




5. Twirl the rubber stopper slowly in a horizontal circle over your head and gradually increase the speed of the rubber stopper until it just stays in a horizontal orbit. *Caution: Be sure the lab partner is in an open area, clear of people and any breakable items, and all lab partners are wearing safety glasses or goggles.*

6. Spin the stopper at an approximately constant rate. Another lab partner should count and record the number of revolutions the stopper makes in a 20-second period when the orbit radius is one meter (1 m). Practice repeating this step until your count of stopper revolutions in 20 seconds is approximately constant before you record any data in Table 1. *Caution: Be sure the lab partner is in an open area, clear of people and any breakable items, and all lab partners are wearing safety glasses or goggles.*

7. Shorten the length of the string above the handle to about 0.5 meters and repeat steps 5–6 for an orbit radius of 0.5 meters. Record your data in Table 1.

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**Table 1**

| Orbital Speed, Period, and Radius | | | |
|---|---|---|---|
| **Orbital Radius (m)** | **Revolutions in 20 seconds** | **Orbital Period, *T* (s)** | **Orbital Speed, *v* (m/s)** |
| **1.0** | | | |
| | | | |

### Part II: Orbital Speed and the Force of Gravity

*How does gravity affect the speed of orbital motion?*

8. **SEP Plan Your Investigation** Design an experimental procedure to determine the effect of the force of gravity on the orbital period and speed of a rotating stopper. Use Figure 2 to guide your experimental design. Describe in detail the measurements that will be made. Record all your data in Table 2.

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**Table 2**

| Orbital Speed and the Force of Gravity | | | | |
|---|---|---|---|---|
| **Orbital Radius (m)** | | | | |
| **Mass of a Washer (kg)** | | | | |
| **Number of Washers** | **Revolutions in ____ seconds** | **Orbital Period, $T$ (s)** | **Orbital Speed, $v$ (m/s)** | **Force of Gravity, $F_g$ (N)** |
| **6** | | | | |
| **18** | | | | |

## Analyze and Interpret Data

1. **SEP Use Models** Draw a free body diagram of the stopper following a circular orbit around the tube handle, and washers hanging from the string. Indicate in your diagram the orbital speed ($v$) of the stopper, the centripetal force acting on the stopper ($F_c$), and the force of gravity acting on the hanging washers ($F_g$).

2. **SEP Use Mathematics** In Part I, calculate the orbital period ($T$, in seconds) of the stopper for the two orbital radii studied. Fill in Table 1 and show a sample of your calculations. Note: Remember that the period, $T$, is the time per single revolution (or orbit).

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3. **SEP Use Mathematics** In Part I, apply Equation 1 to calculate the orbital speed (*v*, in m/s) of the stopper for the two orbital radii (*r*) studied. Fill in your Table 1and show a sample of your calculations.

**Equation 1:** $v = \frac{2\pi r}{T}$

4. **SEP Analyze and Interpret Data** Using the results from Part I, describe the relationship between orbital radius (*r*) and orbital speed (*v*).

5. **SEP Use Mathematics** In Part II, calculate the orbital period (*T*, in seconds) of the stopper for both trials. Fill in Table 2 and show a sample of your calculations. Note: Remember that the period, *T*, is the time per single revolution (or orbit).

6. **SEP Use Mathematics** In Part II, apply Equation 1 to calculate the orbital speed (*v*, in m/s) of the stopper for both trials. Fill in Table 2 and show a sample of your calculations.

**Equation 1:** $v = \frac{2\pi r}{T}$

7. **SEP Use Mathematics** In Part II, calculate the magnitude of $F_g$, the force of gravity acting on the stopper, for both trials. Fill in Table 2 and show a sample of your calculations. Note: Recall that $F_g$, the force of gravity on the stopper, is equal to the mass of the washers ($m$) multiplied by the gravitational acceleration on Earth ($g$).

8. **SEP Analyze and Interpret Data** Using the results from Part II, describe the relationship between orbital speed ($v$) and the gravitational force acting on the stopper ($F_g$).

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9. **SEP Construct an Explanation** Predict what would happen with the rotating stopper if the string holding it suddenly broke off. Explain.

10. **SEP Construct an Explanation** How is this model similar to or different from the orbits of the planets? What do the stopper and the tube handle represent? Explain.

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INQUIRY LAB – OPEN

# Kepler’s Laws of Planetary Motion

**Does Earth revolve at a constant distance from the sun?**

Johannes Kepler (1571–1630) determined that the trajectories of the planets moving around the sun are not circular, as originally thought. Instead, planets follow “stretched out circular paths” called ellipses. In this lab, you will explore the characteristics of elliptical orbits to develop a deeper understanding of planetary motion.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Bolts, 2
- Hexagonal nuts, 6
- Pencil, wood (not mechanical)
- Planetary Orbits platform with holes
- Planetary Orbits paper templates, 3
- Ruler, metric
- Scissors
- String, 60 cm
- Tape, transparent
- Washer

## Safety

*Follow all laboratory safety guidelines. Wash your hands at the end of the lab period.*

## Procedure

### Part I: Drawing Ellipses

*What are ellipses and what do they look like?*

1. Measure and cut a 28 cm long piece of string.

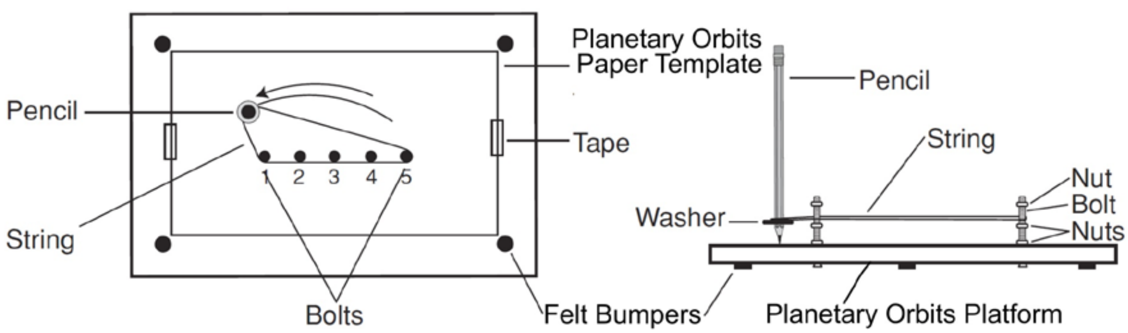
2. Form a loop of string with the 28 cm piece by tying the string's ends together into a knot as shown in Figure 1. Tie the knot close to the ends of the string to make the loop as large as possible.

**Figure 1**


3. Center the Planetary Orbits paper template on the Planetary Orbits platform (on the side without the bumpers) and line up the numbered dots with the holes in the platform.

4. Place a piece of tape on each short side of the template to hold the paper in place on the platform as indicated in Figure 2.

**Figure 2**




5. Using a sharpened wood pencil, poke a hole through dot number 1 of the paper template, and through the corresponding hole in the platform. Repeat this step with dot number 5.

6. Insert the bolts through the outermost holes (1 and 5) of the platform from the bottom and up through the holes in the paper template. Be careful not to tear the paper around the holes.

7. Thread one nut onto each bolt and tighten securely, as shown in Figure 2. Note: The nuts must be as tight as possible so that the bolts will not move with gentle pressure from the side. Too much "play" in the bolts will affect the results.

8. Thread two more nuts part way onto each bolt leaving small spaces between each set of nuts. The gap between the two nuts will serve as a guide to keep the string at the same height when drawing the ellipse.

9. Loop the 28 cm string around both bolts.

10. Insert a wood pencil through the hole of the washer. Press the washer firmly onto the pencil so the washer stays on the pencil. As the ellipse is drawn, the washer will help keep the string at the same height.

11. Adjust the two upper nuts on each bolt so the gap between them is the same height as the washer on the pencil when the pencil is held vertically and the pencil tip touches the template, as seen Figure 2. This will help keep the string level.

12. Place the pencil with the washer inside the loop of string that is around the bolts. Hold the pencil vertically and perpendicular to the platform. Pull the string taut so it rests between the gaps in the nuts and just above the washer. See Figure 2 for guidance.

13. Draw an ellipse by allowing the string to act as the guide for the pencil. Keep the pencil vertical and the string taut, but not so taut as to stretch the string or shift the bolts from a vertical position.

14. Label the template "Ellipse 1."

15. Remove the nuts from the bolts and gently pull the bolts out of the holes, being careful not to tear the paper or make the holes bigger.

16. Remove the paper template from the platform and set it aside for Part II.

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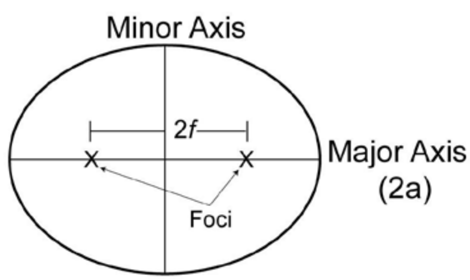
**17. SEP Plan Your Investigation** Using the previous steps as a starting point, describe how you will draw two more ellipses so that they are different from Ellipse 1 in their foci separation or major axis length. Draw these ellipses, label them Ellipse 2 and Ellipse 3, and save them for Part II.

## Part II: Exploring Elliptical Orbits

*What are the mathematical properties of an ellipse?*

**18.** Using a metric ruler, measure the distance between the two foci, 2*f* (from the center of one hole to the center of the other hole) for all three ellipses to the nearest tenth of a centimeter, and record these values in Table 1. See Figure 3 for guidance.

**Figure 3**




**19.** Measure the length of the major axis, 2*a*, for all three ellipses and record these values in Table 1.

**Table 1**

| Drawing Ellipses | | | | | | |
|---|---|---|---|---|---|---|
| **Ellipse** | **String Length (cm)** | **Foci Separation, 2*f*, (cm)** | **Major Axis Length, 2*a* (cm)** | **Eccentricity, *e*** | **Aphelion (cm)** | **Perihelion (cm)** |
| **1** | **28** | | | | | |
| **2** | | | | | | |
| **3** | | | | | | |

## Analyze and Interpret Data

1. **SEP Use Mathematics** The eccentricity of an ellipse, *e*, can be defined as the ratio between the distance 2*f* that separates its foci, and the length *a* of its major axis. This is expressed in Equation 1. Calculate the eccentricity of Ellipses 1–3 and record these values Table 1. Show a sample calculation.
   **Equation 1:** $e = 2f/2a$

2. **SEP Analyze and Interpret Data** Which ellipse has the greatest eccentricity? Which has the lowest eccentricity? Explain.

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3. **SEP Obtain Information** Search on the Internet or a textbook to learn about the eccentricity of the planets in our solar system. How do the orbits of the planets that revolve around the sun compare to the two ellipses constructed in this lab? Explain.

4. **SEP Use Mathematics** If everything else remains the same, what property of the ellipse changes if the length of the string is changed?

5. **SEP Analyze and Interpret Data** Assume that one of the foci on each ellipse corresponds to the location of the sun. Measure the smallest and greatest distances between the center of the sun and each elliptical orbit. Label these distances as the “perihelion” and the “aphelion”, respectively. Record these values in Table 1.

6. **SEP Analyze and Interpret Data** Observe the difference in eccentricity between Ellipses 1–3, and note the perihelion of each “orbit.” How might this explain why one planet is sometimes closer to the sun than another?

7. **SEP Evaluate and Communicate** Kepler’s first law of planetary motion states that all planets travel in elliptical orbits. Write a definition of an ellipse.

8. **SEP Use Mathematics** Kepler's law of planetary periods is represented in Equation 2, where *T* is the orbital period, *a* is the ellipse's semimajor axis, and *k* is a proportionality constant. How would the period of a planet with a semimajor axis length of *a* compare to that of a planet with a semimajor axis length equal to *a*/2?

   **Equation 2:** $T^2 = ka^3$

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SCIENCE PERFORMANCE-BASED ASSESSMENT

# What Causes the Seasons?

**What causes the predictable climate patterns on bodies that orbit stars?**

**Phenomenon** We experience temperature changes throughout the year that depend on our location on Earth. For example, in the Eastern United States, temperatures are predictably cold on average during December, January, and February; and predictably warm during June, July, and August. We refer to these unique sets of climate conditions as seasons.

In this lab, you will develop a model to observe the causes of the seasons, and apply the model to explain the temperature cycle on a comet.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Block of wood, with hole
- String, 70 cm
- Lamp, without shade
- Foamball, 4-inch diameter
- Marker or pencil
- Pushpins, 5
- foam board or cardboard, at least 28” x 28”
- Ruler
- Wire, 8 inches

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## Safety

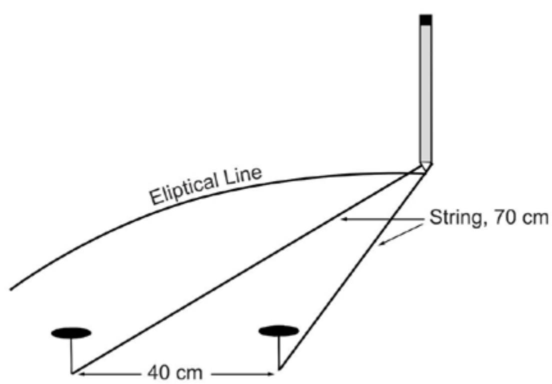
*This lab is considered to be non hazardous. Please follow all laboratory safety guidelines.*

## Procedure

### Part I

1. On the foam board or cardboard , mark two points (foci) 40 cm apart. Use pushpins to fasten each end of the 70-cm piece of string to each of the foci. If necessary, tape the pushpins to the board to keep them from moving.
2. Insert the pencil or mark in the middle of the string that is fastened to the board and use the string as a guide to draw the top half of the ellipse. Be careful not to stretch the string or pull it loose from the surface. Then relocate the pencil or marker the opposite direction on the foci and draw the bottom half of the ellipse. See Figure 1.

**Figure 1**



3. Place the wire into the hole in the center of the block of wood. The wire will be at a 23.5 degree angle, which is the tilt of Earth.
4. Use the foam ball as a model for Earth and draw an equator on it to make it easier to observe the correct angle of Earth's axis. Use a marker to label one side of the Earth model "N" for the Northern hemisphere and the other side "S" for the Southern hemisphere.
5. Carefully push the wire through the center of the foam ball, creating an axis, so that the Northern and Southern hemispheres are positioned correctly.
6. Place the lamp (with the bulb exposed) slightly to the right of the middle of the drawn Earth orbit to represent the sun. Darken the room if possible.
7. Place the assembled Earth model on the Earth orbit line drawn on the surface. Trace the orbit of Earth completely around by sliding the block on the line. Keep the Earth model at the same tilt throughout the demonstration. Do not rotate Earth as you slide it along the orbit.
8. Stop after completing every 90 degrees of the orbit and observe the relative position and angle of Earth and the sun.

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## Part II

10. **SEP Use a Model** Comet 67P changes color as it orbits the sun. Comet 67P is composed of a central, solid nucleus and a gaseous coma that surrounds the nucleus. Throughout its solar orbit, comet 67P appears either blue with a red coma or red with a blue coma. The coma appears red when the small, gaseous dust particles reflect red light. The coma appears blue when there is less gas surrounding the nucleus. Construct an explanation of this phenomenon that draws on what you observed by manipulating your model of the Earth-sun system.

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11. **SEP Use Mathematics and Computational Thinking** A representative sample of comet 67P's heliocentric distances, in astronomical units (AU), as it completes an orbit are 2.552, 2.334, 2.130, 1.967, 1.703, 1.508, 1.350, 1.257, 1.253, 1.340, 1.494, 1.686, 1.897, 2.113, and 2.327. Do these data indicate the comet follows a circular or elliptical orbit? Explain.

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## Analyze and Interpret Data

1. **SEP Construct an Explanation** What does your model indicate is the cause(s) of the seasons?

2. **SEP Identify Limitations of a Model** Describe the limitations of your Earth-sun system model.

3. **SEP Engage in Argument** What does your model imply about the probability of finding other bodies in our galaxy capable of supporting human life? Explain.

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4. **SEP Plan an Investigation** How could you use your Earth-sun system model to explore the phenomenon of night and day?

5. **Apply Scientific Reasoning** What does your Earth-sun system model imply about the temperature near the equator? Explain.

6. **SEP Obtain Information** Go online and search for information related to comet 67P. What are two factors that researchers indicate cause the comet's color cycle?

# Investigation 4

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INQUIRY LAB – OPEN

# Electric Charges and Coulomb's Law

**What determines the magnitude of the electric force between charged objects or particles?**

The saying "opposites attract and equals repel each other" applies very well to electric charges. Atoms are made of subatomic particles that carry different charges. The atomic nucleus is made up of protons and neutrons, and it is surrounded by electrons. Protons are positively charged, neutrons have zero net charge, and electrons are negatively charged. Unlike protons, electrons are mobile and can transfer between atoms or objects composed of atoms or molecules. Because of this, objects may be negatively charged (with an excess of electrons), neutral (the amount of electrons and protons is the same), or positively charged (with a deficiency of electrons). Objects will either attract, repel, or not react to each other's presence depending on the magnitude and sign of their electric charge, and the separation between them. This is mathematically described by Coulomb's law, which you will apply to the design of your investigation.

## Focus on Science Practices

**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Aluminum foil
- Balance, 0.01 g precision
- Fishing line
- Glass rod
- Pith balls
- Plastic straw
- Ruler
- Sewing needle and thimble (optional)
- Support stand with ring
- Tape, transparent, matte finish
- Wool friction pads

## Safety 

*The materials in this laboratory are considered non hazardous. Follow all laboratory safety guidelines. Wash your hands thoroughly at the end of the lab period.*

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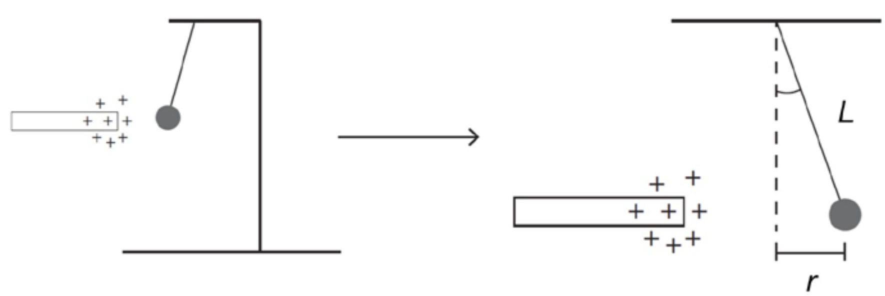
## Procedure

### Part I: The Effect of Positive Charges

*How does a pith ball wrapped in aluminum respond to a positively charged object?*

1. Use aluminum foil to carefully wrap two pith balls. Measure the mass of the pith balls covered in aluminum foil to a 0.01 g precision. Ensure that the pith balls have the same mass within ±0.02 g, and record the masses in the data table.
2. Cut two 15 cm-long pieces of fishing line. Thread one end of the fishing line through one of the pith balls wrapped in aluminum foil. Make a small knot at one end of the fishing line to secure the pith ball. It may help if you slide a needle or pin through the pith ball first, and then slide the fishing line through.
3. Set up the support stand and the ring. Attached one of the pith balls to the ring by the free end of the fishing line. See Figure 1 for guidance.

**Figure 1**




4. Measure the exact length of the fishing line hanging vertically from the ring, and record this value in the data table.
5. Take a glass rod and give it a positive charge by rubbing it with wool.
6. Bring the charged glass rod near the hanging pith ball wrapped in aluminum foil. Use a ruler to measure the horizontal displacement of the pith ball from its original position, as indicated in Figure 1. Record this value in the data table, and write your observations.

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7. Touch the ring stand with the pith ball covered in aluminum foil to discharge it (excess electrons will transfer to the metallic ring; if the ring is not metallic, touch the pith ball with another metallic surface). Repeat steps 5 and 6.

8. Touch the glass rod against the pith ball. Write your observations.

**Table 1**

| The Effect of Positive Charges | | | | |
|---|---|---|---|---|
| **Trial** | **Mass of Pith Ball (g)** | **Length of String (cm)** | **Horizontal Displacement of Pith Ball (cm)** | **Charge on Pith Ball (C)** |
| 1 | | | | |
| 2 | | | | |

## Part II: The Effect of Negative Charges

*How does a pith ball wrapped in aluminum respond to a negatively charged object?*

9. **SEP Plan a Procedure** How can you measure the amount of negative charge transferred to two hanging pith balls? Use what you learned from Part I and the provided materials to set up your investigation. Remember to control your variables. Record your data for two trials in the data table.

**Table 2**

| The Effect of Negative Charges | | | | |
|---|---|---|---|---|
| **Trial** | **Mass of Pith Balls (g)** | **Length of String (cm)** | **Distance between Pith Balls (cm)** | **Charge on Pith Ball (C)** |
| 1 | | | | |
| 2 | | | | |

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## Analyze and Interpret Data

1. **SEP Construct an Explanation** In Part I, what happened when the glass rod approached the pith ball without making contact? What was the sign of the charge on the pith ball? Explain.

2. **SEP Construct an Explanation** In Part I, what happened when the glass rod touched the pith ball? What was the sign of the charge on the pith ball? Explain.

3. **SEP Develop a Model** Draw a free body diagram of the pith ball in Part I after it makes contact with the glass rod and has reached a new equilibrium position (i.e. the pith ball is no longer moving.). Identify in your diagram the electric force vector ($F_E$), the components of the string tension with respect to the x-axis ($F_{Tx}$) and the y-axis ($F_{Ty}$), the weight of the ball (mg) and the angle with respect to the initial position of the string (θ).

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4. **SEP Use Math** Use the free force diagram from question 2 and the data collected to calculate the magnitude of the electric force on the pith ball used in Part I.

5. **SEP Develop a Model** Draw a free body diagram of the charged pith balls in Part II upon reaching a new equilibrium position (i.e. the pith balls are no longer moving.). Identify in your diagram the electric force vector ($F_E$), the weight of the balls (mg), the separation distance (r), the length of the string (L), and the angle with respect to the initial position of the strings (θ).

6. **SEP Use Math** Use the free force diagram from question 4 and the data collected to calculate the magnitude of the electric force on the pith balls used in Part II.

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INQUIRY LAB – OPEN

# Electric Fields

**How can you visualize the electric field surrounding charged objects?**

Charges produce electric fields, and electric fields apply forces to charges. The concept of electric fields is very similar to that of gravitational fields. In both cases, the strength of the field depends on intrinsic properties of the particles involved, that is charge (*q*) in the case of electric fields, and mass (*m*) for gravitational fields. Likewise, the strength of both electric and gravitational fields decreases with the square of the distance between the particles involved (*r*). In this investigation you will map the lines of electric fields created by various charge configurations.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 6** Construct Explanations

## Materials Per Group

- Cardboard sheet, 25 cm × 30 cm
- Conductive paper sheet, 1
- Conductive silver ink
- Corks, 4
- DC power supply or 6 V battery
- Electric field plotting map, 2
- Pushpins, aluminum, 2
- Pushpins, plastic, 4
- Voltmeter or multimeter with test leads, digital
- Wires with alligator clips on both ends, 2

## Safety 

*Silver conductive ink is flammable; keep the cap tightly closed and away from all sources of ignition. Avoid contact with skin and eyes, as it may cause irritation. Slightly toxic if inhaled; ensure adequate ventilation when using. Wear safety glasses and gloves when using. Aluminum pushpins are sharp, and may prick fingers. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines.*

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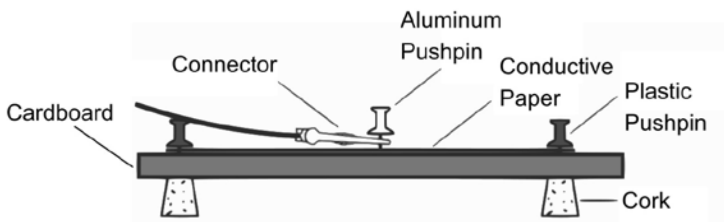
## Procedure

### Part I: Two Point Charges

*What do equipotential lines look like around two point charges?*

1. Attach the conductive paper with the silver “two point charges electrode map” to the cardboard sheet using plastic pushpins and corks, as shown in Figure 1.

**Figure 1**




2. Using the aluminum pushpins, push one into each point on the silver conductor shapes—the pins will be the electrodes. *Note: Do not push the pins all the way down into point charges, as the pinheads will cover the silver point charges.* Instead, push in just enough to make electrical contact between the silver ink and the aluminum electrode, as indicated in Figure 1.
3. Connect the pushpin electrodes to the power supply or battery as shown in Figure 2. Set the power supply to a constant voltage and write down this value. *Note: Disconnect the wires disconnect the wires from the battery when you are not using it to avoid wasting the battery or overheating the wires.*
4. Using a voltmeter, hold the ground lead against the negative silver electrode on the field map. *Note: Do not ground on the aluminum pins, as this will affect the results.*
5. Using the positive lead of the voltmeter, slowly and carefully drag the lead across the conductive paper away from the electrode until the voltmeter reads a given potential value. *Note: Be very careful dragging the leads, and do not scratch the conductive paper!*

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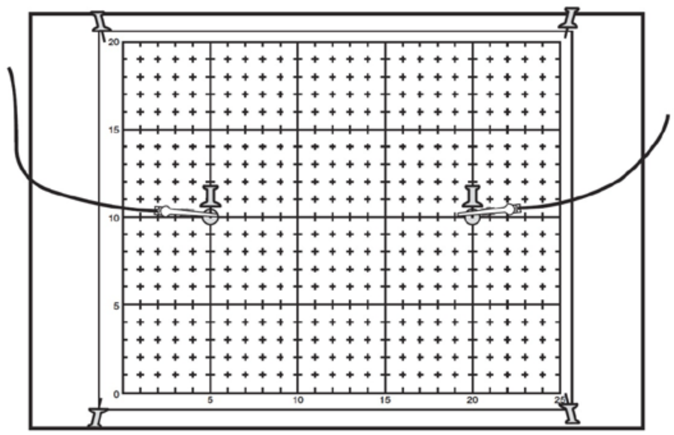
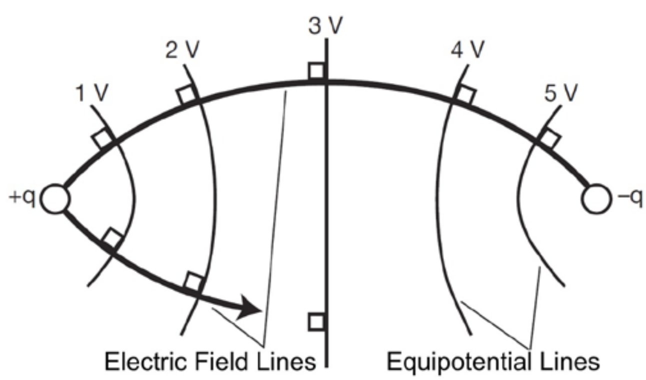
**Figure 2**



6. Mark this point on the board, and record the point on the Electric Field Plotting Map.
7. Find other points on the board with equal potential value as illustrated in Figure 3. Then pick different potential values and repeat the appropriate steps.

**Figure 3**




8. Disconnect the battery or power supply.
9. On the map, draw a rough sketch of a few electric field lines. Start at the electrode and point towards one of the equipotential, slightly curving the field line as needed so that it intersects the equipotential line at a right angle. Continue to trace this field line across the sheet, filling in multiple lines as seen in Figure 3.

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**10.** Scan or take a photo of the map and upload it, or draw a sketch that represents the charges and the shapes of the electric field lines.

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## Part II: Design and Map an Electric Field

*What do equipotential lines look like around two charged parallel plates?*

11. **SEP Plan an Investigation** Design a procedure in which you find, mark, and sketch the equipotential lines of a different charge configuration. Use the same board from Part I, and modify it to obtain a different configuration (e.g. parallel plates, plate and point charge, etc). Describe your procedure in detail and get your instructor's consent.

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**12.** Scan or take a photo of the map and upload it, or draw a sketch that represents the charges and the shapes of the electric field lines.

## Analyze and Interpret Data

1. **SEP Construct an Explanation** Where is the electric field mostly uniform for the two point charges configuration, showing lines most evenly spaced? What do you think is the reason behind this? Explain.

2. **SEP Develop Models** The two point electrodes tested had opposite charges. Sketch your best guess for the field lines of two same-charge point electrodes.

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3. **SEP Construct an Explanation** Describe the electric field generated by the charge configuration designed in Part II.

4. **SEP Construct an Explanation** What happens to the field lines and equipotential lines near the edges of the charges in Part II? Explain.

5. **SEP Construct an Explanation** Why are the electric field lines and the equipotential lines perpendicular to each other? Explain.

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INQUIRY LAB – OPEN

# Electrical Resistance and Resistivity

Metal wires are an integral part of electronic circuits, but are not often the subject of investigation. Why is there a plethora of gauges or thicknesses of wires available for use? In this laboratory you will discover the relationship between the length of a wire and its electrical resistance.

## Focus on Science Practices

**SEP 4** Analyze Data
**SEP 5** Use Math and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Electrical tape
- Meter stick
- Multimeter
- Nichrome wires, 16-, 18-, and 22-gauge, 1.2 m of each
- Vernier calipers

## Safety

*Be cautious of the ends of the wires which may be sharp. Wear safety glasses when performing this experiment.*

## Procedure

### Part I: Resistance and Length of a Wire

*What is the relationship between the length and electrical resistance of a wire?*

1. Lay the nichrome wire longitudinally on a meter stick. Note the gauge of the wire used. The wire should overhang by about 10 cm on both ends. Bend the overhanging wire to the backside of the meter stick. Hold the wire taut against the meter stick.

2. Tape the wire in place with electrical tape about 5–7 cm from the ends of the meter stick.

3. Use Vernier calipers to measure the diameter of the wire in five places along the wire. Record these values in the Wire Diameter data table.

4. Turn the multimeter on and set it to measure resistance (Ω).

5. Press the probes of the multimeter together, and record the measured resistance in the Wire Resistance data table under the "zeroed" resistance.

6. Press and hold one probe on the wire at the 0 cm mark. Press the other probe to the wire at the 20 cm mark. Record the measured resistance in the Wire Resistance Data Table.

7. While maintaining the probe at the 0 cm mark, measure and record the resistance at various distances from the 0 cm mark.

8. Turn the multimeter off when all measurements are collected.

**Table 1**

| Wire Diameter | | |
|---|---|---|
| **Trial** | **16-Gauge** | **22-Gauge** |
| **1** | | |
| **2** | | |
| **3** | | |
| **4** | | |
| **5** | | |
| **Average Diameter (mm)** | | |
| **Cross-section Area ($m^2$)** | | |

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**Table 2**

| ___-Gauge Wire Resistance | | | | |
|---|---|---|---|---|
| **Zeroed (Ω)** | | | | |
| **Trial** | **Length (m)** | **Measured Resistance (Ω)** | **Adjusted Resistance (Ω)** | **Resistivity, ρ (Ω·m)** |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| **Average** | | | | |

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## Part II: Resistance and Thickness of a Wire

*What is the relationship between the thickness and electrical resistance of a wire?*

9. **SEP Plan Your Investigation** Design and write a procedure to determine the effect that thickness of a wire has on its resistance. Use the data tables to collect the appropriate data.

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**Table 3**

| ___-Gauge Wire Resistance | | | | |
|---|---|---|---|---|
| **Zeroed (Ω)** | | | | |
| **Trial** | **Length (m)** | **Measured Resistance (Ω)** | **Adjusted Resistance (Ω)** | **Resistivity, ρ (Ω·m)** |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| **Average** | | | | |

## Analyze and Interpret Data

1. **SEP Construct an Explanation** In step 5, the probes of the multimeter were pressed together and the resistance was measured. Why is this a necessary step? Explain.

2. **SEP Identify Patterns** Identify a trend in your data between resistance and the separation distance of the probes (*L*). Does this trend agree with Equation 1 which correlates resistance (*R*) and wire length (*L*)?

   **Equation 1:** $R = \rho\frac{L}{A}$

3. **SEP Use Mathematics** Rearrange Equation 1 from step 2 to solve for resistivity (ρ). Write the rearranged equation.

4. **SEP Use Mathematics** Using the data you collected in Part II, calculate the resistivity of nichrome wire for each separation distance (*L*). Determine the average resistivity. Record these values in the corresponding data table.

5. **SEP Identify Patterns** Identify a trend in your data between resistivity and the separation distance of the probes (*L*). Does this trend agree with the rearranged equation from step 4 which correlates resistivity (ρ) and wire length (*L*)? Explain.

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6. **SEP Identify Patterns** Identify a trend in your data between resistivity and the cross-sectional area ($A$) of the various gauge wires. Does this trend agree with the rearranged equation from step 4 which correlates resistivity ($\rho$) and cross-sectional area ($A$)? Explain.

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ENGINEERING PERFORMANCE-BASED ASSESSMENT

# Build and Test an Electroscope

**What is the relationship between electric force and the distance between charges?**

**Phenomenon** An electroscope is an apparatus used to detect the presence of electric charges. Typically, an electroscope consists of a transparent glass body or a box body with a transparent window that allows to see the inside of the apparatus; an insulating top closing the body; and a metallic ball connected to an electrode, also made of a conducting material. The electrode enters the body of the electroscope through the insulating top. From the tip of the electrode, two pieces of thin metal foil hang freely; the pieces of foil are commonly made of gold or aluminum. When charge is transferred to the electrode via induction or conduction, the pieces of metal foil too become charged, and they move away from each other due to repulsion.

Your task is to build an electroscope and use it to test Coulomb's law, which describes the relationship between the magnitude of the electric force and the separation distance between charges.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 5** Use Math and Computational Thinking

## Materials Per Group

- Aluminum foil, 1 cm x 6 cm piece
- Erlenmeyer flask, 250 mL
- Friction pads, fur, silk, and/or flannel
- Friction rods, glass and/or rubber
- Pushpin
- Rod, hook and rubber stopper assembly
- Scissors

## Safety

*Please follow normal laboratory safety guidelines. Use care when handling pushpins and scissors.*

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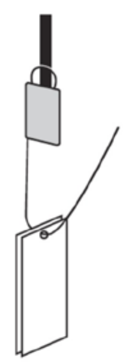
## Procedure

### Part I: Electroscope Assembly

*What parts make up an electroscope?*

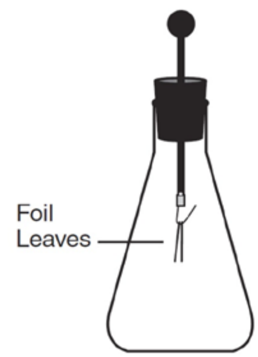
1. Use scissors to cut two identical 0.5 cm × 3 cm pieces of aluminum foil.
2. Use a pushpin to poke a hole near the center of the short edge of one piece of aluminum foil. Make sure the hole is large enough to fit over the hook of the rod, hook and rubber stopper assembly.
3. Repeat step 2 for the other aluminum foil piece.
4. Place the foil pieces on the tabletop and press down to flatten and smooth them.
5. Carefully hang the aluminum foil pieces on the hook, making sure not to bend the aluminum foil. The aluminum foil should hang together and be able to move freely on the hook. If the aluminum foil "sticks" to the hook, remove the foil and widen the hole with the pushpin as necessary (see Figure 1).

**Figure 1**



6. Insert the hook and aluminum foil into the 250 mL Erlenmeyer flask and press the rubber stopper into the opening, as seen in Figure 2.

**Figure 2**




## Part II: Charging the Electroscope

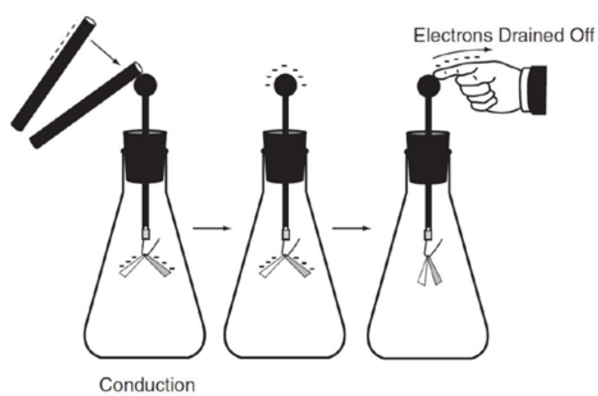
*What happens when an electroscope is charged?*

7. Negatively charge up a hard rubber friction rod by rapidly rubbing it with a piece of flannel or fur. Alternatively, you can positively charge a glass rod by rubbing it rapidly with a piece of wool.

8. *Charge by induction*: Bring the charged friction rod near the metal ball of the electroscope, but do not touch it. Recharge the friction rod if necessary, and repeat.

9. *Charge by conduction*: Touch the metal ball of the electroscope with the charged friction rod, as seen in Figure 3. Slide the friction rod along the metal ball three or four times and then remove the friction rod.

**Figure 3**



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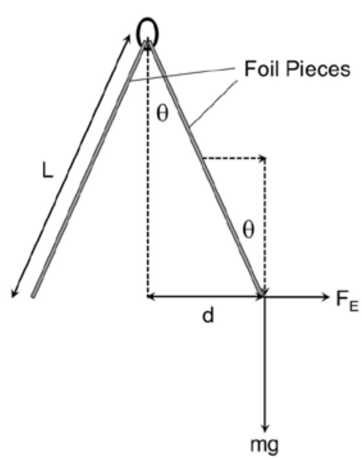
**10.** To discharge and ground the electroscope, touch the metal ball with your free hand. Make sure to ground yourself before touching the metal ball, if necessary, as shown in Figure 3.

