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</table>
How to Read an Investigation

Investigation title

4B Acceleration

What is acceleration?

When you run the back into a sloped ramp, the car can gain speed as it travels down the ramp. The speed of the car is constantly changing. What would a graph of the type of motion look like? Is there more than one way to graph the motion of an object? In this investigation you will use what acceleration is, what the graphs of associated with acceleration look like, and why they look the way they do.

Materials
- Data Collector and 2 photogras
- Energy Car and Track
- Physics stand

Steps Proceed in order

1. Setting up the experiment

Attach the straight track to the 16th hole from the bottom of the Physics Stand.

2. Predicting

A graph is a visual tool that shows how two things are related. Release the car from the top of the track and see how the car’s position and speed changes as it rolled.

   a. Think about what happens to the car’s position you think the position (y) vs. time (t) graph will look like. You need to put any numbers at the end of the line, draw a line, or curve on the graph.

   b. Do the same for the speed (v) vs. time (t) graph.

Data table

<table>
<thead>
<tr>
<th>Table 1: Position vs. time data</th>
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<tr>
<td>Distance from A to B (m)</td>
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<tr>
<td>--------------------------</td>
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<tr>
<td>10</td>
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<tr>
<td>20</td>
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<td>30</td>
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<td>50</td>
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<tr>
<td>60</td>
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</table>

Questions you will answer

1. Position vs. time graph for acceleration

   a. Use your data from Table 1 to make a graph with the position (distance from A to B) on the y-axis and the time (t) on the x-axis. How does the graph from your experiment data compare to your prediction? What happens to the distance traveled as time goes by for the car on the ramp?

   b. Does the graph show that the car did travel at a constant speed?

2. Speed vs. time graph for acceleration

   a. Do another run for the same object, release the car, and record the time through A and B. Use the same graph paper as before.

   b. How does the graph from your experiment data compare to your prediction? What happens to the distance traveled as time goes by for the car on the ramp?

   c. Does the graph show that the car did travel at a constant speed?

3. Speed vs. time graph for acceleration

   a. Do another run for the same object, release the car, and record the time through A and B. Use the same graph paper as before.

   b. How does the graph from your experiment data compare to your prediction? What happens to the distance traveled as time goes by for the car on the ramp?

   c. Does the graph show that the car did travel at a constant speed?

NOTE: You will answer all questions and fill-in data on separate fill-in answer sheets.
Observing safety precautions is an extremely important practice while completing science investigations. Using science equipment and carrying out laboratory procedures always requires attention to safety. The purpose of learning and discussing safety in the lab is to help you learn how to protect yourself and others at all times.

The investigations in this book are designed to reduce safety concerns in the laboratory. The physics investigations use stable equipment that is easy to operate. The chemistry investigations use both household and laboratory chemicals. Although these chemicals might be familiar to you, they still must be used safely.

You will be introduced to safety by completing a skill sheet to help you observe the safety aids and important information in your science laboratory. In addition to this skill sheet, you may be asked to check your safety understanding and complete a safety contract. Your teacher will decide what is appropriate for your class.

Throughout this book, safety icons and words and phrases like “caution” and “safety tip” are used to highlight important safety information. Read the description for each icon carefully and look out for them when reading your book and doing investigations.

| **General safety:** Follow all instructions carefully to avoid injury to yourself or others. |
| **Wear safety goggles:** Requires you to wear eye protection to prevent eye injuries. |
| **Wear a lab apron or coat:** Requires you to wear a lab apron or coat to prevent damage to clothing and to protect from possible spills. |
| **Wear gloves:** Requires you to protect your hands from injury due to heat or chemicals. |
| **Poisonous chemicals:** Requires you to use extreme caution when working with chemicals in the laboratory and to follow all safety and disposal instructions from your teacher. |
| **Skin irritant:** Requires you to use extreme caution when handling chemicals in the laboratory due to possible skin irritation and to follow all safety and disposal instructions from your teacher. |
| **Respiratory irritant:** Requires you to perform the experiment under a laboratory hood and to avoid inhaling fumes while handling the chemicals. |
| **Laser:** Requires you to use extreme caution while using a laser during investigations and to follow all safety instructions. |

Lab safety is the responsibility of everyone! Help create a safe environment in your science lab by following the safety guidelines from your teacher as well as the guidelines discussed in this document.
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1A Measurement

Are you able to use scientific tools to make accurate measurements?

In everyday life we use tools to make our work easier. For example, it is difficult to pound a nail without a hammer, to wrap a gift without tape, or to open clear plastic packages without scissors. In science, it is important to be able to correctly choose and use laboratory equipment to make measurements. During the “Measurement Games” you and a partner will practice choosing the correct tool to make measurements accurately. The group with the best averages overall wins the “Measurement Games!”

Stop and think

a. Are you familiar with the tools necessary to make measurements of length, mass, and volume? Look at the list of materials above and write down a tool used for measuring each property.

<table>
<thead>
<tr>
<th>Property</th>
<th>Tool Used</th>
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<tr>
<td>Length</td>
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</tr>
<tr>
<td>Mass</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td></td>
</tr>
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</table>

b. Do you understand what metric units coincide with length, mass, and volume? Discuss this with your partner and write an appropriate unit that corresponds to each property.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit Used</th>
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<tbody>
<tr>
<td>Length</td>
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</tr>
<tr>
<td>Mass</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
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c. Read about the events listed below in Part 2 and predict the outcome of each event for yourself before you actually perform the task.

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<thead>
<tr>
<th>Olympic Event</th>
<th>Prediction</th>
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<tr>
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<tr>
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<td></td>
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<tr>
<td>Pebble Grab</td>
<td></td>
</tr>
<tr>
<td>Side Step</td>
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<tr>
<td>Hoppity Hop</td>
<td></td>
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</tbody>
</table>
2 Doing the activity

A. Perform the event, collect, and record data.

1. **Straw Javelin:** During this event, you will be throwing a straw as far as you can, like it is a javelin. Your front foot may not cross the start line, and you must throw the straw like a javelin with only one hand. Measure the distance of your throw in meters and centimeters.

2. **Paper Cup Challenge:** How much water can you move from a tank to a beaker in 10 seconds using just one paper cup? Use a graduated cylinder to measure the volume of water you successfully transferred. Be careful so you don’t spill any water!

3. **Pebble Grab:** Who can grab the greatest mass of pebbles? Use ONLY ONE HAND to grab as many pebbles as you can out of a container. Transfer them to an electronic balance to measure the mass. Be sure the balance is measuring in the correct units before you begin!

4. **Side Step:** How far is your leg span? From a starting point step as far as you can to the side. Your partner will measure the length of your step in meters and centimeters.

5. **Hoppity Hop:** Who can hop 10 meters the fastest on one foot? Mark 10 meters on the floor with the masking tape. To use the timer, plug the power cord into an outlet, and then into the side of the electronic timer. Turn the timer on by sliding the small, black button on the side of the timer. To start the clock, push the “A” button; push it again to stop the clock. Push the “reset” button to reset the clock. Time how long it takes your partner to hop 10 meters on one foot!

B. Olympic Results

1. Record your results below. Any result with missing or incorrect units will be automatically disqualified from the Measurement Games!

2. After you have recorded your results there will be a class discussion to see who the winners are in each event. Decide within your group who has the best score for each event. Use that score for the class data set. Record the data in the data table your teacher has drawn on the board. Determine the best overall score for the group winner. Record the individual winner’s results for each event in the data table below.

<table>
<thead>
<tr>
<th>Event</th>
<th>My Results</th>
<th>Winner’s Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw Javelin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper Cup Challenge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pebble Grab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side Step</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hoppity Hop</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 Thinking about what you observed

a. Calculate the difference between the winner’s results and your results for each event. (Don’t forget units!)

<table>
<thead>
<tr>
<th>Event</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw Javelin</td>
<td></td>
</tr>
<tr>
<td>Paper Cup Challenge</td>
<td></td>
</tr>
<tr>
<td>Pebble Grab</td>
<td></td>
</tr>
<tr>
<td>Side Step</td>
<td></td>
</tr>
<tr>
<td>Hoppity Hop</td>
<td></td>
</tr>
</tbody>
</table>

b. In which event were you closest to the winner?

c. In which event were you the farthest away from the winner?

d. How close were you to your predictions?

e. Which measurement were you most familiar with before The Games? Why?

f. Which measurement did you find easiest to make during The Games? Why was it so easy for you?

g. Which measurement did you find to be the most difficult during the Games? Why?

4 Exploring on your own

a. Scientists work hard to be precise in their measurements when experimenting. In real life, most of us are accurate enough, but hardly precise, every time we perform a task that involves a measurement. Do you know the difference? Look it up and draw several examples that represent the difference between accuracy and precision.

b. Create a “quiz” that your classmates could “take” regarding the different tools used in a science lab and their appropriate units. Include an answer key.

c. Find a real science article from a magazine, newspaper, or internet website where scientists are measuring something. Explain in a one-paragraph summary what they are measuring, what tools they are using or could use to make the measurements, and the units associated with the measurements.
**1B Conversion Chains**

*How can you use unit canceling to solve conversion problems?*

Suppose you are traveling in Canada or Mexico, and you see a sign that says the next city is 115 km away. How many miles is that? You could use the dimensional analysis process to figure it out. Dimensional Analysis is a method of using conversion factors and unit canceling to solve unit conversion problems. In this activity, you will use conversion chains to start and solve conversions.

- **Conversion Chain cards**
  - The deck of cards contains:
    - 12 START cards, 12 SOLVE cards, 36 conversion factor cards

  ![Conversion Card Examples]

  1. Look at the cards to identify what START, SOLVE, and conversion factor cards look like.
  2. Shuffle the cards thoroughly!

**1 Creating Conversion Chains**

The object of the game is to have the most points after solving 6 conversion chains.

1. Deal 4 cards to each player (works best with 3–5 players).
2. Choose a player to go first. This player must play a START card and draw one from the deck. If the player draws a START card, it may be played; otherwise play passes to the next player. Play passes until a START card has been played. Anytime a START card is played the player scores 5 points. (Each group must assign a scorekeeper).
3. The next player may play another START card or a conversion card that will continue the conversion chain. That means that the card must have a denominator unit that matches a START card unit, to cancel the starting unit and continue the chain. Only 6 START cards can be played in a game.
4. If the player has more than one card that could be played on multiple START cards, the player must choose only one card to play on each turn.
5. After playing a card, the player must draw a card.

---

**Code | Benchmark**
---|---
MA.912.S.1.2 | Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.
MA.912.S.3.2 | Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.
6. If the player does not have a suitable card, the player must draw one card from the deck. If the card will play, he can play it. If the card won’t play, he must pass his turn.

7. The next player plays a conversion factor card, plays a START card, or draws a card, and play continues.

8. A team can have as many as 3 conversion chains going at once.

9. After a minimum of 3 conversion factor cards have been played on any particular START card, any player is allowed to play a SOLVE card on her turn, and the player immediately scores 5 points for each conversion chain card in the chain.

**Solving a chain and scoring points**

1. Anytime a SOLVE card is played on any conversion chain, all players must record the chain on the answer sheet and calculate the answer with the correct number of significant digits and unit.

2. Players compare answers and determine who has the correct answer. Consult your teacher if there are disagreements.

3. Any player with the correct answer scores 25 points.

4. Keep playing until your team has created and solved 6 conversion chains.

5. At the end of the game, after 6 conversion chains have been scored, players must subtract 5 points per card for unplayed cards remaining in the hand.

6. Total up the points, subtract the unused cards, and determine the winner.

**Reminders and strategy**

1. Whenever you play a START card, you score 5 points! If you draw a START card after 6 chains have already been started, you must keep that card in your hand, and it will cost you 5 points in the end.

2. Remember: you always draw a card at the end of every turn.

3. When a conversion chain has been solved, place the START, chain, and SOLVE cards to the side in a pile. You might want to look at a solved chain later in the game. Also, this will help your team keep track of how many conversion chains have been solved (the goal is to solve 6).

4. You can play a SOLVE card only after there are at least 3 conversion factor cards in any chain. For beginners, a SOLVE card should be played after 3 chain cards are in a chain. For advanced players, a SOLVE card can be held back and played after the chain is much longer. The SOLVE card player benefits, since 5 points are awarded for each chain card in the chain to that player!

5. Record each conversion chain your team creates in Table 1. There are blanks for recording 6 conversion factors per chain. If a chain has less than 6, just leave remaining boxes blank. If you need more than 6, continue on the back of the page.

6. The first row of Table 1 shows an example chain.
## Table 1: Conversion Chains

<table>
<thead>
<tr>
<th>START card</th>
<th></th>
<th></th>
<th></th>
<th>Answer with correct sig figs and unit</th>
<th>Points scored</th>
</tr>
</thead>
<tbody>
<tr>
<td>46.3 m</td>
<td>$\times \frac{1 \text{ km}}{1000 \text{ m}}$</td>
<td>$\times \frac{1 \text{ mi}}{1.6 \text{ km}}$</td>
<td>$\times \frac{5280 \text{ ft}}{1 \text{ mi}}$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td></td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td></td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td></td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
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<td>$\times$</td>
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<td>$\times$</td>
<td>$\times$</td>
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<td>$\times$</td>
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<tr>
<td></td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5 Thinking about the game

a. The conversion chains you create for this game could be quite long, and the actual conversions could be solved with fewer conversion factors. What is the least number of conversion factors you would need to make these conversions, given the cards you have in the deck?

• converting ft to cm
• converting mi to m

b. Because of the limitations of the cards in the deck, to convert from km to cm, you would have to go through English units. What is a much easier way to convert from km to cm? Explain.

c. Explain the math reasoning behind why you are able to “cancel” like units that appear in the numerator and denominator of conversion factors in a conversion chain.
2A Mass, Volume, and Indirect Measurement

How can you find the mass of a single rice grain?

In this investigation you will find the average mass of a single grain of rice. One grain of rice is too small to register a mass value on your electronic scale. There are many situations like this where scientists need to measure something that is too small or too large to measure directly. In these situations, scientists use methods of indirect measurement. To do this, you calculate the measurement you can’t make from other measurements that you can make.

Getting started

To find the average mass of a single grain of rice, you will measure the mass of a 1-cm box filled with rice. You will then estimate how many grains there are in the cube. By dividing the mass of the cube by the number of grains in the cube, you will get a good indirect measurement of the average mass of a single grain of rice.

The first thing we need to do is find out how many grains of rice there are in a cubic centimeter.

1. Cut out and fold up the small cube (made out of an index card) as shown in the diagram. Use tape to hold the cube together. This cube has a volume of 1 cubic centimeter (1 cm³ or 1 cc).

2. Fill the cube level with rice.

3. Carefully empty the rice in the cube onto the table. Count how many grains fit into the cube and record the value in Table 1.
4. Calculate the number of grains of rice per cubic centimeter and record this value in Table 1. Use this formula: \( \frac{\text{number of grains}}{\text{volume of cube}} = \text{grains per cubic centimeter} \)

**Table 1: Data on number of rice grains per cubic centimeter**

<table>
<thead>
<tr>
<th>Volume of cube (cm(^3))</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of grains of rice</td>
<td></td>
</tr>
<tr>
<td>Calculated grains per cubic centimeter</td>
<td></td>
</tr>
</tbody>
</table>

**2 Accuracy, precision, and resolution**

No instrument in science makes perfect measurements. A single cubic centimeter of rice is a very small mass and difficult to measure precisely with an ordinary balance. For example, suppose you want a measurement that is precise to one percent. A typical electronic balance has a resolution of 0.1 grams. That means the smallest mass you can measure with this balance is 100 times as large as its resolution. \(100 \times 0.1 \text{ g} = 10 \text{ g}\) therefore, 10 grams is the smallest mass you can measure to a precision of one percent. Since the mass of one cubic centimeter of rice is less than 10 grams, we will use a much larger amount of rice.

**3 Making a precise measurement**

1. Cut out and fold up the 3 centimeter cube as shown in the diagram. Use tape to hold the cube together.
2. Calculate the cube’s volume and record in Table 2.
3. Place the cube on the balance and reset the balance to zero. The balance display should now read 0.0 grams.
4. Remove the cardboard cube and fill it level with rice. Place the filled cube back on the balance and record the mass.
5. Calculate the number of grains of rice in the cube based on the value of grains per cubic centimeter you calculated in Table 1.
6. Use the mass of rice in the large cube and the calculated number of rice grains to find the average mass of one grain of rice.

**Table 2: Data on the mass of a grain of rice**

<table>
<thead>
<tr>
<th>Volume of cube (cm(^3))</th>
<th>Number of grains of rice in 3 cm cube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of rice in cube (g)</td>
<td>Calculated mass of 1 grain of rice (g)</td>
</tr>
</tbody>
</table>
4 Stop and think

a. Why did the balance show a small negative mass when you removed the empty cardboard cube at the beginning of step 4?

b. Why does this experiment measure the *average* mass instead of the *actual* mass of a grain of rice?

c. Why is the average mass a more useful quantity than the actual mass of any single grain of rice?

d. Compare your average mass of one grain of rice with other groups’ results. How do your results compare? Discuss.
2B Density

How is an object's density related to its volume, mass, and tendency to sink or float?

You may be familiar with the trick question “Which is heavier: a pound of feathers or a pound of bricks?” The answer, of course, is that they have the same weight. However, the pound of feathers has a much greater volume because feathers have a much lower density than bricks. The brick material is squeezed together tightly, while the feathers contain a large amount of empty space. In this investigation you will study the relationship between mass, volume, and density. You will also determine how an object’s density affects whether it sinks or floats in water.

1 Measuring mass and volume

1. Each lab group has a unique set of six objects. Find the mass and volume of one of your objects. Add a second object and find the total mass and volume of both objects. Then find the total mass and volume of three, four, and five objects. Record your data in Table 1. Note: Although your objects look identical, there may be small differences. Do not obtain your data by multiplying the mass or volume of one object by the number of objects you have. Use the displacement method for measuring density.

2. Plot your data on graph paper. Label the x-axis “volume” and the y-axis “mass.” Be sure use the entire space on your graph paper for making your graph.

2 Analyzing your results

a. Is there any pattern to the data points on your graph? For example, the points might form a smooth curve, a straight line, a random scattering, or a cluster in a certain region. Describe any pattern you see.

b. Line up your ruler along the points on your graph so it is as close as possible to all of the dots. The line may not touch all of the dots, but should have an equal number of dots on each side of it. This line is called the “line of best fit.” Draw the line.
c. Find the slope of the line of best fit. To do this, choose any two points on the line. These will be represented as \((X_1, Y_1)\) and \((X_2, Y_2)\). Use the formula below to calculate the slope of the line:

\[
\frac{(Y_2 - Y_1)}{(X_2 - X_1)} = \text{slope}
\]

The slope tells how many grams of matter are contained in each milliliter of material. Some substances, like lead, have quite a few grams of matter packed into each milliliter. Other substances, like styrofoam, have less than a single gram of matter packed into each milliliter.

d. Compare your slope with the result obtained by other groups. Are your slopes similar or different?

e. The relationship between a substance’s mass and volume is called its density. What is the density of the material you tested?

3 Using your knowledge

a. Your graph shows data for five objects. Use your graph to predict the mass of six objects.

b. Next, use the balance to find the total mass of all six objects.

c. How does your value from your graph compare to the mass obtained using the balance?

d. Use the mass that you found in step 3 b. Find that number on the \(y\)-axis of your graph. Now find the point on the line with that \(y\)-value. What is the \(x\)-value of the point?

e. Now, find the volume of six objects experimentally.

f. How does the \(x\)-value from the graph compare with the measured volume?

4 Comparing class data

Collect data from each group in the class to fill in Table 2.

<table>
<thead>
<tr>
<th>Table 2: Class data for density of objects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group1</strong></td>
</tr>
<tr>
<td>volume of one object (mL)</td>
</tr>
<tr>
<td>type of material</td>
</tr>
<tr>
<td>density (g/mL)</td>
</tr>
</tbody>
</table>
Using the data above, answer the following questions:

a. Does density depend on the size of the material? Give evidence to support your answer.

b. Does density depend on the type of material? Give evidence to support your answer.

c. Using what you have observed in this lab, do you suppose that density depends on the shape of the material? Why or why not?

5 Using a different method to find volume

You used the displacement method to find the volume of your objects in the first part of the investigation. The displacement method works because an object’s volume is equal to the volume of water it displaces, or pushes aside. This method is useful for objects with complicated shapes.

If an object has a simple shape, such as a cube, its volume can be found by measuring its dimensions. The volume of a cube is found using the formula:

\[
\text{Volume} = \text{length} \times \text{width} \times \text{height}
\]

When length, width, and height are measured in centimeters, volume is in cubic centimeters or cm³. A 1 cm × 1 cm × 1 cm cube displaces one milliliter of water, so 1 cm³ = 1 milliliter.