## Part III: Test Coulomb's Law Using the Electroscope

*How can Coulomb's law be confirmed using an electroscope?*

**11.** Examine Figure 4. When the pieces of foil are charged up they separate due to electric repulsion. The free body diagram in Figure 4 indicates the directions of the electric force ($F_E$) developed between the pieces of foil, and the weight ($mg$), length ($L$), the horizontal displacement ($d$), and the angle formed between one of the foil pieces and an imaginary vertical line. The same properties apply to the other piece of foil due to symmetry.
From this diagram, one can infer that $\tan(\theta) = F_E/mg$, and $\sin(\theta) = d/L$. When $\theta$ is small, the approximation $\tan(\theta) = \sin(\theta)$ is valid, and therefore $F_E$ is directly proportional to $d$ ($F_E \propto mgd/L$). This means that, when $\theta$ is small, measuring $d$ gives you an estimate of the magnitude of the electric force between the pieces of foil, $F_E$.

**Figure 4**



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12. **SEP Plan an Investigation** Design a brief procedure to measure the horizontal displacement *d*, and the separation between the bottom tips of the two foil pieces, *r*, when the electroscope is charged. Note: You will measure approximate values of *r*, and then calculate *d* from these values; you may use a ruler or any other means that allows you to measure these distances when the electroscope is charged up and the pieces of foil move apart from each other. Write your procedure and collect *d* and *r* values in the data table.

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**Table 1**

| Coulomb's Law | | |
|---|---|---|
| **Separation Distance, *d* (mm)** | **Deflection Distance, *d* (mm)** | **$1/r^2$** |
| | | |
| | | |
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## Analyze and Interpret Data

1. **SEP Use Models** Write the equation that represents Coulomb's law. If you plot electric force against $1/r^2$, what kind of relationship would you observe? Would this be a linear or exponential plot? Explain.

2. **SEP Use Graphs** Plot the horizontal displacement (*d*) against the inverse of the maximum separation distance between the foils ($1/r$) and versus the inverse of the separation distance squared ($1/r^2$) and draw a best fit line through the data points.

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3. **SEP Interpret Data** Based on your plot from question 1, what is the relationship between horizontal displacement, *d*, and $1/r$? What is the relationship between *d* and $1/r^2$? Which plot is the most linear? Explain.

4. **SEP Construct an Explanation** Do any of your plots from question 1 confirm Coulomb's Law? Explain.

5. **SEP Construct an Explanation** If needed, how would you change the experimental setup and the procedure used in this investigation to be able to confirm Coulomb's Law? Explain.

# Investigation 5

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INQUIRY LAB – OPEN

# Magnetic Force and Separation Distance

**How does the force between magnets change with distance?**

The force due to gravity between two massive objects and the force due to electrostatic charge between two electrical charges behave similarly. In both cases, when the distance between the two objects changes, the change in magnitude of the force is inversely proportional to the distance between them ($F \propto 1/d^2$). In this lab you will discover the relationship between the force due to magnetism exerted by two repelling magnets and their separation distance. The separation distance will be measured between two dipole magnets pushed toward each other by a compressing force (mass). By plotting the log (logarithm base 10) of the separation distance versus the log of the force (mass), the slope of the line can be calculated. The negative inverse of the magnitude of the slope will be used to determine the exponent ($n$) to see the relationship between force and distance between two dipole magnets.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data

## Materials Per Group

- Balance, 1 g precision
- Neodymium magnets, 2
- Paper clip
- Plastic container, large
- Plastic container, small
- PVC tube
- Ruler, metric
- Scissors
- Spring scale, 500 g/5 N
- String
- Support stand
- Support stand clamp
- Tape, transparent

## Safety

*The materials in this lab are considered nonhazardous. Use care when handling the strong magnets. The magnets can quickly snap together, resulting in pinched fingers or cracked magnets. Wash your hands thoroughly with soap and water before leaving the laboratory.*

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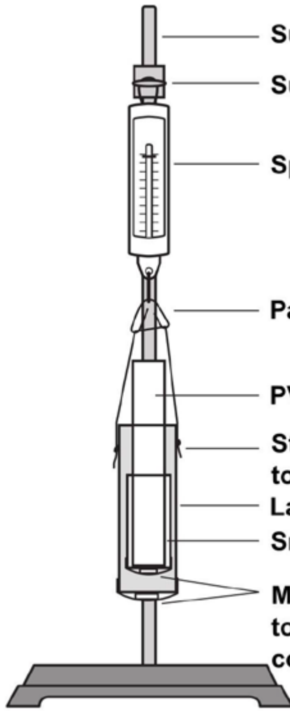
## Procedure

*What is the relationship between separation distance and magnetic force?*

1. Securely tape one of the neodymium magnets to the bottom of the large container on the outside. Make sure the magnet is in the center of the bottom of the cup. Use 2–3 pieces of tape to secure the magnet.
2. Repeat step 1 using the second magnet and the smaller container. Initially, use only one piece of tape.
3. Test the orientation of the magnets. Place the small container inside the large container. The two magnets should repel each other and the small container should “float” inside the large container. Note: If the two magnets attract each other, remove the tape from the small container and flip the magnet over.
4. Once the magnets are in the proper orientation (they repel each other), use 2–3 pieces of tape to secure the magnet to the bottom of the small container.
5. Place the small container with the secured magnet on a balance and record the mass to the nearest gram in Table 1.
6. Place the PVC tube on the balance and record the mass to the nearest gram in Table 1.
7. Use scissors to cut approximately 30 cm of string.
8. With transparent tape, secure one end of the string to the side of the large container near the top. See Figure 1. Use 2–3 pieces of tape to prevent the string from slipping.

**Figure 1**




9. Secure the other end of the string to the opposite side of the large container so that the string is parallel, and the container will remain level and balanced when held by the string. (The string will act like a handle to the plastic “bucket.” The “bucket” cannot be tilted.) Once the string is properly aligned, use 2–3 pieces of tape to secure it completely.

10. Bend a small paper clip as shown in Figure 2.

**Figure 2**

11. Using a support stand and clamp, set up the apparatus as shown in Figure 1. Hang the large container at least 10 cm above the metal base of the support stand.

**12.** Place the small container inside the large container (it should “float”). Do not place the PVC tube inside the small container until step 14.

**13.** Use a metric ruler to measure the separation distance between the magnets. Make sure the small container is level, the magnets are parallel to the tabletop, and the small container “floats” in the center of the large container. Measure from the bottom of the top magnet to the top of the bottom magnet. Measure to the nearest 0.1 cm and record the value in Table 1. The Total Mass will be equal to the mass of the small container and magnet.

**14.** Place the PVC tube into the small container.

**15.** Measure the separation distance between the magnets. Make sure the small container is level, the magnets are parallel to the tabletop, and the small container “floats” in the center of the large container. Measure from the bottom of the top magnet to the top of the bottom magnet. Measure to the nearest 0.1 cm and record the value in Table 1. The Total Mass will be equal to the mass of the PVC tube plus the mass of the small container and magnet.

**16.** **SEP Develop Models** Using the magnetic force setup, develop a way to model how an increase in force affects the separation distance of the magnets. Record your detailed procedure and have your teacher check it before proceeding.

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**Table 1**

| Measuring Magnetic Force | | | |
|---|---|---|---|
| Mass of small container and magnet | | | |
| Mass of PVC tube | | | |
| Total mass (magnetic repelling force) | Separation distance | Log of total mass | Log of separation distance |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

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## Analyze and Interpret Data

1. **SEP Use Graphs** Calculate the log of the total mass and separation distance and record the calculations in Table 1. Use graphing software or the space to construct a graph of the log of separation distance versus the log of total mass. Draw a best-fit line through the data points.

2. **SEP Use a Model** Find the slope of the best-fit line on the graph plot. What does the slope of the line indicate?

3. **SEP Use a Model to Evaluate** The mathematical relationship between the magnitude of the magnetic force and the separation distance is expressed by $F = A/d^n$. Calculate the value of *n* by taking the negative inverse of the slope (–1/slope). Compare the relationship between the force due to a magnet and the separation distance, and the relationship between force due to gravity and the separation distance. Does this result make sense based on your experiences with magnets and gravitational force? Explain.

4. **SEP Identify Limitations of a Model** How does the method of measurement affect the accuracy of the slope and the value of *n*?

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INQUIRY LAB – OPEN

# Electromagnets and Magnetism

**How does electricity induce magnetism?**

Electromagnetism is all around us. Electromagnetism generates motion (electric motors), allows us to see our world (visible light), and provides the means for communicating long distances (microwaves used by cell phones). Learn the basics of electromagnetism by studying the magnetic properties of electric current-carrying wires. Then, coil a current-carrying wire around a nail to make an electromagnet.

## Focus on Science Practices

**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data

## Materials Per Group

- Battery, 9 V
- Compass
- Connector cords with alligator clips, 2
- Foam cup
- Index card, 7.6 cm x 12.7 cm
- Iron nail
- Magnet wire, 175 cm
- Neodymium magnet
- Paper clips, steel, 20
- Sandpaper
- Scissors
- Transparent tape

## Safety 

*While 9-volt batteries are not harmful, small shocks are possible. Do not complete the circuit with the battery for more than ten-second intervals. Since there is very little resistance in the wires, the battery can discharge quickly and become very hot if it is connected for a longer duration. Care should be taken when wrapping and unwrapping the wire. The pointed ends of the wire are hazardous to eyes. Wear safety glasses. Please follow normal laboratory safety guidelines.*

NAME ________________________________________ DATE ____________ CLASS ____________

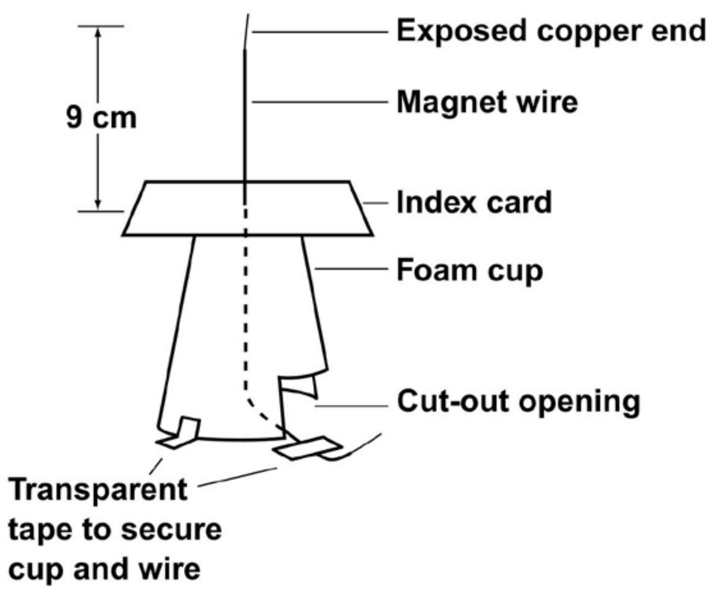
## Procedure

### Part I: Magnetism produced by a current-carrying wire

*What happens to a magnetic field when current direction is reversed?*

1. Use the sandpaper to completely sand off about 2 cm of red enamel at both ends of the magnet wire to expose the shiny copper underneath.
2. Use scissors to cut a 3 cm x 3 cm opening in the side of the foam cup as shown in Figure 1.

**Figure 1**




3. Carefully poke a tiny hold through the center of the bottom of the foam cup with the magnet wire.
4. Place the foam cup upside down on the tabletop and slide the magnet wire through the hole so that it is vertical.
5. Bend the magnet wire at the base of the cup as shown in Figure 1 so that the wire is supported by the tabletop and extends out of the side opening in the cup. Leave approximately 9 cm of magnet wire extending vertically above the inverted cup.

6. Use a small amount of transparent tape to secure the wire to the tabletop (see Figure 1).

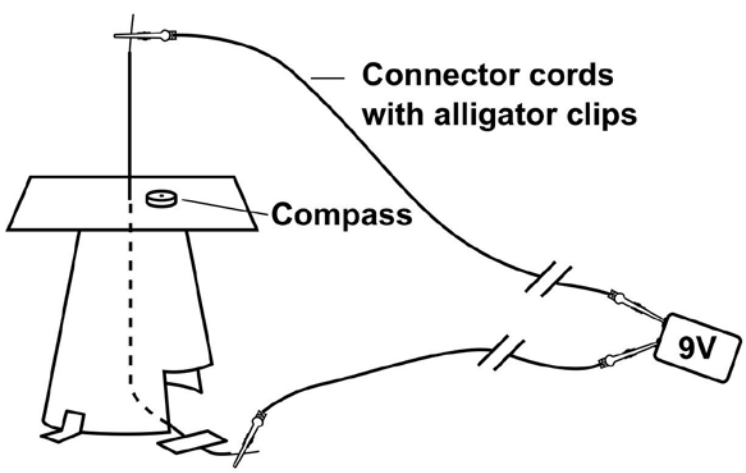
7. Adjust the position of the foam cup so that the magnet wire is vertical. Then, use a small amount of transparent tape to secure the cup to the tabletop.

8. Use the pointed end of a pair of scissors or a sharp pencil point to poke a hole through the center of the index card.

9. Slide the index card over the magnet wire and allow it to rest on the bottom of the cup (see Figure 1).

10. Clip the connector cords to the exposed copper ends of the magnet wire. It may be necessary to bend the end of the magnet wire taped to the tabletop upwards in order to clip it with the alligator clip as shown in Figure 2. Make sure the magnet wire that extends vertically above the cup does not bend and remains vertical and rigid. Also, make sure the connector cord does not interfere with the index card. The index card should remain flat and horizontal. Note: Do not connect the connector cords to the battery until it is time to do the experiment.

**Figure 2**




11. Place the compass on the index card adjacent to the vertical wire (Figure 2).

12. Observe the orientation of the compass needle. Record the initial direction of the red tip of the needle in the data table.

**13.** Bring the neodymium magnet near the compass. Observe the effect on the compass needle by the magnetic field of the magnet. Remove the magnet from the experiment setup. Record your observations in the data table.

**14.** Connect the free ends of the connector cords to the battery.

**15.** Observe the direction the compass needle points after connecting the battery. Quickly move the compass around the wire and observe the direction of the needle. Does the red tip of the needle point clockwise or counterclockwise as the compass is moved? Disconnect the battery and then record the direction of the red tip of the compass needle in the data table. Caution: Do not allow the battery to be connected for intervals longer than 10 seconds.

**16.** Repeat steps 14 and 15 but reverse the connecting leads on the battery so that the current travels in the opposite direction.

**17.** Disconnect the alligator clips from the magnet wire and carefully remove the tape from the foam cup and tabletop (save the cup for future use). Remove the magnet wire from the cup and straighten it.

**18.** Lay the compass on the tabletop. Then place the straight magnet wire over the compass so that the wire and compass needle are parallel to each other.

**19.** Connect the connector cords to the ends of the magnet wire.

**20.** Connect the free ends of the connector cords to the battery and observe the compass needle. Which direction does the red tip of the compass needle point? Record your observations in the data table.

**21.** Repeat steps 19 and 20, but reverse the leads connected to the battery so the current travels in the opposite direction.

**22.** Disconnect the battery.

NAME ______________________________ DATE ____________ CLASS ____________

**Table 1**

| Current-Carrying Wire Observations | |
|---|---|
| | **Observations** |
| **Initial direction of the red tip of the compass needle?** | |
| **Effect of the magnet on the compass needle?** | |
| **Direction of the red tip of the needle with electric current traveling through the wire?** | |
| **What happens when the current is reversed?** | |
| **Effect on the compass needle by the horizontal current-carrying wire?** | |
| **What happens when the current is reversed?** | |

NAME ______________________________ DATE ____________ CLASS ____________

## Part II: Building an Electromagnet

*How does an electromagnet work?*

23. **SEP Plan Your Investigation** Using two different lengths of magnet wire (50 cm and 100 cm), build an electromagnet to investigate how the number of coils impacts its strength. Test your electromagnet with and without an iron core. Record your detailed procedure in the space provided and have your teacher approve it before beginning any lab work.

NAME ______________________________ DATE __________ CLASS __________

**Table 2**

| Electromagnet Observations | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## Analyze and Interpret Data

1. **SEP Make Observations** When the electric current is traveling through the vertical wire, does the compass needle ever point towards the wire?

2. **SEP Analyze Data** Based on your observations, what is the general shape of the magnetic field surrounding a current-carrying wire?

3. **SEP Make Observations** What direction does the compass needle deflect when a horizontal current passes over the compass? What direction does the needle point when the current is reversed?

4. **SEP Analyze Data** Compare the strength of the electromagnet with the iron core to the one without. Why would the iron core have this effect?

5. **SEP Make Observations** What does it mean when an electric current deflects a compass needle?

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INQUIRY LAB – OPEN

# Induction of Electrical Current

**How does magnetism induce current?**

Electricity and magnetism are just two parts of the unifying concept of electromagnetism. Once it was known that electric currents produce magnetic fields, it was natural to wonder if magnetic fields could produce electric currents. Devices such as AC generators, microphones and MRI machines all became possible due to an understanding of electromagnetic induction. The purpose of this investigation is to understand the unity of electricity and magnetism through a discovery of electromagnetic induction. You will investigate how magnetic flux induces a current on a coil of wire.

## Focus on Science Practices

**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data

## Materials Per Group

- Connector cords with alligator clips, 2
- Galvanometer, –500 to +500 μA
- Magnet wire, 22 gauge, 1 m and 4 m lengths
- Neodymium magnets, 2
- Plastic jar, 60 mL
- Sandpaper
- Transparent tape

## Safety

*The materials in this lab are considered nonhazardous. Care should be taken when wrapping and unwrapping the wire. The pointed ends of the wire are dangerous to eyes. Neodymium magnets are very strong and will accelerate towards each other and other metal objects very quickly. Care should be taken to avoid unexpected and significant pinches of skin. Wear safety glasses. Please follow all normal laboratory safety guidelines.*

NAME ______________________________ DATE ____________ CLASS ____________

## Procedure

*How does electromagnetic induction work?*

1. **SEP Plan Your Investigation** Using two different lengths of magnet wire and the materials provided, build an electromagnet induction device. Use your device to investigate how the number of wire coils and neodymium magnet movement affect its current output. Record your detailed procedure in the space provided and have your teacher approve it before beginning any lab work.

NAME ______________________________ DATE ____________ CLASS ____________

**Table 1**

| Electromagnetic Induction Observations | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

NAME ______________________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Make Observations** Does the galvanometer needle deflect more when the magnet approaches the coil rapidly or slowly?

2. **SEP Make Observations** How does the orientation of the magnet affect the observed current?

3. **SEP Analyze Data** Does the needle deflect when the magnet is at rest? Does rotating the magnet induce a current in the coil?

4. **SEP Analyze Data** How does the magnitude of deflection of the galvanometer needle differ between the 4 meter and 1 meter length of magnet wire? What explains this difference?

5. **SEP Plan Your Investigation** A red mini LED bulb needs approximately 10 mA to light. Based on the data from your experiment, how much magnet wire would be needed to light the bulb, and how would the magnets be used?

6. **SEP Interpret Data** When the magnet is oscillated to and from the coil, the needle moves from side to side, indicating a current that changes direction. In your own words, why does the current change direction? Consider Lenz's law in your explanation.

NAME ______________________ DATE ____________ CLASS ____________

ENGINEERING PERFORMANCE-BASED ASSESSMENT

# Build a DC Motor

**How can electricity and magnetism be used to build a motor?**

**Phenomenon** For this simple DC motor, electric charge flows through the coil armature from a direct current power source. Direct current (DC) is current that travels in only one direction, as opposed to alternating current (AC), which switches rapidly. A property of a moving electric charge is that it produces a magnetic field. Therefore, a magnetic field forms around the wires in the coil armature when current flows through it. In order for the motor to work, the coil armature must continue to spin. For this to occur, the magnetic fields must either change direction or disappear once the magnetic fields are aligned. The largest rotational force occurs when the magnetic fields produced by the current in the coil armature and the external magnet are at right angles to each other. The direction of the induced spin is determined by the direction the current is traveling in the coil and the external magnetic field direction. The coil will spin in the direction that will align the magnetic fields.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data

## Materials Per Group

- Alligator cords with clips, 2
- Battery, 9 V
- Copper wire pieces, 16 gauge, 8 cm, 2
- Foam block, 7.5 cm x 7.5 cm x 2.5 cm
- Magnets, ceramic disc, 2
- Magnet wire, 20–22 gauge, 60 cm
- Pliers, needle-nosed with wire cutters
- Sandpaper strip
- Tube or rod, approximately 2 cm in diameter

## Safety

*This activity is considered nonhazardous. Although 9V batteries do not have enough electrical current to be harmful, please exercise caution and follow all normal laboratory safety guidelines.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

*How do magnetic fields induce electrical current?*

1. **SEP Develop Models** Design a DC motor using the materials provided. When constructing your motor, only sand half of the enamel off the ends of the coil armature. Once the motor spins, adjust the position and the polarity of the external magnet and observe how the motor spins. Write your detailed procedure in the space provided and have your teacher check it before beginning any experimental work.

## Analyze and Interpret Data

1. **SEP Make Observations** How did magnet position and polarity affect the spin of the motor?

2. **SEP Interpret Data** Describe why the magnetic field of the ceramic magnets causes the metal coil to rotate when it is connected to the battery.

3. **SEP Use a Model to Evaluate** Predict what would happen to the rotation of the magnetic coil if the alligator clips were switched from one copper post to the other.

4. **SEP Use a Model to Evaluate** If the coil armature was larger or had more windings, how would this affect the performance of the motor?

5. **SEP Analyze Data** What is the purpose of sanding only half the enamel off the ends of the coil armature?

# Investigation 6

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Indirect Observation of the Atom

**How can you study something that cannot be directly observed?**

Most of the time, scientists are trying to learn about things or systems that cannot be seen with the unaided eye, like atoms and molecules. For centuries, physicists and chemists have designed experiments and instruments to investigate the structures of these tiny objects. Rutherford's famous gold foil experiment allowed him to propose the existence of the atomic nucleus based on indirect observations. In this lab, you will use a model that resembles Rutherford's experiment to understand how indirect observations and inferences can help to expand the knowledge of systems that cannot be directly seen.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Binder clips, 4
- Blotting paper, 30.5 cm × 48.3 cm, 6 sheets
- Cardboard square, 43 cm × 43 cm, 1 sheet
- Laser pointer
- Marker
- Meterstick
- Plastic strip, 7.6 cm × 224 cm, 1
- Plexiglas mirrors, 6.3 cm × 8.9 cm, 3
- Transparent tape

## Safety

*Please follow the safety guidelines described by the laser's manufacturer. Never look directly at the laser light. Follow all laboratory safety guidelines. Wash your hands at the end of the lab period.*

NAME ________________________ DATE ____________ CLASS ____________

## Procedure

### Part I: Interaction Between a Laser Beam and Hidden Mirrors

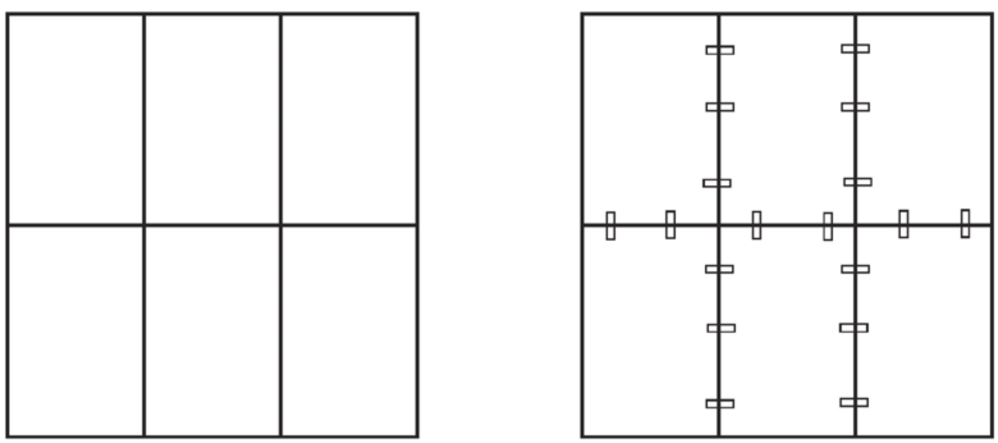
*How do you develop a mental picture of something that you cannot see?*

1. Assemble the plastic ring. Take the strip and overlap the ends by 7 cm. Secure the overlap with four binder clips as shown in **Figure 1**.

**Figure 1**

2. Lay the six sheets of blotting paper out in a two by three grid as indicated in **Figure 2**. Use transparent tape to connect them together as shown in **Figure 2**.

**Figure 2**



3. Use transparent tape to join four mirrors together to form a square.

4. Flip the blotting paper assembly over. Using a meter stick, measure the diagonal of the grid and mark the center point with a marker as shown in **Figure 3**.

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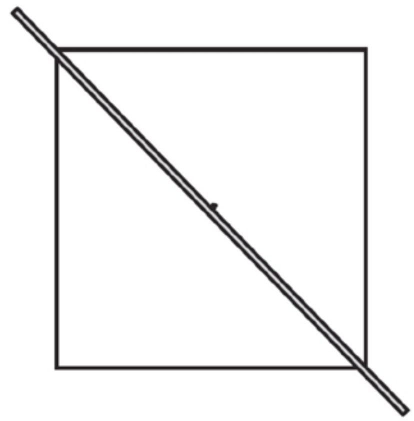
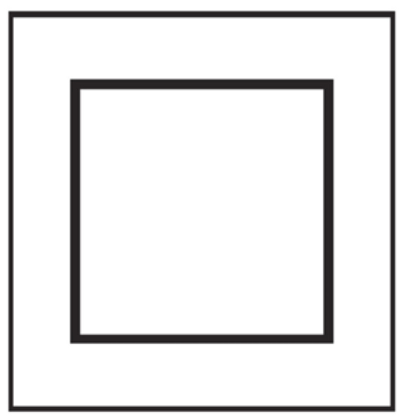
**Figure 3**



5. Place the cardboard top in the center of the blotting paper, and tracing its outline onto the blotting paper as shown in **Figure 4**.

**Figure 4**



6. Center the plastic ring on the blotting paper. Place the mirror assembly in the center of the marked square with one side parallel to one edge of the blotting paper assembly as indicated in **Figure 5**. Place the cardboard square on top of the mirrors in line with the marked square of the paper.

7. Position the laser pointer at the upper left-hand corner of the cardboard blind and fire the beam to the other side as shown in **Figure 6**. Use an arrow to mark the direction in which the laser beam points, and the location of the red dot on the plastic ring on the blank diagram A in **Table 1**.

**Figure 5**

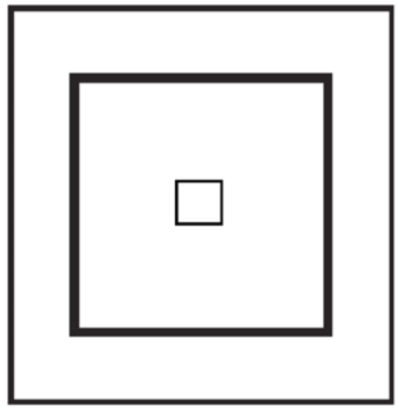
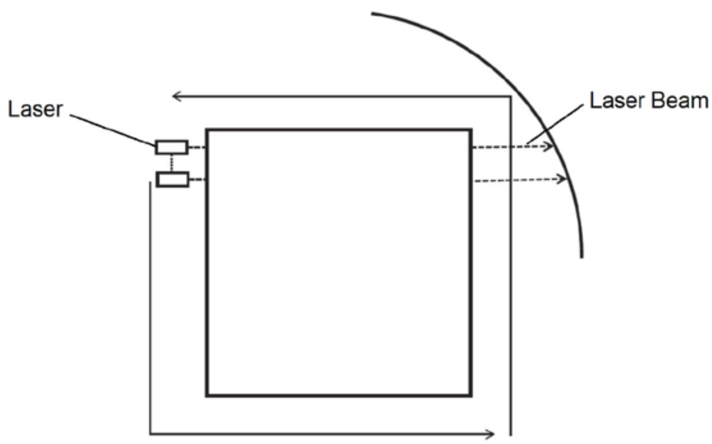


**Figure 6**



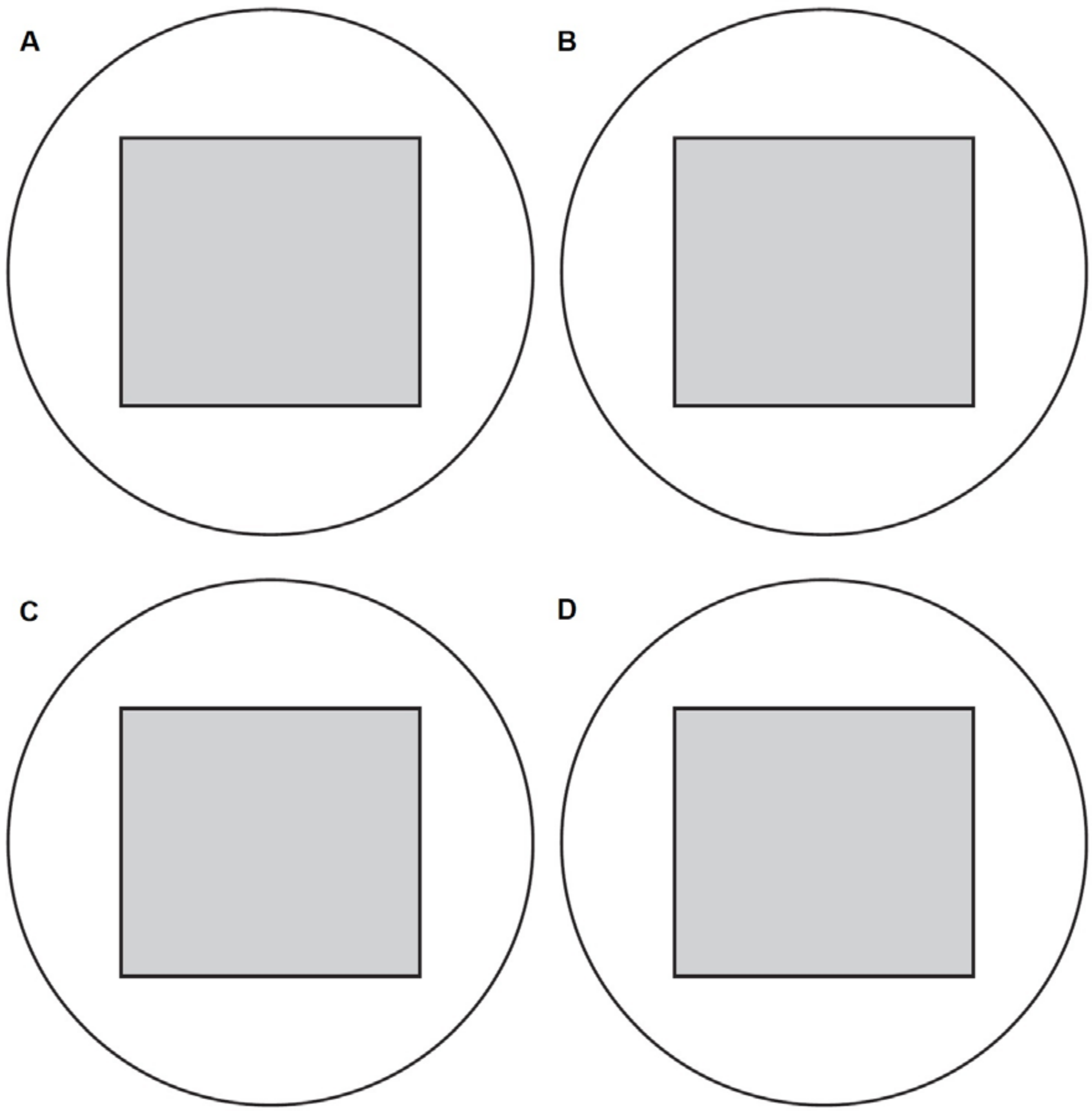

8. Move the laser down 2 cm along the edge of the cardboard square. Fire the laser again. Use an arrow to mark the direction in which the laser beam points, and the location of the red dot on the plastic ring on the blank diagram A in **Table 1**.

9. Repeat the process until all four sides of the object have been explored. Use a different diagram in **Table 1** to mark the direction of the laser beam and its reflection on the plastic ring for each side of the object.

NAME ______________________ DATE __________ CLASS __________

**Table 1**

**Interaction Between a Laser Beam and Hidden Mirrors**



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## Part II: Interaction Between a Laser Beam and a Hidden Object

*What could the interaction between light and a hidden object tell us about the shape, size, and composition of the object?*

10. **SEP Plan Your Investigation** Design an investigation in which you examine a hidden mirror assembly of a different shape. Use Part I as guidance to design your experiment, and write the steps you will follow to probe the hidden object. Use the diagrams in **Table 2** to collect your data. ***Note***: One or two students might be in charge of assembling the mirror object and hide it underneath the cardboard blind, while the other group members probe the hidden object with the laser beam.

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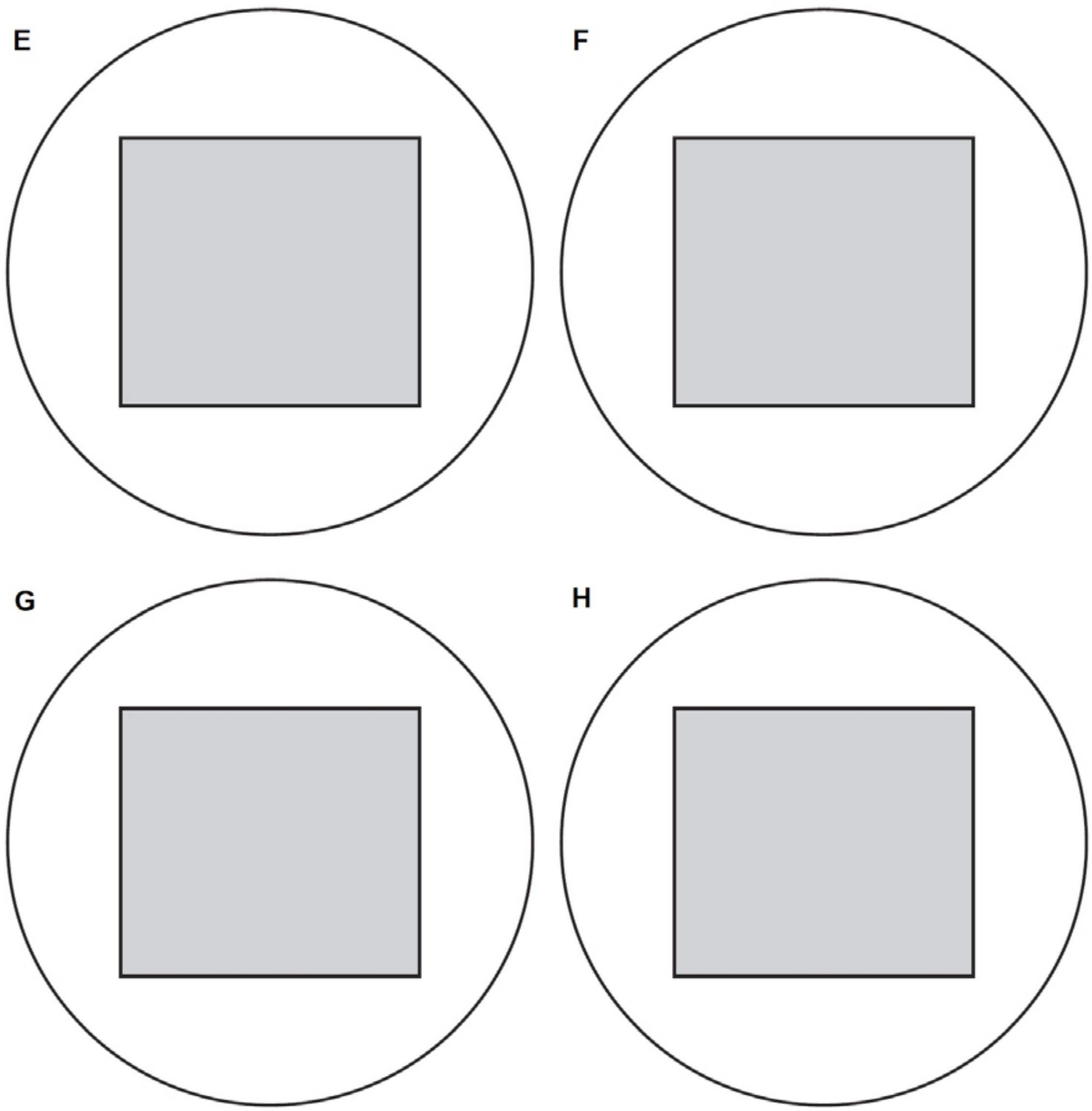
**Table 2**

**Interaction Between a Laser Beam and Hidden Object**



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## Analyze and Interpret Data

1. **SEP Evaluate and Communicate** In Part I, what does the interaction between the laser beam and the object underneath the cardboard tell you about the surface of the hidden object?