1. Use the method demonstrated in the diagram on the right to measure the length, width, and height of the steel cube in centimeters.

2. Record your measurements in Table 3.

3. Calculate the volume of the steel cube. Record your volume calculations in cubic centimeters in Table 3.

4. Repeat steps 1–5 for the other 4 cubes.

Table 3: Cube volume table

<table>
<thead>
<tr>
<th>Material of solid cube</th>
<th>Length (cm)</th>
<th>Width (cm)</th>
<th>Height (cm)</th>
<th>Volume from calculation (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oak</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Calculating the density

Each cube’s volume is almost exactly the same, but their masses are different because they are all made of different materials. Use Table 4 to calculate the density of each cube.

1. Use a balance to determine the mass of the steel cube, and record it in Table 4.
2. Divide the mass by the volume of the steel cube to calculate its density:
   \[ \text{Density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}} \]. Record the density value in Table 4.
3. Repeat steps 1 and 2 and calculate the density of each cube.

<table>
<thead>
<tr>
<th>Material of solid cube</th>
<th>Mass (g)</th>
<th>Volume (cm³)</th>
<th>Density (g/cm³)</th>
<th>Prediction (sink or float)</th>
<th>Result (sink or float)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stop and think

a. How do the volumes compare to each other? Why do you think they might be different?

b. Pick up and hold each cube. Predict whether it will sink or float in water. Record your predictions in Table 4. What did you base your predictions on?

c. What is the density of water in g/cm³?

d. Compare the density of water to the density you calculated for each cube. Take another look at your sink/float predictions. Make any changes you need to based on density.

e. What rule did you use to make your prediction? Write the rule down in one sentence.

Testing the hypothesis

Your predictions from part 7d, and the rule from part 7e, represent a hypothesis. Test the hypothesis by dropping each cube in a beaker of water. Record your results in Table 4.

Thinking about what you learned

a. Describe two different ways you can find the density of a regularly-shaped object like a cube.

b. Explain why two different objects can have equal volumes but different masses.

c. Which method of prediction was better, testing the weight of the cube in your hand, or comparing the density of the cube to the density of water? Why?
3A Measuring Time

How is time measured accurately?

A measurement is a quantity with a unit that tells what the quantity means. For example, 3 seconds is a measurement of time that includes a quantity (3) and a unit (seconds). This investigation will explore time measurement.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
<td>Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.</td>
</tr>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences are drawn from scientific observations and provide examples.</td>
</tr>
</tbody>
</table>

1 Using the Data Collector as a stopwatch

A stopwatch measures a **time interval**. The Data Collector stopwatch shows time in seconds up to 60 seconds. The display shows **min:sec** for times longer than one minute.

1. Go to the Data Collector’s timer function, and select stopwatch mode.
2. Practice starting and stopping the stopwatch.
3. Reset the stopwatch to zero.

2 Observing reaction time

The time it takes a signal from your brain to move a muscle is called **reaction time**.

1. This experiment takes two people. One person (the watcher) watches the stopwatch and the other person (operator) pushes the buttons without looking at the display. The watcher selects a time between 5 and 10 seconds and keeps the time secret.
2. The operator starts (and stops) the stopwatch **without looking at the display**. The watcher looks at the display and says STOP at the secret time. For example, if the secret time is 6 seconds, the watcher should say STOP when the display reaches 6.00 seconds.
3. Repeat the experiment several times, record your results in Table 1, and calculate reaction time by taking and average of the difference in times for all 5 trials.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Secret time (s)</th>
<th>Measured time (s)</th>
<th>Difference (s)</th>
<th>Avg. Difference Reaction time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 Mixed units for time
In physical science, you are usually going to measure time in seconds. However, time is often given in mixed units, which may include hours, minutes, and seconds. Consider the following three time intervals.

1. 16,000 seconds
2. 250 minutes
3. 4 hours, 23 minutes and 15 seconds (4:23:15)

a. Which one is in mixed units?
b. Can you tell which time is longest or shortest?

c. 1 minute = 60 seconds; how many seconds is 250 minutes?
d. 1 hour = 60 minutes; how many minutes are in 4 hours?
e. Use your answer from question d. to figure out how many seconds are in 4:23:15.
f. Arrange the three measurements from smallest to largest.

4 Using the photogates
A photogate allows us to use an infrared light beam to start and stop the Data Collector. When the timer function is in interval mode, it uses photogates to control the clock.

1. Connect a single photogate to the “A” input with a cord.
2. Select interval mode in the timer function of the Data Collector.
3. Try blocking the infrared beam with your finger and observe what happens on the timer display.

Try your own experiments until you can answer the following questions. Be very specific in your answer. Someone who has never used the Data Collector before should be able to read your answer and know what to do with the infrared beam to make the clock start and stop.

a. How do you start the clock?
b. How do you stop the clock?
c. What time interval has the clock measured?
5 Using two photogates

1. Connect a second photogate to the Data Collector.
2. Make sure the light on each photogate is green and press the reset button. Pressing reset clears the clocks and also tells the timer to look at its inputs to see which photogates are connected.
3. Do your own experiments and fill in the rest of Table 2.

<table>
<thead>
<tr>
<th></th>
<th>t_A</th>
<th>t_B</th>
<th>t_{AB}</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do you start the t_A clock?</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>How do you stop the t_A clock?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How do you start the t_B clock?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How do you stop the t_B clock?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How do you start the t_{AB} clock?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How do you stop the t_{AB} clock?</td>
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</tbody>
</table>
Experiments and Variables

How do you design a valid experiment?

Experiments help us collect evidence so we can unlock nature’s puzzles. If an experiment is well planned, the results can provide an answer to a scientific question like “What would happen if I did this?” If the experiment is not well planned, you will still get results, but you may not know what they mean. In this investigation, you will experiment with a car on a ramp. Only by paying careful attention to the variables can you make sense of the results.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.N.1.2</td>
<td>Describe and explain what characterizes science and its methods.</td>
</tr>
<tr>
<td>SC.912.N.1.3</td>
<td>Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.</td>
</tr>
<tr>
<td>SC.912.P.12.2</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
</tbody>
</table>

1 Setting up the experiment

1. Set up the track with a long straight section. Your teacher will tell you which hole in the stand to attach the track. Each group will have a different angle.
2. Put a clay ball on the stop at the bottom.
3. Place two photogates on the track with photogate A higher than photogate B.
4. Roll the car down and record the time it takes the car to pass between the photogates ($t_{AB}$).

2 Stop and think

a. Which track should have the fastest car? Which track should have the shortest time between photogates?

b. Write a one sentence hypothesis that relates the time between photogates to the angle of the track.
c. Use Table 1 to record the results from each group in your class. Record the times in the column labeled “First Trial”. Leave the column labeled “Second Trial” blank. How do the results compare with your hypothesis? Can you give a reason why they did or did not behave as you expected?

<table>
<thead>
<tr>
<th>Attachment hole (holes from bottom)</th>
<th>First Trial</th>
<th>Second Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time from A to B (s)</td>
<td>Time from A to B (s)</td>
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</tr>
</tbody>
</table>

3 Variables

a. List at least six variables in your system which affect the time between photogates.

b. Which variable is the experimental variable in your class? How do you know?

c. What should be done with the other variables (other than the experimental variable)? Why should this be done?

d. Name two variables that should not be included in your system. These variables should not have much (or any) influence on the time from photogate A to B.

4 A controlled experiment

1. With your teacher and the rest of your class, decide on how to control the variables other than the experimental variable.

2. Practice rolling the car until you can get three consecutive times within 0.0010 seconds of each other.

3. Repeat the experiment using the experimental and controlled variables you discussed and decided upon. Record the new data in the column titled “Second Trial.”

5 Applying what you have learned

a. Does the second trial of the experiment produce results that agree with your hypothesis?

b. Why does the second trial produce better agreement with your hypothesis than the first trial did?

c. If something does not work, discuss what you should do to try and find the problem. List at least three steps that relate to variables, experiments, and controls.
4A Speed

Can you predict the speed of the car as it moves down the track?

What happens to the speed of a car as it rolls down a ramp? Does the speed stay constant or does it change? In this investigation, you will measure the speed of a car at different points as it rolls down a ramp. Then you will make a graph that describes the motion, and predict the speed of the car somewhere on the ramp.

1 Describing speed

Suppose you ran in a race. What information do you need to describe your speed? Saying that you ran for 20 minutes would not be enough information. To describe your speed, you need two things:

1. The **distance** you traveled, and
2. The **time** it took you to travel that distance.

<table>
<thead>
<tr>
<th>Example</th>
<th>Distance</th>
<th>Time</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 meters</td>
<td>10 seconds</td>
<td>10 m/s</td>
</tr>
<tr>
<td></td>
<td>50 miles</td>
<td>1 hour</td>
<td>50 mi/hr</td>
</tr>
<tr>
<td></td>
<td>10 feet</td>
<td>15 seconds</td>
<td>0.67 ft/s</td>
</tr>
</tbody>
</table>
Based on the examples above, fill in the boxes to complete the equation for calculating speed.

\[
\text{speed} = \frac{\text{[ ]}}{\text{[ ]}}
\]

2 Making a hypothesis

Where is the car going the fastest on the ramp? Is it going fastest at the top, middle, or bottom?

a. Create a hypothesis about the car’s speed on the ramp - where is it the fastest, and why do you think so?

3 Setting up the experiment

1. Join the two ends of the ramp that say “Energy Car” to each other. The ramp should be straight, without a bend in the middle. Use two threaded knobs to connect the two parts.
2. Attach the ramp to the physics stand using one threaded knob. Your teacher will tell your group which hole on the stand to use. Hole where ramp is attached: _____
3. Place a bumper at each end of the ramp. Place a clay ball on the end of the thumb screw at the bottom of the ramp to stop the car. The thumb screw at the top of the ramp will be the place where you start the car.
4. Attach a photogate to input A of the Data Collector.
5. Place the photogate so its screw is on the round mark that is closest to the front of the car.
Using the photogate to measure speed

As the car passes through the photogate, the Data Collector clock starts and stops. The Data Collector measures the length of time that the light beam is broken. Speed is equal to the distance traveled divided by the time taken. What distance do you use?

If you look at the car you will see a small “flag” on one side. This is the part of the car that blocks the photogate’s light beam. The distance the car moves while the light is blocked is the width of the flag, 1 cm.

a. What is the distance traveled by the car in the example?

b. What is the time taken by the car in the example?

c. What is the speed of the car in the example?

Doing the experiment

1. Place the car at the top of the ramp. Place the photogate 10 cm down the hill from the car. Measure the distance from the front edge of the car’s flag to the middle of the screw that holds the photogate to the track. If you line up the car’s flag over one of the circular markings, measuring is made easier, since each mark is 5 cm away from each other. Record the photogate’s position in Table 1.

2. Release the car without pushing it. Record the time through photogate A in the table.

3. Calculate the speed of the car using the distance traveled (1 cm) and the time at photogate A.

4. Move the photogate 10 cm down the track. Record the position, time, and speed.

5. Repeat the measurements of position, time, and speed for six different places spaced along the ramp. You will have to skip some places in the middle of the track where the photogate won’t attach.
Table 1: Position, time, and speed data

<table>
<thead>
<tr>
<th>Position of photogate A (cm)</th>
<th>Time through photogate A (s)</th>
<th>Distance traveled by the car (cm)</th>
<th>Speed of the car (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
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<td></td>
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<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

6 Analyzing the data

a. From your measurements, what can you say about the car’s speed as it moves down the ramp?

b. Use your data to make a graph which shows how the car’s speed changes as it rolls down the ramp. Put speed on the y-axis and position of the photogate on the x-axis. Be certain to label the axes with the correct variable and the proper unit of measurement. Give the graph a descriptive title. Include the number of the hole you used to connect the ramp to the stand in your title.

c. Describe what the graph shows about how the speed of the car is changing as it moves down the ramp.

d. Compare your graph with that of students who connected their ramps at different heights on the stand. Explain any differences you see.

7 Using your graph

Now that you have gathered, organized, and analyzed your data, it is time to use it to make a prediction. You measured the speed of the car at several places on the ramp as it rolled to the bottom. Now, you will predict what the speed of the car will be at a place you did not measure. There is a way to do this with the information represented by your graph.

1. In Table 2 record a position on the ramp where you did not measure the speed of the car. The position should be between two places where you did measure the speed.
2. Use your graph to find the predicted speed of the car at the selected position. To do this, start on the x-axis at the position you have selected. Draw a line straight up until it intersects with the speed vs. position line on your graph. At the intersection point, draw a line horizontally over to the y-axis where the speed is recorded. This is the speed that corresponds to your predicted location. The graph to the right uses a position of 55 cm as an example. Use a different position. Record your predicted speed in Table 2.

3. Place the photogate at the position you selected in step 1 and record the time it takes for the car to pass through the photogate.

4. Use the wing length (1.00 cm) and the time to calculate the speed. Record the actual speed in Table 2.

5. How does the predicted speed compare with the actual measured speed? What does this tell you about your experiment and measurements?

### Calculating percent error

**a.** Find the difference between the predicted speed and the actual, calculated speed.

\[
\text{Predicted speed} - \text{Actual speed} = \text{Difference}
\]

**b.** Take this difference and divide it by the predicted speed, then multiply by 100.

\[
(D\text{ifference} \div \text{Predicted speed}) \times 100 = \text{Percent error}
\]

**c.** Use the percent error to calculate percent correct. Record percent correct in Table 2.

\[
100 - \text{Percent error} = \text{Percent correct}
\]

**d.** What do you think can account for any error you may have had?
4B Acceleration

What is acceleration?

When you turn the track into a sloped ramp, the car can gain speed as it travels down the ramp. The speed of the car is constantly changing. What would a graph of this type of motion look like? Is there more than one way to graph the motion of an object? In this investigation you will learn what acceleration is, what the graphs of associated with acceleration look like, and why they look the way they do.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
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<tr>
<td>SC.912.N.1.3</td>
<td>Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.</td>
</tr>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.</td>
</tr>
<tr>
<td>SC.912.P.12.02</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration (with respect to a frame of reference) as functions of time.</td>
</tr>
</tbody>
</table>

1. Setting up the experiment

Attach the straight track to the 10th hole from the bottom of the Physics Stand.

- Set up the track as a long straight hill. Attach the track to the 10th hole from the bottom of the Physics Stand.
- Place photogate A at position shown in photo. Keep photogate A in this position.

2. Predicting

A graph is a visual tool that shows how two things (called variables) are related to one another. Release the car from the top of the track and let it roll down the track a few times. Observe how the car’s position and speed changes as it rolls down the track.

- Think about what happens to the car’s position as it rolls down the track. Sketch what you think the position (y) vs. time (x) graph will look like for the Energy Car as it moves down the ramp. No need to
put any numbers on the axes; just label the axes and place a flat line, diagonal line, or curve on the graph, according to your prediction.

b. Do the same for the speed \((y)\) vs. time \((x)\) graph prediction.

3 Doing the experiment

1. Move photogate B to different positions 10 cm apart along the track.
2. For every position of photogate B, release the car and record the time through A and the time from A to B in Table 1.
3. Use the time through A to check the consistency of your release technique. If there is a very different time through A, re-do the trial.

Table 1: Position versus time data

<table>
<thead>
<tr>
<th>Distance from A to B (cm)</th>
<th>Time through photogate A (s)</th>
<th>Time from photogate A to B (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
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<td>50</td>
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<td>60</td>
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</tr>
<tr>
<td>70</td>
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</tbody>
</table>

4 Position vs. time graph for acceleration

a. Use your data from Table 1 to make a graph with the position (distance from A to B) on the \(y\) axis and the time it took to go that far (time from A to B) on the \(x\) axis.

b. How does the graph from your experiment data compare to your prediction? What happens to the distance traveled as time goes by for the car on the ramp?

c. How do you know, from looking at the graph, that the car did NOT travel at a constant speed?

5 Speed vs. time graph for acceleration

Another way to describe the car’s motion is to show how its speed changes with each new time interval from A to B. Speed is a measurement of how fast or slow an object’s position changes. The measurement of how an object’s speed changes is acceleration. You will try the experiment again, and use data to calculate the speed of the car as it travels through photogate B.

1. Keep photogate A in the same place as it was in part 3.
2. Move photogate B to different positions 10 cm apart along the track.
3. For every position of photogate B, release the car and record the time through A, the time through B, and the time from A to B in Table 2.

4. Use the time through A as a check the consistency of your release technique. If there is a very different time through A, re-do the trial.

**Table 2: Speed vs. Time Data**

<table>
<thead>
<tr>
<th>Distance from A to B (cm)</th>
<th>Time through photogate A (s)</th>
<th>Time through photogate B (s)</th>
<th>Time from photogate A to B (s)</th>
<th>Speed at photogate B (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td></td>
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<td>70</td>
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</tbody>
</table>

5. How fast is the car going as it travels through B each time? Calculate the speed of the car at each position of photogate B. Record your speeds in Table 2.

a. Draw a graph with the speed (speed through B) on the y axis and the time it took to go that far (time from A to B) on the x axis.

b. How does the graph from your experiment data compare to your prediction?

c. What happens to the speed as time goes by for the car on the downhill ramp?

### Applying what you’ve learned

a. Did the car accelerate as it traveled down the hill? Justify your answer.

b. Use the formula for acceleration to find the average acceleration of your car. Use data from the trial in Table 2 where photogate B was 70 cm from A. The unit for acceleration will be cm/s/s.

\[
\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time elapsed}}
\]

\[
\text{acceleration of car} = \frac{\text{speed B} - \text{speed A}}{\text{time A to B}}
\]

c. Use your speed vs. time graph to predict how much time would elapse for the car to reach a speed of 200 cm/s.

d. Use your position vs. time graph to predict where on the track the car would reach a speed of 200 cm/s.

e. Test your predictions with a photogate at your predicted location on the track. Were your predictions accurate? Record your observations.
5A What is a Newton?

What is force and how is it measured?

You can think of force as a push or pull. Objects interact with each other (and you) through forces. It takes force to start an object’s motion, and also force to stop an object in motion. This investigation will explore the precise definition of force and measure the strength of forces.

<table>
<thead>
<tr>
<th>Code</th>
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</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
<td>Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.</td>
</tr>
<tr>
<td>MA.912.S.3.2</td>
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</tr>
<tr>
<td>SC.912.N.1.1</td>
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</tr>
<tr>
<td>SC.912.P.12.4</td>
<td>Describe how the gravitational force between two objects depends on their masses and the distance between them.</td>
</tr>
</tbody>
</table>

1 Measuring forces

Forces have two important properties: strength and direction. In the English system of units, the strength of a force is measured in pounds. When you measure your own weight in pounds, you are measuring the force of gravity acting on your body. In the metric system, the strength of a force is measured in newtons (N). A quarter-pound hamburger has a weight of about 1 newton (1 lb = 4.448 N).

1. You can measure force with a spring scale. Before using the spring scale however, you must be sure it correctly starts at zero. Calibrate the spring scale by turning the nut on the top until the plunger lines up with the zero mark.

2. Pull on the hook so the spring extends. When you pull, you are applying a force. Can you make a force of two newtons (2 N)?

2 Weight: the force of gravity

Weight is a common force that you may be familiar with. Objects that have mass also have weight. Weight comes from the action of gravity on an object’s mass.

1. Attach 3 steel washers to a loop of string.
2. Use a calibrated spring scale to measure the weight of the washers in newtons (N).
3. Use an electronic scale or triple beam balance to measure the mass in grams (g). Convert each mass in grams to kilograms (divide by 1000 or move decimal point three places to the left).
4. Repeat the experiment for 6, 9, 12, and 15 washers.
3 Stop and think

What do the results of your experiment tell you about the relationship between weight in newtons and mass in kilograms? Create a graph as described below to answer this question.

a. Make a graph of your data from Table 1. Place weight in newtons on the vertical (y) axis and mass in kilograms on the horizontal (x) axis.

b. Describe the graph. What does it tell you about the relationship between mass and weight?

c. Calculate the slope of your graph. The slope is equal to the strength of gravity (g) on Earth, measured in newtons per kilogram (N/kg).

d. Write an equation that relates weight in newtons, mass in kilograms, and the strength of gravity (g). It should be in the form: weight = ____________

e. If an object has a mass of 10 kilograms, how much does it weigh in newtons?

4 Applying what you have learned

a. Explain how you could estimate the weight and mass of seven of your steel washers.

b. Find the weight and mass for seven of your steel washers. How close is the actual value to your estimated value? Explain some reasons why your value may not be perfectly accurate.
How does friction affect motion?