2. **SEP Evaluate and Communicate** In Part I, how would you describe the shape and dimension of the object underneath the cardboard, based on the observed interaction with the laser beam? Explain. ***Note***: Assume you have to prove to someone that has not seen the hidden object what it looks like based on your experimental observations only.

3. **SEP Evaluate and Communicate** In Part II, what does the interaction between the laser beam and the object underneath the cardboard tell you about the surface of the hidden object?

4. **SEP Evaluate and Communicate** In Part II, how would you describe the shape and dimension of the object underneath the cardboard, based on the observed interaction with the laser beam? Explain. ***Note***: Assume you have to prove to someone that has not seen the hidden object what it looks like based on your experimental observations only.

5. **SEP Identify Limitations of a Model** Could you replace the laser beam used in this experiment for a regular flashlight? Explain.

6. **SEP Obtain Information** Conduct an Internet search or consult your textbook to find information about Rutherford's "Gold Foil Experiment". How does this experiment's setup resemble the one used in that classic experiment? Which parts in both setups would resemble each other? Explain.

7. **SEP Design A Solution** If you had the time and the resources, how would you modify the experimental setup used in this laboratory to more accurately model Rutherford's gold foil experiment? Explain.

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INQUIRY LAB – OPEN

# Cohesive Forces and Surface Tension

**Why do bubbles form in soapy water?**

A solution of soap or detergent in water is commonly used to form air-filled bubbles of various sizes, of spherical or elongated shapes. In this lab, you will explore how and why soap bubbles form in aqueous solutions containing soap or detergent.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 5** Use Mathematics and Computational Thinking
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Dishwashing liquid, 100 mL
- Glycerin, 50 mL
- Distilled or deionized water, 2 L
- Beaker, 1000 mL, or bucket, 2
- Chenille wires, 2
- Graduated cylinders, 25 mL, 250 mL, and 500 mL
- Plastic wrap sheet
- Ruler, metric, clear
- Scissors
- Stirring rod
- Straws, plastic, 2
- Stopwatch or timer

## Safety

*Bubbles break with a fair amount of force; keep them away from your face. The bubble solution will make the floor or pavement slippery; take care to avoid slipping. Glycerin may cause an explosion when contacting strong oxidants. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Follow all laboratory safety guidelines. Wash your hands at the end of the lab period.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

### Part I: Make Soap Bubbles

*What does it take to make soap bubbles of various sizes?*

1. Use a chenille wire to form a circular loop with a diameter of 1 cm at the middle of the wire. Twist the remaining portions of the chenille wire to prevent the unwinding of the chenille wire.

2. Slide the twisted ends of the chenille wire into a straw. This device will be used as a wand to make soap bubbles.

3. Measure 850 mL of deionized or distilled water, and transfer into a 1000 mL beaker.

4. Immerse the bubble wand with the smallest loop in the water-containing beaker from step 3, and swing the wand out of the water in a swift motion. Repeat this step a couple of times and write your observations in the data table.

5. Repeat step 4 blowing some air through the bubble wand's loop after picking it up from the water. Write your observations in the data table.

6. Use a graduated cylinder to measure 100 mL of dishwashing liquid. Use another graduated cylinder to measure 50 mL of glycerin. Pour the dishwashing liquid into the beaker containing 850 mL of water prepared in step 4. Stir the solution without shaking it vigorously to avoid excessive production of lather.

7. Immerse the bubble wand in the soap-water solution prepared in step 6, and swing the wand out of the water in a swift motion. Repeat this step a couple of times and write your observations in the data table.

8. Repeat step 7 blowing some air through the bubble wand's loop after picking it up from the soapy water. Write your observations in **Table 1**.

NAME ______________________ DATE __________ CLASS __________

**Table 1**

| Make Soap Bubbles | |
|---|---|
| **Liquid** | **Observations** |
| **Water** | |
| **Soap-Water Solution** | |

## Part II: The Pressure Inside Soap Bubbles

*How does the pressure inside a soap bubble compare to the pressure outside?*

9. **SEP Plan Your Investigation** Design an investigation to examine the time it takes for half-bubbles of various sizes to burst. Use the items available to you in this lab and **Table 2** to guide the design of your experiment. Write the procedure you will follow to obtain the required data. Add more rows to **Table 2** as needed.

NAME ____________________ DATE __________ CLASS __________

**Table 2**

| The Pressure Inside Soap Bubbles | | |
|---|---|---|
| **Bubble Diameter (cm)** | **Time Until Bubble Bursts (s)** | **Pressure Difference, Δ*P* (dynes)** |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## Analyze and Interpret Data

1. **SEP Obtain Information** Perform an Internet search or consult your textbook to obtain information about the magnitude of the surface tension ($\gamma$) of pure water, and that of soap-water solutions.

2. **SEP Evaluate and Communicate** Compare your results for attempting to make bubbles in pure water and soap-water solution. What did you observe and what explains the outcome?

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3. **SEP Evaluate and Communicate** Compare your results for timing how long soap bubbles of various sizes last before bursting. What was the average diameter and lifetime of the bubbles? Is there any relationship between bubble size and lifetime?

4. **SEP Use Mathematics** The surface tension of the fluid that makes up a half-bubble ($\gamma$) is related to the radius of the bubble (*r*) and to the difference in pressure ($\Delta P$) between the inside ($P_{inside}$) and outside ($P_{outside}$) of the half-bubble. The relationship is expressed by Equation 1. Apply this equation to determine the difference in pressure for the bubbles of various sizes you made. Assume that the surface tension of the soap-water solution used is equal to 25 dynes/cm. Show a sample calculation and fill in the data table.

   **Equation 1:** $\Delta P = P_{inside} - P_{outside} = 2\gamma/r$

5. **SEP Construct an Explanation** Examine the values of pressure difference ($\Delta P$) for the bubbles of various sizes made. What is the relationship between $\Delta P$ and the size of the bubbles? Explain.

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INQUIRY LAB – OPEN

# Physical Properties of Solid Materials

**What determines the differences in solubility, odor, conductivity, and melting point of solid materials?**

Solid materials have in common that they have well-defined shapes and volumes. Liquids or gases, on the other hand, tend to adopt the shape of their containment, and can be compressed (to varying degrees) into smaller volumes. In this lab, you will explore some of the physical properties that describe solid materials. This will give you insight into the forces that hold their atoms and/or molecules together, and how these forces determine the properties and applicabilities of different solid materials.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Unknown solid A, 0.2–0.5 g
- Unknown solid B, 0.2–0.5 g
- Unknown solid C, 0.2–0.5 g
- Unknown solid D, 0.2–0.5 g
- Unknown solid E, 0.2–0.5 g
- Water, distilled or deionized
- Aluminum evaporating dish
- Balance, 0.1 g precision
- Beaker, 150 mL
- Beral-type pipet
- Boiling stones
- Conductivity tester, low-voltage
- Hot plate
- Marking pen
- Paper towels
- Spatula
- Stirring rod
- Test tube holder (clamp)
- Test tubes, small, 5
- Wash bottle
- Weighing dishes, 6
- Wooden or heat-resistant test tube rack

## Safety

*Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and an apron. Follow all laboratory safety guidelines. Wash your hands at the end of the lab period.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

*What do the physical properties of a solid say about the forces between atoms and/or molecules that make up the solid?*

1. Prepare a boiling water bath for later use: Half-fill a 150 mL beaker with water, add a boiling stone, and heat the beaker on a hot plate at a medium-low setting.
2. Label five weighing dishes for the five unknown solid samples A through E.
3. Measure 0.2–0.3 g samples of each solid. Transfer the samples into the appropriate weighing dish. Record the color and appearance of each solid sample in **Table 1**.
4. Test the volatility and odor of each solid by wafting any vapors to your nose with your hand. Record all observations in **Table 1**. ***Note***: To detect the odor of a substance, place the open container about 6 inches away from the nose and use your hand to waft the vapors toward the nose.
5. Test the conductivity of each solid by touching the wires of the conductivity tester directly to the solid. Record the conductivity of each sample in **Table 1**.
6. Use a plastic pipet to add water to each weighing dish. Stir each mixture and observe whether the solid dissolves in water. Record the solubility (soluble, partially soluble, or insoluble) in **Table 1**.
7. For water-soluble substances only: Determine the conductivity of the aqueous solution by placing the wires of the conductivity tester directly into the liquid. Record the results in **Table 1**. ***Note***: Rinse the conductivity tester in between measurements with deionized or distilled water.
8. Obtain an aluminum dish and place a small, pea-sized amount of each solid in separate locations on the dish.
9. Using the test tube clamp, set the dish on top of the boiling water bath and heat the solids for 1–2 minutes. Observe whether any of the solids melt and record the observations in **Table 1**.
10. Dispose of all waste liquids and solids as directed by your instructor.

NAME ______________________ DATE ____________ CLASS ____________

**Table 1**

| Physical Properties of Solid Materials | | | | | |
|---|---|---|---|---|---|
| **Physical Property** | **Unknown Solid A** | **Unknown Solid B** | **Unknown Solid C** | **Unknown Solid D** | **Unknown Solid E** |
| **Color and Appearance** | | | | | |
| **Volatility and Odor** | | | | | |
| **Conductivity as a Solid** | | | | | |
| **Solubility in Water** | | | | | |
| **Conductivity as an Aqueous Solution** | | | | | |
| **Melting Point** | | | | | |
| **Solid Substance Name** | | | | | |

## Analyze and Interpret Data

1. **SEP Evaluate and Communicate** Is it possible to tell apart the solid samples examined in the lab based on their color and appearance? Explain.

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2. **SEP Analyze Data** Compare the volatility and odor of the five solid samples. Which solids are volatile? Which are not?

3. **SEP Evaluate and Communicate** Compare the volatility of the five unknown solid samples. Which solid is the most volatile? What does this tell you about this solid in comparison to the others?

4. **SEP Analyze Data** Compare the conductivity of the solid samples. Which solid(s) would serve to conduct electricity? Which would not?

5. **SEP Evaluate and Communicate** Based on the conductivity results observed for the five unknown solid samples, which solid is most likely to be a metal? Explain.

6. **SEP Evaluate and Communicate** Compare the solubility of the unknown solid samples in water. What do the differences in solubility tell you about the polar or nonpolar character of each solid sample?

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7. **SEP Analyze Data** Which solid(s) melted at temperatures equal to or below 100°C? Which did not?

8. **SEP Evaluate and Communicate** Based on your attempts at melting the unknown solid samples, what can you say about the forces that hold atoms or molecules together in these solids? Explain.

9. **SEP Evaluate and Communicate** The solid samples you analyzed in this lab correspond to sodium chloride, sucrose, aluminum, stearic acid, and silicon dioxide. Perform an Internet search or consult your textbook to learn more about these solids. Then, based on your own experimental observations and the results of your search, determine the identity of each unknown solid sample. Fill in the data table and briefly explain your matches.

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INQUIRY LAB – OPEN

# Structures and Properties of Polymers

**What do all polymers have in common?**

Polymers are large, chain-like molecules, composed of repeating units of smaller molecules called monomers. A typical polymer molecule may be made up of thousands of monomer molecules joined together through chemical bonds. The properties of a polymer depend on the chemical nature of the monomer, the length of the polymer "chain," and the types of bonds that hold the monomers together. In this lab, you will explore the relationship between structure and properties of two commonly used polymeric materials.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Calcium chloride solution, $CaCl_2$, 1%, 100 mL
- Congo red solution, 0.1%, 1 mL
- Copper(II) chloride solution, $CuCl_2$, 0.5%, 50 mL
- Sodium alginate solution, 2%, 6 mL
- Sodium chloride solution, NaCl, saturated, 50 mL
- Distilled or deionized water
- Beaker, 10 mL
- Beakers, 100 mL, 4
- Beral-type pipet, 2
- Forceps
- Marking pen
- Paper towels
- Stirring rod
- Wash bottle
- Waste beaker, 1 L

## Safety

*The polymers used in this experiment have a variety of consumer and commercial uses and are considered nontoxic. Exercise care when pouring hot water, and avoid contact of all solutions with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines.*

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## Procedure

### Part I: The Properties of a Natural Polymer—Sodium Alginate

*What are the physical and chemical properties of sodium alginate, a natural polymer?*

1. Label three 100 mL beakers A, B, and C. Add about 50 mL of the appropriate solution to beakers A, B, and C, as indicated in **Table 1**.

**Table 1**

| Prepare Beakers A, B, and C | | | |
|---|---|---|---|
| **Beaker** | **A** | **B** | **C** |
| **Solution** | Calcium chloride, 1% | Copper (II) chloride, 0.5% | Sodium chloride, saturated |

2. Draw a pipet-full of sodium alginate solution into a clean Beral-type pipet. Slowly squeeze the pipet bulb and add the sodium alginate solution in one continuous stream into the calcium chloride solution in beaker A. Write your observations about the sodium alginate solution in **Table 2**.
3. Repeat step 2, adding sodium alginate into the copper(II) chloride solution in beaker B.
4. Wait about 1–2 minutes until the products form in beakers A and B.
5. Using clean forceps, gently lift some of the polymer products out of the solutions in beakers A and B to observe the appearance of calcium and copper alginate, respectively. Write your observations in the appropriate data table.
6. Using forceps, remove about half of the calcium alginate from beaker A, and add the polymer to the saturated sodium chloride solution in beaker C.
7. Stir the mixture in beaker C for 2–3 minutes. Observe any changes in the appearance of the polymer and the solution, and record observations in the appropriate data table.
8. Discard the contents of beakers A, B, and C into the waste beaker. Rinse each beaker with distilled or deionized water.

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**Table 2**

| The Properties of Sodium Alginate | |
|---|---|
| **Beaker** | **Observations** |
| **Sodium Alginate Solution** | |
| **A** | |
| **B** | |
| **C** | |

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## Part II: Dyeing Calcium Alginate

*Is it possible to dye a polymer?*

9. **SEP Plan Your Investigation** In Part I, you prepared calcium alginate gel. Use the sodium alginate solution, and the congo red solution available to design an investigation in which you explore whether congo red molecules can be incorporated into calcium alginate. Use **Table 3** to help you write your procedure and to collect your observations. Before starting your procedure, have it approved by your teacher. ***Note***: To start, prepare a mixture containing a few drops of congo red and a couple of millimeters of the sodium alginate solution in a clean beaker.

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**Table 3**

| Dyeing Calcium Alginate | |
|---|---|
| **Mixture** | **Observations** |
| **Sodium Alginate + Congo Red** | |
| **Sodium Alginate + Congo Red + $CaCl_2$ Solution** | |

## Analyze and Interpret Data

1. **SEP Obtain Information** Go online or consult your textbook to find the chemical structure of alginate (or alginic acid). Sketch the chemical structure of the monomeric unit of the alginate polymer.

2. **SEP Evaluate and Communicate** Examine the chemical structure of sodium alginate. What chemical change took place when sodium alginate solution was mixed into beaker A, which contained calcium ions, $Ca^{2+}$? What chemical change took place when sodium alginate solution was mixed into beaker B, which contained copper(II) ions, $Cu^{2+}$?

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3. **SEP Evaluate and Communicate** How and why does the appearance of calcium alginate change when it is placed in saturated sodium chloride solution?

4. **SEP Evaluate and Communicate** Calcium alginate is spun into fibers that are used to make gauze-type dressings for burns and other wounds. Suggest some possible advantages of calcium alginate wound dressings compared to other types of materials.

5. **SEP Analyze Data** Describe the appearance, form, and texture of the calcium alginate formed using the sodium alginate + congo red solution.

6. **SEP Evaluate and Communicate** Explain the results of the experiment conducted in Part II. Specifically, explain whether it is possible to dye calcium alginate, and why this could be useful in practical applications.

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ENGINEERING PERFORMANCE-BASED ASSESSMENT

# Structure-Property Relationships

**How can you alter the properties of a material to fit a specific need or application?**

**Phenomenon** The structure-property relationship is foundational to the pharmaceutical, automotive, and electronic device industries. For example, chemical engineers make small changes to the spatial orientations of atoms in molecules that render them useless or effective disease treatments. Similarly, changes to the compositions and structures of the materials that compose a smartphone battery can mean extra hours of battery life and happy customers. In this lab, you will apply the structure-property relationship to rationalize how changes to a polymer's structure cause changes to the polymer's physical properties.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations
**SEP 8** Obtain, Evaluate and Communicate Technical Information

## Materials Per Group

- Polyvinyl alcohol, 4% solution, $[-CH_2CH(OH)-]_n$, 50 mL
- Sodium borate, 4% solution, $Na_2B_4O_7$, 20 mL
- Graduated cylinder, 50-mL
- Wood stick, for stirring
- Paper clips
- Graduated cylinder, 10-mL
- Plastic cup

## Safety

*Use the polymer only for the purposes intended. Do not allow the polymer to remain on clothing, upholstery, carpet, or wood surfaces. The polymer, if colored with food coloring, will stain many surfaces. Clean up any polymer as soon as possible. There are no known toxic effects produced by sodium borate, PVA, or the polymer; however, wash hands thoroughly with soap and water before leaving the laboratory.*

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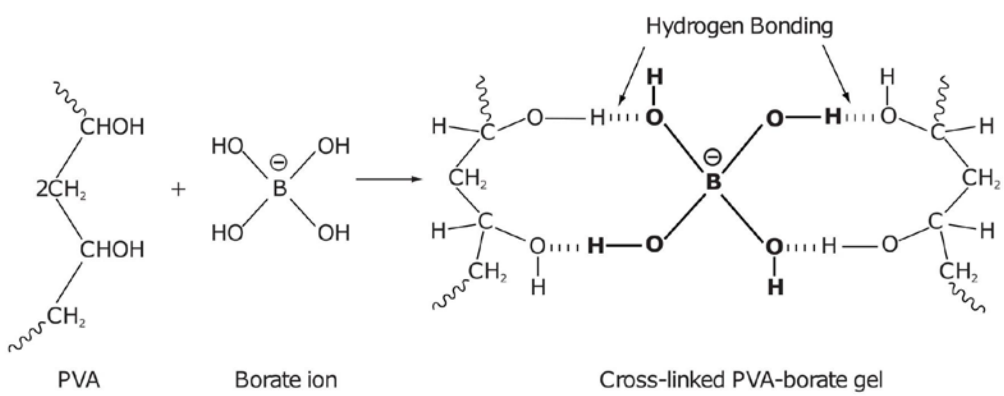
## Procedure

### Part I: Model the Cross-Linking Between Polyvinyl Alcohol (PVA) Chains in a PVA/Borate Polymer

*How do alterations to a polymer's microscopic structure affect its macroscopic properties?*

1. **SEP Develop a Model** PVA is composed of linear chains of repeating vinyl alcohol monomers. The borate ions are tetrafunctional, which means that they are capable of forming four contacts. They connect adjacent chains to each other in a process called cross-linking, shown in **Figure 1**.

   **Figure 1**




   You can model this process by linking adjacent paper-clip chains to each other. Consider two parallel chains of ten paper clips that are held together by another three paper clips oriented perpendicular to the parallel chains. What do the paper clips in the parallel chains represent and what do the paper clips that connect the chains represent? Explain how you could make the polymer model more rigid.

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## Part II: Model Chemical Syntheses that Target Specific Macroscopic, Polymeric Properties.

*How do chemical engineers vary a material's structure to target a specific application?*

2. **SEP Use a Model** Synthesize a small sample of PVA/borate polymer. Use a wood stick to mix 20 mL of 4% aqueous PVA with 5 mL of 4% aqueous $Na_2B_4O_7$ in a plastic cup. Observe the polymer's flexibility and stiffness.

3. **SEP Test Your Solution** Plan and justify a modification to the reaction mixture to increase the stiffness of the polymer. Show your plan to your teacher for approval and then test the modified chemical reaction in a new plastic cup. Observe and explain differences between the two polymers.

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## Analyze and Interpret Data

1. **SEP Use Computational Thinking** The reaction mixture you used to make the polymer is a two-component system. The advantage to a two-component system is its simplicity, i.e. the quantities of just two reactants must be varied. As the number of components in a reaction mixture increases it becomes more difficult to attribute macroscopic property differences in synthesized materials to a single component. Describe a kind of diagram that might be used to systematically vary the reactants in a three-component system so that specific reaction compositions can be linked to specific material properties in the products.

2. **SEP Engage in Argument** If, unlike borate ions, the linker in the polymer were bifunctional, or capable of forming two contacts, do you think more or fewer of the bifunctional linkers would be required to achieve the same amount of stiffness? Explain.

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3. **SEP Identify Limitations of a Model** Describe 2 or 3 limitations of the paper-clip model of the PVA/borate polymer.

4. **SEP Plan an Investigation** What variables that you did not explore might affect the macroscopic properties of the polymer? Explain.

5. **SEP Use Scientific Reasoning** Two polymers commonly used in commercial goods such as plastic bottles and plastic films are high density polyethylene (HDPE) and low density polyethylene (LDPE), respectively. HDPE is composed of long linear chains, whereas LDPE is highly branched, with a lot of smaller chains growing out of longer chains. Explain why this structural difference leads to LDPE having a lower density than HDPE.

6. **SEP Obtain, Evaluate and Communicate Technical Information** One very interesting application of the structure-property relationship is in pharmaceutical development, where enantiomers are often made. Enantiomers are non-superimposable mirror images of each other. For example, consider your hands. You can place your palms against each other to observe that they are mirror images of each other. However, you cannot place the palm of one hand over the top of your other hand such that your thumbs overlap. Your hands are the same except for the fact that they have different spatial orientations. Conduct online research to describe the effects in humans of the two enantiomers of the drug thalidomide. Also, describe how the two molecules are different with respect to their spatial orientations.

# Investigation 7

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INQUIRY LAB – OPEN

# Gas Particles and Work

**How can a chemical reaction do work on a system?**

Work is a form of energy that moves all or part of a system. If a force applied on an object does not make the object move, for example pushing on a brick wall, then no work is performed. Kinetic energy is the energy of motion. Classic examples of energy involve rolling a ball down an incline plane. In this lab, you will look at the kinetic energy of gas particles and their ability to perform work. The number of gas particles will determine how much work can be done to expand the plunger of a syringe. This is a similar process to how a combustion reaction in an engine can power a car.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Calcium carbonate (marble chips), $CaCO_3$, 0.9 g
- Hydrochloric acid solution, 2 *M*, 5 mL
- Hydrochloric acid solution, 4 *M*, 5 mL
- Hydrochloric acid solution, 6 *M*, 5 mL
- Petroleum jelly, foilpac, 1
- Balance, 0.001 g precision
- Clamp, single, buret
- Erlenmeyer flasks, 125 mL, 3
- Gas collection apparatus
    - Syringe, 60 mL
    - Syringe adapter
    - Stopper, one-hole (to fit flask)
- Support stand
- Timer or stopwatch
- Wash bottle

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## Safety 

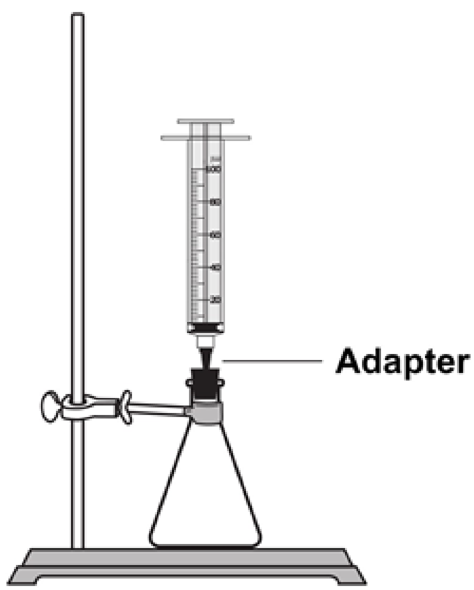
*Hydrochloric acid is corrosive to skin and eyes and toxic by inhalation or skin absorption. Avoid contact with eyes and skin. Clean up all spills immediately. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Do not exceed 0.3 g of calcium carbonate per flask. The concentration of hydrochloric acid must not exceed 6 M in any experiment. Wash your hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.*

## Procedure

*What is the relationship between work and energy of gas particles?*

1. Set up the gas-collection apparatus as shown in **Figure 1**. Make sure the rubber stopper fits securely in the flask. Lubricate the plunger of the syringe with petroleum jelly to reduce friction. Apply a small dab of petroleum jelly to the black rubber gasket only.

**Figure 1**



2. **SEP Develop Models** Using the materials provided, develop a method to show the kinetic energy of gas particles can be used to perform the work of expanding a syringe. Record your detailed procedure and have your teacher check it before proceeding.

NAME ______________________________ DATE ____________ CLASS ____________

**Table 1**

| Gas Collection | | | | | | |
|---|---|---|---|---|---|---|
| Time | Concentration of HCl | | | | | |
| | | | | | | |
| | | | | | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |

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## Analyze and Interpret Data

1. **SEP Use Mathematics** Assuming the gas particles push with a consistent force of 4 N, calculate the work done on the syringe plunger for each concentration.

2. **SEP Analyze and Interpret Data** How does an increase in concentration of acid change the kinetic energy of the gas particles in the syringe?

3. **SEP Identify Limitations of a Model** How can using the work equation to calculate the work done on the syringe plunger lead to discrepancies between the calculated work and the actual work on the syringe plunger?

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INQUIRY LAB – OPEN

# The Impact of Position on Energy

**How can you examine the relationship between position and energy?**

Potential energy is internal energy stored in a system that has the potential to do work. A stretched spring also has potential energy. Kinetic energy is energy in motion. Kinetic energy is proportional to the system mass. Kinetic energy increases with velocity as the square of the velocity. In this lab, a ball bearing will be dropped into floral foam to demonstrate that the potential energy of an object is proportional to its starting height.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Ball bearing, ¾ in. diameter
- Floral foam, 4 in. x 3 in. x 2 in.
- Knife
- Meterstick
- Photogates and timer
- Ruler, metric

## Safety

*Use caution and aim carefully when dropping the ball from great heights. Follow all laboratory safety guidelines. Wash hands thoroughly with soap and water after the lab.*

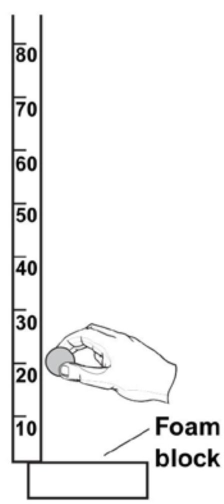
NAME ________________________________________ DATE ____________ CLASS ____________

## Procedure

*What is the relationship between height and energy?*

1. Place the floral foam on the lab bench and make sure the surface of the foam is level.
2. Have your lab partner hold a meterstick vertically with the zero-mark on the edge of the foam. To prevent unwanted indents in the foam, be careful not to push on the meterstick.
3. Attach the first photogate to the meterstick on the zero-mark. It should be sitting on top of the foam.
4. Attach the second photogate to the meterstick at 20 cm. Make sure the photogates are aligned.
5. Connect the photogate timer and set it to two-gate mode.
6. Hold the ball bearing at 20 cm above the left-hand side of the foam block (see Figure 1). Make sure the ball will fall between the two photogate sensors. You may want to do a few practice drops.

**Figure 1**




7. Release the ball into the foam. Record the time of the fall in Table 1.
8. Carefully twist and remove the ball from the foam without significantly changing the indentation size or shape.

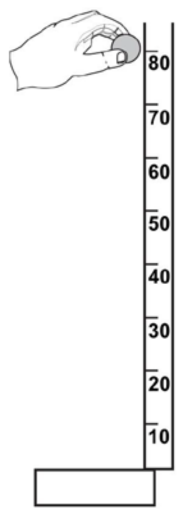
9. Repeat steps 6–8 two more times.

10. Now have your lab partner hold the meterstick vertically with the zero-mark on the opposite edge of the block. Do not move the first photogate.

11. Move the second photogate to 80 cm on the meterstick. Make sure the photogates are aligned.

12. Hold the ball bearing at 80 cm above the right-hand side of the foam block (see Figure 2). Make sure the ball will not land in the same indentation as the first drop and that it will fall between the photogate sensors.

**Figure 2**




13. Release the ball. Record the time of the fall in the Table 1.

14. Carefully twist and remove the ball from the foam without significantly changing the indentation size or shape.

15. Repeat steps 12–14 two more times.

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**16. SEP Use a Model** Using the floral foam and ball bearing, develop a method to quantitatively verify that the kinetic energy of an object is proportional to the square of its speed. Record your detailed procedure and have your instructor check it before proceeding.

**Table 1**

<table>
<tr><th colspan="7">Ball Drop Data</th></tr>
<tr><td>Mass of Ball</td><td colspan="6"></td></tr>
<tr><td rowspan="2"></td><td colspan="4">Time of Drop (s)</td><td rowspan="3">Observations</td><td rowspan="3"></td></tr>
<tr><td colspan="3">Trial</td><td></td></tr>
<tr><td>Height</td><td>1</td><td>2</td><td>3</td><td>Average</td></tr>
<tr><td>20 cm</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>80 cm</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

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## Analyze and Interpret Data

1. **SEP Use Mathematics** Use the equation for work and the work-energy theorem to calculate the kinetic energy of the ball just before it hits the foam after it was dropped from both heights.

2. **SEP Analyze Data** How did the final kinetic energy of the ball change when the height was doubled?

3. **SEP Identify Limitations of a Model** How does the foam block complicate the quantitative measurements?

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INQUIRY LAB – OPEN

# Pendulums and the Conservation of Energy

**How can you examine the relationship between potential and kinetic energy?**

A simple pendulum is composed of a string tied to a rigid object at one end (the anchoring point) with a freely hanging mass, also known as a plumb bob, tied to the other end. When the pendulum is at rest, the plumb bob will hang directly below the anchoring point, and the string will be vertical. When the pendulum is displaced away from the equilibrium (at rest) position and released, the force of gravity will cause the pendulum to swing back and forth along a swing arc. In this lab, you will use the conservation of energy to calculate the velocity of a pendulum that is released from different heights.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Balance, 0.01 g precision
- Calculator
- Clamp holder
- Meterstick
- Plumb bob
- Protractor
- String, 75 cm
- Scissors
- Support rod
- Support stand

## Safety

*Use caution and aim carefully when dropping the ball from great heights. Follow all laboratory safety guidelines. Wash hands thoroughly with soap and water after the lab.*

NAME ______________________________ DATE ____________ CLASS ____________

## Procedure

*What is the relationship between height and velocity?*

1. **SEP Use a Model** Using the materials provided, construct a pendulum and develop a procedure to evaluate different release angles and pendulum velocity. Record your detailed procedure and have your instructor check it before proceeding.

**Table 1**

| Pendulum Measurements | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

NAME ________________________________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Use Mathematics** Use the potential energy equation and the law of conservation of energy to derive an equation for calculating the velocity of the plumb bob.

2. **SEP Use Mathematics** Using your equation from question 1, calculate the velocity of the plumb bob for each angle.

3. **SEP Analyze Data** Describe what happened during the pendulum's swing. Did the plumb bob return to the original height? Did it rise higher or lower than its original height?

4. **SEP Interpret Data** At what location(s) along the pendulum's arc does the plumb have the most potential energy? At what location(s) does it have the most kinetic energy?

5. **SEP Identify Limitations of a Model** What aspects of motion does the mathematical model derived in question 1 not take into account? How will these assumptions affect the accuracy of the calculation for velocity?

NAME ________________________________________ DATE ____________ CLASS____________

ENGINEERING PERFORMANCE-BASED ASSESSMENT

# Energy Conversion

**How do you convert mechanical energy into electrical energy?**

**Phenomenon** Electromagnetic induction refers to the ability of a magnetic field to generate a current in a conducting wire. Generators operate based on this principle when they convert mechanical energy into electrical energy by rapidly changing the position and/or orientation of a magnetic field relative to a conductive material.

In this lab, you will design a device that converts mechanical energy into electrical energy by electromagnetic induction. You will use your device to light an LED and derive an empirical model that relates the amounts of mechanical and electrical energies.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Cardboard tube
- Neodymium magnets, 2
- Iron nail
- Sandpaper sheet
- LED, red
- Scissors
- Magnet wire, 4 m
- Transparent tape

## Safety

*The materials in this lab are considered non hazardous. Care should be taken when wrapping and unwrapping the wire. The pointed ends of the wire are dangerous to eyes. Neodymium magnets are very strong and will accelerate towards each other and other metal objects very quickly. Care should be taken to avoid unexpected and significant pinches of skin. Wear safety glasses. Please follow all normal laboratory safety guidelines.*

NAME ________________________________________ DATE ____________ CLASS____________

## Procedure

### Part I: Converting Energy

*How can you convert mechanical energy into electrical energy?*

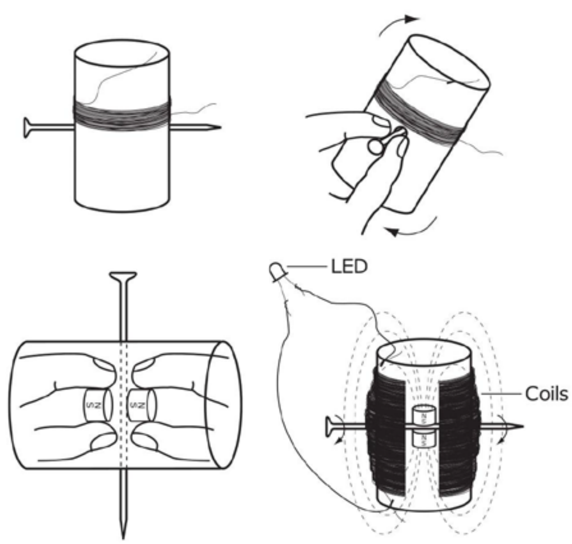
1. Measure the length of the cardboard tube and mark the center.
2. Carefully push the tip of the nail through the cardboard tube at the center mark and drop the nail straight down. Poke a hole through the other side as well. See **Figure 1**.
3. Make a 0.5 cm diagonal cut at the top of the tube to hold the wire.
4. Unwind 10 cm of magnet wire from the coil, and hook it into the cut.
5. Wrap the wire around the cardboard tube at least 300 times. See **Figure 1**.
6. Once you have wrapped the wire the desired number of times, pull an additional 10 cm wire and cut it.
7. Make another diagonal cut on the opposite end of the cardboard tube generator. Secure the wire end in it.
8. Use the sandpaper to remove the coating on the two ends of the wire coiled around the generator.
9. Widen each hole by inserting the nail through one hole at a time and then wiggle the nail using circular motions until the nail can spin easily.
10. Test the nail's ability to spin by holding the nail steady and then rotate the cardboard tube. The tube should spin easily, without much friction to slow it down. If the tube does not rotate easily, repeat step 9 to increase the size of the hole. Leave the nail in its slots. See **Figure 1**.
11. Carefully detach the magnets from each other. Slowly bring one inside the generator, holding it loosely so it will attach to the nail on its own. The magnet should attach by on a flat circular side. See **Figure 1**.

**12.** Reach in and hold the magnet attached to the nail in place. Grasp the other magnet firmly, and slowly and carefully insert it into the other end of the tube. If a force of repulsion is felt, flip the magnet around. Holding both magnets firmly, bring the second magnet as close as possible before releasing it, allowing it to attach to the other side of the nail.

**13.** Wind each shaved end of the wire around the LED's leads, ensuring the leads do not touch each other.

**14.** Turn off or dim the lights in the room and spin the nail with both hands.

**Figure 1**



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## Part II: Describing Energy Conservation

*How can you use equations to explain the flow of energy from one form to another?*

1. **SEP Use Mathematics and Computational Thinking** Reflect on the system you built in Part I. Represent the flow of energy into the system and within the system with a mathematical equation.

2. **SEP Use Mathematics and Computational Thinking** Consider a situation in which the change in rotational kinetic energy attributable to the system is 5.39 J and the change in electrostatic potential energy is 4.12 J. When the work done on the system to spin the cardboard tube about the nail stops, how much energy will have been lost as heat?

NAME ______________________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Use Mathematics and Computational Thinking** Use graphing software or hand draw an x-y graph that illustrates the relationship between mechanical energy and electrical energy as it applies to the device you built. Once you have done that, create another x-y graph with two distinct curves or lines, one that shows the device operating at high power and one that depicts the device at low power. Explain your graphs based on your observations.

2. **SEP Engage in Argument** Is all of the mechanical energy you impart to the spinning generator converted to electrical energy? If not, what do you think the main sources of energy loss are?

3. **SEP Use Scientific Reasoning** Does your device produce an alternating current or a direct current? Explain.

4. **SEP Plan an Investigation** What variables, that you did not explore, do you think might affect the magnitude of a current induced by a magnetic field? How could you observe the relationship between one of the untested variables and the magnitude of the induced current?

5. **SEP Use Scientific Reasoning** Hospitals in areas that are prone to severe weather typically have generators on hand to enable the operation of electrical equipment during power outages. These generators cannot run on the mechanical energy supplied by humans; that would not be practical. Describe the energy conversions that must occur in order for a generator to power a hospital.

# Investigation 8

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Momentum and Impulse During Collisions

**How can you design cars to make collisions safer?**

All objects in motion have momentum. When a force is applied to an object, it causes a change in momentum. Impulse is the term used to describe the application of force over a period of time. A large force quickly applied or a weak force applied for a long time can result in the same impulse, and the same change in momentum. In this lab, you will determine the impulse of a collision by calculating the momentum of a ball immediately before and after it collides with the floor or another surface.