Friction is always present. Sometimes we want friction. For example, friction between tires and the road allows a car to be steered safely and maintain its direction when moving. Other times we want to reduce friction. Putting oil on a bicycle chain allows it to work more efficiently with the gears. This investigation explores different effects of friction.

<table>
<thead>
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</tr>
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<tbody>
<tr>
<td>MA.912.S.3.2</td>
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<tr>
<td>SC.912.P.12.2</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
</tbody>
</table>

### 1 Control setup

The first kind of friction you will be investigating is air friction. You will begin by finding out how the car moves before you add extra air friction.

1. Set up the track as a long straight hill as shown above.
2. Attach the track to the stand at the seventh hole from the bottom.
3. Place one photogate near the top of the track and one near the bottom of the track.
4. Put a steel ball in the middle pocket of the car.
5. Let the car roll down the ramp, and record the time from A to B.
6. Measure the distance between the photogates.
7. Use the distance to calculate the average speed of the car.
8. Repeat two more times, for a total of three trials.
9. Calculate the average speed from your three trials.
Create the “sail” car
A paper plate “sail” adds air friction (drag) to the car.
1. Tape a tongue depressor to the flag on the side of the car.
2. Tape a paper plate to the tongue depressor. Use enough tape to make sure it is securely attached.

Your hypothesis
a. Write a hypothesis that compares the speeds of the “sail car” and the normal car.
b. Explain the reasoning behind your hypothesis.

Do the experiment
1. The track and photogates should be set up as in part 1.
2. Put a steel ball in the middle pocket of the car.
3. Let the sail car roll down the ramp, and record the time from A to B.
4. Calculate the average speed of the car.
5. Repeat two more times, for a total of three trials.
6. Calculate the average speed from your three trials.

Table 1: Control speeds

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time A to B (s)</th>
<th>Distance between A and B (cm)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Average Speed

Table 2: Experimental speeds; sail car

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time A to B (s)</th>
<th>Distance between A and B (cm)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
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</tr>
</tbody>
</table>

Average Speed
Stop and think

a. Did your results confirm your hypothesis? Explain.

b. How did air friction affect the car’s motion?

Applying what you have learned

a. Friction is a force that opposes motion. Explain where the friction force on the sail comes from.

b. How could you increase the air friction on the car? How could you decrease it?

c. Is the sail the only source of friction? Does the car have any friction forces acting on it other than air friction? Explain.

Setting up to measure rolling and sliding friction

1. Set up the track so is exactly level. Put a clay ball on the stopper at one end of the track. Put a rubber band on the other end of the track. As you attach it, twist it once so it makes an X. You will be using the rubber band to launch the car and sled.

2. Adjust the stopper near at the launching end of the track so it is approximately 4 cm from the rubber band.

3. Place the sled on the track so the nose of the sled is touching the rubber band.

4. Place photogate A on the mark just ahead of the flag on the sled. The flag should not be blocking the photogate beam. Place photogate B 45 cm from photogate A.

Do the experiment

1. Launch the sled by resting your hand on the wooden track support and placing your index finger on the finger grip near the front of the sled. Practice a few times.

2. The sled should make it through both photogates. If it stops too soon, adjust the stopper so you can pull the rubber band back farther.

3. Record the time through each photogate and the time from photogate A to B.

4. Repeat for a total of three trials.
Table 3: Sliding friction data - sled

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time through A (s)</th>
<th>Time through B (s)</th>
<th>Time from A to B (s)</th>
<th>Speed through A (cm/s)</th>
<th>Speed through B (cm/s)</th>
<th>Acceleration (cm/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td></td>
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<td>2</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>average</td>
</tr>
</tbody>
</table>

5. The speed of the sled through photogate A is the width of the flag (1 cm) divided by the time through A. Calculate the speed through A. Repeat for photogate B.
6. Use the two speeds and the average time from A to B to calculate the acceleration. Then find the average acceleration.
7. Repeat steps 3 through 6 using the car instead of the sled.

Table 4: Rolling friction data - energy car

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time through A (s)</th>
<th>Time through B (s)</th>
<th>Time from A to B (s)</th>
<th>Speed through A (cm/s)</th>
<th>Speed through B (cm/s)</th>
<th>Acceleration (cm/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>average</td>
</tr>
</tbody>
</table>

9 Thinking about your data

a. Were your accelerations positive or negative. Why is this?
b. Which decelerated more, the sled or the car?
c. What does your answer to the previous question tell you about the rolling friction of the car compared to the sliding friction of the sled?
d. How could you increase the sliding friction between the sled or track? How could you decrease it?
e. How could you increase the rolling friction between the car and track? How could you decrease it?
f. Compare rolling friction, air friction, and sliding friction. Which do you think has the greatest effect on the car’s motion? Which has the least effect?
Newton's First and Second Laws

What is the relationship between force and motion?

The relationships between force and motion are known as Newton’s laws. These are among the most widely used relationships in all of physics. The First Law explains what happens when there is NO net force on an object, and the Second Law explains what happens when there IS a net force. The two laws are closely related. We will focus in this investigation on what happens to the Energy Car’s motion when you change the force and the mass separately. Both laws apply!

Making predictions

Newton’s Second Law explains what happens to the acceleration of an object when you change the force applied or change the mass of the object. For this first part of the investigation you will use different amounts of force to launch the car. You will not measure the resulting acceleration, because you would have to measure it while the car is still being acted upon by the rubber band, and this is impossible. Instead, you will measure the RESULT of the acceleration caused by the force of the rubber band. The RESULT will be measured by looking at changes in the car’s speed as it rolls along the track after the launch.

a. Make a prediction: What will happen to the speed of the car as the force gets larger?

Changing force with constant mass

1. Set up the long straight track with a rubber band on one end and a clay ball on the other end. Adjust the screw so the rubber band deflects about two centimeters. Be sure to stretch the rubber band once or twice before using.
2. Put one photogate on the first square mark after the rubber band.
3. Put one marble in the center of the car. Use the screw to launch the car using the same deflection of the rubber band each time. This means the same force is applied to each launch. Try to get three launches with times that are within 0.0015 seconds. Average these times and record the result in Table 1.
4. Repeat the experiment with two and three rubber bands. Stretch before using!
5. Calculate the car’s speed. Remember to use the tab width, 1.00 cm, for the distance.

<table>
<thead>
<tr>
<th>Number of rubber bands</th>
<th>Time through photogate (s)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3 Stop and think

a. During which portion of the car’s motion is the rubber band affecting its speed?

b. Make a graph showing the speed of the car on the y-axis and the number of rubber bands on the x-axis. As the force was increased, what happened to the speed of the car?

c. Why was the same mass used for all trials (with different force)?

4 Changing mass with constant force

Use 1 rubber band to launch cars with 0, 1, 2, and 3 marbles.

0 marbles

1 marble

2 marbles

3 marbles

1. Put a single rubber band on the launching end of the track. Stretch it before using. Leave the photogate in the same place as it was (on the first square mark after the rubber band).
2. With the screw in the same place, launch cars of four different masses. Record the times in Table 2.
3. Measure the mass of the car with 0, 1, 2, and 3 steel marbles.
4. Calculate the car’s speed. Remember to use the tab width, 1.00 cm, for the distance.

<table>
<thead>
<tr>
<th>Mass of car (g)</th>
<th>Time through photogate (s)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5 Applying what you have learned

a. Use Table 2 to graph the speed of the car (y) against the mass (x). Does your graph show a direct relationship or an inverse relationship?
b. Why did the speed change when the same launching force from the rubber band was applied to cars of different mass? How do your observations support your answer?

c. Newton’s First Law is often called “The Law of Inertia”. How does this law apply to the car’s motion when you changed the mass but kept the force constant?

d. Do you think the force applied to an object causes speed itself or causes changes in speed? Support your answer with at least one sentence of explanation for why you believe your answer is correct.

When an object’s speed changes we say the object accelerates. Acceleration occurs whenever speed changes. To be precise, acceleration means the “change in speed divided by the change in time”.

\[
\text{Acceleration} = \frac{\text{change in speed}}{\text{change in time}}
\]

e. Based on your experimental results, propose a mathematical relationship between the variables \( F \) (force), \( a \) (acceleration), and \( m \) (mass).

### Fun challenge

Try this additional mini-experiment to see something interesting. You will launch the car with one rubber band and no marbles. Then you will launch the car with TWO rubberbands and TWO marbles in the car. This means you will double both the force and the mass at the same time. How will the times compare? Make a prediction.

1. Launch the car with one rubber band. Stretch the rubber band before using. There should be no marbles in the car. Get three times that are within 0.0015 s of each other and average. Record the time average in Table 3.

2. Launch the car with two rubber bands (be sure to stretch first!) and 2 marbles (placed in front and back of car). Get three times that are within 0.0015 s of each other and average. Record the time average in Table 3.

<table>
<thead>
<tr>
<th>Time through photogate (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 rubber band, no marbles</td>
</tr>
<tr>
<td>2 rubber bands, 2 marbles</td>
</tr>
</tbody>
</table>

a. What do you notice about the times?

b. Explain your result. How does it compare to your prediction?
6B Newton’s Third Law

What happens when equal and opposite forces are exerted on a pair of Energy Cars?

When you apply a force to throw a ball you also feel the force of the ball against your hand. That is because all forces come in pairs called action and reaction. This is Newton’s Third Law of motion. There can never be a single force (action) without its opposite (reaction) partner. Action and reaction forces always act in opposite directions on two different objects. You can set up two Energy Cars to study Newton’s Third Law.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.N.1.3</td>
<td>Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.</td>
</tr>
<tr>
<td>SC.912.P.12.3</td>
<td>Interpret and apply Newton's three laws of motion.</td>
</tr>
</tbody>
</table>

1. Setting up and starting the experiment

1. Set up the long straight track with a ball of clay on each stop. Use the bubble level to set the track level.
2. Place one steel marble in each car, and wrap one car with a rubber band.
3. Place two photogates 15-cm apart as shown in the photo.
4. Place the 2 cars, “nose to notch” between the photogates.
5. Squeeze the cars together and attach them with the Energy Car link.
6. Center the attached car pair between the photogates so each is about to break the photogate’s beam, but do not actually break the beam. Check that both photogate indicator lights are still green. Make sure all 4 wheels of both cars are on the track.
7. With a very quick upward motion, pull the link straight up and out from the cars. **CAUTION: Wear eyeglasses or safety glasses to avoid injury.**
8. Observe the time through each photogate. Repeat several times.
2 Thinking about what you observed
   a. What caused the two cars to move when you took out the link?
   
   b. According to Newton’s third law, the cars experienced equal and opposite forces. How can you tell this is true by looking at the time through each photogate?
   
   c. If one car was twice the mass of the other, would the cars still experience equal and opposite forces? Why or why not?

3 Changing the masses

NOTE: Adding two steel marbles to the Energy Car doubles its mass.

1. Try the experiment with the four combinations of mass shown above. Take the average of three trials for each and record your data in Table 1. CAUTION: Wear eyeglasses or safety glasses to avoid injury.

2. Calculate the average speed for each trial and record in Table 1.

<table>
<thead>
<tr>
<th>Marble pairings for connected cars</th>
<th>Time through photogate (s)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>0 marbles</td>
<td>2 marbles</td>
<td>0</td>
</tr>
<tr>
<td>0 marbles</td>
<td>0 marbles</td>
<td>2</td>
</tr>
<tr>
<td>2 marbles</td>
<td>0 marbles</td>
<td>0</td>
</tr>
<tr>
<td>2 marbles</td>
<td>2 marbles</td>
<td>0</td>
</tr>
</tbody>
</table>

4 Applying what you have learned

   a. How does the speed of each car pair compare when masses are equal?
   
   b. How does the speed of each car compare when one of the pair has twice the mass?
   
   c. Explain how your speed data supports the idea that there are equal and opposite action and reaction forces acting on the cars.
   
   d. If the action and reaction forces are equal in strength, when the cars separate, why does one car move at a different speed than the other car when the masses are unequal? Hint: the answer involves the Second Law of Motion.
### 7A Energy in a System

**How is energy related to motion?**

A system is a group of objects that interact with each other. Energy measures the ability of a system to change itself or other systems. This investigation is about systems and energy.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.10.1</td>
<td>Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.</td>
</tr>
<tr>
<td>SC.912.P.10.2</td>
<td>Explore the Law of Conservation of Energy by differentiating among open, closed, and isolated systems and explain that the total energy in an isolated system is a conserved quantity.</td>
</tr>
<tr>
<td>SC.912.P.12.2</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
</tbody>
</table>

#### 1 Making a system

1. Set up the track with the steeper hill and a level section as shown above.
2. Place a rubber band on the thumb screws at the bottom of the track.
3. Attach a photogate near the middle of the level section at the spot marked with a square.

#### 2 Collecting data

1. Measure the distance between the center of the track and the stopper at the top of the track as shown above. Record this distance (the drop position) in Table 1.
2. Hold the car against the stopper and release it without giving it a push.
3. Record the time through the photogate before and after the car bounces off the rubber band. You will have to use the memory button to get the time before the bounce.
4. Calculate the speed of the car before and after it bounces. The speed is the width of the flag (1 cm) divided by the time it takes the flag to pass through the beam of the photogate. Record the speeds in the table.
5. Move the wooden track stop part of the way down the hill. Measure the distance from the center of the track to the metal stopper.
6. Drop the car as you did before. Measure the times and calculate the speeds.
7. Repeat for several drop positions along the hill.

**Table 1: Speed data**

<table>
<thead>
<tr>
<th>Drop position (cm from center)</th>
<th>Before bouncing</th>
<th>After bouncing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time through photogate (s)</td>
<td>Speed (cm/s)</td>
<td>Time through photogate (s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Thinking about what you observed**

a. How high did the car climb up the hill after bouncing? Did it go higher, lower, or the same height as the drop position?

b. How is the drop position related to the speed of the car the first time it passes through the photogate (before bouncing)?

c. How do the speeds before bouncing compare to the speeds after bouncing? Is this the same for all five trials?

d. What could you do to make the car travel farther up the hill after bouncing?

e. In one paragraph, explain how the answers to a, b, c, and d are explained using the idea of energy.
7B Conservation of Energy

What limits how much a system may change?

A car launched up the hill at a given speed will never go higher than a certain point. A car rolling downhill will only reach a certain speed. Why? The answer is that nature keeps an exact balance of energy. Speed uses one form of energy and height uses another. This investigation explores the exchange of energy.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.10.1</td>
<td>Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.</td>
</tr>
<tr>
<td>SC.912.P.10.2</td>
<td>Explore the Law of Conservation of Energy by differentiating among open, closed, and isolated systems and explain that the total energy in an isolated system is a conserved quantity.</td>
</tr>
</tbody>
</table>

1. Energy exchange from potential to kinetic

- Set up the track with the steeper hill and a level section. Make the level section as level as you can. Attach a photogate at the bottom of the hill on the level section.
- Thread a string though the hole in the lower stop and use a photogate to clamp the other end of the string to the stand. Adjust the string so it is parallel to the level section of the track.
- Drop the car from each 5-cm mark on the hill and measure the speed with the photogate. Measure the height of the car from the string to the center of the car.
4. Measure the mass of the car and record it in the table.

<table>
<thead>
<tr>
<th>Drop Height (m)</th>
<th>Mass of car (kg)</th>
<th>Photogate time (s)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
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</table>

### Thinking about what you observed

**a.** Graph the speed of the car vs. the height.

**b.** What does the graph tell you about the relationship between speed and drop height?

### Analyzing the data

**a.** Use the formula for potential energy to fill in the second column of Table 2.

**b.** Use energy conservation to derive a formula for the speed of the car in terms of the energy it has at the start. (Hint: your formula should include only two variables, velocity and height.)

**c.** Use the formula you just derived to fill in the column for the predicted speed of the car.

**d.** Plot the curve for the predicted speed on the same graph as you made in part 2a above.

<table>
<thead>
<tr>
<th>Drop Height (m)</th>
<th>Potential energy (J)</th>
<th>Predicted speed (m/s)</th>
<th>Measured speed from Table 1 (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
4 Thinking about what you observed

a. Explain the relationship between speed and height using the idea of energy conservation.

b. Explain any difference between the predicted and measured speeds. If there is a difference, what does it tell you about the energy of the car as it rolls along the track?

c. Let the car roll downhill, bounce off the rubber band and go back up hill again. Does it reach the same height as it was dropped from? Explain why or why not using the idea of energy conservation.

d. Challenge experiment. Use a rubber band to launch the car uphill so it goes through the photogate with the same speed as it had going down. You won’t be able to get it precisely the same, but come as close as you can. If the speeds are the same, the car’s kinetic energy is also the same. Does the car reach the same height on the hill that it was dropped from to get the same speed in part 1? Explain any difference using the idea of energy.
8A Manipulating Forces

How do simple machines work?

Would you believe that a small child could lift an elephant? It can be done by building a simple machine out of ropes and pulleys. In this investigation, you will learn how to build machines that allow you to lift large weights with small forces. You will also learn how to measure the input and output forces of these machines.

### Setting up the ropes and pulleys

Throughout this investigation you will be measuring forces with a spring scale. To get the most accurate readings, always use a spring scale with the smallest maximum force without going over the limit of the scale. For example, using a 2.5 N scale to measure a force of 1 N will give you a more accurate result than using a 10 N scale.

1. Attach four weights to the bottom pulley block. Use a spring scale to obtain the weight of the bottom block after you attach the weights.
   
   Record the weight of the bottom block: ____ N

2. The output force of this simple machine will be used to lift the bottom block. Attach the top block near the top of the physics stand. The yellow string can be clipped to either the top block or the bottom block. Start with the yellow string clipped to the bottom block.

**Why all the strings?**

- The yellow string will be used to move the bottom pulley block with the weights up and down. You will pull on one end of the yellow string. There is a clip at the other end of the yellow string for attaching to the pulley blocks.
- The yellow string may have several strands that directly support the bottom pulley block. These are called the supporting strands.
- The red string is the safety string. It holds up the bottom block while you rearrange the yellow string.

> **Safety Tip:** Don’t pull sideways or you can tip the stand over!

### Investigating the ropes and pulleys

1. Clip the end of the yellow string to the bottom pulley block. Pass the string over the middle pulley of the top block. Use the marker stop (cord stop) to hook the force scale to the string.

2. Measure the force it takes to slowly lift the bottom pulley block.

---

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
<td>Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.</td>
</tr>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
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<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.12.3</td>
<td>Interpret and apply Newton’s three laws of motion.</td>
</tr>
</tbody>
</table>
1. This arrangement has one strand supporting the bottom pulley block. Record the force in the table below in the row corresponding to one strand.

2. Unclip the yellow string from the bottom block and pass it around the middle pulley in the bottom block as shown in the picture above. Clip the yellow string to the top block.

3. Move the marker and measure the force it takes to slowly lift the bottom pulley block. Record this force in the row for two supporting strands.

4. Rearrange the yellow strings so that you get three, four, five, and six supporting strands. Measure and record the force it takes to lift the bottom pulley block for each new setup.

Table 1: Force to lift pulley block

<table>
<thead>
<tr>
<th>Number of support strands</th>
<th>Force to lift bottom pulley block (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
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<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

a. As you add more supporting strands, what happens to the force needed to lift the bottom block?

b. How does the amount of input force required to lift the bottom block change with the string arrangement? Can you identify a mathematical rule?

3 What did you learn?

a. How are all simple machines alike? How is a lever different from a machine made with ropes and pulleys? (Think about input and output force.)

b. What is the relationship between the number of strings on the ropes and pulleys, and the amount of input force required to lift the bottom block?
8B Work

How can a machine multiply forces?

Simple machines such as ropes and pulleys and levers can create large output forces from small input forces. In this investigation you will explore the nature of work and come to an interesting conclusion that is true for all machines.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
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<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.10.03</td>
<td>Compare and contrast work and power qualitatively and quantitatively.</td>
</tr>
</tbody>
</table>

1 Setting up the experiment

1. Attach four weights to the bottom pulley block. Use a spring scale to measure the weight of the block in newtons. Record this value in column five of Table 1. This value is the output force and does not change in the experiment.

2. Using a ropes and pulleys set, clip the end of the yellow string to the bottom block. Pass the string over the middle pulley of the top block as shown.
3. Use the plastic cord stop to mark where the string leaves the top pulley.

4. Lift the bottom block a fixed height (h). The holes in the stand are 5 centimeters apart and you can use the holes as a height reference. Use at least 20 centimeters as your lifting height.

5. Measure how much string length (L) you must pull to lift the block the chosen distance. You can measure this using the cord stops and a ruler.