## Focus on Science Practices

**SEP 3** Plan and Carry Out Investigations
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Cloth or foam pad
- Meterstick
- Rubber ball
- Textbook

## Safety

*Make sure to check the area around where you intend to drop the ball to ensure that it won't accidentally collide with any fragile objects. Remember to wear safety glasses throughout the lab. Be sure to follow all laboratory safety guidelines and all safety procedures provided by your teacher.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

### Part I: Calculating the Impulse Associated with a Bounce

*How does the height from which a ball is dropped affect the impulse of the collision?*

1. **SEP Make Measurements** What is the mass of your ball?

2. Determine which surface you are going to drop the ball onto.
3. Measure a height 1.0 m above the surface to drop the ball from.
4. Have one person drop the ball while the other watches to observe how high it bounces after the collision. Record the result inTable 1.
5. Repeat step 4 before conducting two trials at a height of 1.5 meters and two trials at 2.0 meters.
6. **SEP Use Mathematics** Calculate the momentum of the ball just before it collides with the surface and just after it collides with the surface and record the magnitude and direction of each in Table 1.
7. **SEP Use Mathematics** Calculate the impulse (change in momentum) for each trial and record the magnitude and direction of each in Table 1.

**Table 1**

| Height and the Impulse of a Collision | | | | |
|---|---|---|---|---|
| **Initial height (m)** | **Bounce height (m)** | **Momentum before (kg·m/s)** | **Momentum after (kg·m/s)** | **Impulse (N·s)** |
| **1.0** | | | | |
| **1.0** | | | | |
| **1.5** | | | | |
| **1.5** | | | | |
| **2.0** | | | | |
| **2.0** | | | | |

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## Part II: Modifying the impact surface

*What effect does the type of surface have on the impulse?*

8. **SEP Plan and Carry Out Your Investigation** Plan an investigation to explore what effect changing the surface type will have on the impulse of the collision from a height of 2.0 meters.

   Record your detailed procedure and any materials to be used. Show your plan to your teacher for approval before you begin. Record your data in Table 2.

NAME ______________________ DATE __________ CLASS __________

**Table 2**

| Surface Type and the Impulse of a Collision | | | | |
|---|---|---|---|---|
| **Surface Type** | **Bounce height (m)** | **Momentum before (kg·m/s)** | **Momentum after (kg·m/s)** | **Impulse (N·s)** |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

## Analyze and Interpret Data

1. **SEP Use Mathematics** Use SI base units to show that momentum and impulse have the same units.

2. **SEP Construct an Explanation** Based on the data you collected, how did the height of the drop affect the impulse associated with the collision? Explain.

3. **SEP Use Mathematics** If the ball dropped from 2.0 m had come to an immediate stop upon striking the surface, what would the impulse of the collision have been?

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4. **SEP Construct an Explanation** Based on the data you collected, how did the surface type affect the impulse associated with the collision? Explain.

5. **SEP Construct an Explanation** Impulse can be approximated as the average force during a collision multiplied by the period of time for the collision. With this in mind, explain why cars have crumple zones.

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INQUIRY LAB – OPEN

# Elastic and Inelastic Collisions

**Which collision will impart more momentum—an object that hits a door and sticks to it, or an object that bounces straight back from the door?**

When an object is set in motion, the object has a property known as momentum. When objects collide momentum is transferred between them. In all collisions momentum is conserved, however, the same is not true of energy. In this lab, you will be exploring the difference between elastic and inelastic collisions and the amount of energy that is transferred in each.

It is important to keep in mind that momentum is a vector quantity, meaning that it has directionality. For example, in a linear system we might decide that anything traveling to the left has positive momentum, which means that anything that travels to the right will have negative momentum.

## Focus on Science Practices

**SEP 3** Plan and Carry out Investigations
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Balance, 0.1 g precision
- Protractor
- Rubber balls, with hook screws, 2
- Ruler
- String, 2 m
- Support stand with crossbar
- Wooden blocks, 2

## Safety

*Make sure to check the area around where you intend to drop the ball to ensure that it won't accidentally collide with any fragile objects. Remember to wear safety glasses throughout the lab. Be sure to follow all laboratory safety guidelines and all safety procedures provided by your teacher.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

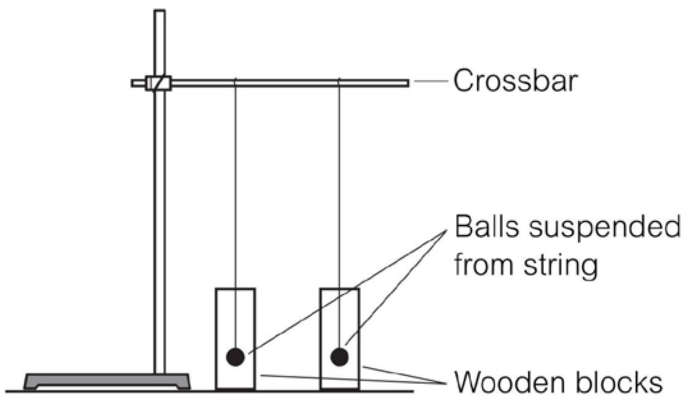
*How does the bounciness of a ball affect its collisions?*

1. **SEP Make Measurements** What is the mass of each ball with a hook?

2. **SEP Make Observations** Drop each ball in turn, making sure that they don't land on their hooks. What happened when each ball collided with the table?

3. Set up the ring stand and crossbar as shown in Figure 1.

**Figure 1**




4. Cut two 1-meter lengths of string.

5. Tie a loop knot on one end of each string as shown in Figure 2.

**Figure 2**

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6. Using the hook, suspend the balls from a loop knot in the string. Attach the strings to the crossbar by wrapping them several times around the crossbar so the balls are at equal heights approximately 8 cm from the ground.

7. Set up the two wooden blocks right in front of both the balls, so that the balls are suspended approximately in the center of each block, and just touching each block as they hang as shown in Figure 1..

8. **SEP Make a Prediction** What do you think will happen when each ball collides with a block?

9. Draw back each ball about 25 cm from the wooden blocks. Then release the balls.

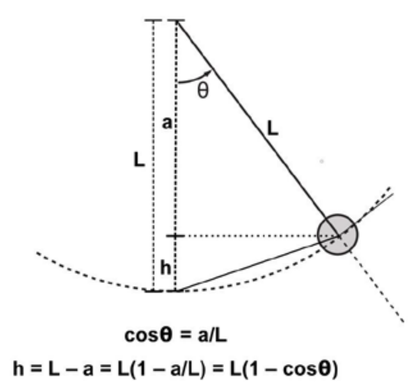
10. **SEP Make Observations** What happened when the balls collided with the wooden blocks? How did this compare to your prediction?

**Part II: Calculating the Momentum Needed to Knock over the Block**

*How can we use release angle to determine momentum?*

11. For a ball that is dropped vertically its velocity is equal to $v = \sqrt{(2gh)}$. However, for a pendulum, the height changes with release angle, as shown in Figure 3, so the formula for maximum velocity becomes $v = \sqrt{(2gL(1 - \cos\theta)}$.

**Figure 3**



NAME ______________________ DATE ____________ CLASS ____________

**12. SEP Plan and Carry Out Your Investigation** Plan an investigation to explore how much momentum the bouncy ball has to transfer into the wooden block in order to knock it over.

Record your detailed procedure and any materials to be used. Show your plan to your teacher for approval before you begin. Record your data in Table 1.

**Table 1**

| Bouncy Ball Collision with Block | | | | | |
|---|---|---|---|---|---|
| **Release Angle** | **Maximum velocity** | **Bounce Angle** | **Return velocity** | **Momentum before (kg·m/s)** | **Momentum after (kg·m/s)** |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

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**13. SEP Use Mathematics** If you assume that the non-bouncy ball has totally inelastic collisions, then the momentum it has at the time of collision is equal to the amount of momentum that will be transferred to the block. Based on this assumption, calculate the release angle needed for the non-bouncy ball to knock over the block.

**14. SEP Test You Solution** Release the non-bouncy ball from your calculated angle. Does the block fall over? Does the result change if the release angle is increased or decreased by 5 to 10 degrees?

NAME ______________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Construct an Explanation** How does the bounciness of the ball affect the collision? Explain.

2. **SEP Use Mathematics** If one of the balls had a mass twice that of the other, would the difference in their momentum values be when they collide with the wooden block? What would be the difference in their kinetic energies?

3. **SEP Use Mathematics** If one of the balls had a velocity twice that of the other, what would the difference in their momentum values be when they collide with the wooden block? What would be the difference in their kinetic energies?

4. **SEP Construct an Explanation** Is total momentum conserved in each type of collision? Is kinetic energy conserved? Is total energy conserved? Explain.

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INQUIRY LAB – OPEN

# Collisions at a Fault Line

**What happens when tectonic plates collide?**

Over time the motion of magma causes pressure to build. The pressure builds up in the rocks until the rocks reach a breaking point and can no longer bend or stretch. The areas where these breaks occur are called faults, and what happens to the surrounding area depends on how the two different sections of crust are moving relative to each other. In this lab, you will model some of the interactions that can occur in Earth's crust using clay.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 3** Plan and Carry out Investigations
**SEP 6** Construct Explanations
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Clay, three different colors
- Knife

## Safety

*Be careful when using the knife to cut pieces of clay. Remember to wear safety glasses throughout the lab. Be sure to follow all laboratory safety guidelines and all safety procedures provided by your teacher.*

## Procedure

### Part I: Earth's Crust Under Stress

*How does Earth's crust respond to pressure?*

1. Work each color of clay in your hands for about 2–3 minutes until it becomes easy to shape.
2. For each color of clay, make a rectangular block, 5 cm wide, 2 cm deep, and 0.5 cm thick.
3. Lay the layers on top of each other and press lightly so that they become fused.
4. Keeping the clay on the table, gently press the two short ends of the clay towards each other. You only need to bring them about 1 cm closer together.
5. **SEP Make Observations** Describe what happened to the clay strips as you pushed them together.
6. **SEP Identify Limitations of a Model** The base of your clay stack was against a rigid table. How might the result have changed if it was instead on top of a material that you also bend and deform?
7. **SEP Make Observations** Pick up the clay, and while firmly holding onto each end, quickly move your hands apart. Describe what happened and what this action models with respect to Earth processes.

NAME ______________________ DATE __________ CLASS __________

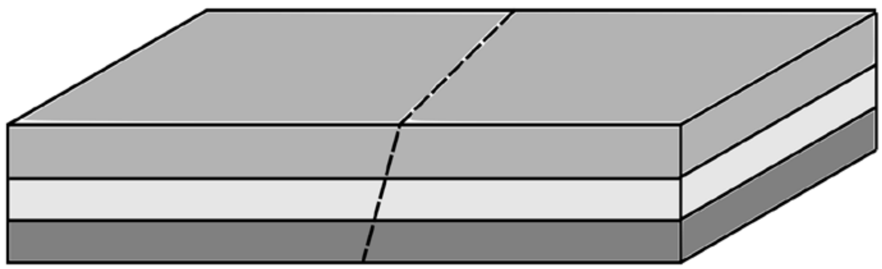
**Part II: Modeling Collisions at a Fault**

*What are the different ways that sections of Earth's crust can collide?*

8. Reform your three layered block of clay into its original shape as best as you can. It's okay if the layers are slightly mixed since the layers of the crust aren't perfectly separated in real life.

9. Cut your block of clay in half at an angle (**Figure 1**).

**Figure 1**



10. With the tip of your knife scratch a pattern into the top of the clay to represent a road, river, forest, or similar feature.

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**11. SEP Plan and Carry Out Your Investigation** Plan an investigation to explore what types of collisions can occur at a fault.

Record your detailed procedure and any materials to be used. Show your plan to your teacher for approval before you begin.

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Make Observations** Describe what happened to the clay strips during your collision at a fault.

2. **SEP Obtain Information** Go online or read in your text about faults around the world. Use the information you find to identify and define the types of faults you modeled. Give a real life example of each type of fault you modeled.

3. **SEP Communicate Scientific Information** What event may occur when a fault forms? Describe this process.

4. **SEP Construct an Explanation** Why is it easier to predict where an earthquake will occur rather than when it will occur?

5. **SEP Apply Scientific Reasoning** Based on your observations, what are some geological clues that a scientist might use to identify that a fault is present in an area? Be as specific as possible.

NAME ______________________ DATE __________ CLASS __________

ENGINEERING PERFORMANCE-BASED ASSESSMENT

# Build Your Own Egg-Transport Vehicle

**Why do cars contain seatbelts and airbags?**

**Phenomenon** During a significant traffic collision, airbags are deployed inside a car. The automobile airbag was developed in the 1970s, and all cars sold in the United States of America are required to have dual front airbags. It is estimated that the use of airbags in conjunction with a seatbelt reduces the number of road fatalities each year by around 15,000. In this activity, you will explore the concepts of force, momentum, and Newton's laws of motion by designing and building a vehicle that will carry and protect a raw egg during a head-on collision with another egg-carrying vehicle.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations and Design Solutions

## Materials Per Group

- Large egg, 1
- Spring scale
- String
- Vehicle materials

## Safety

*Use caution when cutting with scissors or a craft knife. Always cut away from yourself and others. Wear goggles during the entire activity and remain in your assigned seat during each collision. Please follow all laboratory safety guidelines.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

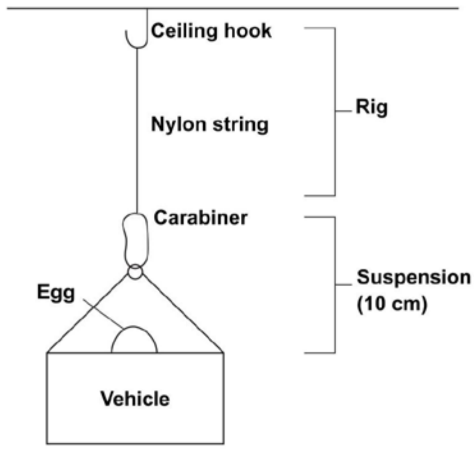
### Part I: Design An Egg Transport Vehicle

*How can you design a vehicle to be safer during a collision?*

1. **SEP Identify Criteria and Constraints** Design a vehicle, using materials of your choice, that will carry and protect a raw egg during a head-on collision with another egg-carrying vehicle. Be sure to follow all listed design criteria and constraints. Otherwise you will be disqualified and unable to compete. As a class you may add to the list.

    - No materials may be used that break and produce harmful fragments (e.g., glass, ceramic, etc.).
    - The total mass of the vehicle cannot exceed 10 N or 1 kg.
    - The dimensions of the vehicle cannot exceed 30 cm × 30 cm × 30 cm.
    - One half of the egg must be visible and left unprotected from all sides.
    - The egg must be the highest point on the vehicle, except for the suspension system.
    - The egg cannot be held in place by any adhesive (e.g., glue, sticky tack, etc.).
    - The vehicle must have a suspension system with loops that will hook to the rig. The suspension system must measure 10 cm from the top of the vehicle (Figure 1).
    - Your vehicle can include offensive weapons, however, they cannot be sharper than an unsharpened pencil (i.e., each must have a blunt end).

**Figure 1**




2. **SEP Design Your Device** Write a short paragraph describing your egg-transport vehicle.

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**3. SEP Design Your Device** Make a scale drawing of your vehicle.

**Part II: Single-elimination challenge**

*How will your vehicle design perform?*

**4.** Your vehicle will be tested in a single-elimination challenge. The challenge will follow these rules:

- Single-elimination pairing will be selected randomly.
- Vehicles will be crashed together until one egg cracks, breaks, or falls out of the vehicle, or until one vehicle falls off its suspension. If both teams meet any of these fates, they will both be eliminated.
- No repairs or adjustments can be made during a battle.
- Adjustments can only be made after a winning battle and before a new battle.

**5.** Help clean up and dispose of your vehicle as directed by your teacher.

NAME ____________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Evaluate and Communicate** Based on your performance in the competition, do you consider the design of your egg-transport vehicle to be successful? Explain.

2. **SEP Refine Your Device** Go online or read in your text about impulse. Use this information to explain how you might improve your design in a future challenge.

3. **SEP Use Mathematics** An egg transport vehicle with mass of 0.95 kg traveling at 1.8 m/s has a head on collision with another egg transport vehicle with mass 0.74 kg traveling at 2.2 m/s. Which vehicle has the greater momentum?

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4. **SEP Construct an Explanation** Why does it not matter if one of the egg-transport vehicles is released from a larger angle than the other?

5. **SEP Identify Limitations of a Model** How might the forces involved with these collisions change if the eggs were accelerated towards each other on a cart rather than suspended from a ceiling?

6. **SEP Analyze Data** Table 1 contains historical data relating to the number of people who have died in motor vehicle crashes in the United States of America in specific years. Use the data provided to determine if the rate of road fatalities has increased, decreased, or remained between 1975-2015?

**Table 1**

| Motor Vehicle Fatalities | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 |
| **Deaths** | 44525 | 51091 | 43825 | 44599 | 41817 | 41945 | 43510 | 32999 | 35485 |

Data Source: U.S. Department of Transportation's Fatality Analysis Reporting System (FARS).

# Investigation 9

NAME ________________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

# Kinetic Energy

**What is going on at the molecular level when something is “hot” or “cold”?**

When you heat an object, where does the energy go? In this activity, you will investigate how temperature, molecule or particle motion, and kinetic energy are related. You will study the energy involved in this lab by using the specific heat of water. The specific heat of a substance lets you know a material’s resistance to changes in temperature. Different materials have their own unique specific heat.

The following terms and equations will help you complete the investigation:

$q = mC\Delta T$

$q$ = heat = change in thermal energy

$m$ = mass of the water

$C$ = specific heat of the water, 4.184 J/g°C

$\Delta T$ = change in water temperature, $T_{final} - T_{initial}$

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Borosilicate beakers, 2, 250 mL
- Food dye
- Graduated cylinder, 100 mL
- Hot plate (optional)
- Marker
- Polystyrene cups, 16 oz., 4
- Stirring rod
- Thermometer
- Water
- Wax pencil

## Safety

*Wear safety goggles when performing this or any lab that uses chemicals, heat or glassware. Use a stirring rod to stir the liquid; never stir with a thermometer. Use caution with hot water. Use heat resistant gloves. Wash hands thoroughly with soap and water before leaving the laboratory.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

### Part I: Observing the Kinetic Energy of a Substance

*What is the relationship between temperature and kinetic energy?*

1. Use the wax pencil to label one of the 250 mL beakers "warm" and the second beaker "cool".
2. Measure 200 mL of room temperature or cold tap water and pour it into the "cool" beaker.
3. From your instructor, measure 200 mL of warm water and pour it into the "warm" beaker.
4. Record the temperature of the water in each beaker in Table 1. *Note:* When recording the temperature of the water, have the thermometer in the middle of the water. Do not let the thermometer touch the glass of the beaker when recording the temperature.
5. Add 1–2 drops of food dye to each beaker and record your observations in Table 1.

**Table 1**

| Part I | | |
|---|---|---|
| **Sample** | **"Cool" Beaker** | **"Warm" Beaker** |
| **Temperature (°C)** | | |
| **Observations** | | |

### Part II: Studying the Transfer of Heat in Water

*How does the temperature change when substances of different temperatures are mixed?*

6. Obtain a target temperature from your instructor. Record it in the space provided.

NAME ________________ DATE ________ CLASS ________

7. **SEP Plan Your Investigation** You must mix two containers of water at different temperatures to obtain 300 mL of your target temperature water. Design your experiment in the space provided and draw any data tables necessary. Get your procedure approved by your instructor before proceeding.

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## Analyze and Interpret Data

1. **SEP Analyze Data** Look at your observations from Part I. Describe what you observed in the "cool" vs. "warm" beaker. What was happening at the molecular level?

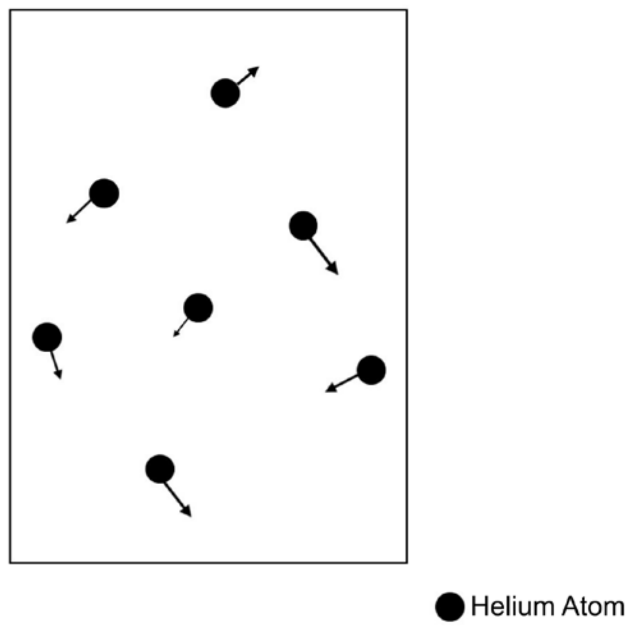
2. **SEP Use Mathematics** In Part II, pick one of the water samples before mixing. How much energy was gained or lost by that sample when it was mixed?

   $q = mC\Delta T$
   q = heat = change in thermal energy
   m = mass of the water sample
   C = specific heat of the water, 4.184 J/g°C
   $\Delta T$ = change in water temperature, $T_{final} - T_{initial}$

NAME ______________________ DATE ____________ CLASS ____________

3. **SEP Use a Model** A rigid sealed container is at 0°C. See Figure 1. Are all the atoms moving at the same speed? Why or why not?

**Figure 1**




4. **SEP Develop a Model** Draw a sketch of the atoms in the container if the rigid container was heated to 75°C.

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5. **SEP Use Models** Use your drawing in Question 4 to explain how the atoms are moving in the rigid container.

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INQUIRY LAB – OPEN

# Heat Transfer

**How can you monitor heat transfer between two objects?**

Imagine a dinner of grilled chicken, steamed veggies, and an ice-cold drink. The food comes straight out of the oven to the countertop and the ice cubes for the drink are straight from the freezer. If, instead of eating it right away, it sits for hours, eventually, the food and drink will come to room temperature. The ice cold drink will warm up and the hot chicken will cool down.

Heat transfer occurs around us all the time, everyday. The transfer of heat or heat flow always occurs in one direction—from a region of higher temperature to a region of lower temperature—until a final equilibrium temperature is reached. In this lab, calorimetry and temperature measurements will be used to observe the change of energy in various metals. The transfer of energy will be detected by measuring the temperature change, $\Delta T$, of the metal and the water in the calorimeter.

## Focus on Science Practices

**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations and Design Solutions

## Materials Per Group

- Balance (0.01-g precision)
- Boiling water bath
- Graduated cylinder, 100 mL
- Hot plate
- Metal samples
- Metal shot sample
- Polystyrene cups, 2
- Stirring rod
- Test tube
- Thermometer
- Tongs
- Water

NAME ______________________________ DATE __________ CLASS ___________

## Safety

*Wear safety goggles when performing this or any lab that uses chemicals, heat or glassware. Take precautions to avoid burns when heating the metal in the boiling water. Use tongs and allow the boiling water to cool before pouring it down the drain to prevent steam burns. Wash hands thoroughly with soap and water before leaving the laboratory.*

## Procedure

### Part I: Identifying a Metal Using Specific Heat Capacity

*What is the relationship between the energy transferred from the metal to water?*

1. Record the metal sample # in Table 1.
2. Weigh your metal sample(s) to the nearest tenth of a gram. Record your data in Table 1.
3. Place the metal sample in a boiling water bath for approximately 5–10 minutes to be sure the temperature of the sample is the same as the water. While the metal sample is heating, set up the calorimeter (Steps 4–6).
4. Place one polystyrene cup inside the other to make a calorimeter.
5. Measure 100 mL of tap water with the graduated cylinder. Record the volume in Table 1 and pour the water into the calorimeter.
6. Record the temperature of the tap water in Table 1.
7. Record the temperature of the boiling water bath in Table 1. **Caution:** Do not let the thermometer touch the glass of the beaker when recording the temperature.
8. Use tongs to lift the heated metal sample out of the boiling water bath and carefully place it into the water in the calorimeter.
9. Stir the water in the calorimeter with a stirring rod, slowly and constantly. Use a thermometer to measure and record the highest temperature that the water reaches. **Caution:** Do not use the thermometer as a stirring rod. Record the highest temperature of the water in Table 1.

NAME ____________________ DATE __________ CLASS __________

**Table 1**

| Part I | | | | | |
|---|---|---|---|---|---|
| **Metal Sample #** | **Mass of Metal (g)** | **Volume of Water in Calorimeter (mL)** | **Temperature of Boiling Water Bath (°C)** | **Initial Temperature of Water in Calorimeter (°C)** | **Final Temperature of Water in Calorimeter (°C)** |
| | | | | | |

**Table 2**

| Specific Heat Capacities of Metals | | |
|---|---|---|
| **Metals** | **Specific Heat Capacity (J/(g · °C))** | **Specific Heat Capacity (cal/(g · °C))** |
| **Aluminum** | 0.899 | 0.215 |
| **Copper** | 0.385 | 0.092 |
| **Steel** | 0.460 | 0.110 |
| **Tin** | 0.222 | 0.053 |
| **Zinc** | 0.385 | 0.092 |

NAME ______________________ DATE __________ CLASS __________

## Part II: Designing a Procedure to Identify an Unknown Sample

*What is the composition of the metal shot?*

10. **SEP Plan Your Investigation** Design a procedure to identify the composition of a metal shot sample and draw any data tables necessary. Get your procedure approved by your instructor before proceeding.

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Use Mathematics** From the data you collected in Part I, use the given equation to calculate the energy transferred to the water by the metal sample.

$q_{water} = m_{water}C_{water}\Delta T_{water}$
$q_{water}$ = energy
$m_{water}$ = mass of the water
$C_{water}$ = specific heat of the water, 4.184 J/(g · °C)
$\Delta T_{water}$ = change in water temperature, $T_{final} - T_{initial}$

2. **SEP Use Mathematics** Determine the identity of the metal from Part I of the lab by calculating its specific heat capacity comparing it to the specific heats of the metals in Table 2. *Note:* Assume no heat loss to the surroundings.

$$q_{water} = -q_{metal}$$

$q_{metal} = m_{metal}C_{metal}\Delta T_{metal}$
$q_{metal}$ = energy
$m_{metal}$ = mass of the metal
$C_{metal}$ = specific heat of the metal.
$\Delta T_{metal}$ = change in metal temperature, $T_{final} - T_{initial}$

3. **SEP Analyze Data** For Part I, calculate the percent error of the specific heat capacity for the metal sample.

4. **SEP Compare Data** For Part I, what factors might account for any difference in the specific heat capacity?

5. **SEP Analyze Data** For Part II, what was the identity of your metal shot?

6. **SEP Construct an Explanation** Lake Michigan is one of five large great lakes in North America. Lake Michigan also has an impact on weather in the towns and cities surrounding the lake. For example, in Chicago in the summertime, the air temperature near the lake is cooler than the suburbs further away from the lake. In the winter, the air temperature near the lake is warmer than the suburbs. Explain this phenomena with regards to specific heat capacity.

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

# Convection, Conduction, and Radiation

**How do convection, conduction, and radiation work?**

Convection, conduction, and radiation occur all around you. Hot air balloons rise because of convection. You may have noticed conduction when heating a pan to cook food. And, radiation occurs in many forms, such as sunlight. You even give off radiation! In this lab, you will explore convection, conduction, and radiation at various lab stations and see how they apply to various processes on Earth.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data
**SEP 6** Construct Explanations and Design Solutions

## Materials Per Group

- Bunsen burner
- Buret clamp
- Ceramic fiber square, heat-resistant
- Conductometer
- Convection tube
- Erlenmeyer flask, 125-mL
- Food dye
- Gloves, heat-resistant
- Hot plate
- Infrared heat lamp, 125 W
- Plastic tub
- Radiation cans (1 silver, 1 black)
- Stopwatch or timer
- Support stand
- Thermometers, 0–100°C, 2
- Water
- Wax pieces

NAME ______________________________ DATE __________ CLASS ___________

## Safety

*Wear safety goggles when performing this or any lab that uses chemicals, heat or glassware. Use caution with all hot objects. Wear safety glasses and heat-resistant gloves when performing these experiments. Allow objects to completely cool before putting them away. Take extra care when heating with a Bunsen burner flame. Do not touch the hot conductometer, convection tube, or radiation cans. Allow the conductometer to cool on a heat resistant ceramic fiber square for at least 10 minutes after the experiment. Use caution with the infrared lamp. Infrared lamps get very hot and can cause burns. Do not leave lamps unattended. The radiation cans may also become very hot and should be handled carefully. To avoid burns, use extreme caution while using heating equipment in this experiment. Please follow all normal laboratory safety guidelines.*

## Procedure

1. Your instructor will assign which station your group will start at in this lab. There are a total of three stations. You will be rotating with other groups to perform and observe all three stations.

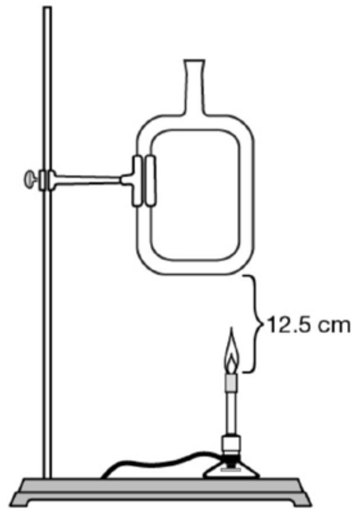
### Part I: Observing Convection Currents

*How do convection currents work?*

2. Review the set up in Figure 1.

NAME ______________________ DATE __________ CLASS __________

**Figure 1**




3. To set up the convection-of-liquids tube, attach a buret clamp to the support stand.
4. Fill the convection-of-liquids with cool tap water.
5. Clamp the convection-of-liquids tube to the support stand.
6. Position the Bunsen burner underneath the lower right-hand corner of the tube. The top of the burner should be about 12.5 cm below the tube (see Figure 1).
7. Light the burner. Then quickly place one drop of food dye in the top of the tube.
8. **SEP Make Observations** Observe the convection of liquid. Write your observations.

9. Allow the water to heat for several minutes.
10. **SEP Make Observations** How did the movement of the water change over time?

**11.** Turn off the Bunsen burner. Allow the convection-of-liquids tube to cool to room temperature.

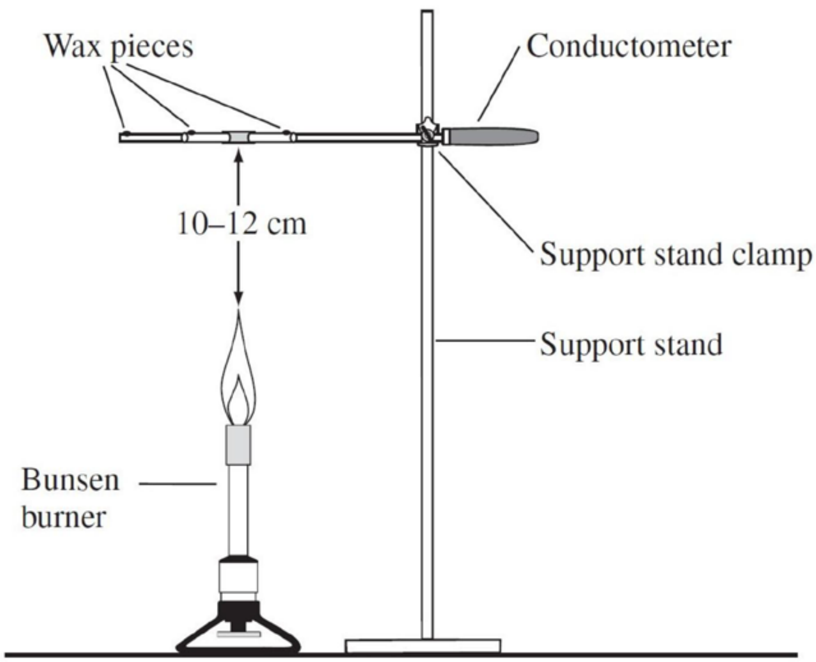
**12.** Empty and rinse out the tube for the next group.

**Part II: Observing Different Metals' Conductive Properties**

*Why do some metals conduct heat better than others?*

**13.** Review the set up in Figure 2.

**Figure 2**




**14.** Secure the conductometer to the support stand with the clamp. Clamp as close to the wood handle as possible. (If a support stand and clamp are not used, carefully hold the conductometer above the Bunsen burner flame positioned as shown in Figure 2.)

**15.** Position the dimples on top and the spokes parallel to the tabletop (see Figure 2).

16. Press one wax piece (clump) in the dimple at the end of each metal spoke. Brush off any excess wax with a paper towel.

17. Place the Bunsen burner below the conductometer and light it. Adjust the flame height to approximately 8–10 cm.

18. Position the center hub of the conductometer approximately 10–12 cm over the Bunsen burner flame, making sure the wax pieces are on top and the spokes are parallel to the tabletop. **Caution***:* Hold the conductometer only by the insulated wood handle.

19. As soon as the conductometer is in position, start the stopwatch to begin timing. Measure the time it takes for the wax to melt completely in each dimple. Record the time measurements in Table 1.

20. After 10 minutes, or when all the wax has melted (whichever is first), remove the conductometer from the flame and place it on a heat-resistant ceramic fiber square and allow it to cool for at least 10 minutes. **Caution:** Do not place the hot conductometer directly on the tabletop. It may scorch the finish or cause a fire.

**Table 1**

| **Conductometer** | |
|---|---|
| **Metal** | **Time to Melt Wax (seconds)** |
| Copper, Cu | |
| Steel | |
| Aluminum, Al | |
| Brass | |
| Nickel-alloy steel | |

21. **SEP Interpret Data** Based on the data you collected, which metal conducts heat the fastest?

**22. SEP Interpret Data** Based on the data you collected, which metal conducts heat the slowest?

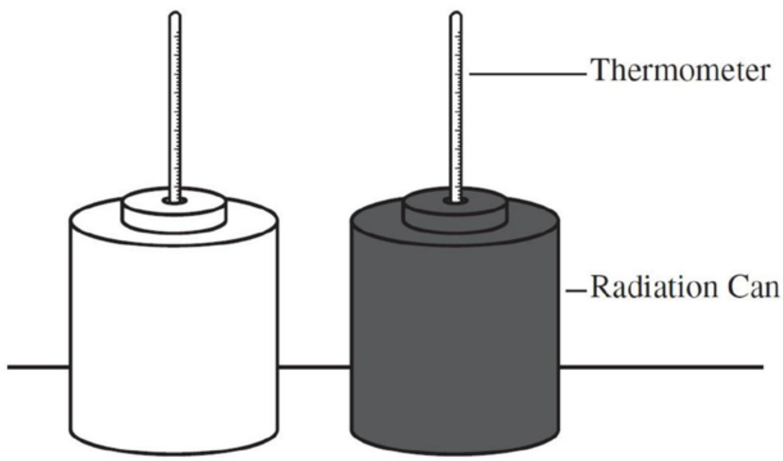
**Part III: Observing Radiation with Radiation Cans**

*Why do some materials heat up faster than others?*

**23.** Fill each radiation can ¾-full with room temperature water.

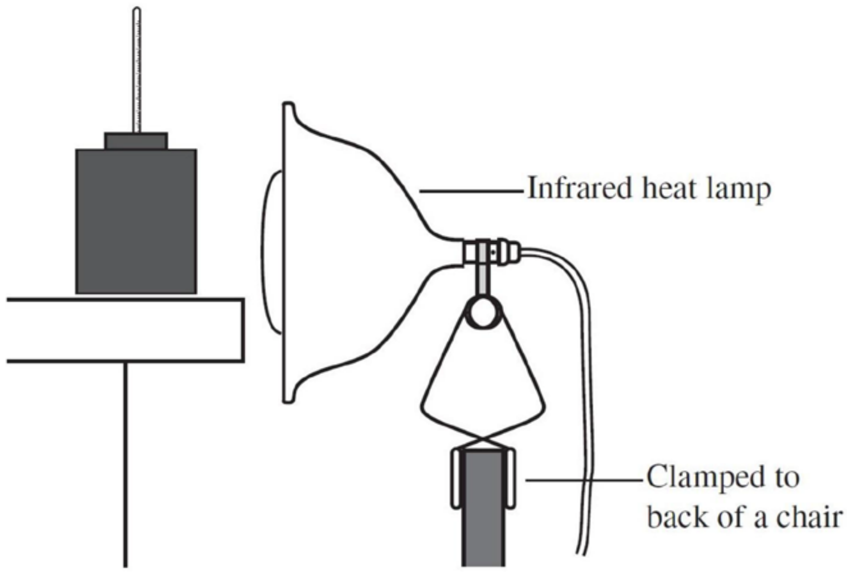
**24.** Place a thermometer into the water in each can (see Figure 3). Measure the initial temperature of the water in each can. Record the values in °C in Table 2.

**Figure 3**




**25.** Shine an infrared heat lamp on the sides of both cans, approximately 10 cm from each can, so that it shines with equal intensity on both cans. Be sure the lamp is equal distance from the outer surface of both cans (see Figure 4).

**Figure 4**




26. Measure the temperature in both cans over the next 10 minutes. Record the values in Table 2.

27. Pour the water out of both cans down the sink.

28. **SEP Use Mathematics** Use graphing software or the space to draw a temperature versus the time graph for the data in Table 2. Use a different coded line (or different color) for each can.

NAME ______________________ DATE ____________ CLASS ____________

**29. SEP Identify Patterns** How did the temperature vary in each can over time? Describe the pattern you observe.

**Table 2**

| Temperature of Radiation Cans (°C) | | |
|---|---|---|
| **Time (minutes)** | **Silver Can** | **Black Can** |
| **0** | | |
| **1** | | |
| **2** | | |
| **3** | | |
| **4** | | |
| **5** | | |
| **6** | | |
| **7** | | |
| **8** | | |
| **9** | | |
| **10** | | |

NAME ______________________ DATE __________ CLASS ____________

## Part IV: Designing a Convection, Conduction, or Radiation Model

*What is another way to model convection, conduction, or radiation in the lab?*

**30. SEP Develop Models** Pick one of the concepts you already studied and develop another model to demonstrate the process. Have your procedure approved by your instructor, before proceeding.

**31. SEP Make Observations** Build your model and record your observations.

NAME ______________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Analyze Data** Research one example of each process (convection, conduction, and radiation) you observed in the lab that occurs on Earth. Describe each example.

2. **SEP Analyze Data** In Part I, other than convection, what other method of heat transfer was taking place in this activity? How do you know?

3. **SEP Identify Patterns** Name at least two other examples of convection found on Earth.

NAME ______________________ DATE __________ CLASS __________

4. **SEP Construct an Explanation** Look at your observations from Part II. Why do some metals conduct heat more slowly and others conduct heat more quickly?

5. **SEP Construct an Explanation** On a sunny summer day, what color shirt—black or white—might be cooler? Use your observations from Part III to explain your reasoning.

6. **SEP Develop Models** Draw a model of the convection currents in Earth's mantle. Use arrows to represent the warm and cool fluid movements.

NAME ________________________ DATE ____________ CLASS ____________

SCIENCE PERFORMANCE-BASED ASSESSMENT

# Heating Curve of Water

**When you heat an object, where does the energy go?**

**Phenomenon** Energy transfer occurs around us all the time. In the absence of work, the transfer of thermal energy or heat flow always occurs from a region of higher temperature to a region of lower temperature until a new final equilibrium temperature is reached. Temperature is the measure of the average kinetic energy of a substance (how much the particles in the substance are moving).

In this activity, you will investigate the energy involved in turning ice water into boiling water. It will be up to you and your partner(s) to determine the energy needed to change the temperature of the water and to also calculate the energy needed to turn the solid water into liquid water ($\Delta U_{fusion}$).

## Focus on Science Practices

**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Balance (0.01 g precision)
- Beaker, borosilicate, 250 mL
- Graduated cylinder, 100 mL
- Hot plate
- Stirring rod
- Support clamp and stand (optional)
- Thermometer or temperature probe
- Timer
- Water, ice
- Water, room temperature

## Safety

*Wear safety goggles when performing this or any lab that uses chemicals, heat or glassware. Use a stirring rod to stir the liquid; never stir with a thermometer. Use caution with hot water. Use heat resistant gloves. Wash hands thoroughly with soap and water before leaving the laboratory.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

1. **SEP Plan and Carry Out Investigations** Plan an investigation to collect data to graph a heating curve of water. As plan your procedure keep the following in mind:

    - Your solution must start as an ice/water mixture.
    - Record the initial mass of the ice and the initial mass of the liquid water.
    - Take at least five temperature readings at the water's boiling point.
    - Use a data table to collect your data.
    - When measuring the temperature of the water, hold or attach it to a ring stand so the thermometer is in the middle of the liquid. Do not allow the thermometer to touch the beaker as this can alter your results

    Have your procedure approved by your instructor before proceeding.

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Use Graphs** Use graphing software or draw a plot using your time and temperature data in the space provided.

2. **SEP Analyze Data** Where on your graph was the ice completely melted?

3. **SEP Analyze Data** What trends do you notice on your graph?

4. **SEP Interpret Data** How would the graph appear if you continued to heat the water beyond the time when it was all converted to steam?

NAME ______________________ DATE ____________ CLASS ____________

5. **SEP Construct an Explanation** Discuss the significance of the plateaus on the graph. What is occurring on the molecular level during the plateaus? What is occurring on the molecular level during the sloped portion(s) of the graph?

6. **SEP Use Mathematics**
   a. If the heat of fusion for water is 333.5 J/g, how much energy was needed to melt your ice? Show work in the space provided.

   b. If the heat of vaporization is 2.23 kJ/g, how much energy would be needed to convert all of the water in the lab from the liquid state to the gas state? Show work in the space provided.

7. **SEP Apply Scientific Reasoning and Use Math** Remembering that the specific heat of water is 4.184 J/g°C, calculate how much energy would be needed for all of the water in your beaker to be converted from the ice/water mixture to steam.

# Investigation 10

NAME ______________________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Build a Battery

**How are batteries built, and how do they provide us with portable power?**

Batteries provide electricity for nearly every small electrical device in a home—from flashlights and watches to power tools. The composition of a battery depends on the purpose for which it will be used. Some batteries, such as those in an artificial heart pacemaker, need to operate for a very long time. Other batteries need to be reliable and ready to supply electricity at any time, even after several years of storage. In this lab, you will construct an aluminium-air battery and measure its power output under a variety of conditions.

## Focus on Science Practices

**SEP 2** Developing and Using Models
**SEP 5** Using Mathematics
**SEP 6** Constructing Explanations

## Materials Per Group

- Aluminum foil, 30 cm x 30 cm
- Charcoal, activated, 10–15 g
- Sodium chloride solution, NaCl, saturated, 50 mL
- Balance
- Beaker, 100 mL
- Chromatography paper
- Connector cords with alligator clip leads, 2
- Forceps
- Multimeter
- Paper clips, metal, 2
- Paper towel
- Pipet, disposable
- Scoop or spatula
- Weighing dish

## Safety

*Charcoal is a flammable solid. Keep away from flames. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Be sure all circuit connectors and work surfaces are dry before conducting the experiments. Do not touch any part of the circuit with wet hands. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.*

NAME ________________ DATE ________ CLASS ________

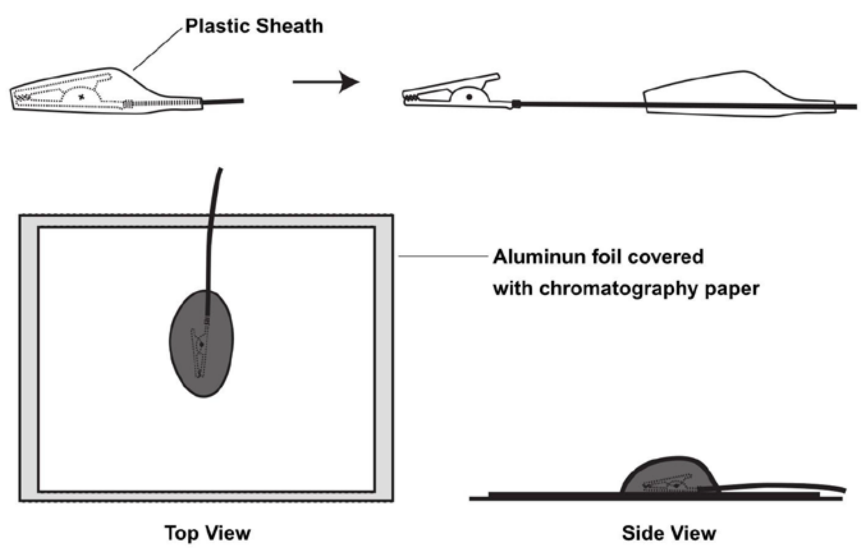
## Procedure

### Part I: Battery Construction

*How are batteries built?*

1. Place the aluminum foil sheet flat on the tabletop. Place the chromatography paper on top of the paper towel lying flat on the tabletop.
2. Use the disposable pipet to add the saturated sodium chloride solution to the chromatography paper lying on the paper towel. Wet the entire chromatography paper. The excess solution will be pulled through to the paper towel.
3. Using forceps, or a gloved hand, place the wet chromatography paper onto the center of the aluminum foil sheet.
4. Slide the protective plastic sheath on one of the alligator clips back towards the wire section of the connector cord to expose as much of the alligator clip as possible.
5. Place the exposed alligator clip in the center of the wet chromatography paper. Extend the connector cord along the centerline of the chromatography paper as shown in Figure 1.

**Figure 1**



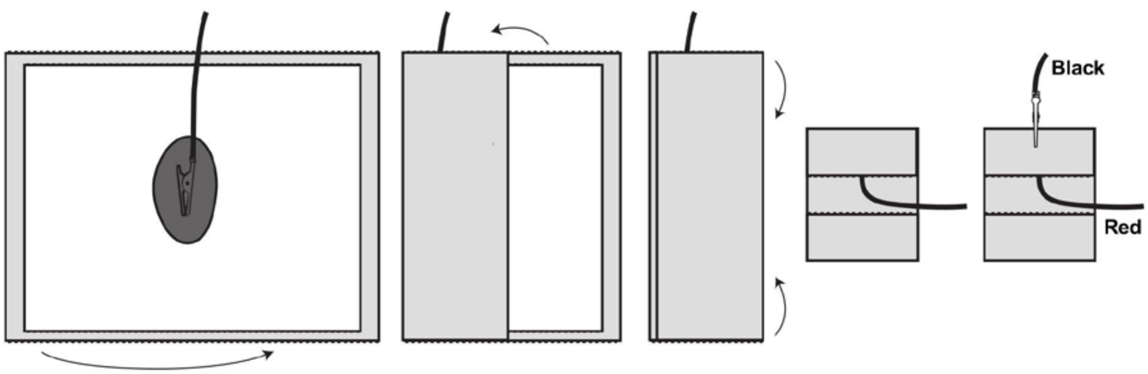
NAME ______________________ DATE __________ CLASS __________

6. Measure 10–15 g of activated charcoal from the chemical dispensing station. Place the activated charcoal into a weighing dish or 400-mL beaker. Note: Be careful! Activated charcoal powder will easily leave a black residue on skin, clothing, and the tabletop. Scoop and pour this material slowly and in small quantities.

7. Use a scoop or spatula and carefully cover the exposed alligator clip in the center of the chromatography paper with the activated charcoal as shown in Figure 1. Make sure the metal of the alligator clip is completely covered with the charcoal.

8. Carefully fold the aluminum foil and blotting paper into thirds, then fold the ends in (like a "burrito") as shown in Figure 2. Note: Be sure the chromatography paper stays between the aluminum foil and the activated charcoal.

**Figure 2**




9. Clip one end of the black connector cord to the aluminum foil.

10. The battery is now complete.

NAME ______________________ DATE ____________ CLASS ____________

## Part II: Testing the Battery

*How much power can the battery provide?*

11. **SEP Plan and Carry Out Your Investigation** How can you measure the power output of your battery? Develop a procedure that uses a multimeter to measure the current and voltage of your battery. Use the following to help you plan:

    **a.** You should measure your battery's output both when sitting on the table and when pressed.

    **b.** Team up with another group to measure the current and voltage of two batteries in series and parallel.

    **c.** Calculate the power of your battery in each situation.

    Record your detailed procedure and any materials to be used. Show your plan to your teacher for approval before you begin.

NAME ________________________ DATE ____________ CLASS ____________

**Table 1**

| Battery Performance | | | |
|---|---|---|---|
| | Current (A) | Voltage (V) | Power (W) |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

## Analyze and Interpret Data

1. **SEP Use Data to Construct an Argument** Based on the data you collected, what effect does compressing the battery have? Make sure your answer addresses the difference between current and voltage.

2. **SEP Construct an Explanation** How did the voltage and current change when two batteries were connected in parallel? Explain.

3. **SEP Use Mathematics** A portable radio contains four 1.5 V batteries connected in series. What is the voltage that these batteries supply?

4. **SEP Refine a Device** If you were asked to manufacture a battery with maximum power output, based on your experimental data, how would you go about it?

5. **SEP Construct an Explanation** Describe the flow of electrons through the battery when probed by the multimeter. Where is the energy for this electron transfer coming from?

6. **SEP Use a Model to Evaluate** In this activity you built an aluminum-air battery. Commercial alkaline batteries use manganese(IV) oxide as their source of oxygen. What are the advantages and disadvantages of using atmospheric oxygen as opposed to manganese(IV) oxide?

NAME ____________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Energy Transmission in Circuits

**How do electrons transfer energy through a circuit?**

When a battery is connected to a circuit, electrons flow from the negative terminal toward the positive terminal. As the electrons travel, they will power various components and may even encounter junctions, where there will be two wires that the electron could travel down. In this lab, you will investigate how the arrangement of the components in a circuit affects where the electrons travel and how they expend their energy.

## Focus on Science Practices

**SEP 5** Use Mathematics
**SEP 6** Construct Explanations
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Battery, 6 V, or equivalent
- Cord connectors, black and red, 5 each
- Multimeter
- Parallel circuit pins, 4
- Resistors, varying resistance, 4

## Safety

*If a resistor begins to darken or smoke, immediately disconnect the circuit and do not touch the resistor—it will be hot. Allow it ample time to cool. Handle pins with caution, as they are sharp. Be sure to follow all laboratory safety guidelines and all safety procedures provided by your teacher.*

NAME ______________________ DATE __________ CLASS __________

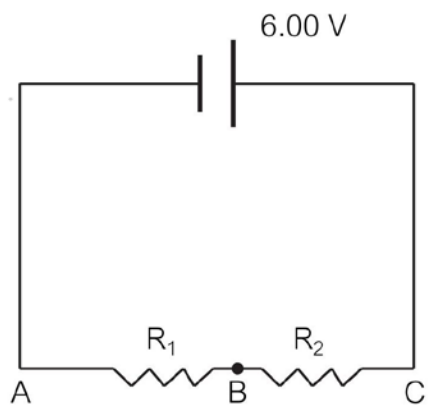
## Procedure

### Part I: Series Circuit

*How do resistors behave when placed in series?*

1. Assemble the circuit shown in Figure 1. You can use any of the supplied resistors as $R_1$ and $R_2$.

**Figure 1**




2. **SEP Obtain Technical Information** In Table 1, record the color bands and stated resistance of each resistor.

3. **SEP Plan and Carry Out Your Investigation** Develop a procedure to measure the individual and combined characteristics of the resistors in your circuit. Record your results in Table 1.

NAME ______________________ DATE ____________ CLASS ____________

**Table 1**

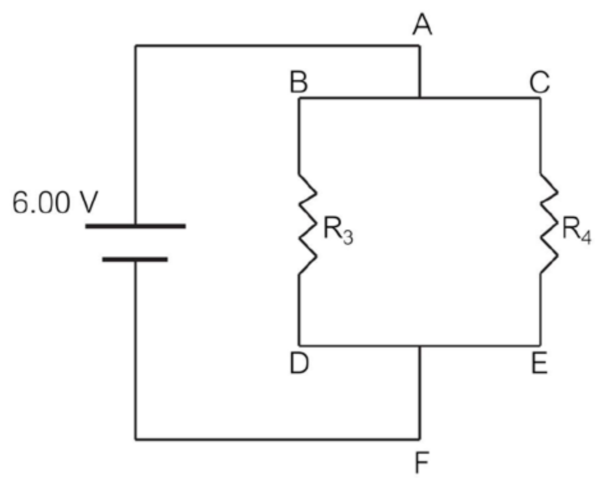
| Series Circuit | | | | | |
|---|---|---|---|---|---|
| **Number** | **Color Code** | **Stated Resistance (Ω)** | | | |
| $R_1$ | | | | | |
| $R_2$ | | | | | |
| $R_{1,2}$ | | | | | |

**Part II: Parallel Circuit**

*How do resistors behave when placed in parallel?*

4. Assemble the circuit shown in Figure 2. Use the remaining two resistors as $R_3$ and $R_4$.

**Figure 2**




5. **SEP Obtain Technical Information** Record the color bands on the resistors in Table 2. Then determine the stated resistance of each resistor.

NAME ______________________ DATE ____________ CLASS ____________

6. **SEP Plan and Carry Out Your Investigation** Develop a procedure to measure the individual and combined characteristics of the resistors in your circuit. Record your results in Table 2.

**Table 2**

| Parallel Circuit | | | | | |
|---|---|---|---|---|---|
| **Number** | **Color Code** | **Stated Resistance (Ω)** | | | |
| $R_3$ | | | | | |
| $R_4$ | | | | | |
| $R_{3,4}$ | | | | | |

NAME ____________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Analyze Data** According to the data you have collected, do these resistors follow Ohm's law ($V = I \cdot R$)? Explain.

2. **SEP Analyze Data** According to the data you collected in part 1, how does the total resistance of a series circuit relate to the resistance of each individual resistor.

3. **SEP Analyze Data** According to the data you collected in part 2, how does the total resistance of a parallel circuit relate to the resistance of each individual resistor.

4. **SEP Construct an Explanation** Why is the current through two different resistors the same when they are in series, but different when in parallel?

5. **SEP Use Mathematics** A circuit is constructed with a 12.0 V battery and three resistors, $R_1$, $R_2$, and $R_3$. The resistors are connected in series. The resistance values of $R_1$ and $R_2$ are the same. The current entering $R_3$ is 158 mA, and $R_3$ has a resistance of 50.0 Ω. Based on what you have determined, calculate the resistance of $R_1$.

6. **SEP Construct an Explanation** Kirchhoff's loop rule states that the sum of the voltages around any closed loop is zero. With reference to the conservation of energy, explain why this must be true.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Electric Motors and Generators

**How does the conversion of electrical energy and mechanical energy take place in electric motors and generators?**

Electric motors are extremely useful devices that can be found in toys, kitchen appliances, and various types of vehicles. In essence, electric motors transform electricity (the flow of electric charges through a conductor) into motion, or mechanical energy. The spinning of electric motors is utilized to move all sorts of objects, and the rate at which the motor spins depends on the electric power at which it operates. Electric power is the rate at which electrical energy is transferred by an electric circuit to perform work, i.e. to move things. In this lab, you will build a fan powered by an electric motor, and you will explore how the electrical energy generated by the motor is transformed into the mechanical energy that makes the fan spin. In addition, you will turn the fan into a generator, using the spinning motion of the fan blades to produce a current inside the electric motor, in the absence of a battery, or power supply.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 6** Construct Explanations and Design Solutions

## Materials Per Group

- Batteries (or variable DC power supply), 1.5 V and 6 V
- Buret clamp with clamp holder
- Manila folder
- Cork, size 11
- DC motor (with attached plastic cap), 1.5 V
- Fan, small and portable
- Glue
- Hot glue gun (optional)
- Masking tape, electrical
- Multimeter with leads, digital
- Pushpins, 2
- Ruler, metric
- Scissors
- Support stand
- Wires with alligator clips on each end, 2

## Safety

*Wear eye protection as rotor components may separate during testing. Never touch any bare wires in an electric circuit with a current. Please follow all laboratory safety guidelines.*

NAME ______________________ DATE __________ CLASS __________

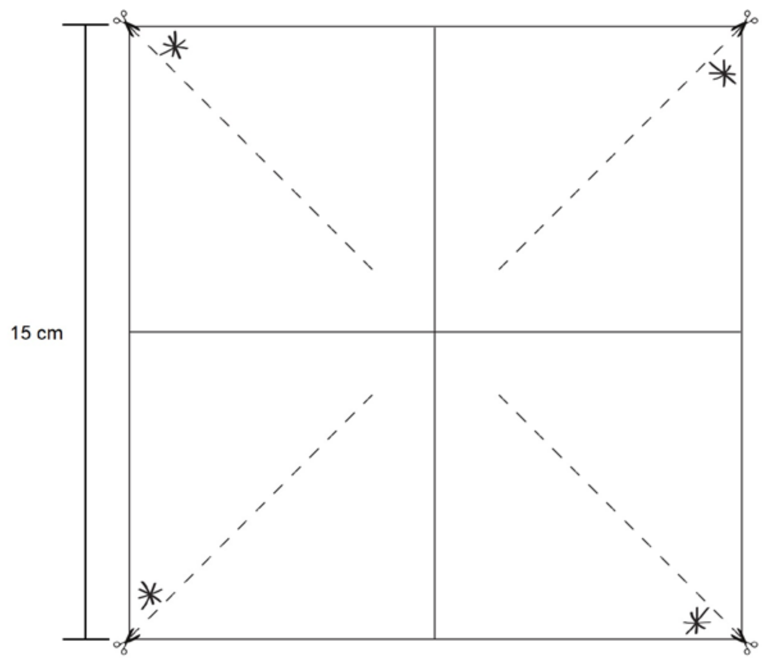
## Procedure

### Part I: Make the Fan Blades

*How can an electric motor transform electricity into mechanical energy?*

1. Use **Figure 1** to draw the template for a four-blade fan (square) on a manila folder sheet.

**Figure 1**




2. Use scissors to cut out the square template. Afterwards, cut along the dotted lines of the shapes. Do not cut along the solid lines.
3. Grab one of the corners of one of the square template with an asterisk (*) and fold it into the center.
4. Hold the pieces in the center and continue folding all of the asterisk corners towards the center.
5. Insert a pushpin through the center of the resulting four-blade fan. Note: If the pieces do not stay in place with the addition of the pushpin, place one small drop of hot glue underneath the first piece as it is folded toward the center. With the pin through each of the four layers hold the fan together tightly until the glue dries. Set the fan aside.

## Part II: Build a Fan Using a DC Motor

*How can a DC motor be used to power a small fan prototype?*

6. Hold the DC motor firmly by its metallic body and insert the motor shaft into the larger-diameter face of the cork. The cork should fit tightly against the shaft and inside the plastic cap.
7. Attach the fan to the center of the cork by pressing the pushpin against the cork.
8. Attach a buret clamp to the support stand. Then, use the clamp to hold the DC motor in place by its metallic body. Do not apply excessive pressure to the motor's body with the clamp as this may damage the motor.
9. Plug the multimeter leads so that the black wire is connected to the ground port, and the red wire is connected to the maxADC port, which in most multimeters is the 10Amax or 20Amax port. *Note: Have your instructor check out your multimeter's setup before proceeding*.
10. Connect the black wire's alligator clips hanging from the DC motor to the negative terminal on the 1.5-V battery. Use masking tape to hold the alligator clip in place, if necessary.
11. Connect the red wire's alligator clip attached to the DC motor to the ground lead of the multimeter.
12. Use the second multimeter lead to contact the positive terminal on the 1.5-V battery. Observe whether the fan spins smoothly, and remove anything that could come into contact with the fan blades.
13. Measure the current ($I$) in amps (A) shown on the multimeter's display and record the value in Table 1. Note: If the current reading is too low, switch the multimeter's knob to measure in the 200-mA range.
14. Unplug the alligator clips connecting the 6-V battery to the DC motor. Replace the 1.5-V battery with a 6-V battery.
15. Repeat steps 9–14 for the fan powered by the 6-V battery. Record the current ($I$) flowing through the assembly with the 6-V battery.

NAME ______________________________ DATE ____________ CLASS ____________

**Table 1**

| Build a Fan Using a DC Motor | | |
|---|---|---|
| **Battery Voltage (V)** | **Current, $I$ (A)** | **Power, $P = V \times I$ (W)** |
| **1.5** | | |
| **6** | | |

## Part III: Turn a Fan into a Generator

*How can a fan be used to generate electricity?*

16. **SEP Plan Your Investigation** Consider the experiment conducted in Part II. How could you modify this experiment to generate electric power from the motion of the fan instead of using a battery? Write a detailed experimental procedure to explore this possibility. Use Table 2 to guide your measurements, and have your instructor check your procedure before proceeding with the experiment.

NAME ______________________ DATE __________ CLASS __________

**Table 2**

| Turn a Fan into a Generator | | | |
|---|---|---|---|
| **Portable Fan Speed** | **Voltage, *V* (V)** | **Current, *I* (A)** | **Power, *P* = *V* × *I* (W)** |
| | | | |
| | | | |
| | | | |

## Analyze and Interpret Data

1. **SEP Use Models** Use your observations with the motor-fan-generator assembly, and describe the types of energy involved in the investigation. Describe how energy transforms from one type to another when the motor-generator is connected to a battery and when it is not.

2. **SEP Use Mathematics** Calculate the power (*P*) in watts (W) generated by the DC motor-fan assembly in Parts II and III using the formula for electric power given in the corresponding data tables. Show a sample calculation, and fill out the respective column in each data table. Note: Remember that 1 W = 1 V × 1 A, where W, V, and A represent the units of watts, volts, and amperes, respectively.

NAME ______________________ DATE __________ CLASS __________

3. **SEP Construct an Explanation** How does the electric power (*P*) of the DC-motor fan in Part II compare to that of the generator built in Part III? Explain the possible cause(s) of this discrepancy.

4. **SEP Construct an Explanation** In your own words, describe why the same setup used in Part II can work as a generator of electric current in Part III.

5. **SEP Construct an Explanation** Is there a relationship between the speed of rotation of the paper fan in Part III and the magnitude of electric power generated? Explain.

6. **SEP Apply Scientific Reasoning** Predict what would happen if the fan were to spin in a counterclockwise direction in Part III of the experiment. How would this affect, if at all, the readings of voltage and current? Would the power generated be affected at all?

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

# Natural Resource Management

**How can citizens make informed decisions about how to allocate natural resources?**

Earth's human population, which must be fed with crops harvested from arable land, is increasing at the same time investment in renewable energy sources to reduce carbon emissions is increasing. One source of renewable energy is the sun. For the same reasons certain land areas are ideal for growing crops, those land areas are also ideal locations for solar panels that convert sunlight into electricity. Thus, the goals of supporting a growing population and reducing carbon emissions through solar energy must be balanced. There are economic, environmental, and social questions to consider. In this activity, you will explore the relationships between resource management, human sustainability, and biodiversity as they pertain to the use of a finite natural resource, arable land.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Spreadsheet program

## Safety

*This laboratory activity is considered non-hazardous.*



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## Procedure

1. **SEP Develop and Use a Model** Region A is a hypothetical rural area that has characteristics similar to those of a state in the American Midwest. Region A encompasses 23,000,000 arable acres and 10,000,000 people. The citizens of Region A have democratically decided to implement a land-allocation plan that gradually, year over year, allocates some of the arable land to leases for solar arrays that convert sunlight to electricity. Each acre of land leased to solar energy providers yields 275,000 kWh/year, and the average household of four people uses 10,649 kWh/year. Design a simulation in a spreadsheet program that demonstrates how land allocation changes in Region A, when implemented over a 50-year time period, impact the region's ability to support food and energy needs simultaneously.

2. **SEP Develop and Use a Model** The table provides crop revenue and lease price data for the arable land in Region A. Assume you are a farmer with 10,000 acres. Design a simulation to explain which economic conditions favor crop growth, which economic conditions favor solar leases, and which conditions allow for flexibility and the consideration of non-economic factors in land allocation. Describe how your simulation can be used to inform land allocation decisions. Use the data in Table 1 in your spreadsheet.

**Table 1**

| Year | Yield Per Acre, Bushels | Price Per Bushel, $ | Lease Price Per Acre, $ |
|---|---|---|---|
| 1 | 205 | 3.90 | 500 |
| 2 | 180 | 3.25 | 700 |
| 3 | 200 | 4.00 | 800 |

3. **SEP Plan an Investigation** Propose an experiment to measure the impact the installation of a solar array on a 250-acre parcel of the 10,000-acre farm would have on the local biodiversity. How could you incorporate your data into the simulation(s) you designed?

## Analyze and Interpret Data

1. **SEP Use Mathematics** How many acres in Region A must be allocated to solar leases in order for Region A to achieve energy independence? Explain.

NAME ________________________ DATE __________ CLASS ____________

2. **SEP Use Mathematics** Assuming that 1.5 acres of arable land per capita are needed to support the population given its average per capita consumption, and no more than 1,000 acres of new land can be allocated to solar leases each year, can region A achieve energy and food independence at the same time? Explain.

3. **SEP Obtain information** Conduct online research to describe how a farm can grow crops and accommodate solar panels on the same land.

4. **SEP Evaluate a Question** What motivations, in addition to economic ones, might influence a hypothetical farmer's thinking about how best to allocate her 10,000 acres of arable land? Consider that electricity from coal emits 820 kg $CO_2$eq/Mwh and electricity from photovoltaics (solar panels) emits 5 kg $CO_2$eq/Mwh.

5. **SEP Construct an Explanation** It has been observed by some that, regardless of whether arable land supports solar panels or crops, the land is harvesting energy from the sun. Explain this idea.

6. **SEP Obtain Information** Conduct online research to determine what kind of solutions can be pursued to increase the yield per acre of arable land and to decrease the cost of electricity derived from solar panels.

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ENGINEERING PERFORMANCE-BASED ASSESSMENT

# Design, Build, and Refine A Wind-Turbine Rotor

**How does rotor design affect the amount of power derived from a wind turbine?**

**Phenomenon** Wind is a renewable resource that can be converted into electricity using wind turbines, with energy conversion efficiency dependent in part on the design of the rotors. The purpose of this engineering performance-based assessment is to design and build a rotor that produces the greatest amount of power. The rotor includes the windmill blades attached to a central hub and can only be made with provided materials. The voltage and amperage of the spinning rotor will be measured with a multimeter to determine the amount of generated power. Improvements will then be made to the rotor to increase the amount of power produced.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations and Design Solutions
**SEP 7** Engage in Argument from Evidence

## Materials Per Group

- Bamboo skewers
- Blade material, choose from the following
  - Cardboard sheet
  - Foam sheet
  - Manila folder
  - Polystyrene sheet
- Calculator
- Cork
- Glue or tape
- Ruler
- Sandpaper
- Scissors
- Testing station, shared
- Timer

## Safety

*Exercise caution when handling sharp bamboo skewers. Sandpaper may be used to smooth rough edges. Wear eye protection as rotor components may separate during testing. Never touch any bare wires in an electric circuit with a current. Please follow all laboratory safety guidelines.*

NAME ______________________________ DATE __________ CLASS __________

## Procedure

**Part I: Designing and Building a Rotor**

*What variables should be considered when designing a wind turbine's rotor?*

1. Read through the entire procedure before beginning.
2. **SEP Design a Solution** Take 5–10 minutes to plan the rotor design using only materials provided by the instructor. Consider how many blades the rotor will have, how the blades will attach to the hub (cork), what material will form the blades, what size and shape the blades will be, and the weight of the blades. Note: The small end of the cork should face the fan that will be generating the wind. Describe your rotor design.
3. Once the group has determined the rotor design, obtain the necessary materials from your instructor.
4. Using the design plans from Step 2, assemble the rotor. Note: Do not glue the blades to the hub so adjustments may be made if necessary.
5. **SEP Test Your Solution** Take the completed rotor assembly to the testing station where your instructor will attach the rotor to the motor at a set distance from the fan. Turn the fan on high speed.
6. Set the multimeter to measure volts.
7. With the fan on high speed, note the highest voltage displayed in 20 seconds. If the voltage is a negative number, reverse the current by switching the connections to the multimeter. Record the value in Table 1.

8. With the fan still running, adjust the multimeter to register milliamps.

9. Note the highest amperage displayed in 20 seconds. Record the value in Table 1.

10. Observe other groups' rotors as they are tested.

11. Once each group has tested its rotor, adjust the height of the motor on the support stand so the rotor hub is halfway between the center and the top of the fan. Repeat Steps 7–10 with the rotor in this new position.

12. Calculate the power output in milliwatts for each test.

**Table 1**

| **Rotor—Initial Design** | | | |
|---|---|---|---|
| **Trial** | **Voltage (V)** | **Milliamps (mA)** | **Power (mW)** |
| Rotor Hub Facing Center of Fan | | | |
| Rotor Hub Above Center | | | |

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**Part II: Refine Your Rotor Design**

*What adjustments should be made to your group's rotor to increase the power output from Part I?*

13. **SEP Evaluate Solutions** Make a list of problems, if any, the rotor experienced during testing and how modifications might be made to correct the problems.

14. **SEP Test Your Solution** Based on the results from Part I, choose where your rotor will be positioned for the final test—either in line with the center of the fan or raised up. Note the highest voltage displayed in 20 seconds and record the value in Table 2.

**Table 2**

| Rotor—Refined Design | | | |
|---|---|---|---|
| **Rotor Position** | **Voltage (V)** | **Milliamps (mA)** | **Power (mW)** |
| | | | |

NAME ________________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Engage in Argument** Is all of the mechanical energy you impart to the spinning generator converted to electrical energy? If not, what do you think the main sources of energy loss are?

2. **SEP Analyze Data** Compare the power output of the original rotor to the modified rotor. Which modifications made a difference in the power output? Explain.

3. **Use Scientific Reasoning** Traditionally a motor uses electric current to spin objects. In this laboratory activity the constructed rotor is connected to a motor but the motor is not attached to any source of electricity. As the shaft of the motor turns, electric current runs through the wires. What must be inside the motor for this to happen? What is the motor actually functioning as in this activity?

4. **SEP Engage in Argument** Wind power provides less than 2% of the electricity in the United States, but may provide as much as 20% in the future. What are some reasons why wind is not being used as much as a resource to generate electricity?

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5. **SEP Construct Explanations** A recent manuscript published in a peer-reviewed scientific journal indicates that if only 1% of land ideal for wind turbines is allocated to its use, enough energy could be produced to satisfy global demand. However, the paper also indicates that the most significant impediment to this is “local energy demand.” Explain.

# Investigation 11

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INQUIRY LAB – OPEN

# Mechanical Waves

**How can you model different waves and describe the characteristics of waves traveling through a medium?**

Ocean waves, seismic waves, sound waves, electromagnetic waves—waves are all around us. The majority of information we receive on a daily basis from different devices, such as cell phones, reaches our personal technology in the form of waves. All waves transmit energy based on the characteristics of the wave, and mechanical waves can only be propagated through a medium. Throughout this lab, you will use a spring toy, the medium, to investigate the properties of two different types of mechanical waves, traverse and longitudinal. While investigating each wave type, you will determine the relationships, if any, that exist among different properties of mechanical waves.

## Focus on Science Practices

**SEP 2** Developing and Using Models
**SEP 5** Use Mathematics
**SEP 6** Constructing Explanations

## Materials Per Group

- Meter stick
- Nylon string, 10 cm
- Wave motion rope, optional
- Recording device, optional
- Scientific calculator
- Spring toy
- Timer
- Masking tape

## Safety

*Please take care and do not suddenly release a stretched spring toy. Springs can snap back rapidly, which may cause injury to yourself and others or cause damage to the spring toy. Remember to wear safety glasses throughout the lab. Be sure to follow all laboratory safety guidelines and all safety procedures provided by your teacher.*

NAME ______________________ DATE __________ CLASS __________

## Procedure

### Part I: Transverse Waves—Amplitude

1. **SEP Plan and Carry Out Your Investigation** How can you show the relationship between amplitude and wave speed in transverse waves? Develop a procedure that shows this relationship in transverse waves. Use the following to help you plan:

   **a.** Use the data table as a guide as you develop your procedure.

   **b.** Use masking tape and a meter stick to set up an x-y grid on the floor to help you observe wave characteristics such as amplitude, wavelength, and frequency.

   **c.** If available, consider using a camera or smartphone to make better observations of the waves.

   Record your detailed procedure and any materials to be used. ***Caution: Do not stretch the spring toy more than three meters.*** Show your plan to your teacher for approval before you begin.

NAME ______________________ DATE ____________ CLASS ____________

**Table 1**

| Transverse Waves—Amplitude | | |
|---|---|---|
| **Total Distance: 6 m** | **Amplitude: 0.1 m** | **Amplitude: 0.2 m** |
| **Trial** | **Time (s)** | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| **Average Time (s)** | | |
| **Average Wave Speed (m/s)** | | |

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## Part II: Transverse Waves—Wavelength and Frequency

2. **SEP Plan and Carry Out Your Investigation** How can you show a relationship between wave speed and wavelength/frequency in transverse waves? Develop a procedure that shows this relationship in transverse waves. Use the following to help you plan:

   **a.** Use the data table as a guide as you develop your procedure.

   **b.** Reuse the x-y grid you set up on the floor to help you observe wave characteristics such as amplitude, wavelength, and frequency.

   **c.** If available, consider using a camera or smartphone to make better observations of the waves.

   Record your detailed procedure and any materials to be used. ***Caution: Do not stretch the spring toy more than three meters.*** Show your plan to your teacher for approval before you begin.

NAME ______________________ DATE ____________ CLASS ____________

**Table 2**

| Transverse Waves—Wavelength and Frequency | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Length of Stretched Spring, *L* (m)** | **No. of Crests** | **Wavelength (m)** | **Time for 10 Cycle(s), Trial 1, Trial 2, Avg.** | | | **Period, T (s)** | **Frequency (Hz)** |
| 3 | 1 | | | | | | |
| 3 | 2 | | | | | | |
| 3 | 3 | | | | | | |
| 3 | 4 | | | | | | |

## Part III: Longitudinal Waves

3. **SEP Plan and Carry Out Your Investigation** How do the characteristics of longitudinal waves and its relationships compare to the characteristics of a transverse waves and its relationships? Develop a procedure to generate a longitudinal wave and to measure its speed. Use the following to help you plan:

   **a.** Use the data table as a guide as you develop your procedure.

   **b.** Reuse the x-y grid you set up on the floor to help you observe wave characteristics such as amplitude, wavelength, and frequency.