6. Using the spring scale, measure the force needed to lift the block in newtons (N). This is the input force.

7. Record the input force, height difference for the block (h), and string length (L) in Table 1.

8. Unclip the string from the bottom block, and clip it onto the underside of the top block. Pass the string around the middle pulley on the bottom block, and loop it up over the middle pulley of the top block as shown. Pull the string to lift the bottom block the same height (h) that you used for the first set-up. Measure the string length (L) that you must pull the string. Record the values in the second row of Table 1.

9. Rearrange the yellow string so it passes over 3, 4, 5, and 6 pulleys. You should always be pulling down on the string to raise the block, and you should always lift the bottom block the same height.

10. For each combination record the input force and string length (L).
Analyzing the data

a. Calculate the work done on the block. This work is equal to the output force (weight of the block in newtons) times the height difference. The work done on the block should be the same for all configurations of the strings because the weight of the block and the height it was lifted did not change.

b. Next, calculate the work you did as you pulled on the string to lift the block in each trial. Your work is found by multiplying the input force by the string length.

c. As the number of supporting strings increased, what happened to the input force needed to lift the block?

d. As the number of supporting strings increased, what happened to the length of string that was pulled to raise the block?

e. As the number of supporting strings increased, what happened to the amount of work you had to do (work input) to lift the block?

f. Use your answers to the last three questions to explain the meaning of the statement, “Nature does not give things away for free.”
9A Levers

How does a lever work?

How can you lift up a car—or even an elephant—all by yourself? One way is with a lever. The lever is an example of a simple machine. What variables can you change to make a lever do things like lift a car or an elephant?

<table>
<thead>
<tr>
<th>Code</th>
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</tr>
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<tbody>
<tr>
<td>MA.912.S.1.2</td>
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</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.10.03</td>
<td>Compare and contrast work and power qualitatively and quantitatively.</td>
</tr>
<tr>
<td>SC.912.P.12.3</td>
<td>Interpret and apply Newton’s three laws of motion.</td>
</tr>
</tbody>
</table>

1. **Setting up the lever**

   1. Use loops of string to make hangers for the weights. You can put more than one weight on a single string.
   2. Slide the loop of string through the hole in the weight.
   3. Pull the knotted end through the loop itself and tighten by pulling on the knot.
   4. Slide a short thumbscrew through the hole in the middle of the lever.
   5. Attach the lever to the physics stand by sliding the short thumbscrew through one of the holes on the front of the stand.
   6. Use a knob to secure the lever and thumbscrew onto the back of the stand.
   7. The knob should be tightened snugly on the thumbscrew and press lightly against the back of the stand.
   8. The weights can be hung from the lever by hooking the string over the center peg in the holes. Make sure that the string is all the way around the peg.
2 Levers in equilibrium

a. The lever is in equilibrium when all the weights on one side balance all the weights on the other side. Hang the weights as shown below. Does the lever balance? Note: when the lever is in equilibrium, the lever arm is not necessarily perfectly horizontal.

b. What variables can be changed to balance a lever?

3 Trying different combinations to balance the lever

Make different combinations of weights and positions that balance. Use the chart below to write down the numbers of weights you put in each position. If you want to conduct more than four trials, write your results on a separate sheet of paper.
4 Determine the mathematical rule for equilibrium

a. Draw a lever and label these parts: fulcrum, input arm, output arm, input force, and output force.

b. Using the data in the chart above, determine a mathematical rule for levers in equilibrium. Use these variables: *input force*, *output force*, *length of input arm*, and *length of output arm*. First, make some calculations, then write your rule as an equation. The equation will have two variables on each side, with an equal sign in the middle.

5 What did you learn?

a. There are two ratios that can be used to determine mechanical advantage in levers. What are the two equations? What is the relationship between the two equations?

b. What could you do to the input side of a lever to increase the amount of output force? (HINT: There are two different things you could do).
Levers and the Human Body

What types of levers does your body have?

Arms, legs, fingers, toes, the jaw, even the head and neck work like levers. Contracting and extending muscles provide the force to move our levers. Our joints are the fulcrums around which these levers pivot and move. Our bones are the levers themselves. In this investigation, you will look at the human arm and examine how it works like a lever.

1. Attach the lever to the stand, but this time use the hole on the left-most side of the lever. Use one of the short thumbscrews. Do not tighten the knob all the way. Leave a little room so the lever can still pivot.
2. Use a loop of string to hang one weight on the right-most side of the lever. Measure its weight in newtons using a force scale (the green one). Record it in Table 1.
3. Measure this distance from the pivot point to the position of the hanging weight and record it in Table 1.
4. Measure the distance from the pivot point to the next hole on the lever. This is where we will apply force to lift the lever. Record the distance in Table 1.
Levers and the Human Body

Investigation 9B

<table>
<thead>
<tr>
<th>Output force (N)</th>
<th>Input arm (cm)</th>
<th>Output arm (cm)</th>
<th>Mechanical advantage</th>
<th>Predicted input force (N)</th>
<th>Measured output force (N)</th>
</tr>
</thead>
</table>

### Table 1: Input and output data

2. **The lever arm model**
   
   a. Calculate the mechanical advantage of the lever. Record your result in Table 1.
   
   b. Based on the mechanical advantage, predict the force required to lift the lever up and keep it horizontal. Record it in Table 1.
   
   c. The connective tissue in your arm attaches your biceps to your forearm at the inside of the elbow. Since the muscle provides the lifting force close to the elbow joint, we will provide the lifting force for the lever close to the pivot point. Hook a force scale (the red one) to the lever at the hole just to the right of the pivot point and lift up until the lever is horizontal. Keep it horizontal and record the force needed to keep it there in Table 1.
   
   d. How does your predicted value match your measured value? Why do you think this is?
   
   e. Test your reason why the values are different. What did you find?
   
   f. Draw a diagram showing how the lever setup models an arm lifting a weight.
How can observing the melting point identify a pure substance or a mixture?

Matter can be divided into two main categories: mixtures and pure substances. Pure substances are homogeneous throughout. They have the same chemical properties no matter where the sample is obtained or how large the sample is. Mixtures are combinations of two or more substances, with each substance retaining its chemical identity.

In this lab, you will obtain four test tubes containing unknown solids. The melting point, or the temperature at which the matter changes from a solid to a liquid, will be measured to determine if the matter is a mixture or a pure substance. Any given pure substance will always have the same melting point. Pure substances usually melt over a small temperature range while mixtures often melt over a very wide temperature range.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences can be drawn from scientific observations and provide examples.</td>
</tr>
<tr>
<td>SC.912.P.8.1</td>
<td>Differentiate among the four states of matter.</td>
</tr>
<tr>
<td>SC.912.P.8.2</td>
<td>Differentiate between physical and chemical properties and physical and chemical changes of matter.</td>
</tr>
<tr>
<td>SC.912.P.12.11</td>
<td>Describe phase transitions in terms of kinetic molecular theory.</td>
</tr>
</tbody>
</table>

1 Thinking about what you will do

Why do you think a pure substance will melt over a smaller range of temperatures than a mixture?

2 Doing the experiment

1. Attach the temperature probe to the Data Collector and set it to meter mode for the entire experiment. Record your sample label (A-D) in Table 1.

2. Add approximately 200 mL of cold water to a 250 mL beaker. Place the beaker on the hot plate, and turn the hot plate on to medium.

3. Place the first sample into the water bath and have one group member hold the temperature probe about halfway in the water.

4. Another group member should stir the contents of the test tube with a stirring rod as it heats.

5. Watch the contents of the test tube carefully. At the moment the contents begin to melt, measure and record the temperature in Table 1.

6. Continue stirring the contents of the test tube and watching the contents until the entire sample is liquefied. Once the last solid particle melts, measure and record the temperature in Table 1.

7. Return your sample to your instructor.

8. Pour out the hot water in the beaker.

9. Repeat steps 2-8 for each of the remaining samples. Be sure to start with a fresh sample of cold water for the water bath.
3 Analyzing the data
   a. How would you know which test tubes contain pure substances and which contain mixtures?
   b. If a sample contained 1 gram of pure substance A and another test tube contained 4 g of pure substance A, how would the melting points differ? How would the experiment differ?
   c. Name two possible sources of error for this experiment. How would they affect your data?

4 Applying your knowledge
A white, waxy substance is heated in a test tube. Part of the substance melts almost immediately, and is poured off into a separate test tube after a minute of further heating, leaving a little more than half of the original sample behind.
   a. Explain why you think the original sample was a pure substance or a mixture.
   b. Is the melted portion that was poured off a pure substance or a mixture? What evidence do you base your answer on?
   c. Can you be sure that the remaining portion left behind in the test tube is a pure substance or a mixture? How could you know for sure?
10B Determining Freezing/Melting Point

How do you determine the freezing/melting point of cetyl alcohol?

A cooling/heating curve is a plot of temperature vs. time. It illustrates the effect on a substance as the temperature decreases/increases through a phase change. In this experiment, you will study the effects of cooling and heating cetyl alcohol through a phase change. The data will be recorded using a data collector and then plotted on graphs. Based on your observations, measurements, and graphs you will be able to determine the freezing/melting point of cetyl alcohol.

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</tbody>
</table>

1 Thinking about what you will do

a. The cetyl alcohol you will be using is a pure substance. What do you expect to observe in terms of the temperature range for the freezing/melting point?

b. Suppose your cetyl alcohol sample became contaminated with another substance. How would this affect the freezing/melting point?

2 Melting cetyl alcohol

1. Fill a 250 mL beaker with cold water.
2. Fill a 400 to 600 mL beaker with approximately 250 mL of hot water (75–80 °C).
4. Measure the temperature of the hot water to make sure it is within the range in step 1.
5. Quickly immerse the temperature probe into the cold water. Then remove and dry it making sure it is cooled to room temperature.
6. Place the temperature probe into the test tube and put the test tube containing the solid into the water bath and press START on the Data Collector. View the experiment in graph mode.
7. Stir the solid vigorously with the temperature probe.
8. Continue to stir as long as some solid remains.
9. Once all of the material is liquid, stop and store the experiment. Record the experiment name assigned by the Data Collector.
3 Stop and think

a. Predict the effect of sample size on the melting/freezing point.

b. Describe and carefully sketch the shape of the graph from Part 2.

4 Freezing cetyl alcohol

1. Observe the cetyl alcohol in the test tube to make sure it is still all liquid. If some solid has formed, pour out the water in the warm beaker and add more warm water.

2. Remove the test tube from the warm beaker and start a new experiment on the data collector.

3. Stir the liquid vigorously with the temperature probe as the solid begins to form.

4. Continue to stir until all of the liquid turns into a solid. (NOTE: If you need to repeat any part of the experiment, you may re-use your sample.)

5. When you are finished recording data return your sample of cetyl alcohol to your teacher.

6. Record the name of the experiment from the data collector in your notebook.

5 Thinking about what you observed

a. Describe and carefully sketch the graph from Part 4.

b. Referring to both of your graphs, determine the melting and freezing point of cetyl alcohol. Are they the same? Should they be?

c. Based on the shapes of your curves, which data do you think is more reliable - the heating or cooling data? Why do you think this is so?

d. What is happening to the molecules of cetyl alcohol during the diagonal portions of the heating curve? What about the plateau?

e. Your graph from Part 2 shows that during a change from solid to liquid, the temperature stays the same. Explain why the temperature does not increase, even though energy is being added.
11A Temperature and Heat

How are temperature and heat related?

Hot and cold are familiar sensations. What happens when something hot comes in contact with something cold? Think about putting some ice cubes in a drink. Things don’t remain the same, changes occur and these changes have to do with the movement of energy from one material to the other. This investigation will explore the difference between temperature and thermal energy, and how the movement of thermal energy relates to the concept of heat.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>SC.912.N.1.3</td>
<td>Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.</td>
</tr>
<tr>
<td>SC.912.P.10.4</td>
<td>Describe heat as the energy transferred by convection, conduction, and radiation, and explain the connection of heat to change in temperature or states of matter.</td>
</tr>
<tr>
<td>SC.912.P.10.5</td>
<td>Relate temperature to the average molecular kinetic energy.</td>
</tr>
</tbody>
</table>

1 Making a prediction

Suppose you mix equal masses of water. One sample is at 0 °C and the other is at 50 °C. What do you think the final temperature of the mixture will be? Why?

2 Mixing hot and cold water

1. You will need three 12 ounce foam cups for this experiment. Label two of the cups as follows: HOT and COLD.
2. Prepare an ice bath by placing approximately 250mL of water in the unlabeled cup and add 4 or 5 ice cubes.
3. Connect the temperature probe to the Data Collector and select Meter mode for this experiment.
4. Place the temperature probe in the ice water bath.
5. Use a graduated cylinder to measure 100 mL of very hot tap water. Pour the hot water into the HOT cup.
6. Use a graduated cylinder to measure 100 mL of the ice water. Pour the cold water into the COLD cup.
7. Place the temperature probe into the COLD cup, wait until the reading stabilizes and record the temperature in Table 1.
8. Place the temperature probe into the HOT cup. Wait until the reading stabilizes and record the temperature in Table 1.
9. Immediately pour the hot water into the cold water. This is the mixture.
10. Stir well using the temperature probe and measure the final temperature (when it has stabilized). Record your data in Table 1.
11. Do not throw away your ice water. You will be using it again in the second part of the investigation.
3 Thinking about what you observed

a. Did the result of your experiment agree with your prediction (within 3 degrees)? Discuss why the temperature value may not have matched exactly your predicted value.

b. How do you think your results would have been different if you had used more hot water than cold water, instead of equal masses?

4 Making another prediction

Suppose you mix equal masses of cold water and hot metal. Will the final temperature follow the same pattern as the experiment you did in Part 2? Explain your answer.

5 Combining hot metal and cold water

1. Find the mass of the aluminum cube and record in Table 2.
2. Connect the temperature probe to the Data Collector and select Meter mode for this experiment.
3. Place the temperature probe in the ice water bath that was left from part 2 of the experiment.
4. Place the aluminum cube in a foam cup and cover it with very hot tap water. Let the aluminum cube stay in the hot water for several minutes so it gets warm.
5. Measure out a mass of water from the ice water bath that is equal to the mass of the aluminum cube and pour it into a foam cup. Record the mass of the cold water in Table 2. Make sure there is no ice in the foam cup of cold water.
6. Move the temperature probe from the ice water bath to the cup of cold water and record the temperature of the cold water in Table 2.
7. Record the temperature of the hot water and aluminum cube just before putting the cube in the cup of cold water. Record the value in Table 2.
8. Use the tongs to put the aluminum cube in the foam cup containing the cold water.
9. Stir the mixture with the temperature probe.
10. Record the temperature of the cold water and metal cube when the temperature has stabilized. Do not wait longer than one minute to measure the temperature. Record this value in Table 2.
### Table 2: Temperature data for combining water and metal

<table>
<thead>
<tr>
<th>Metal mass (g)</th>
<th>Metal temp. before mix (°C)</th>
<th>Cold water mass (g)</th>
<th>Cold water temp. before mix (°C)</th>
<th>Mixture temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</table>

**Thinking about what you observed**

a. Why didn’t the temperature of the water and aluminum mixture come out halfway between the temperature of the cold water and hot aluminum cube, even though you mixed equal masses?

b. Explain what is happening between the aluminum cube and water in terms of temperature and energy.

c. How much energy does it take to raise the temperature of one gram of aluminum by 1 °C compared to raising the temperature of one gram of water by 1 °C? (Look up this value.) Relate your answer back to your experimental results.

d. Heat and temperature are related, but they are not the same thing. According to your results, what does the concept of heat energy take into account that temperature does not?
11B The Specific Heat of a Metal

How can you use specific heat to identify an unknown metal sample?

If you have ever walked barefoot on a concrete walkway or street during a hot and sunny day, you have felt its warmth on your feet. In fact, the thermal energy transferred to your feet may send you retreating to the grass or even a swimming pool. Why is the temperature of the concrete so different compared to the temperature of the soil or the swimming pool? Even though the sunlight shines on all three surfaces, it is easier to raise the temperature of concrete compared to the water in a swimming pool. A hot summer day may only raise the temperature in a pool by one or two degrees.

In this investigation, you will use a calorimeter, the specific heat of water, and the law of conservation of energy to determine the specific heat of a sample of copper and two unknown metal samples.

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</tr>
<tr>
<td>SC.912.P.10.2</td>
<td>Explore the Law of Conservation of Energy by differentiating among open, closed, and isolated systems and explain that the total energy in an isolated system is a conserved quantity.</td>
</tr>
<tr>
<td>SC.912.P.10.4</td>
<td>Describe heat as the energy transferred by convection, conduction, and radiation, and explain the connection of heat to change in temperature or states of matter.</td>
</tr>
<tr>
<td>SC.912.P.10.5</td>
<td>Relate temperature to the average molecular kinetic energy.</td>
</tr>
</tbody>
</table>

1. Doing the experiment

   1. Place your sample of copper on the balance and record its mass in Table 1.
   2. Make a calorimeter by nesting two foam cups.
   3. Pour about 150 mL of room temperature water into the calorimeter. Use the balance to measure and record the mass of the water you add to the calorimeter (Density of water = 1g/mL). (Note: Make sure there is sufficient water in the calorimeter to submerge your metal samples COMPLETELY).
   4. Fill a styrofoam cup 2/3 with hot water.
   5. Place your sample of copper into the cup with hot water. Allow the copper sample to sit in the water for about a minute so it will get warmed by the hot water.
   6. Use the temperature probe to measure the temperature of the hot water, and record this temperature once it stabilizes as the initial temperature of the metal in Table 1.
   7. Place the temperature probe in the calorimeter. When the temperature stabilizes record it as the initial temperature of water. Leave the temperature probe in the calorimeter.
   8. Use the tongs to remove the copper from the hot water and place the copper into the calorimeter. Try to transfer as little hot water as possible into the calorimeter when moving the copper. Go as quickly as possible but do not spill any hot water.
   9. Once the temperature stabilizes, record the final temperature in Table 1.
   10. Repeat steps 1–9 with each unknown metal provided by your teacher. You may be asked to conduct two trials with your unknown samples, if time allows.
Table 1: Mass and temperature data

<table>
<thead>
<tr>
<th></th>
<th>Copper</th>
<th>Unknown Metal #1</th>
<th>Unknown Metal #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Metal (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of Water in Calorimeter (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Temperature of Water (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Temperature of Metal (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Temperature of Mixture (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2 Processing the Data

a. Calculate the temperature change of the water.

b. Calculate the temperature change of the metal.

c. Calculate the heat gained by the water using the equation below:

\[ E = mc_p(T_2 - T_1) \]

Where:  
- \( E \) = thermal energy (Joules) lost or gained by the water in the calorimeter
- \( m \) = original mass of the measured water in the calorimeter
- \( c_p \) = specific heat of water (4.184 J/g °C)
- \( T_2 - T_1 \) = change in temperature of the water (also referred to as \( \Delta T \))

d. The amount of energy released by the metal is equal to the energy absorbed by the water. Knowing the value of \( E \) for the metal, calculate the specific heat (\( c_p \)) of the metal. (Remember, since the energy is being released by the metal, change the sign of \( E \) from answer #3 to use for #4).

e. Identify your unknown metal(s) by comparing your calculated value of its specific heat to known specific heat values of common metals provided by your teacher.

f. Calculate the percent error for your unknown sample(s).
Thinking about what you observed

a. What did you determine was the identity of your unknown metal(s)?

b. Looking at your data/class data, were the experimental values too high or too low? Based on the experimental procedure, give an explanation for your observations.

c. How does the Law of Conservation of Energy allows us to make the calculations needed to determine the specific heat of the mystery metal?

d. The second unknown metal sample you tested is an alloy containing up to 80% of one of the other two metals you tested. The specific heat of this alloy should be almost the same as one of the other two metals. According to your results, which metal makes up 80% of the second unknown metal?

e. Water has a high specific heat. How does the fact that humans are largely made up of water help us regulate our body temperature?
12A Mystery Material

How do solids and liquids differ?

Review, in your mind, what you know about solids and liquids. You know, for example, that liquids do not keep their shape. They flow. Solids do not flow, they keep their shape. Consider the possibility of a material that is able to act like both a solid and a liquid. Could that be? In this investigation, you will not only consider the possibility, but actually play with such a material.

1. **Doing the experiment**
   
   1. Your teacher will give you a sample of mystery material on a piece of wax paper or in a small plastic bowl.
   
   2. Feel it. Smell it. Look at it. Use your senses to make as many observations as you can. Write down your observations in Table 1.