   **c.** If available, consider using a camera or smartphone to make better observations of the waves.

   ⚠ Record your detailed procedure and any materials to be used. ***Caution: Do not stretch the spring toy more than three meters.*** Show your plan to your teacher for approval before you begin.

NAME ________________________ DATE ____________ CLASS ____________

**Table 3**

| Longitudinal Waves | |
|---|---|
| **Total Distance: 6 m** | **Amplitude: 0.2 m** |
| **Trial** | **Time (s)** |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |
| **Average Time (s)** | |
| **Average Wave Speed (m/s)** | |

## Analyze and Interpret Data

1. **SEP Use Data to Construct an Argument** Based on the data you collected, which of the following properties, amplitude, frequency, and wavelength, affect the wave speed of the stretched spring? Explain.

2. **SEP Analyze and Interpret Data** In solid materials, the longitudinal wave is typically faster than the transverse wave by a factor of about 1.7. Is that what you found? If not, construct an explanation for why not.

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3. **SEP Use Math** A wave is propagated through a spring. A point on the spring moves perpendicular to the motion of the wave for a total distance of 32 cm during one complete wave cycle. What is the amplitude of the wave?

4. **SEP Construct an Explanation** One characteristic of the sound we hear is pitch. Pitch is determined by the frequency of the sound wave. Explain how a guitar player can produce so many different notes with only six strings. Note that guitar strings tend to vibrate with a wavelength that is twice the length of the vibrating part of the string.

5. **SEP Construct an Explanation** Discuss sources of error in your investigation and ways you could reduce their impact. To what degree was this lab susceptible to human error?

6. **SEP Construct an Explanation** When investigating the relationship between wavelength and wave speed in transverse waves, why is it not necessary to attempt to keep the amplitude constant across trials?

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Interference of Sound Waves

**How do sound waves interact with each other?**

Send a sound wave along two paths of different lengths. What happens if one path is blocked?

## Focus on Science Practices

**SEP 5** Use Math
**SEP 6** Design a Solution
**SEP 8** Communicate Technical Information

## Materials Per Group

- Funnels, polypropylene, 2
- Markers (optional)
- Petroleum jelly
- Ruler or measuring tape
- Scissors
- Thermometer
- Tubing connectors, Y-shaped, glass, 2
- Tubing, latex, 6 cm, 2
- Tubing, latex, 11 cm
- Tubing, latex, 60 cm
- Tuning fork, 256 Hz (optional)
- Tuning fork, 385 Hz
- Tuning fork, 512 Hz
- Tuning fork activator or rubber mallet

## Safety

*Although latex is not considered hazardous, not all health related aspects of this substance are known. Latex may be an allergen. Wear safety glasses and gloves when working with glass tubing. Please follow all laboratory safety guidelines.*

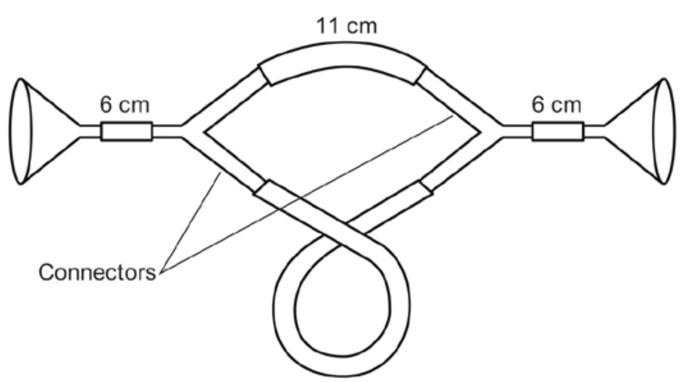
NAME ________________________________ DATE __________ CLASS __________

## Procedure

*How far must sound waves travel in order to interfere with each other?*

1. **SEP Develop A Model** How can you show the relationship between how far a wave must travel in order to interfere with itself, and the wave's frequency? Develop a model that shows this relationship. Use the following to help you develop a model:
   a. Carefully examine Figure 1. This diagram depicts Quincke's tube, a device used to demonstrate destructive interference of sound waves. By directing the sound wave from a tuning fork down two paths of differing length, the waves will be out of phase. These two paths are the 11 cm tube at the top, and the longer tube of unknown length at the bottom. When the lengths of these paths differ by one-half of the wavelength, the waves will cancel each other out due to destructive interference.

**Figure 1**




2. Check the room temperature with the thermometer, and record this value in the data table.

3. **SEP Calculate** Calculate the speed of sound in air using Equation 1 and record this value in the data table.

   **Equation 1:** $331.4 + 0.6T_c = v_{sound}$

   Where $T_c$ is the temperature of the air (in degrees Celsius), and $v_{sound}$ is the speed of sound (in meters per second, m/s).

4. Obtain a tuning fork and record its frequency in the data table.

5. Using the calculated speed of sound and the frequency of the tuning fork, calculate the wavelength of a sound wave produced by the tuning fork and record this value in the data table.

6. Based on your results from steps 2–4, determine the path length difference required for destructive interference of the sound wave produced by this tuning fork. Record this value in the data table using the correct units.

7. With the help of your instructor and following the example of Figure 1, build a Quincke’s tube using the materials available to you in the lab.

8. **SEP Plan Your Investigation** Using the information and calculations from steps 2–5, and the data tables, design a procedure in which Quincke’s tube is used to demonstrate the destructive interference of sound waves produced by tuning forks of different frequencies. Plan on using two tuning forks of different frequency in your experiment. Have your procedure checked and approved by your instructor before you begin.

NAME ______________________ DATE __________ CLASS __________

**Table 1**

| Sound Wave Interference | | |
|---|---|---|
| **Room temperature (°C)** | | |
| **Speed of sound at room temperature (m/s)** | | |
| | **Tuning fork 1** | **Tuning fork 2** |
| **Frequency (Hz)** | | |
| **Wavelength (m)** | | |
| **Half-wavelength (m)** | | |
| **Path length for destructive interference (m)** | | |

**Table 2**

| Observations |
|---|
| **Tuning fork 1 ( _______ Hz)** |
| |
| **Tuning fork 2 ( ______ Hz)** |
| |

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## Analyze and Interpret Data

1. **SEP Construct an Explanation** What happens with the sound wave when it travels through both the shorter and longer tubes? What happens with the sound wave when it travels through the shorter tube only? Explain.

2. **SEP Construct an Explanation** Why is it important to measure the temperature of the air and take it into account when calculating the length of the longer tube?

3. **SEP Design A Solution** How would you modify the design of the tube used in this activity to demonstrate interference using tuning forks of different frequencies, under various conditions of temperature and air humidity?

4. **SEP Communicate Technical Information** Based on your results, describe a possible process that could be used to reduce sound on a noise canceling device.

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INQUIRY LABS – OPEN

# Reflection and Refraction

**How can you model the behavior of light waves, and describe what they do when they bounce off of objects or pass from one medium into another?**

Visible light is a form of energy that is given off by natural or human-made objects such as the Sun or a lightbulb. Other objects may reflect light, enabling them to be seen. Light waves change direction as they are reflected by other objects, and may also change speed and direction as they pass from one transparent medium into another. Explore the principles of reflection and refraction as these properties of visible light are investigated.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 7** Engage in an Argument from Evidence
**SEP 8** Obtain, Evaluate and Communicate Information

## Materials Per Group

- Cork
- Mirror, plane
- Mirror, support
- Protractor sheet
- Pin
- Semicircular lens, 1
- Water, 100 mL

## Safety 

*Optics materials are considered safe. Do not look through lenses at bright light objects especially the sun, as it can be harmful to the eyes. Follow all laboratory safety guidelines.*

NAME ______________________ DATE __________ CLASS ___________

## Procedure

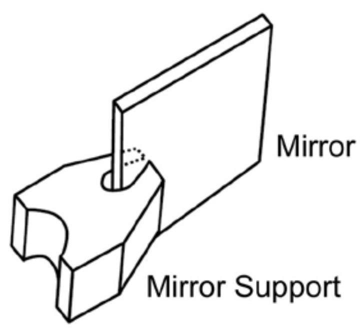
### Part I: Reflection

*What is the relationship between the angle of incidence and the angle of reflection?*

**SEP Develop a Model** Use the following procedure to explore the relationship between the angle of incidence and the angle of reflection for visible light. The procedure provides directions on how to set up the available equipment and supplies, but does not stipulate how their use might yield pertinent data. Once you have set up the equipment you will be directed to develop a procedure that can help you model the relationship between the angle of incidence and the angle of reflection.

1. Insert the pin into the narrow end of one cork and set aside for step 7.
2. Place the mirror in the mirror support as shown in Figure 1. Note: Make sure the bottom of the mirror support is flat against the work surface so the mirror stands upright without leaning forward or back.

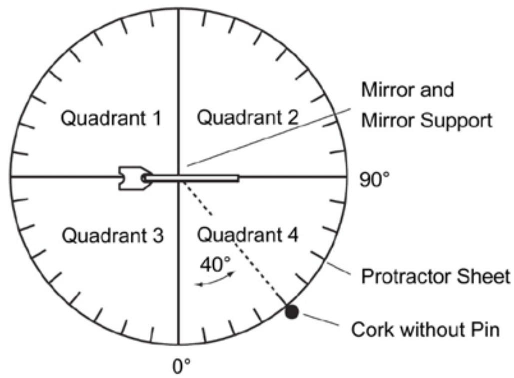
**Figure 1**




3. Place the mirror in the center of the protractor sheet as shown in Figure 2. The mirror should be on the horizontal line (90°) on the protractor sheet.

NAME ______________________________ DATE __________ CLASS __________

**Figure 2**




4. Place the cork without the pin at the 40° mark in Quadrant 4 on the protractor sheet as seen in Figure 2.
5. Close one eye and look at the reflection of the cork in the mirror from Quadrant 3.
6. Adjust your line of sight so the image of the cork is in line with the center of the protractor. Note the angle on the protractor corresponding to your eye position (line of sight). Record the angle and Quadrant number in the data table.

1. Develop a procedure to explore the relationship between the angle of incidence and the angle of reflection, using the apparatus you have set up. Record your detailed procedure; and identify the independent variable(s), the dependent variable(s) and the control variable(s).

NAME ________________________ DATE ____________ CLASS ____________

**Table 1**

| Reflection | | | | | | |
|---|---|---|---|---|---|---|
| **Cork Position** | | **Eye Position** | | **Position of Cork with Pin** | | **Observations** |
| **Quadrant** | **Angle** | **Quadrant** | **Angle** | **Quadrant** | **Angle** | |
| 4 | 40° | | | | | |
| 4 | | | | | | |
| 3 | | | | | | |

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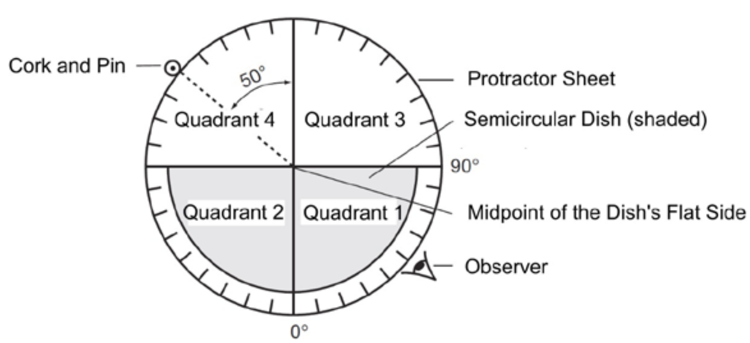
**Part II: Refraction**

*What happens to the direction of light as it moves from one medium into another, does it change?*

**SEP Develop a Model** Use the following procedure to explore whether and how light changes direction when it travels from one medium into another. The procedure provides directions on how to set up the available equipment and supplies, but does not stipulate how their use might yield pertinent data. Once you have set up the equipment you will be directed to develop a procedure that can help you understand what occurs when light passes from one medium into another.

7. Fill the semicircular dish ¾ -full with water (approximately 100 mL.)
8. Place the protractor sheet on the work surface so Quadrants 1 and 2 are toward the observer.
9. Carefully place the dish on the protractor sheet so the flat side faces Quadrants 3 and 4, the midpoint line on the dish is centered at the intersection of the quadrants, and the curved section is in Quadrants 1 and 2 as shown in Figure 3.

**Figure 3**




10. Insert the pin into the narrow end of the cork.
11. Place the cork at the 50° mark in Quadrant 4 on the protractor sheet.
12. Close or cover one eye and look through the water-filled dish from Quadrant 1 so your line of sight is from the 50° mark to the center vertical

line on the dish. Note: For best results, keep your eye level at the same height as the tabletop.

**13.** Are you able to see an image of the cork and pin in the water? Record your observations for 50° in the data table.

**14.** Keeping one eye closed, move your head and line of sight along the curved part of the dish until the cork-and-pin image appears in the water. Which way did your line of sight move with respect to the normal line (0°)? Add to your observations for 50° in the data table.

**15.** Continue to move your head and line of sight along the curved part of the dish until the cork-and-pin image in the water lines up with the vertical line on the flat side of the dish.

**16.** With the image of the pin and vertical line aligned, take the toothpick and place it vertically along the outside of the curved part of the dish so it is aligned with the vertical line and the image of the pin. This will mark your line of sight.

**17.** Note the angle on the protractor where the toothpick is placed and record the angle and Quadrant number in the data table.

**18.** Develop a procedure to further explore how light bends as it transitions from air into water. Record your detailed procedure; and identify the independent variable(s), the dependent variable(s) and the control variable(s).

NAME ______________________ DATE ____________ CLASS ____________

**Table 2**

| Refraction | | | | | |
|---|---|---|---|---|---|
| **Light Transmission** | **Observations** | **Pin Quadrant** | **Pin Angle** | **Toothpick Quadrant** | **Toothpick Angle** |
| Air to Water | | 4 | 50° | | |

NAME ______________________ DATE __________ CLASS __________

| | | | | | |
|---|---|---|---|---|---|
| Air to Water | | 4 | 30° | | |
| Air to Water | | 4 | 70° | | |

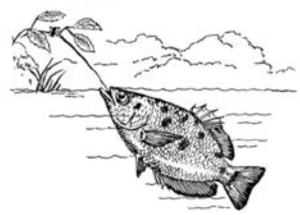
## Analyze and Interpret Data

1. **SEP Communicate Scientific Information** The relationship between the angle of incidence and the angle of reflection is known as the Law of Reflection. Based on your observations, write the Law of Reflection.

2. **SEP Evaluate Evidence** Five students are seated at their desks, which are spaced equally apart, in the front row of a classroom (see diagram). The instructor places a large plane mirror on the board directly in front of the middle student. When student 1 looks at the center of the mirror, which student's image will be seen? Use observations from the lab to support your explanation.

NAME ______________________ DATE __________ CLASS ___________

3. **SEP Evaluate Evidence** The archer fish captures its prey by knocking insects off a branch with a stream of water from its mouth. To compensate for the refraction of light as it is transmitted from air into water, would the fish aim above or below the image of the insect it sees? Use observations from the lab to support your explanation.



NAME ______________________ DATE ____________ CLASS ____________

SCIENCE PERFORMANCE-BASED ASSESSMENT

# Discovering the Speed of Sound in Open Air

**How can you determine the speed of a sound wave for a given sound wave?**

**Phenomenon** We experience sound in many ways, such as through talking, music, and noise. However, we do not hear sound as soon as it happens. During a lightning storm, we see the lightning before we hear the thunder from the lightning. Jets, when flying at a certain speed, can cause a booming sound because sound travels at a finite speed.

In this lab, you will build a resonance tube and develop a method to determine the speed of sound in air. You will have access to tools that produce sound waves at different frequencies to compare the speed of sound each tool makes.

## Focus on Science Practices

**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Clamp holders, 2
- Clamps, universal extension, 2
- Graduated cylinder, 250-mL
- Petroleum jelly (optional)
- Plastic tube, clear, 1” diameter, 2 ft
- PVC tube, white, ½ ” diameter, 2 ft
- Rubber stopper, #5
- Ruler, metric
- Support stand
- Tuning forks, set of 8
- Tuning fork activator
- Water, 200-mL

## Safety

*This lab is considered to be nonhazardous. Please follow all laboratory safety guidelines.*

NAME ________________________ DATE ____________ CLASS ____________

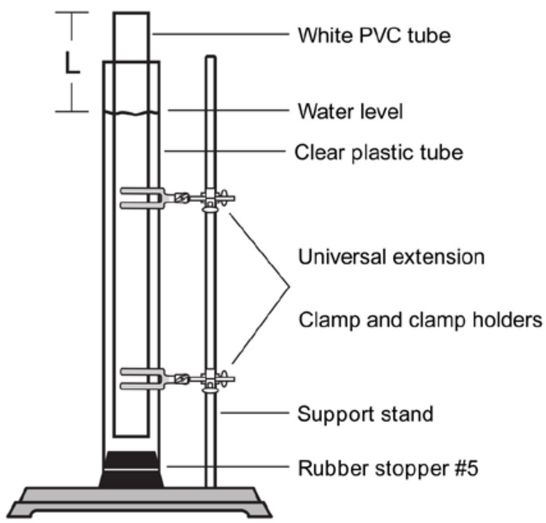
## Procedure

### Part I: Build a Resonance Tube

*How can you build a resonance tube to measure the speed of sound?*

1. Set up a support stand and attach one universal extension clamp to the top of the rod, and a second universal extension clamp to the bottom of the rod.
2. Place a rubber stopper in the bottom of the clear plastic tube.
3. Attach the clear plastic tube to the support stand using the universal extension clamps as shown in **Figure 1**. The rubber stopper should be resting on the base of the support stand.

**Figure 1**




4. Place the white PVC tube inside of the clear plastic tube.
5. Fill a large graduated cylinder with 200 mL of water.
6. Make sure the end of the clear plastic tube is completely sealed by pouring a small amount of water into the tube and watching for any leaks. Petroleum jelly may be put around the edge of the stopper if leaking does occur.
7. Pour the rest of the water from the graduated cylinder into the sealed plastic tube. The water should be near the top of the tube but not overflowing.

## Part II: Use a Resonance Tube

*How can you use a resonance tube to find the speed of sound?*

8. **SEP Plan an Investigation** Plan a procedure to determine the speed of sound in open air using the resonance tube you set up. How can the resonance tube help you determine your dependent variable(s)? Use the provided materials in your procedure. Use Table 1 as a guide.

   Record your detailed procedure. Before you carry out your investigation, get your teacher's approval.

NAME ______________________ DATE ____________ CLASS ____________

**Table 1**

| Speed of Sound | | | | | |
|---|---|---|---|---|---|
| **Frequency (Hz)** | **Tube Length (cm)** | **Tube Length “L” (m)** | **Wavelength (m)** | **Speed of Sound (m/s)** | **Average Speed of Sound (m/s)** |
| 256 | | | | | |
| 288 | | | | | |
| 320 | | | | | |
| 341 | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

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## Analyze and Interpret Data

1. **SEP Use Math** Show the formula needed to calculate wavelength. Show the calculations for one of the frequencies you tested. Remember to use the correct units. Complete the Wavelength column of Table 1 for the other frequencies.

2. **SEP Use Math** Show the formula needed to calculate the speed of sound. Show the calculations for one of the frequencies you tested. Label the answers with the correct units. Complete the Speed of Sound column of Table 1 for the other frequencies.

3. **CCC Patterns** Look at your data in the frequency and wavelength columns of Table 1. As the frequency increases, what happens to the wavelength?

4. **SEP Construct an Explanation** Based on your data, what similarities and/or differences do you notice between the different frequencies and the speed of their respective sound waves? Use the equation from question 2 to explain how the similarities and/or differences occur.

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5. **SEP Use Math** The expected average speed of sound for all those tuning forks in air at STP, standard temperature (273 K) and pressure (1 atm), is 331 m/s. How does your measured average speed of sound in air compare to the actual accepted value? Calculate the percent error between your measured average and the accepted average speed of sound.

6. **SEP Use Math** An easy way to estimate the speed of sound in air produced by a 256 Hz tuning fork is to calculate the following 331.5 m/s + 0.6($T$) ; where $T$ is the temperature measured in Celsius. Measure the temperature in your lab or classroom using a thermometer. Calculate the expected speed of sound produced by a 256 Hz tuning fork at that temperature and compare it to the expected speed in a very hot area, where the temperature is 38°C.

7. **SEP Apply Scientific Reasoning** In general, do you think the speed of sound would increase or decrease if it travels through a liquid or solid? Explain the reasoning for your answer.

# Investigation 12

NAME ______________________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

# Diffraction

**How can you use properties of light to measure the width of an object?**

A variety of methods are available for measuring objects, and using the appropriate instrument is important. For example, a ruler may be used to determine the thickness of a book, while a meter stick would be more reasonable for measuring the height of a table. What if the object is less than a millimeter wide? Explore how the unique nature of light can be used to measure the dimensions of very small objects such as the width of a wire or a human hair.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 6** Construct Explanations and Design Solutions
**SEP 7** Engage in an Argument from Evidence
**SEP 8** Obtain, Evaluate and Communicate Information

## Materials Per Group

- Copper wire, 30-gauge, 6 cm
- Fishing line, monofilament, 6 cm
- Human hair, 6 cm
- Binder clips, small and medium, 1 each
- Book, 2–3 cm high
- Laser pointers, red and green
- Measurement frame, 2½″ × 3″
- Meter stick
- Metric ruler
- Paper, white
- Scissors
- Tape, masking

## Safety

*Do not aim the laser pointer directly into anyone's eyes and never look directly into the laser beam. The low-power, coherent light can cause damage to the sensitive retina and may lead to permanent eye damage. Do not aim the laser at any reflective surfaces such as mirrors or highly polished metal. Prevent stray laser light from projecting beyond the classroom to eliminate any unintentional exposure to the laser light. When refracting the laser light, it is best to do this on a low work surface to keep the refracted laser light below "normal" eye level. For people with sensitive eyes, it is recommended that dark, IR-protective safety glasses be worn. Follow all laboratory safety guidelines.*

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## Procedure

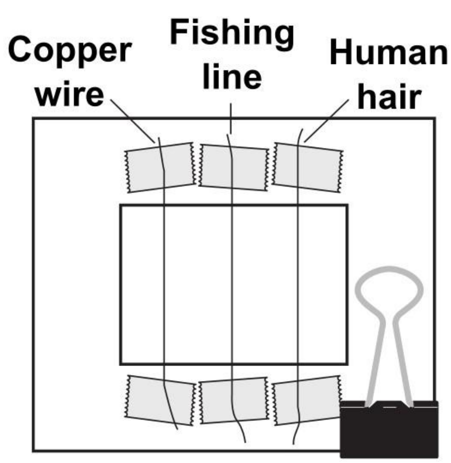
### Part I

*What happens when monochromatic laser light is shone on very thin objects, is there evidence that light behaves as a wave?*

1. Orient the measurement frame so the longer sides are at the top and bottom. Stretch the 6-cm piece of fishing line vertically across the center of the frame opening.

2. Tape the fishing line to the top and bottom of the frame, making sure the line is vertical and taut as shown in Figure 1.

**Figure 1**




3. Tape the 6-cm piece of 30 gauge copper wire to the frame to the left of the fishing line, leaving one centimeter of space between them.

4. Have one person in the group carefully pull or cut one strand of hair from his or her own head. Measure 6 cm of hair. Tape the hair to the frame to the right of the fishing line as shown in Figure 1, leaving one centimeter between them.

5. Attach a small binder clip to one bottom corner of the frame as shown in Figure 1 so the frame will stand up.

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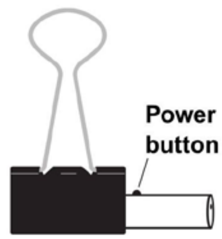
6. ⚠ Use the medium binder clip as a stand for the laser by placing the laser pointer inside the medium clip with the power button on top and visible beyond the edge of the clip as shown in Figure 2. The clip will help keep the laser steady during use. ***Caution: Make sure you have read the Safety Precautions regarding the use of lasers. Do not press the power button to turn on the laser until the set-up is complete. Leaving the light on too long will affect its wavelength, which in turn will affect the results.***

**Figure 2**

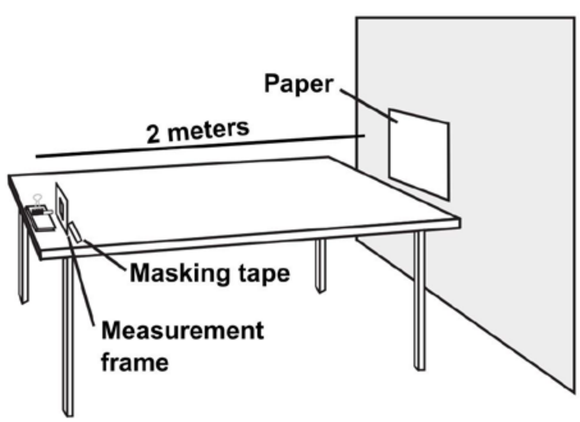



7. Place the frame on a level surface 1.5–3 meters away from a wall. Note: The farther away the laser is from the wall, the more spread out the diffraction pattern will be. Measurements will be easier, but the diffraction pattern will be dimmer.

8. Place a piece of masking tape on the level surface to mark the position of the measurement frame.

9. Place a 2- to 3-cm thick book directly behind the frame and place the laser on the book. The lens of the laser should point at the fishing line across the opening of the frame (see Figure 3).

**Figure 3**



10. Tape a piece of white paper to the wall as a screen where the laser beam will shine when it is on.

11. Place the tip of the laser pointer within 1 cm of the fishing line.

12. ⚠ Holding the back of the binder clip, press the power button and hold it down to turn on the laser light. ***Caution: Never look directly into the beam of the laser—serious eye injury may result!***

13. Aim the laser beam directly at the fishing line. When the laser is positioned correctly, a horizontal diffraction pattern of light and dark bands will be seen on the screen, with a brighter red spot in the middle (see Figure 4). Measure distance between the dark bands and record the value in table 1.

**Figure 4**

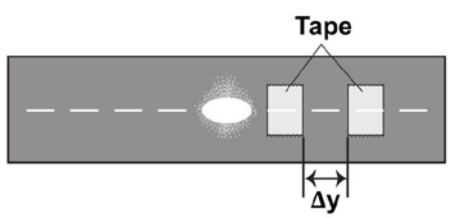



**Table 1**

| **Red Laser** | | | | |
|---|---|---|---|---|
| **Object** | **Distance from object to screen, *L* (mm)** | **Distance between dark bands, Δy (mm)** | **Wavelength of laser light, λ (mm)** | **Object width (mm)** |
| Fishing line | | | | |
| Copper wire | | | | |
| Hair | | | | |

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## Part II

*What is the relationship between the wavelength of monochromatic laser light and the features of the diffraction patterns it forms?*

1. **SEP Make a Claim** What effect would you expect to observe if you carried out the procedure outlined in Part I with light of a different color? Explain.

2. **SEP Plan an Investigation** Develop a procedure to test your prediction. Identify independent, dependent and control variables. If you are not able to carry out your procedure for lack of equipment your teacher will provide data for analysis.

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**Table 2**

| Green Laser | | | | |
|---|---|---|---|---|
| **Object** | **Distance from object to screen, *L* (mm)** | **Distance between dark bands, Δy (mm)** | **Wavelength of laser light, λ (mm)** | **Object width (mm)** |
| Fishing line | | | | |
| Copper wire | | | | |
| Hair | | | | |

## Analyze and Interpret Data

1. **SEP Analyze Data** Use the equation $d = \lambda L/\Delta y$ to determine the widths of the copper wire, fishing line, and human hair. Complete Tables 1 and 2. How do the widths of these objects compare?

2. **SEP Engage in Argument from Evidence** What evidence does your lab provide that indicates light can be described by a wave model?

3. **SEP Construct Explanations** Construct a conceptual explanation that explains why the distance between the centers of dark bands on the interference pattern created by a green laser (532 nm) are closer together than those of a red laser (635 nm).

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4. **SEP Develop a Model** What other examples of things that behave like waves, insofar as they diffract and create interference patterns, can you find, in the everyday world and from a search of the internet?

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INQUIRY LAB – OPEN

# Particle Nature of Light

**What evidence can you use to make an argument about the particle-like behavior of light?**

Light's ability to behave as both a wave and a particle is called particle-wave duality. The previous experiment demonstrated light's wave behavior, because a red laser shone at a very thin object produced a diffraction pattern. In this experiment you will explore the particle nature of light.

## Focus on Science Practices

**SEP 3** Planning and Carrying Out Investigations
**SEP 6** Constructing Explanations
**SEP 7** Engage in Argument from Evidence

## Materials Per Group

- Cardboard box "shield" (optional)
- Photon Demonstrator Card
- Sunlight
- Ultraviolet lamp, short-wavelength (optional)
- Ultraviolet lamp, long-wavelength (optional)

## Safety

Ultraviolet light may damage the eyes and cause cataracts. Wear safety glasses when using an ultraviolet light source and do not look directly at the light. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ________________________ DATE __________ CLASS __________

## Procedure

*What happens when electromagnetic radiation interacts with non-living matter?*

1. **SEP Plan an Investigation** You are an experimental physicist gathering evidence to describe how electromagnetic radiation behaves as a particle. You will be given a set of materials and an information set from which your exploration can proceed. Based on these facts and ideas you must develop a procedure to explore what happens electromagnetic radiation interacts with matter. Your procedure must include a prediction and an explanation of how that prediction, if confirmed, supports the hypothesis that light behaves as a particle.

   **a.** The phosphorescent strip glows when excited electrons on its surface fall back to their ground states and emit energy in the electromagnetic spectrum.

   **b.** The filter is composed of plastic films of different colors: black, red, yellow, green, blue and violet. The blue filter transmits blue light but absorbs the other wavelengths, the red filter transmits red light but absorbs the other wavelengths, and so on.

   Record your detailed procedure. Have your teacher approve your procedure before beginning any experiment.

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## Analyze and Interpret Data

1. **SEP Engage in Argument from Evidence** What evidence do you have that indicates light can behave as a particle?

2. **SEP Construct and Explanation** If one photon of incident light causes the emission of one electron from sodium, how many electrons are emitted if the intensity of the same light is doubled?

3. **SEP Engage in Argument from Evidence** Which of two light sources, a short-wavelength ultraviolet light, or a long-wavelength ultraviolet light, is more likely to cause the phosphorescent strip to glow? Explain.

4. **SEP Engage in Argument from Evidence** Summarize your understanding of light's particle-wave duality. Use evidence you collected.

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INQUIRY LAB – OPEN

# Electromagnetic Radiation and Matter

**How do different wavelengths of electromagnetic radiation affect how they interact with living tissue?**

Ionizing electromagnetic radiation is energetic enough to eject electrons from living and nonliving materials. This can result in harmful side effects such as cancer when skin cells are negatively impacted. The fact that electromagnetic radiation including visible and ultraviolet light can transfer enough energy to the materials it interacts with, via collisions, to affect them to such a degree, implies that electromagnetic energy behaves as particles do. That is, electromagnetic radiation can concentrate its energy into discrete units, including photons. In this lab you will observe how light interacts with metals, and from your observations, infer how light can affect living tissues. You will use your observations from the lab to evaluate a claim made in an article published in a peer-reviewed, science journal on the relationship between exposure to electromagnetic radiation and skin cancer.

## Focus on Science Practices

**SEP 6** Construct Explanations
**SEP 7** Engage in Argument from Evidence
**SEP 8** Obtain, Evaluate and Communicate Information

## Materials Per Group

- Electroscope
- Flashlight or incandescent lamp
- Rubber rod
- Wool
- Zinc foil, 8-cm square
- Sandpaper
- Ultraviolet lamp, short-wavelength (optional)
- Ultraviolet lamp, long-wavelength (optional)

## Safety

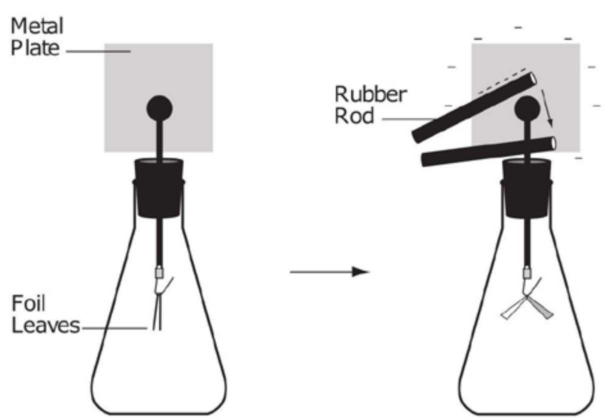
*Ultraviolet light may damage the eyes and cause cataracts. Wear safety glasses when using an ultraviolet light source and do not look directly at the light. Wash hands thoroughly with soap and water before leaving the laboratory.*

## Procedure

*How can electromagnetic radiation ionize a material, or jolt an electron(s) loose when it hits the material?*

1. Balance the zinc plate against the top of the electroscope so that the plate is almost perpendicular to the ground. The plate should be touching the wire pole and metal sphere and should face in a direction which will make it easy to observe the deflection of the electroscope leaves. Use a piece of transparent tape to hold the zinc plate in place, if needed. Also, polish the zinc plate with sandpaper because the oxide coating on the zinc surface will prevent the photoelectric effect. See Figure 1.

**Figure 1**




2. Charge the electroscope negatively by conduction: rub the rubber rod vigorously with wool, then gently slide the rod against the metal sphere on top of the electroscope. The rubber rod and the electroscope must be in direct contact. Repeat this process until the foil leaves of the electroscope are fully deflected. The foil leaves repel each other because each possesses electrons electrons, which repel each other owing to their negative charges.

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**3. SEP Plan and Carry Out Your Investigation** If a light source is able to ionize the metal plate the plate will become positively charged and attract the excess electrons away from the foil leaves. When the foil leaves lose their excess electrons they become neutral and do not repel each other. Plan a short procedure to determine what effects, if any, wavelength or frequency has on electromagnetic radiation's ability to ionize matter. Record your procedure; and identify the independent, dependent, and control variables. Carry out your procedure after your teacher approves it. Record your observations.

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Engage in Argument from Evidence** Based on your data, is it likely that electromagnetic radiation has more harmful effects on living tissue at shorter wavelengths or longer wavelengths? Explain.

2. **SEP Construct Explanations** Construct an explanation, based on your data, that supports the idea that electromagnetic radiation behaves in a particle-like manner.

3. **SEP Evaluate and Communicate** Go online and find the article "The Role of Optical Radiation in Skin Cancer" in the National Center for Biotechnology Information (NCBI) Journal. Do your observations support or contradict the claims made in the article? Explain.

NAME ______________________ DATE __________ CLASS __________

SCIENCE PERFORMANCE-BASED ASSESSMENT

# Clothing and Sun Protection

**How can different clothing materials protect us from the sun?**

**Phenomenon** Exposure to ultraviolet (UV) radiation has been linked to a number of human health problems, including sunburn, skin cancers, premature aging of the skin, cataracts, and alteration of the immune system. UV radiation penetrates Earth's ozone layer in two wavelength bands, UVB (290–320 nm) and UVA (320–400 nm). UVB rays are higher in energy and act directly on biological molecules causing skin cancer, aging, and the delayed sunburn. In contrast, the lower energy UVA rays act more indirectly, causing an "immediate" sunburn that diminishes within several hours after exposure. Concern about the adverse effects of UV radiation exposure has led to the development of sunscreens and clothing that block the UV radiation. These products work by absorbing the UV radiation and dissipating the absorbed energy as heat before it can damage biological molecules.

In this lab you will develop a procedure to observe how different fabrics protect us from UV exposure over time.

## Focus on Science Practices

**SEP 3** Plan and Carry Out Investigations
**SEP 4** Analyze and Interpret Data
**SEP 7** Engage in Argument from Evidence
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Sun print paper, 12 cm × 9 cm, 3
- Cotton fabric, 2.5 cm × 5 cm, 3
- Black construction paper strip, 2.5 cm × 5 cm, 3
- Multifiber test fabric strips, 2 cm, 3
- Foam board, 20 cm × 20 cm
- Water bowl with water
- Pins, 18

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## Safety

*Ultraviolet rays are damaging to the eyes. Never look directly into the UV light or the sun. Wash hands thoroughly with soap and water before leaving the laboratory. Wear goggles and gloves. Follow all laboratory safety precautions.*

## Procedure

*How can you determine which fabric offers the most protection from UV rays?*

1. Indoor daylight or incandescent light will not damage the sun print paper if the exposure time is short. Read all of the directions for this laboratory. Become familiar with the entire procedure so that work can proceed quickly once the sunprint paper is removed from its storage container.

2. **SEP Plan Your Investigation** Develop a procedure that tests how different fabrics can protect us from UV exposure over time. Use the materials provided to record your detailed procedure. Be sure to add proper controls. Have your teacher check your procedure before proceeding. As you plan your procedure keep the following in mind:

   **a.** The fabrics included in the strip, in order, are: wool (cream colored), acrylic, polyester, nylon, cotton, and acetate.

   **b.** For bright sunlight, exposure cannot exceed 2 minutes. If the sky is overcast, exposure should not exceed 6 minutes.

3. **SEP Carry Out Your Investigation** When the preparation is complete, take the entire setup outside and place it in the sunlight. Be careful not to overexpose the paper.

4. When exposure is complete, immediately soak the sun print paper in the container of water for about one minute. This will develop the sun print paper and make the exposures permanent.

5. Remove the paper from the water. Let it drip dry for about one minute. Lay the paper flat on the foam board and pin it into place and let it dry. The images will sharpen during the drying time.

6. Allow the paper to dry completely (overnight drying time may be required). When the paper is completely dry insert a picture(s) of the developed print.

NAME ______________________ DATE __________ CLASS __________

## Analyze and Interpret Data

1. **SEP Analyze Data** Based on your results, rank the fabric materials in order of their UV resistance from best to worst?

2. **SEP Interpret Data** What fabric property do you think most contributes to its UV protection?

3. **SEP Use Scientific Reasoning** What role does color play in a fabric's ability to absorb or block UV radiation?

4. **CCC Cause and Effect** How would wetting the fabric affect its performance against UV radiation?

5. **SEP Engage in Argument** Rayleigh scattering is the scattering of light by particles that are smaller than the wavelength of the light. The absorption of UV light by sunscreen is specific to certain wavelengths. Do your observations in this lab demonstrate electromagnetic radiation as fitting a wave model or a particle model of light?

6. **SEP Evaluate and Communicate** Go online and find the article “The Role of Optical Radiation in Skin Cancer” in the National Center for Biotechnology Information (NCBI) Journal. Based on the research findings communicated in the article, is it more important that young children or adults wear clothing during prolonged sun exposure? Based on your observations, what type of clothing should people wear to achieve maximum protection against harmful electromagnetic radiation? Explain.

NAME ____________________ DATE __________ CLASS __________

# Investigation 13

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INQUIRY LAB – OPEN

# Binary Logic

**How do computers store and process information?**

Binary uses ones and zeros to represent information. Computers use binary to store and process information. For a simple binary number, the rightmost column is the ones column, the one to the left of it is the twos column, and to the left of that is the fours column. For example the number five is written as 101. There is one four and one one. Adding them together gives 5. Considering how simple binary sounds, and how complicated the tasks that computers can perform are, it quickly becomes clear that there is something more going on. The answer is logic gates.

Logic gates provide a predictable output depending on the input signals. These inputs and corresponding outputs are summarized in truth tables. These can be as simple as if light A is powered, then light B is unpowered; and if light A is unpowered, then light B is powered. The truth table for this system is shown in Table 1.

**Table 1**

| Gate | |
|---|---|
| **Input** | **Output** |
| 0 | 1 |
| 1 | 0 |

In this activity you will use switches, in both series and parallel circuits, to assemble simple logic gates and determine their corresponding truth tables.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations and Design Solutions

NAME ________________________________________ DATE ____________ CLASS ____________

## Materials Per Group

- Breadboard
- Switches, 2
- LED
- 100 Ω Resistor
- Batteries or 3 V power source
- Battery holder
- Wire
- Wire cutter
- Wire stripper

## Safety ⚠

*Take care that the circuits are assembled correctly before connecting the power supply. If too much power flows through electrical components, they can become very hot and break. LEDs only work when wired with the correct polarity and can be damaged by improper installation.*

## Procedure

Breadboards (Figure 1) provide a convenient way to construct prototypes and assemble temporary circuits. The outermost columns, marked with + and − symbols, are the power rails and the holes are vertically connected. The central rows are the terminal strips and are horizontally connected. The large gap in the center is called the DIP support and separates the board into two separate sections. Integrated circuits (DIP chips) can be placed bridging the DIP support, allowing for more complicated circuits to be prototyped on a breadboard.

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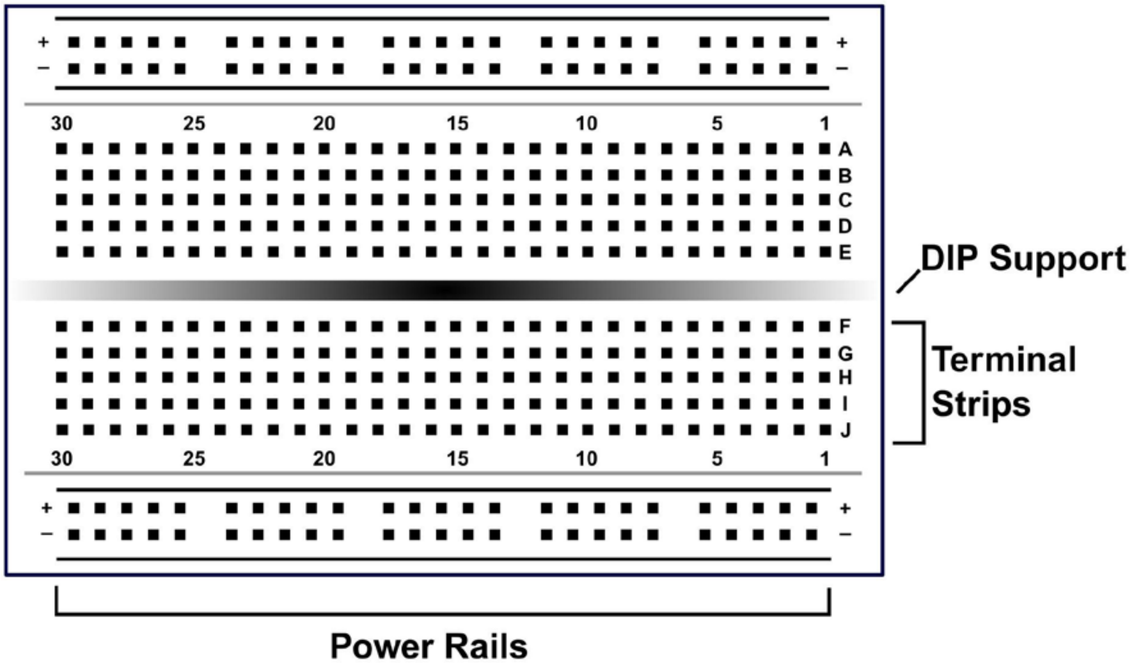
**Figure 1**




## Part I: NOT Gate

*How does a NOT gate work?*

1. Assemble the breadboard circuit shown in Figure 2 (do not attach the battery yet). You may need to cut and strip appropriate lengths of wire. The switch in Figure 2 is in the off position.

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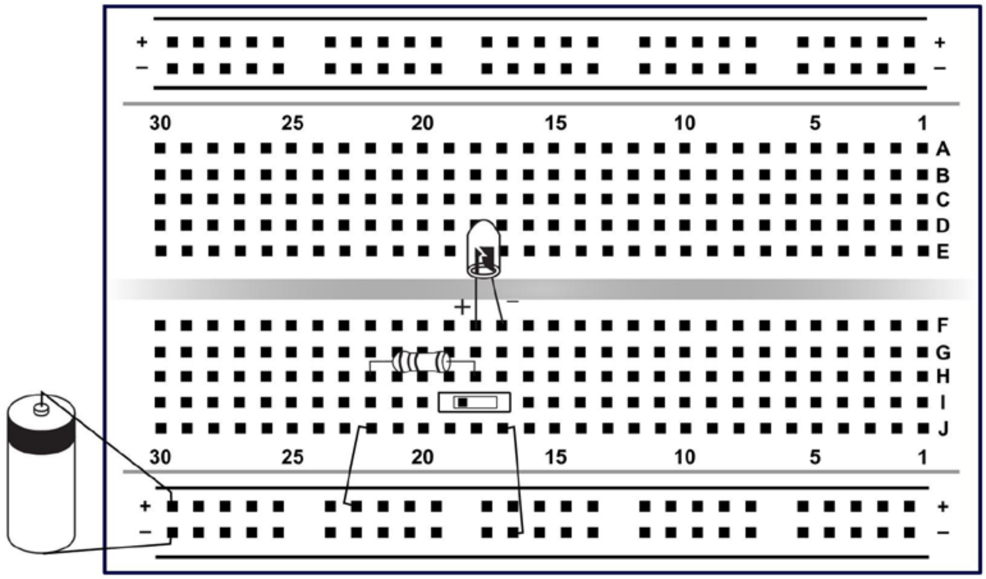
**Figure 2**




2. With the switch in the off position, connect the battery.
3. Record the state of the LED in the data table.
4. Move the switch to the on position and record the state of the LED in the data table.

**Table 2**

| NOT Gate | |
|---|---|
| **Switch Position** | **LED Status** |
| | |
| | |

NAME ______________________ DATE __________ CLASS __________

**Part II: AND Gate**

*How does an AND gate work?*

5. **SEP Plan an Investigation** An AND gate should only be on when both switches are in the on position. Design a breadboard circuit with two switches that will function as an AND gate.

6. After showing your design to your teacher, assemble your circuit. Then with switch 1 and 2 in the off position connect the battery.
7. Record the state of the LED in the data table.
8. Move the switch 1 to the on position and record the state of the LED in the data table.
9. Move the switch 2 to the on position and record the state of the LED in the data table.
10. Move the switch 1 to the off position and record the state of the LED in the data table.

NAME ______________________ DATE ____________ CLASS ____________

**Table 3**

| AND Gate | | |
|---|---|---|
| **Switch 1 Position** | **Switch 2 Position** | **LED Status** |
| | | |
| | | |
| | | |
| | | |

## Part III: OR Gate

*How does an OR gate work?*

11. **SEP Plan an Investigation** An OR gate should be on when either or both switches are in the on position. Design a breadboard circuit with two switches that will function as an OR gate.

12. After showing your design to your teacher, assemble your circuit. Then with switch 1 and 2 in the off position connect the battery.
13. Record the state of the LED in the data table.
14. Move the switch 1 to the on position and record the state of the LED in the data table.

15. Move the switch 2 to the on position and record the state of the LED in the data table.
16. Move the switch 1 to the off position and record the state of the LED in the data table.

**Table 4**

| OR Gate | | |
|---|---|---|
| **Switch 1 Position** | **Switch 2 Position** | **LED Status** |
| | | |
| | | |
| | | |
| | | |

## Analyze and Interpret Data

1. **SEP Apply Scientific Reasoning** A NAND gate combines an AND gate with a NOT gate in a cascade (series). First, two inputs are fed into an AND gate. Then,the output of this gate is put through a NOT gate. Use this information and the results of your investigation to complete the truth table for a NAND gate.

**Table 5**

| NAND Gate | | |
|---|---|---|
| **Switch 1 Position** | **Switch 2 Position** | **LED Status** |
| | | |
| | | |
| | | |
| | | |

2. **SEP Apply Scientific Reasoning** A NOR gate combines an OR gate with a NOT gate in a cascade (series). First two inputs are fed into an OR gate. Then, the output of this gate is put through a NOT gate. Use this information and the results of your investigation to complete the truth table for a NOR gate.

**Table 6**

| NOR Gate | | |
|---|---|---|
| **Switch 1 Position** | **Switch 2 Position** | **LED Status** |
| | | |
| | | |
| | | |
| | | |

3. **SEP Calculate** Computers store all of their information in base 2 (binary). Convert the numbers 17 and 4 into base 2 and add them together.

4. **SEP Construct an Explanation** By combining logic gates, how are computers able to perform complex calculations and tasks?

5. **SEP Identify Limitations of a Model** What are some of the possible limitations associated with the way that computers digitally handle information?

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INQUIRY LAB – OPEN

# Converting Electrical Signals to Sounds

**How do speakers use magnets and wires to produce sound?**

In a sound system, a tuner decodes various types of electrical signals and converts the signals into oscillating electric current that is proportional to the frequency and amplitude of sound waves. The signals get an electrical boost in the amplifier, which then sends the electrical signal to the wire coils in the speakers. In this lab you will build an audio speaker and discover how it converts electrical signals into sound.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 3** Plan and Carry Out Explanations
**SEP 6** Construct Explanations and Design Solutions
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Alligator clips, 2
- Cups, plastic, 2
- Headphone-jack plug
- Magnet wire, 50 cm
- Magnets, neodymium, 2
- Pencil or pen
- Radio (to be shared by class)
- Sandpaper strip, 5 cm x 7.5 cm
- Scissors
- Speaker wire, 30 cm
- Tape, transparent
- Wire cutters/strippers

## Safety

*Neodymium magnets have very strong magnetic fields, but are themselves very brittle. Be careful not to pinch your fingers between them and do not bring them close to any electronic equipment. Handle wire cutters carefully. Be cautious of the ends of the wire as they may be sharp. Wear safety glasses. Wash your hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.*

NAME ________________________________ DATE ____________ CLASS ____________

## Procedure

### Part I: Building the Speaker

*How can magnets be used to produce sound?*

1. **SEP Develop a Model** Design and build a simple speaker using wire, magnets, and cups. Record your detailed procedure. Have your teacher approve your design before proceeding.

### Part II: Connecting the Headphone-Jack Plug and Leads

*What is the relationship between the amount of wire in contact with the plug and sound quality?*

2. Using scissors, carefully cut down the middle of the speaker wire between the two sheathed wires and then separate them to make a Y shape (see Figure 1).

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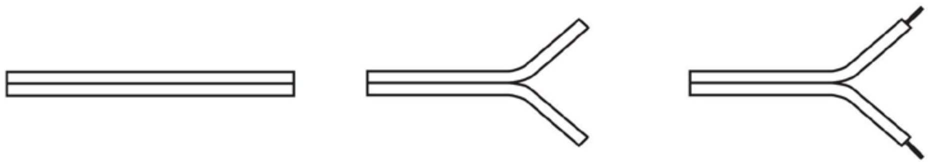
**Figure 1**



3. Use wire cutters or wire strippers to remove about 3 cm of the plastic sheath off the two split ends (see Figure 1). Several strands of wire will be exposed under the plastic sheath. Use care not to cut the fine wires during the wire-stripping process.

4. Repeat steps 2 and 3 for the other end of the speaker wire.

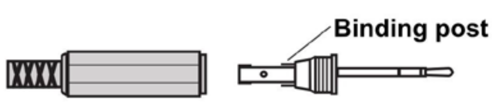
5. Thread the fine wire strands from one wire end into the hole at the end of the alligator clip.

6. Tightly wrap the loose wires around the end of the alligator clip. Use tape to bind the wire and alligator clip, if necessary. (If available, a soldering iron and solder can be used to bind the wire to the alligator clip).

7. Repeat steps 5 and 6 using the separated wire adjacent to the wire that was just attached to an alligator clip.

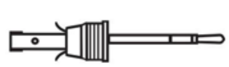
8. Unscrew the plastic covering off the metal plug. This will expose the binding posts for the speaker wire (see Figure 2).

**Figure 2**




9. Carefully bend the two binding posts outward to allow room to thread the wire (see Figure 3.)

**Figure 3**

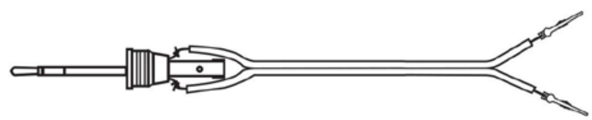


10. Thread the wire strands from one of the free ends of the speaker wire into the hole in one of the binding posts.

11. Tightly wrap the loose wires around the binding post. Make sure extraneous wire strands do not make contact with other metal parts of the headphone–jack plug. Use scissors to cut off any extra wire, if necessary.

12. Repeat steps 10 and 11 for the other wire end and binding post. The completed headphone–jack plug and leads should look like Figure 4.

**Figure 4**



**Part III: Testing the Speaker**

*How does magnet position affect sound?*

13. Attach one of the alligator clips to one of the sanded wires extending from the coil at the bottom of the speaker. Attach the second alligator clip to the second extended wire.

14. Plug the headphone–jack plug into the output port on the radio. Adjust the radio volume to its maximum setting.

15. Turn the tuning knob until noise/music can be heard from the speaker. Try both AM and FM stations. Hold the speaker near your ear, but do not touch the speaker to your ear (this will prevent the speaker cone from vibrating). If no radio stations tune in on the radio (due to interference), listen for "white noise" to determine the functionality of the speaker. Best reception is usually obtained near a window with the radio held high and upright.

16. Adjust or modify the speaker design, such as the position of the magnets, the number of coils on the diameter of the coil, etc., to obtain the best audible sound, if needed.

17. Compare the sound emitted by speakers built by different groups.

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## Analyze and Interpret Data

1. **SEP Make Observations** Describe the volume and quality of the sound emitted by the speaker. How did the sound from your speaker compare to that of your classmates?

2. **SEP Design a Solution** What modifications or adjustments can be made to your speaker to improve the sound quality?

3. **SEP Evaluate and Communicate** Based on your observations, explain how a speaker works?

4. **SEP Communicate Scientific Information** Why does it not matter which pole of the magnet is pointing up in a speaker?

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INQUIRY LAB – OPEN

# Converting Sunlight to Electricity

**How is energy from the sun used to produce electricity?**

Not only is the sun a source of heat and light, it is a source of electricity, too. Solar cells are used to convert sunlight to electricity. Solar cells can provide electricity for all kinds of equipment, from calculators and watches to roadside emergency phones and even vehicles. In this lab you will use solar technology to make your own solar-powered car.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 6** Construct Explanations and Design Solutions
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Cardboard base, 10.5 cm x 14 cm
- DC motor
- Ruler
- Solar car accessory bag of wheels, axles, and gears
- Solar mini panel, 1-V, 400 mA
- Scissors
- Straw
- Tape
- Timer or stopwatch
- Wire stripper

## Safety

*Although the current generated by the solar panel is small and not harmful, use caution when connecting the wires. Do not touch bare wires that are part of a "live" circuit. Wear sunscreen and sunglasses when working in bright sunlight. Never look directly at the sun. Wash your hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.*

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## Procedure

### Part I: Chassis Assembly

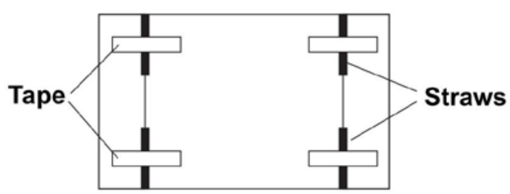
*How does wheel placement affect car movement?*

1. With a pencil, draw a line across the cardboard base 2 cm from one end. Repeat at the other end (see Figure 1).

**Figure 1**

2. Cut the straw into four pieces, each 4 cm long. Tape one piece of straw along one line on the base, with the end of the straw even with the edge of the base. Repeat with a second straw on the opposite end of the line.
3. Repeat step 2 with the other two pieces of straw on the other line (see Figure 2).

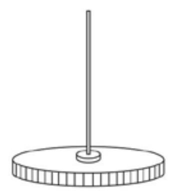
**Figure 2**




4. Insert the end of one axle into one wheel hole. Insert the other end of the axle through the straws on one end of the base.
5. Press a second wheel onto the free end of the axle. *Note:* If the fit is too tight, set the axle vertically with one wheel resting on the work surface. Press down on the top wheel, being careful to not bend the axle with too much pressure. It may be necessary to gently tap the wheel with a hammer or rubber mallet.
6. Using the largest gear from the accessory bag, place the flat side of the gear on the work surface.

**7.** Insert a second axle into the gear (see Figure 3).

**Figure 3**



**8.** Lift the axle and gear and push the gear about 1 cm onto the axle.

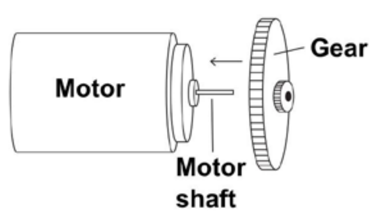
**9.** Insert the end of the axle with the gear into a wheel hole.

**10.** Repeat steps 4–5 with the other end of the base.

**11.** Attach the tires to the wheels.

**12.** Using the smallest gear, insert the motor shaft through the hole in the gear with the flat side of the gear facing the motor (Figure 4).

**Figure 4**



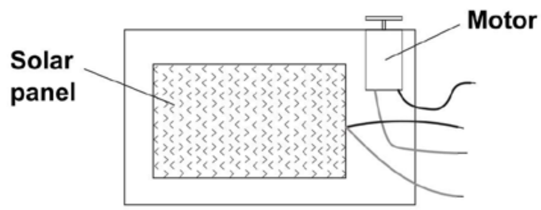

**13.** Mount the motor on top of the base with tape so the small outer gear attached to the motor meshes with the large gear on the axle. *Note*: It may be necessary to raise the motor up slightly by placing a small piece of folded paper under the motor. Test for proper alignment by setting the car on the work surface and moving it back and forth. When the motor is properly placed, the gear on the motor should mesh with the gear on the axle and turn easily without slipping.

## Part II: Attaching the Solar Panel

*What is the relationship between visible bare wire and solar panel performance?*

14. Note the ends of the wires on the solar panel. If less than 1 cm of bare wire is visible, use wire strippers to remove more of the insulation.
15. Repeat step 14 for the motor wires.
16. Make a loop of masking tape with the sticky side out and place it in the center of the upper side of the chassis.
17. Gently press the solar panel on top of the tape to secure it near the center of the chassis (see Figure 5).

**FIgure 5**




18. Bend the black wires of the solar panel and the motor so they are under the chassis.
19. Turn the chassis over so the solar panel is covered.
20. Twist the bare ends together securely and tape the wires to the underside of the chassis so they will not touch the work surface.
21. Repeat steps 18–20 with the red wires of the solar panel and motor. Make sure the wires will not interfere with the motion of the car.

## Part III: Testing the Car

*How does the intensity of the sun affect solar panel performance?*

22. Take the car outside to an area designated by the instructor, keeping the solar panel covered with your hand or a piece of paper.

**23.** Set the car on the ground and uncover the solar panel. The car should start moving across the ground. If it does not, check the following.

   **a.** If the motor does not turn, check the wire connections.

   **b.** If the motor spins but the car does not move, check the gear alignment. Make any necessary adjustments.

**24.** Note which direction the car moves. If the motor is in front, the car has "front-wheel drive". If the motor is in the back as the car moves, the car has "rear-wheel drive". *Note*: Switching the wire connections will reverse the current and the motor will spin in the opposite direction.

**25.** If the car veers to the right or left, check the axle alignment and adjust as needed.

**26.** Once the car is functioning well, go to the start of the prepared race track.

**27.** Set the car down at the start and time how long it takes to travel 3 meters. Record the time and any observations in your data table.

**28.** Repeat step 27 for a total of 5 trials.

**29.** Calculate the car's speed for each trial and average speed. Record the values in the data table.

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**Table 1**

| Solar Car Performance | | | | |
|---|---|---|---|---|
| **Trial** | **Distance (m)** | **Time (s)** | **Speed (m/s)** | **Observations** |
| **1** | | | | |
| **2** | | | | |
| **3** | | | | |
| **4** | | | | |
| **5** | | | | |
| **Average** | | | | |

## Part IV: Design Challenge

*Which variables are most important for solar car movement?*

**30. SEP Design a Solution** Modify the solar car you previously built in order to achieve a faster average speed on the same 3 meter track. The solar panel, motor, motor gear, wheels and axles must remain the same. The cardboard base must be used for the chassis, but it may be modified. Record the modifications to your design. Conduct five trials on the track and record the time for each trial in the data table.

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**Table 2**

| Modified Solar Car Performance | | | |
|---|---|---|---|
| **Trial** | **Distance (m)** | **Time (s)** | **Speed (m/s)** |
| **1** | | | |
| **2** | | | |
| **3** | | | |
| **4** | | | |
| **5** | | | |
| **Average** | | | |

## Analyze and Interpret Data

1. **SEP Analyze Data** How did the modified design compare to the original? Was your group able to increase the speed of the car?

2. **SEP Communicate Scientific Information** Describe the types of energy involved in this lab and how energy is transferred to cause a solar car to move?

**3. SEP Communicate Scientific Information** Some solar panels can be adjusted to different angles. Why would this be necessary?

**4. SEP Evaluate and Communicate** What are some disadvantages to using solar energy to generate electricity?

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ENGINEERING PERFORMANCE-BASED ASSESSMENT

# Send Messages with a Telegraph

**How does a telegraph send messages?**

**Phenomenon** The term telegraph is most often used when referring to the electrical telegraph that was developed in the 19th century. A simple operator key and the famous Morse code enabled operators to communicate using a series of “dots and dashes” and later using the sound of clicks produced by an electromagnet-activated key. Telegraph systems quickly spread through the United States and Europe. Circuitry advancements allowed for the simultaneous transmittance of multiple messages on the same line. The telegraph was a major factor in the rapid rate of industrialization in the second half of the 19th century known as the Technological Revolution.

In this lab, you will develop a simple wired telegraph and demonstrate its effectiveness by sending coded messages to other lab groups.

## Focus on Science Practices

**SEP 1** Ask Questions and Define Problems
**SEP 2** Develop and Use Models
**SEP 8** Obtain, Evaluate, and Communicate Information

## Materials Per Group

- Alligator clip wire, black, 2
- Alligator clip wire, red, 2
- Batteries, D-cell, 1.5 V, 2
- Battery holders, 2
- Contact key, 1
- Iron nail, 2”, 1
- Iron strip, 1
- Magnet wire, 5 m
- Morse Code handout, 1
- Pink foam base, 1
- Pliers
- Ruler, metric
- Sandpaper strip, 1
- Tape
- Weight, 1 kg, 1

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## Safety

*While the batteries are not harmful, small shocks are still possible. Do not complete the circuit with the battery for more than ten-second intervals. Since there is very little resistance in the wires, the battery can discharge quickly and become very hot if it is connected for a longer duration. Care should be taken when wrapping and unwrapping the wire. The pointed ends of the wire may be sharp. Wear safety glasses. Please follow normal laboratory safety guidelines.*

## Procedure

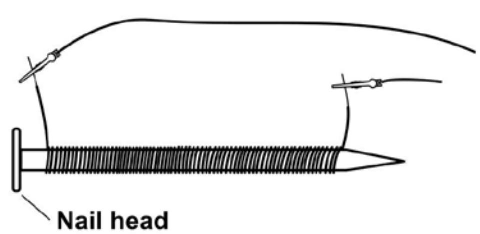
### Part I: Assembling the Telegraph

*How can wire and an iron nail create magnetic current?*

1. Tightly wind the magnet wire up and down the length of the nail, leaving about 8 cm of free wire on each end. Make sure the wire is wound as tightly as possible while taking care not to break the thin wire.

2. Sand off about an inch of insulation off the free ends of the wire. See Figure 1.

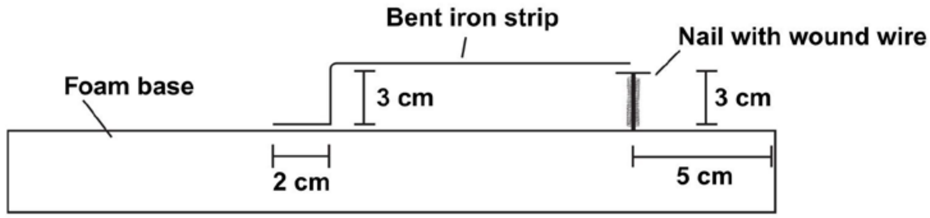
**Figure 1**




3. The nail should be placed about 5 cm from the short edge of the foam base as shown in Figure 2. Push the pointed tip of the iron nail into the foam base so that it protrudes about 3 cm from the surface.

4. Using pliers, bend the iron strip at a 90-degree angle at a point 2 cm from the end. The strip will look like an "L". Now, 3 cm from the first bend, bend the long side of the "L" away from the short side at a 90-degree angle. See Figure 2.

**Figure 2**




5. Position the long end of the strip over the iron nail, as seen in Figure 2. Tape the 2-cm end of the iron strip to the surface of the foam base as tightly as possible so that it stays in place.

6. Take a 1 kg weight and place it on top of the 2 cm end of the iron strip. This is to ensure that the strip does not move underneath the tape.

**Part II: Testing the Telegraph and Sending a Message**

*How can an electromagnet be used to send a message?*

7. **SEP Develop a Model** Determine the method of connection for the contact key, D-cell batteries, and battery holders to the telegraph. When the contact key is pressed, the iron strip must respond by tapping the top of the iron nail. Verify your telegraph is working properly by having another group observe a one word Morse code transmission and decode it. Record your detailed procedure. Before you carry out your investigation, get your teacher’s approval.

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## Analyze and Interpret Data

1. **SEP Use a Model to Evaluate** Explain how electricity flows in the circuit and why the iron strip is attracted to the nail.

2. **SEP Define Problems** Was it possible to transmit a message from your telegraph to that of another group? If not, what prevents this from occurring?

3. **SEP Evaluate and Communicate** If a light bulb was added to the system between the battery and the contact key, would it still work? If not, why do you think that is?

4. **SEP Identify Limitations of a Model** What difficulties did you encounter when transmitting a message with the telegraph? How could you improve your design?

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5. **SEP Evaluate and Communicate** What are the limitations of a telegraph system? How have modes of communication improved today?

# Investigation 14

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INQUIRY LAB – OPEN

# Subatomic Particles

**How do the fundamental forces in the universe come together to form atoms?**

Prior to the 1930s, the structure of matter was thought to be pretty well understood in terms of protons, neutrons, and electrons. As scientists' knowledge of nuclear structure exploded with the discoveries of nuclear fission and cosmic rays, it became clear that more fundamental particles were needed to explain the structure of matter. The list of fundamental particles now includes quarks, gluons, positrons, muons, neutrinos, etc. In this lab you will build a model of an atomic nucleus down to its quarks.

## Focus on Science Practices

**SEP 2** Developing and Using Models
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Foam counter, 10
- Marbles, magnetic, blue, 2
- Marbles, magnetic, red, 2

## Safety

*Always wash hands thoroughly with soap and water before leaving the laboratory.*

## Procedure

*How do the parts of an atom influence its activity?*

1. **SEP Develop Models** Use the materials provided to build a model of a neutron and a proton. Decide on which material will represent which particle. Describe your choices.

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2. **SEP Use Models** If you need to change your model of a proton into a model of a neutron, what changes need to take place?

3. The nuclear fusion of deuterium and tritium produces a helium atom. How many protons and neutrons does each atom contain?

4. **SEP Use a Model to Evaluate** Using your model from step 1, how would the fusion reaction described in step 3 look? Are there any particles left over? Add an image or drawing of your reaction.

5. Nuclear fission can take place when uranium-235 is bombarded with a neutron. One of many results is barium-141, krypton-92, 3 neutrons, and a great amount of energy. How many protons and neutrons does each atom contain?

6. **SEP Use a Model to Evaluate** Using your model from step 1, how would the fission reaction described in step 5 look? Are there any particles left over? Add an image or drawing of your reaction.

## Analyze and Interpret Data

1. **SEP Use a Model to Evaluate** What conclusions can you draw about the number of atoms, protons, and neutrons from the fusion and fission reaction equations?

2. **SEP Identify Limitations of a Model** What aspects of nuclear fusion and fission is this model unable to demonstrate?

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**3. SEP Use Mathematics** For the fusion of deuterium and tritium to form helium, the total mass of the reactants is $8.35 \times 10^{-27}$ kg. The total mass of the products is $8.32 \times 10^{-27}$ kg. Use $E = mc^2$ to calculate the amount of energy released in MeV (1 joule = $6.242 \times 10^{12}$ MeV). For $c$, the speed of light, use the value $3.00 \times 10^8$ m/s.

**4. SEP Use Mathematics** For the fission of uranium–235 to barium-141 and krypton-92, the total mass of the reactants is 236.053 amu. The total mass of the products is 235.867 amu. Use $E = mc^2$ to calculate the amount of energy released in MeV.
(1 amu = $1.6605 \times 10^{-27}$ kg).

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INQUIRY LAB – OPEN

# Forces and Atomic Nuclei

**What holds the nucleus of an atom together?**

Nuclear forces are the strong forces that bind nucleons into atomic nuclei. They are stronger than the electronegative forces that repel protons, but have a limited range. As a result, we don’t usually experience the effects of nuclear forces directly but, if those forces are disrupted the potential energy stored in atomic nuclei can be released on a catastrophic scale. Modeling is a safe way to study nuclear forces in the laboratory.

## Focus on Science Practices

**SEP 2** Developing and Using Models
**SEP 4** Analyzing and Interpreting Data

## Materials Per Group

- Marbles, glass, 16 mm, 2
- Pliers
- Rubber bands, 9 cm x 0.3 cm, 5
- Ruler, metric, 30 cm
- Spring, 7.6 cm x 1.3 cm

## Safety

*Wear safety goggles when performing this lab. Be careful not to pinch your fingers when extending and compressing the spring. Use caution when bending the ends of the spring with pliers. Always wash hands thoroughly with soap and water before leaving the laboratory.*

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## Procedure

*What is the relationship between nuclear bonds and energy?*

1. **SEP Develop Models** Using the materials provided develop a model to demonstrate the attractive and repulsive forces in an atomic nuclei. Record your detailed procedure in the space provided. Have your teacher check your procedure before beginning any lab work.

NAME ______________________________ DATE ____________ CLASS ____________

| Attraction versus Repulsion | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

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## Analyze and Interpret Data

1. **SEP Use Models** What do the marbles, rubber bands and spring represent in this experiment?

2. **SEP Analyze Data** How did the addition of rubber bands affect the total force exerted on the marbles and how does this apply to nuclear forces?

3. **SEP Use a Model to Evaluate** Large nuclei tend to have a higher neutron-to-proton ratio. How can you use your model to explain this?

4. **SEP Use a Model to Evaluate** What conclusions can you draw about nuclear forces from the model constructed in this lab?

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5. **SEP Identify Limitations of a Model** What aspects of nuclear forces is this model unable to demonstrate?

6. **SEP Develop a Model** How could you modify this model to show the effects of adding a proton?

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INQUIRY LAB – OPEN

# Nuclear Reactions and Critical Mass

**How does a nuclear reactor sustain fission to produce energy?**

Uranium-235 is a fissionable isotope of uranium that when struck by a neutron can produce a chain reaction resulting in the output of large amounts of energy. The chain reaction will continue as long as there is enough fuel. Critical mass is the minimum amount of fissionable material needed to sustain a chain reaction. In this lab you will model a chain reaction with dice. The dice represent the fuel. As certain numbers are rolled you either gain dice or lose them.

## Focus on Science Practices

**SEP 2** Developing and Using Models
**SEP 4** Analyzing and Interpreting Data

## Materials Per Group

- Dice, six-sided, 20

## Safety

*Always wash hands thoroughly with soap and water before leaving the laboratory.*

NAME ______________________________ DATE ____________ CLASS____________

## Procedure

### Part I: Below Critical Mass

*How does low mass affect reactor output?*

1. **SEP Develop Models** Using only ten dice, develop a model to demonstrate a nuclear reactor that has fuel below the critical mass. You will need to run three trials. Record your detailed procedure in the space provided. Have your teacher check your procedure before beginning.

| Nuclear Reactor Fuel–Below Critical Mass | |
|---|---|
| **Trial** | **Number of Rolls Until Reaction Termination** |
| **1** | |
| **2** | |
| **3** | |

NAME ______________________________ DATE ____________ CLASS ____________

**Part II: Critical Mass**

*How does high mass affect reactor output?*

2. **SEP Develop Models** Develop a model to demonstrate a nuclear reaction that has fuel at critical mass. Record your detailed procedure in the space provided. Have your teacher check your procedure before beginning.
   - **a.** Start with 10 dice, do not exceed 20.
   - **b.** Should be able to complete ten rolls.
   - **c.** Record number of dice used on each roll.

NAME ________________________________________ DATE ____________ CLASS____________

| Nuclear Reactor Fuel–Critical Mass | | | |
|---|---|---|---|
| **Roll** | **Total number of dice** | | |
| **1** | | | |
| **2** | | | |
| **3** | | | |
| **4** | | | |
| **5** | | | |
| **6** | | | |
| **7** | | | |
| **8** | | | |
| **9** | | | |
| **10** | | | |

## Analyze and Interpret Data

1. **SEP Analyze Data** In part I, did each of your trials produce a similar number of rolls before the reaction terminated? Explain any differences between the trials in terms of probability.

2. **SEP Use a Model** How does the model in part I represent a nuclear reactor not at critical mass?

3. **SEP Analyze Data** In part II, it is possible that your group or another group in your class did not reach 10 rolls. Using your model as a guide, what could be a real-world explanation for the reaction terminating earlier than expected?

4. **SEP Use a Model to Evaluate** How did the number of dice in each roll fluctuate? With an unlimited number of dice, do you think you could have kept going another ten rolls?

5. **SEP Use Model** How does this model represent a nuclear reactor at critical mass?

6. **SEP Identify Limitations of a Model** What aspects of nuclear fission was this model not able to demonstrate?