2. **Thinking about what you observed**
   
   a. What happens when you squeeze the mystery material and when you release it?
   
   b. How does this material mimic some of the properties of solids and liquids?
   
   c. The mystery material is made of only two ingredients - cornstarch and water. Using your answer from #1, what do you think is happening to the cornstarch and water when you squeeze it and let go? Or when you hit it quickly or stick your finger slowly into it?
   
   d. A colloidal suspension is a suspension of tiny particles of one substance in a medium of another substance. (The suspension remains intact indefinitely because it is unaffected by gravity). Based on your observations and the first part of this definition, is the cornstarch and water mixture a colloidal suspension?

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
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<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
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Table 1: Observations about the Mystery Material

<table>
<thead>
<tr>
<th>1.</th>
<th>7.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>8.</td>
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<tr>
<td>3.</td>
<td>9.</td>
</tr>
<tr>
<td>4.</td>
<td>10.</td>
</tr>
<tr>
<td>5.</td>
<td>11.</td>
</tr>
<tr>
<td>6.</td>
<td>12.</td>
</tr>
</tbody>
</table>
3 Stop and Think

a. How is the cornstarch and water mixture similar to quicksand?

b. Why does a substance that acts as both a solid and a liquid seem unusual?

c. Can you think of any common material/products that might act as both a solid and a liquid?
Can you make a clay boat?

A solid material will float if it is less dense than the liquid in which it is immersed, and sink if it is denser than the liquid. You may have noticed, however, that ships are often made of steel, which is obviously denser than water. So how does a steel boat float? In this investigation, you will experiment with modeling clay to discover how and why boats can be made of materials that are denser than water.

1 Measuring your stick of clay

Take your stick of clay and find its density. Use a balance to measure its mass. Use the length \times width \times height method to calculate its volume. Record your measurements in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Mass, volume, and density of clay stick data</th>
</tr>
</thead>
<tbody>
<tr>
<td>length (cm)</td>
</tr>
<tr>
<td>×</td>
</tr>
<tr>
<td>Mass (g)</td>
</tr>
<tr>
<td>÷</td>
</tr>
</tbody>
</table>

a. The density of water is 1g/cm³. How does the density of your clay compare to water?

b. Make a prediction: Will your stick of clay sink or float? Why?
2 Doing the Experiment

A. Testing your prediction

1. Prepare the displacement tank for use. Place a cup or beaker under the spout to catch the overflow water. Fill the displacement tank all the way up until it just starts to overflow into the cup or beaker. Once it stops remove the cup or beaker that was catching the overflow water.

2. Place a dry beaker under the spout to catch the overflow water displaced by your clay.

3. Gently put your stick of clay in the water. Did your stick of clay sink or float?

B. Finding the mass and volume of the displaced water

1. Pour the displaced water from the beaker into a 100-mL graduated cylinder. Record the volume in Table 2.

2. Now, calculate the mass of the displaced water using water’s density and the volume of displaced water you measured. Record this value in Table 2.

C. Calculating the weight of your clay and the displaced water

Mass and weight measure two different properties of matter. Mass refers to how much matter the object contains. Weight measures the gravitational pull between the object and (in our case) Earth. The gravitational force between a 1-kilogram object and Earth is 9.8 newtons. So a 1-gram object’s weight on Earth is 0.0098 newtons.

1. Use the mass of your clay to calculate its weight. Use the formula below and record the mass and weight in Table 2.

\[
\text{mass in grams} \times (0.0098 \text{ N/g}) = \text{weight in Newtons}
\]

2. Calculate the weight of the displaced water. Use the formula above and record your data in Table 2.

<table>
<thead>
<tr>
<th>Table 2: Mass and volume of clay and displaced water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of clay (g)</td>
</tr>
<tr>
<td>Stick of clay</td>
</tr>
<tr>
<td>Clay boat</td>
</tr>
</tbody>
</table>
3 Challenge: Can you mold your clay into a shape that floats?

For this part of the investigation, you must use ALL of your clay. Mold it into a shape that you believe will float. Before you do, make a prediction;

**How much water will the boat displace compared to the stick of clay?**

1. When you are ready to test a shape, lower it into a container of water approximately three-quarters full. If the clay sinks, retrieve it immediately and dry it with a paper towel. Avoid mixing water into your clay, or it will get very slimy. Keep trying until you get a boat that floats.

2. When you have successfully molded a boat that floats, take it out of the water and dry it with a paper towel. Then, prepare your displacement tank just as you did in step 2A.

3. Carefully place your boat into the displacement tank. Avoiding making waves. When the water stops flowing, move the beaker away from the displacement tank spout. Safely remove a little water from the displacement tank so it doesn’t overflow. Retrieve your boat and set it aside to dry.

4. Pour the displaced water from the beaker into a graduated cylinder. Record its volume in Table 2.

5. Use the density of water to calculate the mass of the displaced water. Calculate its weight using the formula from Step C1. Record both the water’s mass and weight in Table 2.

6. When your boat is dry, first measure its mass, then calculate its weight using the formula from Step C1. Record both the mass and weight in Table 2.

4 Analyzing your data

a. Did the weight of the clay change during the investigation? Give a reason for your answer.

b. Which displaced more water – the stick of clay or the clay boat, and how much more?

c. Which weighed more – the stick of clay or the water it displaced, and how much more?

d. Which weighed more – the clay boat or the water it displaced, and how much more?

5 Why the boat floats

Use your mass and volume data from Table 2 to calculate the apparent density of your clay boat. This value is called the *apparent* density because the total volume of the floating boat is not displaced. The part of your floating boat that is above the surface isn’t displacing any water. To find out how much of the boat is below the surface and is displacing water, look at the total amount of water you measured that spilled out into the beaker when the boat was floating.

**Table 3: Data for boat**

<table>
<thead>
<tr>
<th>Mass of boat (g)</th>
<th>Volume of water displaced by the boat (mL)</th>
<th>Apparent density of the boat (g/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thinking about what you observed

a. Which displaced more water, the stick of clay or the floating clay boat?

b. Assuming the mass of the clay did not change, how do you explain the difference in the volumes displaced by the stick of clay and the clay boat?

c. Look at the boat’s apparent density. Why is it different than the density of the stick of clay? What other substance has a density very similar to the boat’s apparent density?

d. Out of all the properties you measured and calculated in this investigation, which property tells you the most about whether an object or material will float in water, and how would you use that property to determine whether it will float?

e. Explain why a solid stick of clay sinks but a clay boat can be made to float.

f. What would happen if you added “cargo,” like pennies, to your boat? Is there a limit to how much mass you can add before the boat sinks? Does the volume of displaced water increase or decrease when the boat gets heavier? Why? Try the experiment.
13A Boyle’s Law

How are pressure and volume of a gas related?

Robert Boyle (1627–1691) conducted a series of experiments to investigate the physical properties of air. It was through these experiments he discovered the relationship between pressure and volume for an enclosed gas. Using a simple experiment, we will measure the pressure of a gas inside a syringe with a gas pressure sensor. You will use your data to derive the mathematical relationship between the pressure and volume of an enclosed gas at constant temperature.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.N.1.3</td>
<td>Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.</td>
</tr>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences are drawn from scientific observations and provide examples.</td>
</tr>
<tr>
<td>SC.912.P.12.10</td>
<td>Interpret the behavior of ideal gases in terms of kinetic molecular theory.</td>
</tr>
</tbody>
</table>

1 Thinking about pressure and volume

a. When you blow up a balloon, what happens to the volume of air inside the balloon?

b. What about the pressure? Does the pressure increase, decrease, or stay the same?

c. Now think about both pressure and volume together. Make a hypothesis about the relationship between pressure and volume of an enclosed gas. (Hint: When volume changes, what do you think happens to pressure?)

2 Setting up the experiment

1. Connect the 4 cm piece of tubing to the pressure sensor connector as shown.
2. Connect the other end of the tubing to the syringe.
3. Adjust the syringe until the volume of air is 12.0 mL.
4. Screw the pressure sensor connector onto the pressure sensor.
Doing the experiment

1. Start the data collector. Record the pressure at 12.0 mL (in kPa) in Table 1.
2. Pull the syringe out until it measures 16.0 mL. Hold it until the pressure stabilizes. Again, record the pressure in Table 1.
3. Repeat Step 3 for volumes of 18.0 mL and 10.0 mL.
4. Repeat Step 3 with a volume of 6.0 mL, however, take the measurement quickly to prevent air from escaping.
5. Stop the data collection. Do not disconnect the syringe from the sensor yet!

Graphing your data

a. Use your data to make a graph of pressure vs. volume.

b. Does the graphical model support your hypothesis? Explain your answer.

c. What happens to the pressure of an enclosed gas when the volume increases?

Finding a relationship between pressure and volume

a. Multiply the pressure and volume values for each trial and record the values in the third column of Table 1. Remember to use appropriate numbers of significant figures.

b. Divide the pressure by the volume for each trial and record the values in the last column of Table 1. Again, use the correct number of significant figures.

c. Boyle’s law states that there is a mathematical relationship between pressure and volume that always equals a constant value. Based on your calculations, is that relationship $P \times V$ or $P/V$?

d. According to your data, what is the constant value?

Using Boyle’s law to make a prediction

a. Using your constant value, calculate what the pressure would be when the volume of the syringe is set to 14.0 mL.

b. Using your graph, what is the pressure that corresponds to 14.0 mL? How does this compare to your calculated value?

c. Test your predicted pressure value for 14.0 mL. How do the values compare?
13B Pressure and Temperature Relationship

How are temperature and pressure of a gas related?

Gas molecules are in constant motion. When the temperature of a gas increases, the molecules move faster. When this happens, the velocity and number of molecular collisions increases. The opposite is true for a gas when the temperature decreases. In this experiment, you will study the relationship between the pressure a gas exerts and the temperature of the gas.

### Thinking about temperature and pressure

**a.** Car manuals tell you to inflate the tires to a certain pressure when the tires are cold (before driving around on them). Why do you think this is important?

**b.** Make a hypothesis about the relationship between pressure and temperature of an enclosed gas. (Hint: When temperature increases, what do you think happens to the pressure?)

### Setting up the experiment

1. Fill the displacement tank with ice cold water to the 1200 mL mark.
2. Place a temperature probe in the water and connect the probe to the Data Collector. The water temperature should be about 10–12 °C, but any cold starting temperature is fine.
3. Place the rubber stopper/tube assembly into the 125-mL Erlenmeyer flask. Attach the pressure sensor to the tube.
4. Connect the pressure sensor to the Data Collector.
**3 Doing the experiment**

1. Place the flask into the cold water bath and allow it to sit for 2 min. Record the temperature and pressure in Table 1 after 2 minutes have passed.
2. Take the flask out of the water. Use a container to remove 400 mL of water from the displacement tank.
3. Get 400 mL of hot water from your teacher and pour it into the displacement tank.
4. Place the flask into this warmer water after it has been in the water for 2 min, record the temperature and pressure in Table 1.
5. Repeat steps 2–4 two more times so you have a total of 4 data points.
6. Convert Celsius temperatures to Kelvin and record in Table 1.

**Table 1: Pressure and temperature data**

<table>
<thead>
<tr>
<th>Pressure (kPa)</th>
<th>Temperature (°C)</th>
<th>Temperature (K)</th>
<th>P/T (kPa/K)</th>
<th>P • T (kPa • K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**4 Graphing your data**

a. Use your data to make a graph of pressure vs. temperature.

b. Does the graphical model support your hypothesis? Explain your answer.

c. What happens to the pressure of an enclosed gas when the temperature increases?

**5 Finding a relationship between pressure and temperature**

a. Divide the pressure and temperature values for each trial and record the answers in the fourth column of Table 1. Remember to use appropriate numbers of significant figures.

b. Multiply the pressure by the temperature for each trial and record the values in the last column of Table 1. Again, use the correct number of significant figures.

c. There is a mathematical relationship between pressure and temperature that always equals a constant value. Based on your calculations, is that relationship $P/T$ or $P \times T$?

d. According to your data, what is the constant value?
Using the pressure-temperature relationship to make a prediction

a. Using your constant value, calculate what the pressure of the air in the flask would be when the temperature is 333K.

b. Using your graph, what is the pressure that corresponds to 333K? How does this compare to your calculated value?

c. How would you use the experiment setup to test your predicted pressure value for 333K?

Thinking about what you observed

a. You used a water bath to change the temperature of the air in the flask. Draw a diagram of the experiment setup and use arrows to show the heat transfer that took place when more and more hot water was added to the displacement tank.

b. What two factors in the experiment were constant?

c. Go back to your answer to question 1a. Would you answer the question the same way now? Explain.
14A The Atom

What is inside an atom?

We once believed that atoms were the smallest units of matter. Then it was discovered that there are even smaller particles inside atoms! The structure of the atom explains why nearly all the properties of matter we experience are what they are. This investigation will lead you through some challenging and fun games that illustrate how atoms are built from protons, neutrons, and electrons.

1. **Modeling an atom**

   In the atom game, colored marbles represent the three kinds of particles. Red or green marbles are protons, blue marbles are neutrons, and yellow marbles are electrons.

   ![Atom Diagram]

   1. Build the atom above using three red or green, three blue, and three yellow marbles.

2. **Thinking about the atom**

   a. What is the number below the element symbol? What does this number tell you about the the atom?

   b. What is the number(s) above the element symbol called? What does this number tell you about the atom?

   c. Why do some elements have more than one number above the symbol? What are the variations in this number called?

---

**Code Benchmark**

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.8.4</td>
<td>Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles.</td>
</tr>
<tr>
<td>SC.912.P.10.11</td>
<td>Explain and compare nuclear reactions (radioactive decay, fission and fusion), the energy changes associated with them and their associated safety issues.</td>
</tr>
<tr>
<td>SC.912.P.10.12</td>
<td>Differentiate between chemical and nuclear reactions.</td>
</tr>
<tr>
<td>SC.912.P.8.5</td>
<td>Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.</td>
</tr>
</tbody>
</table>
### Making atoms

Build the 6 atoms shown on the chart and fill in the missing information. Protons and neutrons go in the middle of the board. Electrons go in the outside and fill up the holes from the lowest row to the highest.

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic number</th>
<th>Mass number</th>
<th>Protons</th>
<th>Neutrons</th>
<th>Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3d</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3e</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3f</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Stop and think

a. Two of the atoms you made were the same element. What was different about them?

b. One of the atoms had just enough electrons to completely fill the first two rows. Which atom was this? Where on the periodic table is it found?

c. Which atom had an atomic number of 8?

d. Which atom had a mass number of 14?

e. One atom is found in a lightweight, silvery metal used in airplanes. Which atom was it?

f. One atom represents an element that makes up about 21% of the air you breathe. You could not live without this element.
<table>
<thead>
<tr>
<th>Periodic Table of the Elements</th>
<th>Stable Isotopes (Stable Isotopes)</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>2</td>
<td>H</td>
</tr>
<tr>
<td>F</td>
<td>9</td>
<td>Be</td>
</tr>
<tr>
<td>Ne</td>
<td>10</td>
<td>Li</td>
</tr>
<tr>
<td>O</td>
<td>8</td>
<td>C</td>
</tr>
<tr>
<td>N</td>
<td>7</td>
<td>Si</td>
</tr>
<tr>
<td>P</td>
<td>15</td>
<td>Al</td>
</tr>
<tr>
<td>S</td>
<td>16</td>
<td>Cl</td>
</tr>
<tr>
<td>Ar</td>
<td>18</td>
<td>K</td>
</tr>
<tr>
<td>Kr</td>
<td>36</td>
<td>Ba</td>
</tr>
<tr>
<td>Xe</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

**Table of Isotopes**

<table>
<thead>
<tr>
<th>Element</th>
<th>Mass Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>3.4</td>
</tr>
<tr>
<td>F</td>
<td>9</td>
</tr>
<tr>
<td>Ne</td>
<td>10</td>
</tr>
<tr>
<td>O</td>
<td>16</td>
</tr>
<tr>
<td>P</td>
<td>31</td>
</tr>
<tr>
<td>S</td>
<td>32</td>
</tr>
<tr>
<td>Cl</td>
<td>35</td>
</tr>
<tr>
<td>Ar</td>
<td>39</td>
</tr>
<tr>
<td>Kr</td>
<td>86</td>
</tr>
<tr>
<td>Xe</td>
<td>132</td>
</tr>
</tbody>
</table>

**Atomic Number**

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>9</td>
</tr>
<tr>
<td>Ne</td>
<td>10</td>
</tr>
<tr>
<td>O</td>
<td>8</td>
</tr>
<tr>
<td>P</td>
<td>15</td>
</tr>
<tr>
<td>S</td>
<td>16</td>
</tr>
<tr>
<td>Cl</td>
<td>17</td>
</tr>
<tr>
<td>Ar</td>
<td>18</td>
</tr>
<tr>
<td>Kr</td>
<td>36</td>
</tr>
<tr>
<td>Xe</td>
<td>54</td>
</tr>
</tbody>
</table>

**Stable Mass Numbers**

<table>
<thead>
<tr>
<th>Element</th>
<th>Stable Mass Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>3.4</td>
</tr>
<tr>
<td>F</td>
<td>9</td>
</tr>
<tr>
<td>Ne</td>
<td>10</td>
</tr>
<tr>
<td>O</td>
<td>16</td>
</tr>
<tr>
<td>P</td>
<td>31</td>
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<tr>
<td>S</td>
<td>32</td>
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<td>35</td>
</tr>
<tr>
<td>Ar</td>
<td>39</td>
</tr>
<tr>
<td>Kr</td>
<td>86</td>
</tr>
<tr>
<td>Xe</td>
<td>132</td>
</tr>
</tbody>
</table>

**Note:** The table above is a representation of the periodic table with a focus on stable isotopes and atomic numbers. The key indicates the graphical representation of the periodic table elements and their isotopes.
How were the elements created?

During the middle ages, people believed you could turn lead into gold if you followed the right procedures. Later, we learned that lead and gold are different elements with different kinds of atoms. You have to change the atoms inside to make lead into gold. Lead atoms have 82 protons in the nucleus. Gold atoms have 79 protons.

Building the elements

About 13 billion years ago, when the universe was much younger, the only atoms in existence were hydrogen, helium, and a small amount of lithium. These are the three lightest elements. Today, we find carbon, oxygen, iron, and even uranium atoms. Where did these heavy atoms come from? All the elements were created in the super-hot cores of stars. Stars get their energy by combining hydrogen atoms together to make other elements, such as helium. Along the way, a few protons get converted to neutrons and electrons, too.

Quick review of the atom

In the atom game, colored marbles represent the three kinds of particles. Red or green marbles are protons, blue marbles are neutrons, and yellow marbles are electrons.
The Three Rules

Rule #1: The number of protons matches the atomic number
Rule #2: The total number of protons and neutrons equals a stable mass number
Rule #3: The number of electrons matches the number of protons

3 The game of atomic challenge

This game simulates how the heavy elements were created inside stars. Each player takes a turn adding protons, neutrons, and electrons to the atom to build heavier and heavier elements.

1. The winner of the game is the first player to run completely out of marbles.
2. Each player should start with 6 blue marbles (neutrons), 5 red or green marbles (protons), and 5 yellow marbles (electrons).
3. Each player takes turns adding 1 - 5 marbles, but not more than 5. The marbles may include any mixture of electrons, protons, and neutrons.
   FOR EXAMPLE: you can add one blue, one red or green, and one yellow marble in a turn. That makes three total marbles, which is less than 5.
4. Marbles played in a turn are added to the marbles already in the atom.
5. Only atoms where the electrons, protons, and neutrons match one of the naturally occurring elements on the table are allowed. If you add marbles that make an atom NOT on the red periodic table you have to take your marbles back and lose your turn.
6. A player can trade marbles with the bank INSTEAD of taking a turn. The player can take as many marbles, and of as many colors as they need but must take at least as many total marbles as they put in. For example, a player can trade 2 yellows for 1 yellow, 1 blue, and 1 red or green.

4 Stop and think

Atoms which are not on the periodic table shown may exist in nature but they are radioactive and unstable. For example, carbon-14 (C\textsubscript{14}) is unstable and is not listed although C\textsubscript{12} and C\textsubscript{13} are stable.

a. What four elements make up almost all of the mass in your body?

b. How many stable isotopes does oxygen have?

c. Find one element on the chart that has no stable isotopes.

d. What element has atoms with 26 protons in the nucleus?

e. On most periodic tables, a single atomic mass is listed instead of the mass numbers for all the stable isotopes. How is this mass related to the different isotopes?
**15A The Periodic Table**

*How is the periodic table organized?*

Virtually all the matter you see is made up of combinations of elements. Scientists know of 118 different elements, of which about 90 occur naturally. Each element has its own unique kind of atom. The periodic table is a chart that shows all of the elements in order of increasing atomic number.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.8.4</td>
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</tr>
<tr>
<td>SC.912.P.8.5</td>
<td>Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.</td>
</tr>
</tbody>
</table>

**1 Building the periodic table**

Every element is given a symbol of one or two letters. For example, the symbol for hydrogen is a capital letter H. The symbol for lithium is two letters, Li. Each element also has a unique number called the atomic number. The periodic table is a chart that shows the elements in an arrangement that helps us recognize groups of elements with similar properties. The picture below shows the shape of the periodic table and the first few elements in sequence from left to right. The elements are arranged from lowest to highest atomic number.