NAME ______________________ DATE __________ CLASS __________

SCIENCE PERFORMANCE-BASED ASSESSMENT

# Model Nuclear Forces

**How do models help us understand what we cannot see?**

**Phenomenon** Nuclear particles and forces are all around. We may not observe or feel them directly, but they play an important role in how atoms interact. The forces that act between nucleons are called strong nuclear forces. These forces bind the protons and neutrons into atomic nuclei. Protons have +1 charge and experience an electric charge that tries to push them apart, but the nuclear forces holding them in are stronger and overcome the electromagnetic force. The energy required to hold protons together against their electric repulsion is stored as the protons and neutrons are brought together to form the nucleus. When the nuclear force holding them together is disrupted, this potential energy is released. Nuclear forces are substantially stronger than the chemical bonds that hold atoms together in molecules. In this lab, you will model how nuclear stability changes as nucleons are added to the nucleus.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 6** Construct Explanations and Design Solutions

## Materials Per Group

- Chips, green, 150
- Chips, red, 150
- Die, 6-sided, 10

## Safety

*Always wash hands thoroughly with soap and water before leaving the laboratory.*
*Please follow normal laboratory safety guidelines.*

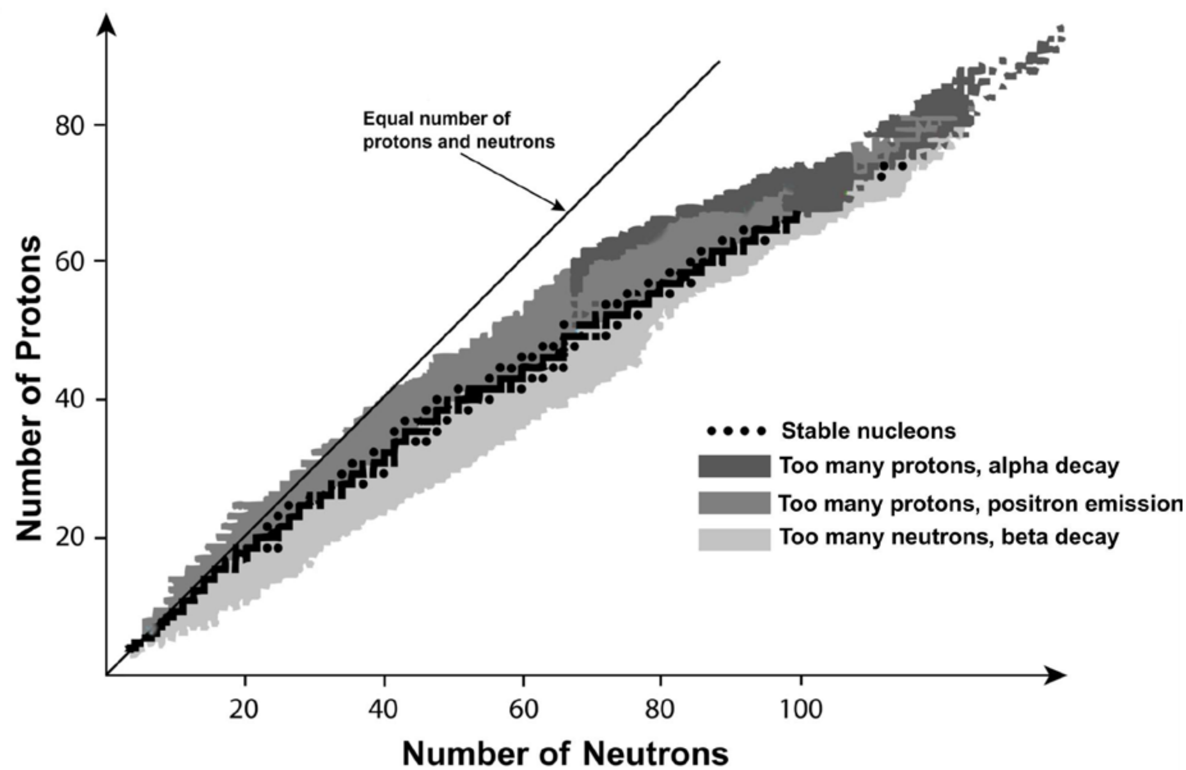
NAME ______________________ DATE __________ CLASS __________

## Procedure

*What is the relationship between nucleus stability and the proton to neutron ratio?*

1. Use **Figure 1** to determine how stable your nucleus is after each proton or neutron addition.

**Figure 1**



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2. **SEP Develop a Model** Using the materials provided, develop a model to demonstrate how nuclear stability changes as nucleons are added to the nucleus of a helium atom. Your model must be able to show the different effects adding protons versus neutrons has on the overall stability.

NAME ______________________ DATE ____________ CLASS ____________

| Nuclear Stability | | | | |
|---|---|---|---|---|
| **Round** | **Proton or Neutron Added?** | **Number of Protons** | **Number of Neutrons** | **Stable or Unstable?** |
| **1** | | | | |
| **2** | | | | |
| **3** | | | | |
| **4** | | | | |
| **5** | | | | |
| **6** | | | | |
| **7** | | | | |
| **8** | | | | |
| **9** | | | | |
| **10** | | | | |

## Analyze and Interpret Data

1. **SEP Use a Model to Evaluate** In this activity you started with a light atom, helium, and added nucleons to its nucleus. How would the trend of stability change if you instead used a heavy element, such as lead-207?

2. **SEP Identify Limitations of a Model** What are some weaknesses in your model's ability to demonstrate nuclear forces?

3. **SEP Apply Scientific Reasoning** Based on your results from this activity and the trend shown in **Figure 1**, is there a limit to nuclei growth?

# Investigation 15

NAME ________________________________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

# Half-Life Simulation

**How can half-lives determine the age of Earth?**

Radioactive decay is a spontaneous and completely random process. There is no way to predict how long it will take a specific atom of a radioactive isotope to disintegrate and produce a new atom. The probability, however, that a specific atom will decay after a certain period of time can be simulated by studying other random processes, such as a coin toss or a “roll of the dice.” These simulations have produced reliable models that geologists can use to date rocks and look at the formation of Earth.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 6** Construct Explanations and Design Solutions
**SEP 7** Engage in Arguments from Evidence

## Materials Per Group

- Cardboard box (optional)
- Dice, multi-sided, 10

## Safety

*Always wash hands thoroughly with soap and water before leaving the laboratory.*

NAME ______________________________ DATE ____________ CLASS ____________

## Procedure

*What is the probability an atom will decay?*

1. **SEP Develop Models** Your teacher will assign you a set of multi-sided dice and a “decay number”. Record the number of sides on the dice and the assigned decay number in the data table. Develop a model that simulates radioactive decay by the rolling of dice. You will start by rolling 100 dice (ten dice, ten times). Record your detailed procedure and have your teacher check it before proceeding.

NAME ________________________________ DATE ____________ CLASS ____________

| Radioactivity Half-life Simulation | | | | |
|---|---|---|---|---|
| Number of sides on the dice | | | | |
| Assigned "decay number" | | | | |
| | | | | |
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NAME ________________________________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Use Graphs** Use graphing software or the space provided to graph the results obtained for the “radioactive decay” of dice. Include a point on the graph for “100” as the number of dice “remaining” after zero rolls of the dice.

2. **SEP Analyze Data** Determine the half-life by choosing two points on the y-axis, where the first point is about twice as large as the second (e.g. 80 dice and 40 dice). How many rounds are needed for one-half of the dice to decay?

3. **SEP Interpret Data** Verify the half-life by choosing another set of two points on the y-axis. Is the half-life constant for the decay of the dice?

4.

4. **SEP Use a Model to Evaluate** What percentage of dice decayed after 100 dice were rolled? Compare your decay with another group that had the same-sided dice but a different decay number. Does the half-life depend on the “decay number”?

5. **SEP Develop Models** How could the model be adjusted to simulate an isotope that decays more quickly?

6. **SEP Construct an Explanation** Uranium-lead dating is a common method for determining the age of rocks. Uranium-235 has a half-life of about 700 million years and uranium-238 has a half-life of about 4.5 billion years. What is the benefit of using both isotopes when describing the formation of Earth?

7. **SEP Use Evidence** How do the long half-lives of uranium-235 and uranium-238 help us examine the movement of tectonic plates and help determine the age of Earth?

NAME ________________________________________ DATE ____________ CLASS____________

INQUIRY LAB – OPEN

# Radiometric Dating of Rocks

**What can isotopes tell us about the past?**

Radiometric dating is used to determine the ages of different materials using radioactive isotopes. Some methods yield only relative dates, while others can provide absolute ages. A geologist recently collected samples from five different layers of rock. Your job is to determine the age of four samples.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 6** Construct Explanations and Design Solutions

## Materials Per Group

- "Rock" samples, 4
- Calculator (optional)

## Safety 

*Always wash hands thoroughly with soap and water before leaving the laboratory.*

## Procedure

*How does the half-life of a radioactive isotope determine the age of an object?*

1. **Table 1** shows information regarding the isotopes and half-life of the parent ion that will be used to date your samples.

**Table 1**

| Uranium-235 Isotope | | |
|---|---|---|
| **Color of Radioactive Parent Isotope** | **Color of Stable Daughter Isotope** | **Half-life of Parent** |
| Green | Yellow | 700 million years |

NAME ________________________ DATE ____________ CLASS ____________

2. **SEP Use Graphs** Using graphing software or the space provided, graph the percentage of parent isotope (y-axis) remaining for each half-life transpired (x-axis). Connect the data points with a smooth, curved line.

3. **SEP Develop Models** Using the samples provided by your teacher, develop a procedure using the space provided to evaluate rock samples from four different layers. You need to determine what the half-life of the samples are and use that information to determine the age of each rock. Have your teacher approve your procedure before beginning.

NAME ________________________ DATE ____________ CLASS ____________

**Table 2**

| Radiometric Dating of Rock Samples | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

## Analyze and Interpret Data

1. **SEP Use a Model to Evaluate** Which excavated layer number contained the oldest rock sample? Which one contained the most recent?

2. **SEP Use Models** Based on the results of this activity, estimate the possible age range of the rock from the layer that was not dated by your group.

3. **SEP Use a Model to Evaluate** What do the red chips in the rock samples most likely represent?

NAME ____________________ DATE __________ CLASS __________

4. **SEP Use a Model to Evaluate** It is possible that some of the daughter isotope is already present at the formation of a particular rock. How would this affect the accuracy of dating the rock?

5. **SEP Construct an Explanation** The limit to radiometric dating using a particular radioisotope is usually 8–10 half-lives. Suggest a possible reason why this might be true.

6. **SEP Apply Scientific Reasoning** How could radiometric dating be used to study the formation of Earth?

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INQUIRY LAB – OPEN

# Plate Tectonics and Seafloor Spreading

**What can the density of rocks tell us about the age of Earth's crust?**

Seafloor spreading and plate tectonics shape our planet continuously, from the ancient supercontinent Pangaea to the different continent arrangement we see today. This activity will show you how the continental and oceanic plates shift and what types of patterns result. The continental and oceanic crusts form through different processes and the rocks at these locations have varying densities. Continental crust is generally less dense than oceanic crust.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 7** Engage in Arguments from Evidence

## Materials Per Group

- Graduated cylinder, 0.1 mL graduations
- Balance, electronic, 0.1 g precision
- Basalt pieces, 3
- Calculator
- Granite pieces, 3
- Ocean Base, blue, laminated
- Pangaea Continental Plates Worksheet, green, laminated
- Ocean Crust Worksheet, yellow, laminated
- Ocean Crust Worksheet, red, laminated
- Ocean Crust Worksheet, purple, laminated
- Marker, dry-erase
- Paper towels
- Scissors
- Water
- Water displacement cup

## Safety 

*This activity is considered non-hazardous. Follow all normal classroom guidelines. Always wash hands thoroughly with soap and water before leaving the laboratory.*

NAME ________________________ DATE ____________ CLASS ____________

## Procedure

### Part I: Density of Continental and Oceanic Rocks

*What is the relationship between crust density and age?*

1. **SEP Develop Models** Using the materials provided, develop a method to evaluate the density of rock samples. Each rock type comes with three samples to be measured and an average density calculated for all three. Record your detailed procedure and have your teacher approve your procedure before beginning any lab work.

NAME ________________________________ DATE ____________ CLASS ____________

| Density of Continental and Oceanic Rocks | | | | |
|---|---|---|---|---|
| **Sample Type** | | | | **Average Density** |
| Granite | | | | |
| | | | | |
| | | | | |
| Basalt | | | | |
| | | | | |
| | | | | |

**Part II: The Current Ocean Floor to Pangaea**

*How can we observe seafloor spreading?*

2. Cut out all of the continental plates on the green (G) Pangaea Continental Plate Worksheet. Note that the continental plate cutouts show the smooth edges of the continental plates and not the current day coastlines.
3. The continental plates are numbered as follows:
    1. North America
    2. Greenland
    3. Eurasia
    4. South America
    5. Africa
    6. Adriatic Promontory
    7. Arabia
    8. Antarctica
    9. Madagascar
    10. India
    11. Australia
4. Use scissors to cut out all of the ocean crust pieces from the yellow (Y), red (R), and purple (P) Ocean Crust Worksheets.
5. Assemble all of the Pangaea Continental and Oceanic Crust pieces on the blue ocean base as shown in Figure 1. Note that not all of the pieces are interlocking. This is a representation of Earth's current ocean floor, not an exact map.

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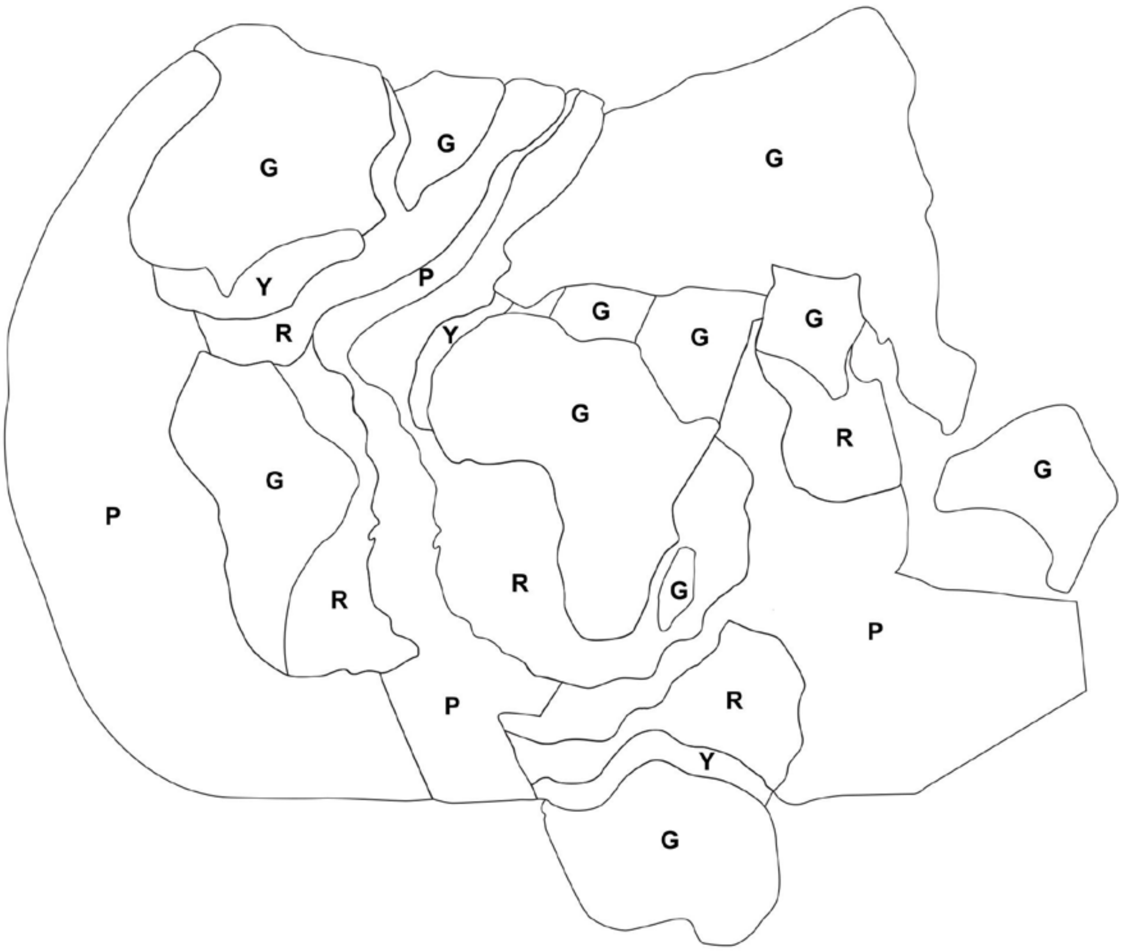
**Figure 1**




6. Use a dry-erase marker to draw lines down the center of the purple ocean crust cutouts. These lines represent the mid-ocean ridges where magma poured out onto the ocean basin and new ocean crust formed.

7. Use the dry-erase marker to label all of the purple ocean crust pieces “0 to 66 MY.” The purple ocean crust pieces represent the ocean crust from the present day to 66 million years ago.

8. Use the dry-erase marker to label all of the red ocean crust pieces “66 to 144 MY.” The red ocean crust pieces represent the ocean crust from 66 to 144 million years ago.

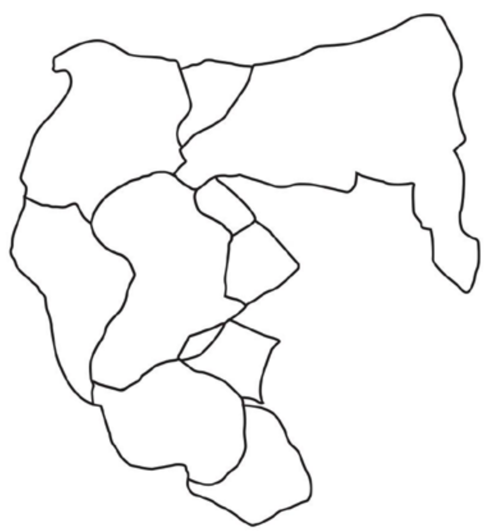
9. Use the dry-erase marker to label all of the yellow ocean crust pieces “144 to 164 MY.” The yellow ocean crust pieces represent the ocean crust from 144 to 164 million years ago.

10. Remove all the purple ocean crust pieces from the blue ocean base. Push all of the continents and remaining ocean crust pieces together until they are connected.

11. Remove all the red ocean crust pieces from the blue ocean base. Push all of the continents and remaining ocean crust pieces together until they are connected.

12. Remove all the yellow ocean crust pieces from the blue ocean base. Push all of the continents together into one large land mass. This represents the supercontinent Pangaea (Figure 2).

**Figure 2**



**Part III: Evidence of Continental Drift**

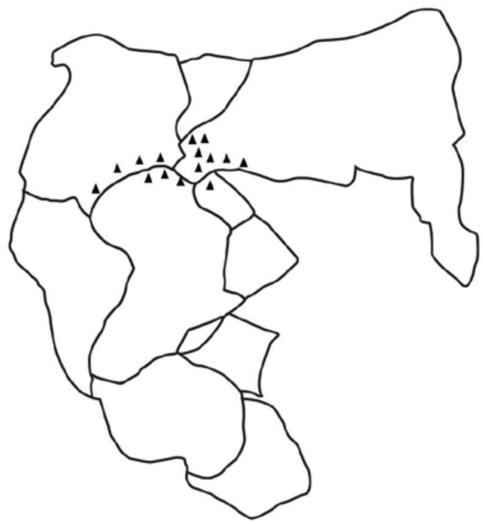
*What evidence do we have that Pangaea existed?*

13. Notice that a single large ocean surrounds the Pangaea land mass. Using a dry-erase marker, label this ocean Panthalassa on the blue ocean base.

14. Notice the small sliver of water between Eurasia and the Adriatic Promontory. This is the Thetys Sea. Label this sea on the blue ocean base.

**15.** Evaporite (water-soluble mineral sediments) and calcium carbonate deposits have been found in North America, Europe, and Africa. Using Figure 3 as a guide, label these deposits with a dry-erase marker on the continental plates with triangles.

**Figure 3**



**16.** Every continent consists of a stable core crust mass called a craton. Cratons are classified into four groups based on their structure. Four different types of cratons are shown—shield, extended, platform, and basin. They are identified as follows:

a. Shield—rocks crop out from the surface
b. Extended crust—area where crust is pulled apart or rifted
c. Platform—covered by sedimentary rock
d. Basin—a low sinking region

## Analyze and Interpret Data

1. **SEP Use Evidence** Compare the densities of granite and basalt. Which of the two rocks would make up most of the continental crust, and which would make up most of the oceanic crust? Explain your reasoning.

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2. **SEP Evaluate Evidence** Oceanic crust is generally younger than continental crust. Why is this the case?

3. **SEP Cite Evidence** A pattern of magnetic lines runs parallel to the mid-ocean ridges and is symmetrical on either side of the ridge. How can the age of the seafloor be determined from this information?

4. **SEP Use a Model to Evaluate** In this activity we used continental pieces that had smoother edges that did not represent current coastlines. What is one advantage and one disadvantage to this approach?

5. **SEP Use a Model to Evaluate** What are some of the key features of continental and oceanic plate movements that this model was unable to convey?

6. **SEP Use Evidence** How can rock from different cratons be used to evaluate continental plate movement and support the existence of Pangaea?

NAME ________________________________ DATE ____________ CLASS ____________

SCIENCE PERFORMANCE-BASED ASSESSMENT

# Uranium-Lead Dating

**How can dating methods be combined for a more accurate result?**

**Phenomenon** Radiometric dating is a common and useful approach to geologic dating of rock samples. Various methods can be used depending on the matter that makes up the rocks. Some dating methods are less precise and can only provide a relative age. Other methods, like uranium-lead dating, can be used to determine the absolute age of a rock. This method is quite precise since both uranium-235 and uranium-238 can be used. In this lab, you will analyze a rock sample using both uranium isotopes and determine its age. Uranium-235 has a half-life of 700 million years and uranium-238 has a half-life of 4.5 billion years.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 4** Analyze and Interpret Data
**SEP 6** Construct Explanations and Design Solutions
**SEP 7** Engage in Arguments from Evidence

## Materials Per Group

- "Rock" sample
- Weighing dish, large

## Safety

*Always wash hands thoroughly with soap and water before leaving the laboratory. Please follow normal laboratory safety guidelines.*

## Procedure

*How can different isotopes give the same age?*

Your teacher will provide you with a rock sample. The sample includes both uranium-235 and uranium-238 parent isotopes along with their lead daughter isotopes. The uranium-235 isotopes are represented by marbles, the lead-207 isotopes are represented by kidney beans, the uranium-238 isotopes are represented by red chips, and the lead-206 isotopes are represented by corks.

NAME ______________________ DATE __________ CLASS __________

1. **SEP Use Graphs** Using graphing software or the space provided, graph the percentage of parent isotope (y-axis) remaining for each half-life transpired (x-axis). Connect the data points with a smooth, curved line.

2. **SEP Use a Model** Develop a procedure using the space provided to evaluate your rock sample. You need to determine what the half-life of your sample is for each isotope and use that information to determine the age according to uranium-lead dating. Have your teacher approve your procedure before beginning.

NAME ________________ DATE ________ CLASS ________

| Radiometric Dating of Rock Sample | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |

## Analyze and Interpret Data

1. **SEP Use a Model to Evaluate** What do the pom poms and gravel in the rock sample most likely represent?

2. **SEP Identify Limitations of a Model** Did both uranium isotopes reveal the same age for the rock sample? What could have caused a discrepancy?

3. **SEP Apply Scientific Reasoning** Based on the half-lives for the uranium isotopes, what are the dating limitations for the uranium-lead dating method?

NAME ______________________ DATE __________ CLASS __________

**4. SEP Evaluate Evidence** Some zircon samples contain zones with dramatically different ages. What leads to these mixed ages and how can scientists determine an accurate age?

# Investigation 16

NAME ________________________________ DATE ____________ CLASS____________

INQUIRY LAB – OPEN

# Sunlight Intensity and Solar Flares

**How does energy from the sun reach Earth?**

Sunspots and solar flares are two features that are relatively common on the surface of the sun. Like Earth, the sun has a magnetic field. Sunspots form in areas where the magnetic fields are stronger. These magnetic fields interact and can tangle together, causing them to reorganize, which can cause a solar flare. A solar flare is the sudden release of large amounts of energy in the form of both electromagnetic radiation and the energetic ionized particles of solar wind. The radiation is emitted across the spectrum, from gamma rays to radio waves, so most of the energy of the solar flare is not visible. Some intense solar flares can interfere with radio communication here on Earth. In this lab, you will use a solar panel and multimeter to model the increased energy produced by a solar flare.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 5** Use Mathematics and Computational Thinking

## Materials Per Group

- Box
- Flashlight, LED high intensity
- Flashlight, incandescent
- Multimeter, with probes
- Ruler, metric
- Solar panel, 1 V, 400 mA
- Ultraviolet pen light
- Wire strippers (optional)

## Safety

*Do not point any of the flashlights at anyone and do not look directly into the beam. The LED high intensity and ultraviolet flashlights can cause serious damage to eyes. Follow all laboratory safety guidelines. Wash hands thoroughly with soap and water after the lab.*

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## Procedure

*How does sunlight intensity change with a solar flare?*

1. **SEP Develop a Model** Use the materials provided to construct a model that shows how sunlight intensity changes when solar flares are emitted from the surface of the sun. Your model should include different types of energy emitted from the sun. Use Table 1 to record your data. Record your detailed procedure and have your instructor check it before proceeding.

**Table 1**

| Solar Panel Voltage | |
|---|---|
| | |
| | |
| | |
| | |
| | |

NAME ________________________ DATE ____________ CLASS ____________

## Analyze and Interpret Data

1. **SEP Use a Model to Evaluate** What do the different flashlights represent in this model?

2. **SEP Use Mathematics** The average distance between the sun and Earth is 149,600,000 kilometers. Calculate the time it takes a photon to travel that distance. The speed of light is $3 \times 10^8$ m/s.

3. **SEP Identify Limitations of a Model** What aspects of solar flares is this model unable to show?

4. **SEP Use a Model to Evaluate** Solar flares can short out satellites or cause power surges. How can the model in this lab be used to describe the effect solar flares have on radio communication equipment?

5. **SEP Use a Model to Evaluate** Why did the UV light show a lower voltage output than the incandescent flashlight?

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INQUIRY LABS – OPEN

# Elemental Composition of Stars

**How can we determine which elements are present inside a star?**

In 1814, Joseph von Fraunhofer separated the light from the sun into its different colors. By carefully observing this spectrum, Fraunhofer discovered dark lines at set positions. He then examined the spectrum of other bright stars and found that they also contain dark lines. However, the dark lines were often in different places. Almost half a century later, Gustav Kirchoff and Robert Bunsen identified the origins of the lines when they heated metallic salts and observed the emission of bright lines. These emitted spectral lines corresponded to the dark lines previously observed by Fraunhofer, leading scientists to correctly conclude that these elements were present in the sun. In this lab, you will observe the emission spectra of several different elements. You will then draw on this experience to think about stellar spectroscopy and the information it can provide us about our place in the universe.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 3** Plan and Carry Out an Investigation
**SEP 8** Obtain, Evaluate, and Communicatie Information

## Materials Per Group

- Copper(II) chloride, $CuCl_2 \cdot 2H_2O$, 1–2 g
- Lithium chloride, LiCl, 1–2 g
- Sodium chloride, NaCl, 1–2 g
- Strontium chloride, $SrCl_2 \cdot 2H_2O$, 1–2 g
- Water, distilled or deionized, 125 mL
- Beakers, 250 mL, 2
- Laboratory burner
- Rainbow glasses
- Watch glasses, 4
- Wooden splints, 4
- Water, tap, 125 mL

NAME ___________________________________________ DATE _____________ CLASS _____________

## Safety

*Copper(II) chloride is highly toxic by ingestion; avoid contact with eyes, skin, and mucous membranes. Lithium chloride is moderately toxic by ingestion and is a body tissue irritant. Fully extinguish the wooden splints by immersing them in a beaker of water before discarding them in the trash to avoid trash can fires. Wear chemical splash goggles, chemical-resistant gloves, and a chemical resistant apron. Follow all laboratory safety guidelines. Wash hands thoroughly with soap and water after the lab.*

## Procedure

*How can emitted light be used to identify an element?*

1. **Table 1** lists the wavelengths of some of the more prominent dark lines in the solar spectrum. It lists the designation Fraunhofer assigned the line as well as its wavelength.

**Table 1**

| Designation | Wavelength |
|---|---|
| B | 686.7 |
| C | 656.3 |
| D1 | 589.6 |
| D2 | 589.0 |
| E | 527.0 |
| F | 486.8 |
| G | 430.8 |
| H | 396.8 |
| K | 393.4 |

2. **SEP Communicate Scientific Information** Draw a diagram representing the visible light spectrum (380–700 nm) with each of the tabulated lines marked on it.

3. **SEP Plan an Investigation** Devise an experiment to observe the emission spectra of four different metal salts. You should use a laboratory burner to excite the metal atoms, and make observations with both rainbow glasses and your unaided eye. Use **Table 2** to help you develop your procedure and to record your data. Record your procedure and have your teacher check it before proceeding with any lab work.

NAME ____________________ DATE __________ CLASS __________

**Table 2**

| Flame Test Observations | | |
|---|---|---|
| **Salt** | **Flame Color** | **Observations** |
| $CuCl_2$ | | |
| LiCl | | |
| NaCl | | |
| $SrCl_2$ | | |

4. Do any of the dark lines match with one of the elemental emission spectra you observed? (If you're not sure, go back and repeat the relevant flame test.)

## Analyze and Interpret Data

1. **SEP Communicate Scientific Information** Explain the difference in the spectral lines you observed in your investigation versus the spectral lines emitted by the sun.

NAME ________________ DATE ________ CLASS ________

2. **SEP Make Observations** How did the rainbow glasses make it easier to identify certain salts?

3. **SEP Develop Models** How can spectral lines be used to determine the elemental composition of a star?

4. **SEP Form a Hypothesis** Some of the dark lines observed by Fraunhofer have since been attributed to molecular oxygen. Propose an explanation for the origin of these lines, and describe an experiment that could be used to test your hypothesis.

5. **SEP Use a Model to Evaluate** How can the mass, size, and elemental composition of a star be used to provide information about how and when it might have formed?

6. **SEP Use a Model to Evaluate** How can the elemental composition of a planet be used to provide information about how and when it might have formed?

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INQUIRY LAB – OPEN

# The Expansion of the Universe

**Is the rate of expansion the same across the entire universe?**

The Big Bang theory asserts that the universe keeps expanding. In 1929, Edwin Hubble presented evidence that almost all galaxies appear to be moving away from Earth. In reality, Hubble's work shows that all galaxies are moving apart from each other because the entire universe is expanding. The speed at which the galaxies move away from our planet is directly proportional to their distance from Earth. In this lab, you will explore the expansion of the universe and the shifting of the galaxies using a simple model.

## Focus on Science Practices

**SEP 4** Analyze and Interpret Data
**SEP 5** Use Mathematics and Computational Thinking
**SEP 6** Construct Explanations

## Materials Per Group

- Balloon, round, 2
- Balloon pump (optional)
- Clothespin, wooden, 1
- Labeling tape, various colors
- Scissors
- Stopwatch or timer
- Tape measure, metric, 1

## Safety

*Wash hands thoroughly with soap and water before leaving the laboratory. Please follow normal laboratory safety guidelines.*

## Procedure

### Part I: Expansion and Change in Distance

*How far away can galaxies move as the universe expands?*

1. Use tape of various colors to cut five shapes that are less than half a centimeter (0.5 cm) across to represent different galaxies. Label each galaxy shape with a number from 1 to 5.

2. Put the small shapes aside on a clean surface, without letting them stick completely onto the surface.
3. Blow air into one of the balloons so that it is round and taut but not fully inflated. One lab partner should use their fingers or a clothespin to close the opening of the balloon so that it does not deflate.
4. Stick the galaxy shapes randomly spaced out onto the balloon.
5. Choose one of the galaxies to be the Milky Way (the galaxy where our solar system is located), and use a metric tape to measure the distance from the center of the Milky Way to the center of each one of the other galaxies on the balloon. Record these distances in the appropriate column of the data table.
6. Continue to inflate the balloon until its size has doubled or tripled. Be careful not to over inflate the balloon. If the balloon pops, start over again from step 3.
7. Tie the balloon opening to prevent deflation.
8. Use a metric tape to measure the new distance from the center of the Milky Way galaxy to the center of each one of the other galaxies on the balloon. Record these final distances in the appropriate column of Table 1.

**Table 1**

| Expansion and Change in Distance | | | |
|---|---|---|---|
| **Galaxy** | **Initial Distance, $d_1$ (cm)** | **Final Distance, $d_2$ (cm)** | **Distance Change, $\Delta d = d_2 - d_1$ (cm)** |
| **1** | | | |
| **2** | | | |
| **3** | | | |
| **4** | | | |
| **5** | | | |

NAME ______________________ DATE ____________ CLASS ____________

**Part II: The Speed of Expansion**

*Is the universe expanding at a constant speed everywhere?*

9. **SEP Plan Your Investigation** Use the procedure and results of Part I, to design an experimental procedure to determine the speed at which each one of the galaxies move apart from each other on the surface of an inflating balloon. Place 7 to 10 galaxy stickers on the surface of the balloon. Write a detailed procedure and record all relevant data in Table 2. Note: Remember that speed (*v*) is equal to the change in distance in a given time period.

NAME ______________________ DATE ____________ CLASS ____________

**Table 2**

| The Speed of Expansion | | | | |
|---|---|---|---|---|
| Expansion Time (s) | | | | |
| Galaxy | Initial Distance, $d_1$ (cm) | Final Distance, $d_2$ (cm) | Distance Change, $\Delta d = d_2 - d_1$ (cm) | Speed of Expansion, $v$ (cm/s) |
| 1 | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

## Analyze and Interpret Data

1. **SEP Use Mathematics** Calculate the change in distance ($\Delta d$) between each galaxy and the Milky Way galaxy in Part I. Fill out the corresponding column in Table 1.

2. **SEP Analyze Data** Examine the change in distance values ($\Delta d$) between each galaxy and the Milky Way galaxy in Part I. Are the $\Delta d$ values constant for all the galaxies? Explain.

3. **SEP Use Mathematics** Calculate the change in distance (Δ*d*) between each galaxy and the Milky Way galaxy in Part II. Fill out the corresponding column in Table 2.

4. **SEP Use Mathematics** Calculate the speed of expansion, *v*, for each galaxy in Part II and show a sample calculation.

5. **SEP Use Graphs** Use graphing software or the space to plot the speed of expansion ($v$ in cm/s) versus the final distance ($d_2$ in cm) for the galaxies in Part II. Draw a trendline that crosses most of the points on your plot.

6. **SEP Construct an Explanation** Hubble demonstrated that distant galaxies are moving away from Earth and apart from each other because of the expansion of the universe. The speed at which a galaxy moves away from Earth (*v*) is directly related to the distance between the galaxy and Earth (*d*). Do your results with the balloon model agree with Hubble's observations? Explain.

7. **SEP Obtain Information** The speed of expansion for a galaxy with respect to Earth is represented by Equation 1, where *v* is velocity of expansion, *d* is the galaxy's distance from Earth, and *H* is the Hubble constant. Go online or consult a textbook to find the value of the Hubble constant. What is the meaning of this constant? Explain.

**Equation 1:** $v = Hd$

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SCIENCE PERFORMANCE-BASED ASSESSMENT

# Life Cycle of Stars

**Why do stars not explode from the pressure generated by burning fuel?**

**Phenomenon** Stars burn tremendous amounts of fuel without exploding from the outward pressure generated because the outward pressure is balanced by the inward force of gravity. This balancing of the two forces is called hydrostatic equilibrium. In this activity you will model the hydrostatic equilibrium in stars to understand why they are stable for billions of years, until one of the forces yields to the other.

## Focus on Science Practices

**SEP 2** Develop and Use Models
**SEP 7** Engage in Argument from Evidence
**SEP 8** Obtain, Evaluate and Communicate Information

## Materials Per Group

- Syringe
- Syringe cap
- Syringe plunger

## Safety

*The materials in this lab are considered non hazardous. Wear safety glasses. Please follow all normal laboratory safety guidelines.*

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## Procedure

### Part I: Researching Opposing Forces in Stars

*How do opposing forces prevent stars from imploding and exploding?*

1. **SEP Obtain, Evaluate, and Communicate Information** Go online and research the life cycles of stars. Describe the two opposing forces that prevent stars from imploding and exploding. Describe how the relationship between the forces changes as stars age. Indicate the sources of information you used and why you believe they are credible.

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**Part II: Modeling the Opposing Forces in a Star**

*How can you model the opposing forces in a star?*

2. **SEP Develop and Use a Model** Develop a model that uses a syringe and syringe cap to demonstrate the coexistence of the two opposing forces that allow stars to persist without imploding or exploding. Explain how your syringe model may be manipulated to demonstrate the coexistence of the opposing forces you identified in Part I, at each of the following stages for a low-mass star: main sequence, old age, and death.

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## Analyze and Interpret Data: Sample Answers

1. **SEP Use a Model** How would you use your model to demonstrate the difference between a low-mass star and a high-mass star, at the death stage in their life cycles? You may propose modifications to the model.

2. **SEP Engage in Argument** What kind of stars would you expect to live longer lives, low-mass stars or high-mass stars? Explain.

3. **SEP Use a Model** Describe how two magnets might be used to demonstrate the coexistence of gravity and pressure in a star.

4. **SEP Use a Model** Identify some of the limitations associated with your model.

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5. **SEP Engage in Argument** Why do extremely large stars not "burn out" by continuously fusing lighter elements into heavier ones? In other words, why does the core of a massive star eventually become inert?

6. **SEP Use Scientific Reasoning** Apply what you know about stars to explain why Earth's atmosphere becomes less dense as the distance from sea level increases.

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