Using the chart as a guide, build the periodic table out of the periodic table tiles. The only tile you should use yellow-side up is the hydrogen tile. The colors will show a pattern when you are finished. There is a tricky part near the bottom of the table. The table breaks off between element 56 (Ba) and element 71 (Lu), and fills in the first of two long rows underneath the main part of the chart.
Organization of the periodic table

Look at the periodic table you put together out of the tiles. Use the diagram below, and your model of the periodic table, to answer the questions below.

a. Which elements are in group 1?

b. Which elements are in group 8?

c. Name three transition metals.

d. To which group does chlorine belong? What other elements are in that group?

e. Which elements are in the 2nd period?

Applying what you have learned

a. Each row (period) of the periodic table contains only a certain number of elements. What does this have to do with the structure of the atom? Research this question in your textbook.

b. Which group of the periodic table above contains the element argon? What characteristic do the elements in this group share?

c. Which group contains the element carbon? What characteristic do the elements in this group share?
15B Periodic Table Challenge

What information can you get from the periodic table?

Each box on the periodic table tells you the element symbol, atomic number, and atomic mass for all the known elements. This is very useful information, but did you know that the arrangement of the elements on the periodic table gives you even more information? Each major column of elements represents a group of elements with similar chemical behavior. Can you see why the arrangement of elements on the periodic table is important?

1 The challenge

Periodic Table Challenge is a bingo-like game that helps you understand how the elements on the periodic table are arranged. Each player will fill out their own five-by-five grid with element symbols, and then the caller will read element clues. The players must interpret the clues and highlight any boxes on the grid that fit the clue. The first player that correctly highlights five boxes across, up-and-down, or diagonally in a row is the winner.

2 Rules of play

1. Designate one member of your group to be the caller. The caller will call out clues and keep track of them on the checklist.

2. Each player will have a sheet of 4 blank grids. Fill out one of the grids with random element symbols (other grids can be used for additional games). You may choose elements in the atomic number range of 1–54 (hydrogen through xenon). Do not repeat symbols on the card. You will only be able to fit 25 of the possible 54 symbols on the card. You choose which ones to use, and where to place them on the grid.

3. The caller will randomly pick clues from the list, and as a clue is called out, the caller will check off the clue. The answers are only for the caller to check the winner’s card!

4. When a clue is called, players check the grid to see if any of the elements fit the clue. Any elements that fit the clue must be highlighted. If no elements fit the clue, then no boxes are highlighted on that turn.

5. When a player has five boxes highlighted in a row up and down, across, or diagonally, play stops. The caller will double check the clue list and answers to see if the clues indeed match the elements. Play continues until a true winner is determined.
## Caller’s clues

Clues can be called in any order. Check off each clue as you use it.

<table>
<thead>
<tr>
<th>Clue</th>
<th>Possible Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>A member of the carbon family</td>
<td>C, Si, Ge, Sn</td>
</tr>
<tr>
<td>Chemical properties similar to calcium, but not calcium</td>
<td>Be, Mg, Sr</td>
</tr>
<tr>
<td>A transition metal that has a “C” in the symbol</td>
<td>Sc, Cr, Co, Cu, Tc, Cd,</td>
</tr>
<tr>
<td>A member of the oxygen family</td>
<td>O, S, Se, Te</td>
</tr>
<tr>
<td>Chemical properties similar to cesium, but not cesium</td>
<td>H, Li, Na, K, Rb</td>
</tr>
<tr>
<td>A member of the noble gas family</td>
<td>He, Ne, Ar, Kr, Xe</td>
</tr>
<tr>
<td>A nonmetal in the nitrogen family</td>
<td>N, P</td>
</tr>
<tr>
<td>A metal in the boron family</td>
<td>Al, Ga, In</td>
</tr>
<tr>
<td>A gas in the oxygen family</td>
<td>O</td>
</tr>
<tr>
<td>A solid in the halogen family</td>
<td>I</td>
</tr>
<tr>
<td>An element that is liquid at room temperature</td>
<td>Hg, Br</td>
</tr>
<tr>
<td>A transition metal with less than 25 protons</td>
<td>Cr, V, Ti, Sc</td>
</tr>
<tr>
<td>A transition metal commonly found in jewelry</td>
<td>Ni, Cu, Ag</td>
</tr>
<tr>
<td>A metalloid in the carbon family</td>
<td>Si, Ge</td>
</tr>
<tr>
<td>Chemical properties similar to aluminum, but not aluminum</td>
<td>B, Ga, In</td>
</tr>
<tr>
<td>A transition metal with 39 – 43 protons</td>
<td>Y, Zr, Nb, Mo, Tc</td>
</tr>
<tr>
<td>An element symbol with a first letter that is different from the first letter of the name</td>
<td>Na, K, Fe, Ag, Sn, Sb</td>
</tr>
<tr>
<td>A member of the nitrogen family with a one-letter symbol</td>
<td>N, P</td>
</tr>
<tr>
<td>A transition metal from period 5</td>
<td>Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd</td>
</tr>
</tbody>
</table>
Periodic Table Challenge Investigation

Periodic table challenge card

Fill in each of the squares with the symbol of an element with atomic number between 1 and 54 (hydrogen-xenon).

You may not use the same element symbol twice.
16A Chemical Bonds

Why do atoms form chemical bonds?

Most of the matter on Earth is in the form of compounds. Even when a substance exists as a pure element, it tends eventually to combine with other elements. For example, if you leave an iron nail outside in the rain, it will quickly combine with the oxygen in the air to form iron oxide, better known as rust. In this investigation, you will build models of atoms and discover one of the fundamental ideas in chemistry: how electrons are involved in the formation of chemical bonds.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.08.4</td>
<td>Explore the scientific theory of atoms (also known as atomic theory) by describing the structure of atoms in terms of protons, neutrons and electrons, and differentiate among these particles.</td>
</tr>
<tr>
<td>SC.912.P.8.5</td>
<td>Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.</td>
</tr>
<tr>
<td>SC.912.P.8.7</td>
<td>Interpret formula representations of molecules and compounds in terms of composition and structure.</td>
</tr>
</tbody>
</table>

1 Reviewing atomic structure

Let’s review what you already know about atoms:

- A neutral atom has the same number of electrons and protons.
- The electrons occupy energy levels surrounding the nucleus.
- Since electrons are attracted to the nucleus, they fill the lower energy levels first.

Once a given level is full, electrons start filling the next level.

2 How many electrons in the outermost level?

Using the atom building game, build each element in the table. For each element, record the number of electrons in the outermost energy level and the number of unoccupied spaces in the outermost energy level.

<table>
<thead>
<tr>
<th>element</th>
<th>atomic number</th>
<th>electrons in outermost level</th>
<th>unoccupied spaces in outermost level</th>
</tr>
</thead>
<tbody>
<tr>
<td>hydrogen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>helium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lithium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fluorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>neon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sodium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>argon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>potassium</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 What are valence electrons?
Examine the table you just completed and record the answers to the following questions:

a. Use your textbook to find out about *valence electrons*.
b. What do lithium, sodium, and potassium have in common?
c. What do fluorine and chlorine have in common?
d. What do neon and argon have in common?

4 Modeling a chemical bond
Atoms that have a complete outermost energy level are stable. If there are empty holes, an atom will either gain, lose, or share electrons with another atom in order to complete its outermost level and become stable. When atoms gain, lose, or share electrons with another atom, they form *chemical bonds*.

Using two atom building games, build a sodium atom and a chlorine atom. Put them next to each other and answer the questions below.

a. In order to complete its outermost energy level, do you think sodium will tend to lose its only valence electron, or gain seven? Explain your answer.
b. In order to complete its outermost energy level, do you think chlorine will tend to lose all of its valence electrons or gain one electron? Explain your answer.
c. Why might these two atoms bond together to form a molecule? In your answer, describe what you think might happen when sodium and chlorine form a chemical bond.
5 Determining oxidation numbers
An element’s oxidation number is equal to the charge an atom has when it ionizes, that is, gains or loses electrons.

Use your models of sodium and chlorine to answer the questions below.

a. Remove the valence electron from sodium. What has happened to the balance of positive and negative charges? What is sodium’s oxidation number?

b. Move the electron you took from sodium into the chlorine. What happens to chlorine’s charge when it gains the electron from the sodium atom? What is chlorine’s oxidation number?

c. When sodium and chlorine form a chemical bond, what is the overall charge of the molecule? Why do you think sodium and chlorine combine in a 1:1 ratio?

6 Modeling chemical bonds
Use multiple atom boards for this part of the investigation. First, build each atom. Next, move the boards together to model the formation of a chemical bond.

a. One carbon atom and four hydrogen atoms

b. Two lithium atoms and one oxygen atom

c. One beryllium atom and two fluorine atoms

7 Applying your knowledge
Read in your textbook about Lewis dot diagrams. Draw a dot diagram for each compound in Part 6.
Why do atoms combine in certain ratios?

Chemists have long noticed that groups of elements behave similarly. The periodic table is an arrangement of the elements grouped according to similar behavior. In this investigation, you will discover how the arrangement of electrons in atoms is related to groups on the periodic table. You will also learn why atoms form chemical bonds with other atoms in certain ratios.

1 Oxidation numbers and ions

An element’s oxidation number indicates how many electrons are lost or gained when chemical bonding occurs. The oxidation number is equal to the charge an atom has when it ionizes, that is, gains or loses electrons to become an ion. The partial periodic table below shows the most common oxidation numbers of the elements. The oxidation numbers are written above the group number above each column on the table. The most common oxidation numbers for the main group elements are shown.
2 Stop and think

a. How are elements grouped according to the number of valence electrons in their outermost levels?

b. Why do elements in group 2 have an oxidation number of 2+?

c. Why do elements in group 17 have an oxidation number of 1–?

d. Why do the oxidation numbers in the first two groups tend to be positive?

3 Predicting chemical formulas

A binary compound is composed of two different elements. Predict the chemical formulas for the binary compounds that are made up of the pairs of elements in the table below. Use the following steps:

1. Using the periodic table on the previous page, determine the ion formed by each element.
2. Figure out how many periodic table tiles of each element will be needed to make the compound electrically neutral.
3. Form the compound with your tiles and write the chemical formula for each compound based on the number of tiles of each element.

<table>
<thead>
<tr>
<th>Table 1: Writing chemical formulas for binary compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>element 1</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>hydrogen</td>
</tr>
<tr>
<td>magnesium</td>
</tr>
<tr>
<td>calcium</td>
</tr>
<tr>
<td>aluminum</td>
</tr>
<tr>
<td>potassium</td>
</tr>
<tr>
<td>lithium</td>
</tr>
<tr>
<td>rubidium</td>
</tr>
</tbody>
</table>
4 Naming compounds

Naming binary ionic compounds is very simple if you follow these rules:

1. Write the name of the element with a positive oxidation number first.
2. Write the root name of the element with a negative oxidation number second. For example, chlor- is the root name of chlorine. Subtract the -ine ending.
3. Add the ending -ide to the root name. Chlor- becomes chloride.

Using these rules, write the name of each of the compounds in Table 1.

5 Playing Compound Crossword

Now that you understand how elements combine to form compounds, you are ready to play Compound Crossword. In this game, you will score points by forming stable compounds, crossword style. Players use the oxidation numbers of the elements to form correct compounds. Points are determined by adding up the atomic numbers of each atom in the compound.

Sample game after four turns:
- CH₃OH scores 18 points
- Fe₂O₃ scores 76 points
- SiO₂ scores 30 points
- H₂SO₄ scores 50 points

Starting the game

Each player starts with ten randomly selected tiles. The remaining tiles should be placed in a box or paper bag so that additional tiles may be drawn without being seen. The playing surface can be any flat table (or floor) with minimum dimensions of 75-by-75 centimeters.

Each player draws a tile from the bag; the highest atomic number goes first. Once the starting player has been determined, those tiles are returned to the bag. The play continues to the starting player’s right.

Play

1. Players take turns adding a compound to the crossword by using tiles from their set of ten. Either side of a tile may be used.
2. The elements in a compound may be arranged in any order, as long as they are in a single horizontal or vertical row.
3. Each new compound must be shown by the player to have oxidation numbers that add up to zero. Otherwise the player must take back the compound and wait until the next turn.
4. If the compound is correct, the player adds up the atomic numbers of all the atoms in the compound to determine the points and then draws new tiles to restore a set of ten.
5. Play continues until all the tiles in the bag are used and one player is out of tiles, or until all players are unable to make a compound with their remaining tiles.

6. The winner is the player with the highest score at the end of the game.

**Determining correct compounds**

The oxidation numbers found directly above each element on the periodic table provided are used to determine whether a molecule is correct. The oxidation numbers of all the elements in the compound must add up to zero. In some cases there is more than one oxidation number for an element. Iron (Fe), for example, has oxidation numbers of +2 and +3. The player may choose either oxidation number to add to the total.

The Special Bonds card included with the Periodic Table Tiles gives some additional possibilities for forming compounds.

**Examples of correct and incorrect compounds:**

<table>
<thead>
<tr>
<th>CH₃OH - Oxidation states</th>
<th>Fe₂O₃ - Oxidation states</th>
<th>FOSi - Oxidation states</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 1</td>
<td>Fe 26</td>
<td>F 14</td>
</tr>
<tr>
<td>C 6</td>
<td>Fe 26</td>
<td>O 8</td>
</tr>
<tr>
<td>H 1</td>
<td>O 8</td>
<td>Si 14</td>
</tr>
<tr>
<td>H 1</td>
<td>O 8</td>
<td>8</td>
</tr>
<tr>
<td>O 8</td>
<td>8</td>
<td>not correct!</td>
</tr>
</tbody>
</table>

The oxidation number for each element in a compound is counted once for every atom present. The two iron atoms contribute a total of +6, which is balanced by the -6 from the three oxygen atoms.

Note: The Special Bonds card has some extra ways compounds can form when two atoms of the same element bond together, and when hydrogen is involved in unusual ways. The example of CH₃OH (methanol) above uses one of the special bonds that hydrogen can make with carbon.

**Miscellaneous rules and strategies:**

The noble gases do not form bonds; therefore they can’t be played. Players may decide at the start of the game to remove these tiles. As another option, players can choose to turn the noble gas tiles over, revealing the + symbol. This symbol could be used as a wildcard in which the player chooses which element the + should represent. The symbol scores no points but allows the player to complete a molecule. Players must agree on the use of the noble gas tiles before the game begins.
How are atoms conserved in a chemical reaction?

A chemical reaction involves changes in substances that react to form new products. This process involves the breaking of chemical bonds and the formation of new ones. A chemical equation shows the chemical formulas of the substances that react, called reactants, and the chemical formulas of the substances that are produced, called products. The number and type of atoms in the reactants must be exactly equal to the number and type of atoms in the products. How do you write a chemical equation so that the number and type of atoms on the reactants and products sides are balanced?

### Writing chemical equations

Magnesium metal reacts with water to produce magnesium hydroxide and hydrogen gas.

The statement above is the word form of a chemical reaction. It tells you the names of the reactants and the products. To write it as a chemical equation, you need to determine the chemical formulas of each of the substances in the reaction:

1. Magnesium metal is an element and exists as an atom. Its chemical formula is Mg.
2. The chemical formula for water is H₂O.
3. Magnesium hydroxide is an ionic compound. To write its chemical formula, you need to find out the charges of each ion it is made out of. The magnesium ion is Mg²⁺. The hydroxide ion is OH⁻. You need 1 Mg²⁺ and 2 OH⁻ to make a neutral compound so the formula is Mg(OH)₂.
4. Pure hydrogen gas always exists as a diatomic molecule so its chemical formula is H₂.

The chemical equation is written as:

```
magnesium metal       | reacts with       | water          | to produce          | magnesium hydroxide | and | hydrogen gas
Mg                    | +                 | H₂O            | →                  | Mg(OH)₂            | +   | H₂
```

### Trying out the reaction with periodic table tiles

Use periodic table tiles to make the reactants above.

Rearrange the reactants to make the products. Is there any problem? What are you missing?
3 Balancing the reaction

Chemical equations must always balance. This means that you must use all of the atoms you start with and you cannot have any leftover atoms when you are finished. If you need more atoms to make the products, you can only add them in the form of a chemical formula. You cannot simply add the extra atoms that you need, unless the chemical formula is a single atom - like Mg. Which atoms did you need more of for the reaction you tried? Since you needed more oxygen and hydrogen atoms, you can only add them in the form of another water molecule. Try adding another water molecule to the reactants and rearrange them to form the products again. Did the reaction work this time?

4 Writing balanced chemical equations

To balance the equation for this reaction, you needed to add another water molecule to the reactants side. You ended up with the correct amount of products. Since one magnesium atom reacted with two water molecules to form one magnesium hydroxide molecule and one hydrogen gas, the proper way to write the balanced chemical equation is:

\[ \text{Mg} + 2\text{H}_2\text{O} \rightarrow \text{Mg(OH)}_2 + \text{H}_2 \]

The 2 in front of water is called a coefficient. This number tells you how many water molecules are needed in the reaction. The rest of the reactants and products in the reactants show no coefficients. This is because when the coefficient is 1, there is no need to write it.

5 Try balancing these chemical equations

The following chemical equations have the proper reactants and products. Try to balance each using the following steps:

1. Assemble the reactants out of the appropriate tiles.
2. Rearrange the reactants to form the products.
3. Figure out the number of each reactant and product required to make the equation balance and write the numbers (the coefficients) in the boxes.

\[
\begin{align*}
\text{Fe} & + \text{O}_2 & \rightarrow & \text{Fe}_2\text{O}_3 \\
\text{CH}_4 & + \text{O}_2 & \rightarrow & \text{CO}_2 \\
\text{HCl} & + \text{NaOH} & \rightarrow & \text{NaCl} \\
\text{Na} & + \text{Cl}_2 & \rightarrow & \text{NaCl} \\
\text{CO}_2 & + \text{H}_2\text{O} & \rightarrow & \text{C}_6\text{H}_{12}\text{O}_6 \\
\end{align*}
\]
Challenge! Balancing difficult equations

Use the Periodic Table Tiles to help you balance these harder equations.

Each of these equations has three reactants:

Can you balance this equation without using the tiles?
17B Conservation of Mass

How do scientists describe what happens in a chemical reaction?

A French chemist named Antoine Lavoisier was the first to prove the law of conservation of mass. This law says that the total mass of the reactants in a chemical reaction is always equal to the total mass of the products. This is not as easy to see as you might think! As you do this investigation, you will discover how tricky it is to show the law of conservation of mass.

Table 1: Conservation of mass data

<table>
<thead>
<tr>
<th>Step</th>
<th>Data and observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Find the mass of the effervescent tablet.</td>
</tr>
<tr>
<td>2.</td>
<td>Put the paper cup on the balance and tare it to zero. Fill the cup about halfway with water. Record the mass.</td>
</tr>
<tr>
<td>3.</td>
<td>Put the tablet on the balance beside the cup, but don’t put it in the water yet. Record the total starting mass.</td>
</tr>
<tr>
<td>4.</td>
<td>Drop the tablet into the cup of water. You can do this while the cup is still on the balance. Record your observations.</td>
</tr>
<tr>
<td>5.</td>
<td>Wait for the reaction to stop. Then, tap the cup gently to release as many bubbles as you can. Measure the mass.</td>
</tr>
<tr>
<td>6.</td>
<td>Subtract the final mass (5) from the starting mass (3). This is the mass difference between the products and reactants.</td>
</tr>
</tbody>
</table>
2 Stop and think

a. Does this experiment agree with the law of conservation of mass? Look at the data that you just recorded. Use it to help you to explain why or why not.

b. Explain why you observed a difference in mass. Where did the missing mass go? Did it really disappear?

3 Modeling the reaction

Scientists write chemical reactions like mathematical formulas. The reactants are to the left of the arrow and the products are to the right of the arrow.

Reactants → Products

The effervescent tablet contains a chemical called sodium bicarbonate. This chemical reacts with water according to the following reaction.

\[ \text{H}_2\text{O} + \text{NaHCO}_3 \rightarrow \text{NaOH} + \text{CO}_2 + \text{H}_2\text{O} \]

1. Build the reactants side (\(\text{H}_2\text{O} + \text{NaHCO}_3\)) of the chemical reaction above using the periodic table tiles.
2. Build the products side (\(\text{NaOH} + \text{CO}_2 + \text{H}_2\text{O}\)) of the chemical reaction using more periodic table tiles.

4 Stop and think

Table 2: Counting atoms of each element

<table>
<thead>
<tr>
<th>Element</th>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Fill in Table 2 with the numbers of each type of atom on the reactant side of the equation and on the product side of the equation.

b. How do the numbers of atoms of each element compare on the reactant and product side of the equation? What does this imply for the law of conservation of mass?

c. In what phase are each of the reactants (solid, liquid, or gas)? In what phase are each of the three products (solid, liquid, or gas)?
5 Proving that mass is conserved in a reaction

According to the law of conservation of mass, the mass of the products of the reaction should be exactly equal to the mass of the reactants. Can you design an experiment to prove this is true for the reaction you just observed?

Examine the materials your teacher has given you. These include:

- effervescent tablet
- 2 beakers
- beaker of water
- 2 plastic pipettes
- 2 baggies with zippers
- electronic balance or mass scale

1. Working with your lab partner, devise an experiment that will prove that mass is conserved in the reaction of the tablet and water. You may request additional materials if your teacher has them available.

2. List the materials you will need and their use in the experiment.

3. List the steps you will follow in the experiment.

4. Before you try out your experiment, request approval from your teacher.

5. If your experiment does not work, adjust your procedures and/or materials and try it again.

6. Record your procedures, data, and results.

6 Presenting your results to the class

Prepare a brief presentation for the class about your experiment. Use the following format for your presentation:

a. Purpose

What questions were you trying to answer?

b. Materials

What materials and equipment did you choose and why?

c. Procedures

What were the steps you followed? You may demonstrate your procedures if time and materials allow.

d. Data

What was the data you collected?

e. Conclusions

What does your data prove? If your experiment did not yield satisfactory results, what would you change in your procedures or materials and why?
18A Energy and Chemical Changes

How do chemical changes involve energy?

Atoms come together in compounds by making chemical bonds with other atoms. Chemical bonds are a form of energy. When atoms change their bonds in a chemical reaction, energy can either be used or given off. In this investigation, you will make chemical reactions and deduce whether they use energy or give off energy.

Special Safety Note: Use extreme caution when handling hydrochloric acid and other chemicals. Wear safety goggles and an apron during the entire investigation.

1 Stop and think

What evidence should you look for that indicates a chemical change (a chemical reaction) is taking place?

2 Reaction #1: Magnesium and hydrochloric acid

In this reaction, you will observe the temperature while adding a 4 cm piece of magnesium ribbon to 50 mL of hydrochloric acid solution.

1. Measure 50 mL of hydrochloric acid solution and place it in a pair of nested Styrofoam cups.
2. Place the temperature probe in the solution. Set the Data Collector to record 1 sample per second (default setting).
3. Measure a 4 cm piece of magnesium ribbon with a ruler.
4. When the temperature of the solution has stabilized, press start and drop the magnesium ribbon in the hydrochloric acid solution.
5. Stir the reaction continuously with the temperature probe.
6. Collect data until all the magnesium ribbon has disappeared and the temperature has stabilized.
7. Save the experiment and note the file name.
Thinking about what you observed

a. Study the temperature vs. time graph on the Data Collector. Did the temperature go up, down, or stay the same when you did the experiment?

b. Why does a change in temperature indicate a change in energy?

Reaction #2: Vinegar and baking soda

In this reaction, you will add 5 grams of baking soda (sodium hydrogen carbonate) to 50 mL of vinegar (acetic acid solution).

1. Rinse the Styrofoam cup with water and dry it with a paper towel.
2. Put 50mL of vinegar in the pair of nested Styrofoam cups.
3. Place the temperature probe in the vinegar. Select a new experiment on the Data Collector and make sure it is set up to record 1 sample per second.
5. When the temperature of the vinegar has stabilized, press start and drop the baking soda in the vinegar.
6. Stir the reaction continuously with the temperature probe.
7. Collect data until the temperature stabilizes.
8. Save the experiment and note the file name.

Thinking what you observed

a. Study the temperature vs. time graph for the second experiment. Did the temperature go up, down, or stay the same?

b. Look at the graph of each reaction. What is the maximum temperature change in each reaction? What does each graph show about energy changes in each reaction?

c. A reaction that gives off energy is called exothermic. Which reaction(s) are exothermic? Support your answer with your data.

d. A reaction that uses energy is called endothermic. Which reaction(s) are endothermic? Support your answer with your data.
Can we measure the heat released/energy absorbed by instant hot and cold packs?

All chemical reactions are either exothermic (release energy) or endothermic (absorb energy). However, some physical processes such as dissolution (dissolving) can also release/absorb energy. This is the basis for commercially available instant hot packs and cold packs. Most hot and cold packs work by breaking a membrane that separates a solid and water. Once the membrane is broken, the solid dissolves in the water. Depending on the nature of the compound, heat is either released (hot pack) or absorbed (cold pack) during the process. In this investigation, you will examine the temperature changes of hot and cold packs and determine the energy absorbed or released during the chemical reactions that take place.

### Stop and think

Calcium chloride is used to melt ice on winter roads. Would that process be exothermic or endothermic? Why?

### Doing the experiment

**Part A: Hot Pack - Record all measurements in Table 1.**

1. Use a graduated cylinder to measure 50 mL of water. Record the mass of the water in Table 1 (HINT: 1 mL of water = 1 g).
2. Pour the water into 2 nested foam cups and place the temperature probe into the water.
3. Use a balance to measure out about 10 g of calcium chloride (CaCl₂). Record the mass of the CaCl₂ in Table 1.
4. Select new experiment on the Data Collector and press Go. Wait for the temperature of the water to stabilize and record that temperature in Table 1 (initial temperature).
5. Pour the CaCl₂ into the water and stir with the temperature probe.
6. Watch the graph and the temperature reading as the reaction proceeds.
7. Watch for the highest temperature reading before the temperature starts to go down again. Record that temperature in Table 1 (final temperature).
8. Pour the solution down the drain and then rinse and dry your foam cups.

### Table 1: Hot pack mass and temperature data

<table>
<thead>
<tr>
<th>Mass of water (g)</th>
<th>Mass of CaCl₂ (g)</th>
<th>Initial temp. (°C)</th>
<th>Final temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part B: Cold Pack

1. Use a graduated cylinder to measure 50 mL of water. Record the mass of the water in Table 2 (HINT: 1 mL of water = 1 g).
2. Pour the water into 2 nested foam cups and place the temperature probe into the water.
3. Use a balance to measure out about 10 g of ammonium nitrate (NH₄NO₃). Record the mass of the NH₄NO₃ in Table 2.
4. Select new experiment on the Data Collector and press Go. Wait for the temperature of the water to stabilize and record that temperature in Table 2 (initial temperature).
5. Pour the NH₄NO₃ into the water and stir with the temperature probe.
6. Watch the graph and the temperature reading as the reaction proceeds.
7. Watch for the lowest temperature reading. Record that temperature in Table 2 (final temperature).
8. Pour the solution down the drain and then rinse and dry your foam cups.

Table 2: Cold pack mass and temperature data

<table>
<thead>
<tr>
<th>Mass of water (g)</th>
<th>Mass of NH₄NO₃ (g)</th>
<th>Initial temp. (°C)</th>
<th>Final temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Analyzing the Data

a. Calculate the temperature change of the CaCl₂ and water reaction.

b. Calculate the heat gained by the solution using the equation below: Assume the specific heat of the solution is equal to the specific heat of water. The specific heat of water is 4.184 J/g °C.

**HEAT EQUATION**

\[ E = mC_p (T_2 - T_1) \]

Where: \( E \) = heat lost or gained
\( m \) = mass of solution in the calorimeter
\( C_p \) = specific heat of substance
\( T_2 - T_1 \) = change in temperature (also referred to as \( \Delta T \))

c. Calculate the amount of energy (in Joules) released per gram of CaCl₂. Remember: \( Q \) is the opposite sign of the value you calculate.

d. Calculate the temperature change of the NH₄NO₃ reaction.
Thermodynamics of Hot Packs/Cold Packs

**Investigation**

**e.** Calculate the heat lost by the solution using the heat equation: Assume the specific heat of the solution is equal to the specific heat of water.

Where: 
- \( E = \text{heat lost or gained} \)
- \( m = \text{mass of solution in the calorimeter} \)
- \( C_p = \text{specific heat of substance} \)
- \( T_2 - T_1 = \text{change in temperature (also referred to as } \Delta T) \)

**f.** Calculate the amount of energy (in Joules) absorbed per gram of \( \text{NH}_4\text{NO}_3 \). Remember: \( Q \) is the opposite sign of the value you calculate.

**Thinking about what you observed**

**a.** Look at the reactions below. Place the energy value on the appropriate side of the two equations.

\[
\text{CaCl}_2(\text{s}) \rightarrow \text{Ca}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq})
\]

\[
\text{NH}_4\text{NO}_3(\text{s}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{NO}_3^-(\text{aq})
\]

**b.** When \( \text{CaCl}_2 \) dissolves in water the true value for \( E = -747 \text{ J/g} \). When \( \text{NH}_4\text{NO}_3 \) dissolves in water the true value for \( E = 326 \text{ J/g} \). Compare your experimental values by calculating the percent error for each reaction.

**c.** Describe why your skin feels cool when a cold pack is applied and warm when a hot pack is applied.
19A Solubility Curve of KNO₃

What is a solubility curve?

Solubility refers to the amount of solute that can be dissolved in a certain volume of solvent under certain conditions. In this experiment, you will be examining the relationship between temperature and the solubility of potassium nitrate (KNO₃). The solvent will be water. Using class data, you will construct a solubility curve for KNO₃.

Stop and think

Based on what you know about dissolving substances in water, do you think the solubility of KNO₃ will increase or decrease with temperature?

Doing the experiment

1. Fill a 400 mL beaker ¾ full with water. Place it on a hot plate. Allow it to heat and go on to the next step.
2. Your teacher will assign you a specific amount of KNO₃. Use a balance to obtain the exact mass of potassium nitrate you will be using and put it in a test tube. Record the mass in Table 1.
3. Add 5 mL of water to your test tube containing your KNO₃. Record this volume in Table 1.
4. Place the test tube with the KNO₃ and water into your hot water bath. Allow it to heat until all the KNO₃ dissolves, while stirring. The temperature of the water may need to reach approximately 85 °C.
5. Once all solid has dissolved, remove the test tube from the hot water bath and allow it to cool.
6. Place a thermometer in the test tube and watch for the first signs of crystallization. (Hint: Stirring occasionally may help you see the small crystals that form). When you start to see your first crystal gather at the bottom of the test tube, record your temperature in Table 1.
7. If crystals still do not form when the temperature cools down to 30 degrees, place the test tube in a beaker of room temperature water.
8. If the crystals still do not form when the temperature cools down to 25 degrees, take the test tube out of the room temperature water and place it in a beaker of ice water (provided by your teacher).
9. Show your teacher your results. If your teacher gives you permission, place your test tube back in the hot water bath and re-dissolve the solid. Flush the solution down the drain with plenty of hot water.
10. Rinse and clean all remaining apparatus and put it away.

### Table 1: KNO₃ crystal formation data

<table>
<thead>
<tr>
<th>Mass of KNO₃ (g)</th>
<th>Volume of water (mL)</th>
<th>Mass of water (g)</th>
<th>Temp. when crystals first appeared (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Calculations

a. In the lab you measured out 5.0 mL of water. What is the mass of 5.0 mL of water? Explain.

b. Knowing how many grams of your solid can dissolve in 5.0 g of water, how many grams could dissolve in 100.0 g of water? Report this value to the class (Hint: Set up a ratio). Record your results and those of the other groups in Table 2.

### Table 2:

<table>
<thead>
<tr>
<th>Group</th>
<th>Temperature (°C)</th>
<th>Solubility (g/100g H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 1g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2 2g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3 4g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4 6g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#5 8g</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Thinking about what you observed

a. Using the class data, construct a solubility curve. Plot the temperature (0 °C – 100 °C) on the x-axis and the solubility of potassium nitrate (g KNO₃/ 100g H₂O) on the y-axis. Make sure your graph has a title and the axes are labeled including units. Connect all points with a smooth curve when complete.

b. In your own words, explain how solubility of KNO₃ varies with temperature.

c. From your solubility curve, predict the solubility of KNO₃ at

1. 65 °C
2. 50 °C
3. 25 °C

d. Is this solubility curve useful for temperature values above 100 °C?

e. How many grams of KNO₃ can be dissolved in 200.0 mL of water at 35 °C?
19B Acids, Bases, and pH

What is pH?

Life exists inside a certain range of pH values. A pH value describes whether a solution is acidic, basic (alkaline), or neutral by describing the concentration of hydronium ions in a solution. An acid is a substance that produces hydronium (H$_3$O$^+$) ions when dissolved in water, and a base (or alkali) is a substance that produces hydroxide (OH$^-$) ions when dissolved in water. Neutral solutions have equal numbers of H$_3$O$^+$ and OH$^-$ ions.

In this investigation, you will learn the pH of several common solutions by making a pH scale using a pH indicator and chemicals of known pH. You will also identify two ‘mystery’ chemicals with your pH scale.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.8.8</td>
<td>Characterize types of chemical reactions, for example: redox, acid-base, synthesis, and single and double replacement reactions.</td>
</tr>
<tr>
<td>SC.912.P.8.11</td>
<td>Relate acidity and basicity to hydronium and hydroxyl ion concentration and pH.</td>
</tr>
</tbody>
</table>

1. **Stop and think**

Look at the table in the investigation. Using the pH values listed, predict whether the antibacterial soap will be acidic or basic and whether the apple juice will be acidic or basic. Of the solutions in the list, to which are they most closely related?

2. **Doing the experiment**

   **A. Make a pH scale using indicators**

   1. To create your pH scale, you will be using solutions 1 to 7 in the table below. Place the following labels for these solutions in order on a well plate. If you don’t have seven wells in a row on one well plate, place two plates side by side. The labels should describe the solution and its pH: Lemon – pH 2, Vinegar – pH 3, Seltzer water – pH 4, Red cabbage juice (the control) – pH 6.5, Baking soda – pH 8.5, Bar soap – pH 10, and Ammonia – pH 11.

   2. Using a pipette, place three drops of red cabbage juice in each of the seven labeled wells.

   3. Using a pipette, add two drops of each of the solutions to the appropriately labeled well. Use a different eyedropper or pipette for each solution. However, if you must use the same dropper or pipette, thoroughly rinse it in fresh water after each solution before using it for a new solution. Record the color changes in your data table. The color series you see on the plate(s) represents a pH scale. We will refer to it as the pH test plate. You will use it to identify the pH of other solutions.
4. Dip the red litmus paper and the blue litmus paper into each well of the pH test plate. Record the results according to the directions in the data table.

<table>
<thead>
<tr>
<th>Name of solution</th>
<th>Color when mixed with red cabbage juice</th>
<th>Red litmus paper: if paper turns blue, write “base” or make an “x”</th>
<th>Blue litmus paper: if paper turns red, write “acid” or make an “x”</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lemon</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>2. Vinegar</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>3. Seltzer</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>4. Red cabbage juice</td>
<td></td>
<td></td>
<td></td>
<td>6.5</td>
</tr>
<tr>
<td>5. Baking soda solution</td>
<td></td>
<td></td>
<td></td>
<td>8.5</td>
</tr>
<tr>
<td>6. Bar soap solution</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>7. Ammonia</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>8. Green tea</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Antibacterial cleaner</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Apple juice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Mystery solution A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Mystery solution B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
B: Using pH indicators to measure unknown pH

1. Repeat steps A2 through A4 for solutions 8 to 12. Use another well plate for these five solutions. The labels should describe the solution. At this point, you do not know the pH of these solutions.

2. Identify the pH of solutions 8 to 12. Compare the color reactions and the litmus paper results for solutions 8 to 12 with the pH test plate.

3 Thinking about what you observed

a. What is the role of a pH indicator? What is the range of pH measured by each of the indicators you used (red cabbage juice, red litmus paper, blue litmus paper)?

b. Which of your solutions has the highest concentration of \( \text{H}_3\text{O}^+ \) ions? Which has the highest concentration of \( \text{OH}^- \) ions? Explain your reasoning.

c. The red cabbage juice used in the investigation has two roles. It is the pH indicator and, in the series on the pH test plate, it is a control. Why is a control needed on the pH test plate?

d. Mystery solutions A and B are identical to two other solutions you used in this lab. Use your results to identify these solutions. What is the identity of mystery solution A? What is the identity of mystery B? List evidence to support your claims.

e. List the pros and cons of using red cabbage juice and litmus paper as pH indicators.

f. Various professions use pH indicators. For example, photographers traditionally used and still sometimes use stop bath in developing, and swimming pools are maintained using information from pH indicators. Find out how these pH indicators work in these (or other) situations, and what the color changes mean.
20A Electricity

How do you measure voltage and current in electric circuits?

We use electricity every day, nearly every minute! In this investigation you will build circuits and learn about voltage (volts) and current (amps) which are fundamental quantities that describe the electricity we use.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
<td>Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.</td>
</tr>
<tr>
<td>SC.912.P.10.15</td>
<td>Investigate and explain the relationships among current, voltage, resistance, and power.</td>
</tr>
</tbody>
</table>

1 Building a circuit

1. Build the circuit shown in the diagram with one battery, a switch, and a bulb.
2. Open and close the switch and see what happens.

2 Thinking about what you observed

a. How can you tell electric current is flowing in the circuit? Can you see the current?

b. Current flows from positive to negative. Trace the flow of current around the circuit with your finger.

c. How does the switch cause the current to stop flowing?

d. Why does the bulb go out when you open the switch?
3 Conductors and insulators

Materials through which electric current flows easily are called **conductors**. Materials through which current does not flow easily are called **insulators**.

Connect circuit through each object

- Paper clip
- Plastic straw
- String
- Rubber band
- Pen cap

1. Break one connection in your one-bulb circuit.
2. Complete the circuit by touching different materials between the wire and the post.
3. Which materials allow the bulb to light and which do not?

4 Thinking about what you observed

a. Make a table listing the materials as either conductors or insulators.

b. What characteristics are shared by the conductors you found?

c. What characteristics are shared by the insulators you found?

5 Circuit diagrams

For describing electric circuits we use the language of **circuit diagrams**. In a circuit diagram wires are represented by solid lines. Electrical devices like switches, batteries, and bulbs are represented by symbols.

a. Using these symbols, draw a picture of the circuit you built with one battery, switch, and light bulb.
6 Measuring the voltage of a battery

Turn the dial of your multimeter to DC volts. Red goes to the positive terminal and black to the negative terminal. When you touch two points in a circuit with the leads, the meter reads the voltage between the two points.

a. Measure the voltage of the battery and record your reading.

b. Take a second battery and connect it to the first by touching the ends together.

c. Measure the voltage for the four possible ways to connect two batteries (+ to –, + to +, – to –, – to +). How do your readings compare to the voltage of just one battery?

7 Measuring current

To measure current, the meter must be connected so the current has to flow through it. This is different from voltage measurement. To measure current you must force the current to flow through the meter by eliminating all other paths the current could go. Follow the instructions below carefully. Too much current can damage the meter.

1. Set the multimeter to measure DC amps (current).

2. Open the switch and touch the red lead of the meter to the metal part of the switch closest to the battery’s positive terminal (+).
3. Touch the black lead of the meter to the metal part on the other side of the switch.
4. The bulb should light, showing you that current is flowing through the meter. The meter should display the current in amps. This is the total current flowing around the circuit carrying power from the battery to the bulb. Remove the meter.

   a. How much current is flowing in the circuit when the bulb is making light?

8 A circuit with a dimmer switch

The potentiometer (or pot) is an electrical device that can be used to make a dimmer switch. When the dial on the pot is turned one way the pot acts like a closed switch and current flows freely through it. When the dial is turned the other way the pot resists the flow of current.

1. Connect the circuit in the diagram using the pot, a battery, wire, and a bulb.
2. Adjust the dial and watch what happens to the bulb.
3. Use the meter to measure the voltage across the bulb for different settings of the pot. Record your data in table 1.

Table I: Pot settings and voltage across bulb

<table>
<thead>
<tr>
<th>Pot dial position</th>
<th>Voltage across bulb (V)</th>
<th>Observed light output of bulb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9 Thinking about what you observed

   a. As you changed the settings of the pot, what happened to the voltage across the bulb?
   b. Did you observe a relationship between the voltage across the bulb and the light output?
   c. Propose a relationship between power and voltage that would explain the light output of the bulb.
20B Resistance and Ohm’s Law

What is the relationship between current and voltage in a circuit?

Electrical devices get the energy they use from the current that flows through them. When designing an electrical device or a circuit, it is important for the proper amount of current to flow for the voltage that is available. Resistance is the property of electricity that helps regulate the current in the circuit. You will explore resistance and Ohm’s law, the equation that relates voltage, current, and resistance.

1 Mystery resistors

A resistor is used in a circuit to provide resistance. You have green, blue, and red resistors in your kit with values of 5 Ω, 10 Ω, and 20 Ω, but you don’t know which is which!

1. Make a circuit with a switch, battery, and resistor, as pictured above.
2. Set the meter to measure current (DC amps). Open the switch. Measure the current by connecting the meter across the open terminals of the switch.
3. Set the meter to measure voltage (DC volts). Close the switch. Measure the voltage across the mystery resistor as pictured above.
4. Repeat the current and voltage measurements for each of the mystery resistors.

Table 1: Resistor Currents

<table>
<thead>
<tr>
<th>Resistor color</th>
<th>Voltage across resistor (V)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Use your knowledge of Ohm’s law to determine which resistor is which. The resistance you calculate from Ohm’s law will not come out exactly to 5, 10, or 20 because the meter itself has a small resistance.
Resistance and potentiometers (pots)
The potentiometer (pot) you used in the previous investigation is really a variable resistor. A variable resistor allows you to change its resistance by turning a dial. Many dials you use every day, like dimmer switches, are actually potentiometers.

1. Use the meter to measure the resistance of the pot for different positions of the dial. The pot does not have to be in the circuit; you can just touch the leads across the pot.
2. Take your first reading with the pot turned all the way to the left and take 4 or 5 readings until the pot is turned all the way to the right.

Table 2: Pot settings and resistance

<table>
<thead>
<tr>
<th>Pot dial position</th>
<th>Resistance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

The bulb dimmer circuit

1. Build the dimmer circuit with two batteries, the pot, a switch, and a bulb.
2. Close the switch and observe how the brightness changes as you change the dial on the pot.
   a. Use the concept of resistance to explain how the pot controls the brightness of a bulb.
The voltage drop

The voltage in a circuit is reduced whenever current flows through a device that has a resistance greater than zero. The reduction of voltage is called the voltage drop.

1. Connect the dimmer circuit with the pot, switch, two batteries, and a light bulb.
2. The voltage drop is measured by touching the meter leads to the terminals of each device.
3. Measure the voltage drop across the pot and across the bulb for different dial settings of the pot.

Table 3: Pot settings and voltage drops

<table>
<thead>
<tr>
<th>Pot dial position</th>
<th>Voltage drop across pot (V)</th>
<th>Voltage drop across bulb (V)</th>
<th>Observed light output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Record the observed light output at each dial position measured.

a. What is the relationship between the voltage drop across the pot and the voltage drop across the bulb?

b. What does the voltage drop tell you about the electrical energy carried by the current?

c. What relationship do you observe between the measured voltage drops and the battery voltage?
21A Electric Circuits

What are the different types of circuits?

A simple electric circuit contains one electrical device, a battery, and a switch. Flashlights use this type of circuit. However, most electrical systems, such as a stereo, contain many electrical devices connected together in multiple circuits. This investigation introduces two ways to connect multiple devices in a circuit.

---

**Table 1: Voltage Measurements (volts)**

<table>
<thead>
<tr>
<th>Between A and B (V)</th>
<th>Between B and C (V)</th>
<th>Between C and D (V)</th>
<th>Between A and D (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

1. **Series circuits**

   1. Using two batteries, build the simple circuit with three light bulbs and a switch as shown above.
   2. Set the meter to DC volts. Close the switch and measure the voltage across the different places by touching the meter’s leads to the bulbs’ terminals. Record the voltages in Table 1.

   "Build this circuit"

   [Diagram of a circuit with A, B, C, D labeled and three bulbs.]

---

**Thinking about what you measured**

a. What relationships do you see among the voltage measurements in Table 1?

b. What do the voltage measurements tell you about the flow of energy in the circuit?
3 The current in series circuits

1. Set the meter to DC amps. Measure the current by opening the switch and touching the leads of the meter to the terminals of the switch in the three bulb circuit. Record your measurements in Table 2.
2. Remove one bulb and replace it with a wire. Measure and record the current for the two-bulb circuit.
3. Remove a second bulb and replace it with a wire. Measure and record the current again for the one-bulb circuit.

Thinking about what you observed

a. What happens to the current in the circuit as the number of bulbs is reduced? Explain why this occurs using Ohm’s law and the concept of resistance.

b. What happens to the other two bulbs when one bulb is removed from the three-bulb circuit? Try it and explain why the circuit behaves as it does.
Short circuits

A short circuit is an easy (but dangerous) shortcut that current can travel through to avoid one or more of the electrical components in the circuit.

1. Rebuild your three-bulb circuit with the switch open.
2. Check the current and observe which bulbs light and how bright they are.
3. Add a section of wire that bridges the last two bulbs in the circuit. This wire is the “short circuit.”
4. Complete the circuit (with the switch open) using the meter to measure the current. Observe which bulbs light and how bright they are.

Thinking about what you observed

Table 3: Short Circuit Current Measurements (amps)

<table>
<thead>
<tr>
<th>Three bulbs in series (A)</th>
<th>Three bulbs with two short circuited (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Compare the current in the three-bulb circuit with the current when two bulbs are bypassed by a short circuit. Which is greater? Use Ohm’s law and the concept of resistance to explain why.

b. How does the current in the “short circuit” version compare with the current you measured in a one-bulb circuit? Explain why this should be true.

c. How does the resistance of a wire compare to the resistance of a bulb? Measure the resistances to test your answer. NOTE: Most meters cannot measure very low resistance and display “0.00” when the resistance is lower than 0.01 Ω.

d. Why would a short circuit be dangerous? Discuss (as a class) the consequences of very large currents in wires of different sizes.
7 Parallel circuits

Build this circuit

1. Build a circuit with two batteries, a switch, and three bulbs as shown in the diagram.
2. Close the switch and measure the voltage across the battery. All three bulbs are lit.
3. Measure the voltage across each bulb by touching the leads of the meter to the terminals of each bulb separately.
4. Set the meter to DC amps. Measure the total current in the circuit by opening the switch and touching the leads of the meter to the terminals of the switch.

Table 4: Voltage and current in a parallel circuit

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Total circuit</th>
<th>Bulb 1</th>
<th>Bulb 2</th>
<th>Bulb 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8 Thinking about what you observed

a. Compare the brightness of the bulbs in the parallel circuit with the brightness in the series circuit.

b. Compare the total current in the single-bulb circuit, the three-bulb series circuit, and the three-bulb parallel circuit. Propose a relationship between the currents that agrees with the brightness of the bulbs.

c. Do the other two bulbs continue to light when the third bulb is removed from the parallel circuit? Try it. How does this differ from what happened with the series circuit?

d. Do you think the electrical outlets in your home are connected in a series or parallel circuit? Give two reasons why one type of circuit has an advantage over the other for connecting outlets.
21B Electrical Energy and Power

How much energy is carried by electricity?

A voltage of one volt means one amp of current can do one joule of work each second. This definition of a volt is really a formula for calculating power from current and voltage. If the voltage and current are multiplied, the result is the power used by the circuit. In this investigation, you will explore the relationship between voltage, current, and power.

### Energy and power in an electrical system

**| Voltage (V) | Current (A) | Power (W) |
---|---|---|---|
| | | |

1. Connect a simple circuit with a single bulb, switch, and battery.
2. Use the meter to measure the voltage and current in the circuit when the bulb is lit.
3. Use the formula above to calculate the power used by the bulb in watts.
4. Repeat the experiment with two batteries connected so the bulb receives 3 V instead of 1.5 V.

**Table 1: Power used by a bulb**

### Thinking about what you observed

a. How did the power used by the bulb compare at the two different voltages?

b. Was the bulb brighter, dimmer, or about the same at 3 V compared to 1.5 V? Explain any difference you observed using the concept of power.
1. Find the capacitor (labeled *super cap*). This capacitor acts like a battery that charges almost instantly when you touch its terminals to a battery.

2. Make the circuit in the diagram. The positive terminal of the capacitor should meet the red (+) lead of the meter. The meter will probably read zero volts.

3. Touch the positive wire from the battery to the positive (+) terminal of the capacitor for 5 seconds. Remove the positive battery wire once the capacitor is “charged” up to 1.5 V.

4. Touch the leads of the multimeter across the capacitor and watch what happens to the voltage (DC volts) over time. The bulb should light up then dim and go out as the voltage drops.

### Thinking about what you observed

**a.** How was energy flowing when the capacitor was “charging up”? What was the source of the energy and where did it go?

**b.** How was energy flowing when the bulb was connected and the battery was removed? What was the source of the energy and where did it go?

**c.** Why did the bulb go out after a few seconds? Explain what you observed in terms of the ideas of energy and power.
5 Energy and power

You are going to use the Timer to measure how long the capacitor can keep one or more bulbs lit.

1. Set up the three circuits above, one at a time.
2. For each circuit, charge the capacitor for 5 seconds then use the Data Collector to measure how long the bulb produces light. Start the Data Collector when you close the switch to light the bulb. Stop the Data Collector when you can no longer see any light. Use stopwatch mode.
3. Repeat the test three times and take the average. Use Table 2 to record your data.

Table 2: Energy and power data at 1.5 V

<table>
<thead>
<tr>
<th>Starting voltage (V)</th>
<th>Number of bulbs</th>
<th>Time until bulb goes out (s)</th>
<th>Average of 3 trials (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

6 Thinking about what you observed

a. What is the total power used by 1, 2, and 3 bulbs connected in parallel? In a parallel circuit each device draws current as if it were the only device in the circuit. (Hint: look back at your data from Part 1).

b. What relationship do you observe between the time the bulbs stay lit and the total power used?

c. Since power is energy ÷ time, the formula can be rearranged to give energy = power × time. For example, if you use 10 watts for 10 seconds, you have used a total of 100 joules of energy (100 J = 10 W × 10 s). Use your data to estimate how many joules of energy are stored in the capacitor at 1.5 V.
**22A Magnetism**

*How do magnets and compasses work?*

Magnets are used in almost all electrical and electronic machines from motors to computers. How far does magnetic force reach? How can you use a compass to detect magnetic forces? In this investigation, you will use magnets and a compass to answer these and other questions about magnetism.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.N.4.1</td>
<td>Explain how scientific knowledge and reasoning provide an empirically based perspective to inform society’s decision making.</td>
</tr>
<tr>
<td>SC.912.P.10.18</td>
<td>Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.</td>
</tr>
</tbody>
</table>

**1 How far does magnetic force reach?**

How far does the magnetic force of a magnet reach? This is an important question concerning machines such as motors and generators that use magnets.

**How far does the magnetic force reach?**

1. Place one magnet at the 0 cm mark of the ruler and slide a second magnet closer and closer until the first magnet moves. Practice the technique several times before recording data.
2. Record the distance between the magnets when you first see movement.
3. Try each of the combinations of poles—north-north, south-south, and north-south.
4. For each combination, complete three trials, and average your three distances.

**Table 1: Magnetic forces between two magnets**

<table>
<thead>
<tr>
<th>Distance 1 (mm)</th>
<th>North-South</th>
<th>South-South</th>
<th>North-North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance 2 (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance 3 (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average distance (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average estimated error (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2 Thinking about what you observed

a. What is the average estimated error for each magnet combination? Subtract each individual distance for the North-South magnet combination from the average of the three distances. Drop any negative signs. Once you have found these 3 differences, average them and record in Table 1. Repeat for the other 2 magnet combinations.

b. Are the attract and repel distances significantly different? Your answer should include a comparison between average estimated errors and the differences between magnet combination average distances.

3 Using a compass to detect magnetic forces

The needle of a compass is a permanent magnet. Earth is magnetic, so a compass needle is attracted to north in the absence of other (stronger) magnets.

1. Set a compass on your table far from any magnets. Rotate the compass so the needle, dial, and arrow are all aligned with north.
2. Place a metric ruler to the side of the compass and line it up perpendicularly with the north pole of the compass. Move a small magnet near the compass and note the distance at which the needle moves 20 degrees from north.
3. Reverse the pole of the small magnet and note the distance at which the needle moves 20 degrees in the opposite direction.

4 Thinking about what you observed

a. At a distance of 10 cm, which is stronger: the magnetic force from Earth or the magnetic force from the small magnet? How is your answer supported by your observations?

b. Is the end of the compass needle a magnetic north or a magnetic south pole? How is your answer supported by your observations?

c. Is the geographic north pole of the planet Earth a magnetic north or a magnetic south pole? How is your answer supported by your observations?
How are electricity and magnetism related?

Almost every electrical device that creates motion, such as a motor, uses magnets. Permanent magnets are not the only type of magnets used in these devices. Often, electromagnets are used. Electromagnets create magnetic forces through electric currents. This investigation will explore the properties of electromagnets.

**1 Electromagnets**

1. Attach the coil, battery, and switch in the circuit shown above. Leave the switch open so no current flows.
2. Place a permanent magnet about 1 centimeter away from the coil. Stand the magnet up on its end.
3. Close the switch and watch what happens to the magnet. DON’T leave current running or the coil will overheat. Open the switch after each trial.
4. Turn the permanent magnet around so its other pole faces the coil. Close the switch and see what happens now.
5. Reverse the wires connecting the battery to the circuit. This makes the electric current flow the other way. Repeat steps 3 and 4 of experiment with the magnet.

**2 Thinking about what you observed**

a. Write 2–3 sentences that explain what you saw when the switch was closed.

b. Propose an explanation for why the magnet moved.
c. When the magnet was reversed, did the force between it and the coil change direction? How did the force change?

d. When the coil wires were switched, did the force from the coil change direction? How do you know?

e. How is a current-carrying coil like a magnet? How is it different? Explain how this shows that electricity and magnetism are related.

3 Comparing the electromagnet to a permanent magnet

1. Attach the potentiometer, coil, battery, and switch in the circuit shown in the diagram. Leave the switch open so no current flows.

2. Set the compass so the needle, ring, and arrow are all aligned with north. Put the coil about 10 cm from the center of the compass.

3. Place a permanent magnet on the side of the compass opposite the coil. Bring the magnet close enough to deflect the needle 20 degrees away from north.

4. Close the switch and adjust the potentiometer so the needle returns to north. The coil should deflect the compass needle back toward north. Reverse the permanent magnet if the needle moves the wrong way. DON’T leave current running or the coil will overheat. Open the switch after each trial.

5. Try moving the permanent magnet to different distances and using the potentiometer to return the compass needle to north with force from the electromagnet.

4 Stop and think

a. The permanent magnet is pulling the compass needle to the left. The electromagnet is pulling the needle in the opposite direction to the right. When the needle returns to north what can you say about the magnetic forces from the permanent magnet and electromagnet?
5 Iron and electromagnets

Trial # 1: Coil only

Permanent magnet

Trial # 2: Coil and steel pin

Permanent magnet

Steel pin

1. Use the same circuit as for part 3 with one battery, switch, coil and potentiometer.
2. Rotate the compass until the needle and dial are aligned with north. There should be no magnets nearby, and no current in the coil for this step.
3. Move a permanent magnet close enough to deflect the needle 20 degrees from north.
4. The coil should be 10 cm from the center of the compass (see diagram above). Close the switch, then use a multimeter to measure and record how much current it takes for the coil to bring the needle back to north. Adjust the current with the potentiometer. Once you have recorded the measurement in Table 1, open the switch to stop the current.
5. Put the steel pin in the coil so its head is against the coil and 10 cm from the center of the compass.
6. Adjust the distance of the permanent magnet so the compass needle is deflected 20 degrees from north, like you did in step 3. There should be no current in the coil for this step.
7. Close the switch, then use a multimeter to measure and record the current it takes to return the needle to north with the steel pin in the coil.

Table 1: Electromagnet current with and without the steel pin

<table>
<thead>
<tr>
<th>Current with bare coil</th>
<th>Current with steel pin</th>
<th>Difference in current</th>
<th>Percent difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6 Thinking about what you observed

a. How did the steel pin affect the magnetic force created by the coil? Was the magnetic force reduced, increased, or did it stay about the same? Use your observations to support your answer.
23A Harmonic Motion

How do we describe the back-and-forth motion of a pendulum?

Harmonic motion is motion that repeats in cycles. Many important systems in nature and many useful inventions rely on harmonic motion. For example, the phases of the moon and the seasons are caused by Earth's harmonic motion. This investigation will explore harmonic motion using a pendulum. The concepts you learn with the pendulum will also apply to other examples of harmonic motion.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.N.1.4</td>
<td>Identify sources of information and assess their reliability according to the strict standards of scientific investigation.</td>
</tr>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.</td>
</tr>
<tr>
<td>SC.912.N.1.7</td>
<td>Recognize the role of creativity in constructing scientific questions, methods and explanations.</td>
</tr>
<tr>
<td>SC.912.N.2.1</td>
<td>Identify what is science, what clearly is not science, and what superficially resembles science.</td>
</tr>
<tr>
<td>SC.912.N.2.2</td>
<td>Identify which questions can be answered through science and which questions are outside the boundaries of scientific investigation.</td>
</tr>
<tr>
<td>SC.912.P.12.02</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
<tr>
<td>SC.912.P.12.03</td>
<td>Interpret and apply Newton's three laws of motion.</td>
</tr>
</tbody>
</table>

1 Setting up the pendulum

Attach the pendulum to one of the top holes in the stand.

Start the pendulum swinging and watch it for a minute. Think about how to describe the motion.

a. Write one sentence about the motion using the word “cycle.”

b. The **amplitude** is the maximum amount the pendulum swings away from its resting position. The resting position is straight down. One way to measure amplitude is the angle the pendulum moves away from center. Write one sentence describing the motion of your pendulum using the word “amplitude.”

c. Draw a sequence of sketches that describe one complete cycle using arrows to indicate the direction the pendulum is going at that point in the cycle.
2 Oscillators and period

a. Use the stopwatch function of the Data Collector to measure the period of your pendulum. Time ten cycles. Do three trials and use Table 1 to record your data.

b. Divide the average time for ten cycles by 10 to get the period.

c. Write a one sentence description of how you measured the period.

<table>
<thead>
<tr>
<th>Table 1: Pendulum period data: Time for 10 cycles (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>Period of pendulum (average divided by 10)</td>
</tr>
</tbody>
</table>

3 Measuring period with a photogate

1. Attach the photogate as shown in the diagram. The pendulum breaks the light beam when it swings through the photogate. Try to keep the string length close to the length you used in part 2.

2. Put the Data Collector in period mode and let the pendulum swing through the light beam.

3. If you press the GO button once the display freezes allowing you to write down a number before it changes. Pressing GO a second time starts another measurement.
4 Thinking about what you observed

a. Write down the time measurement you get from the Data Collector.

b. Is the time you get from the Data Collector the period of the pendulum? Explain why the time is or is not the period of the pendulum (hint: compare to your results from part 2).

c. Explain how the time measured by the Data Collector is related to the period of the pendulum.

5 What variables affect the period of a pendulum?

In this experiment, the period of the pendulum is the only dependent variable. There are three independent variables: the mass of the bob, the amplitude of the swing, and the length of the string.

1. The amplitude can be changed by varying the angle that the pendulum swings.
2. There are washers that you can use to change the mass of the bob.
3. The length of the string can be changed by sliding it through the slot in the peg. Measure the length of the string from the bottom of the string peg to the bottom of the washers.

Design an experiment to determine which of the three variables has the largest effect on the period of the pendulum. Your experiment should provide enough data to show that one of the three variables has much more of an effect that the other two. Be sure to use a consistent technique that gives you consistent results.

a. Think of three experiments you can do to see what variables affect the period of the pendulum. Write down one sentence describing each experiment.

b. Do the three experiments and record the measurements you make to assess the effect of changing each variable.

6 Analyzing the data

a. Of the three things you can change (amplitude, mass, and string length), which one has the biggest effect on the pendulum, and why? In your answer you should consider how gravity accelerates objects of different mass.
b. Split up your data so that you can look at the effect of each of the three variables by making a separate graph showing how each one affects the period. To make comparison easier, make sure all the graphs have the same scale on the y-axis (period). The graphs should be labeled like the example below.

<table>
<thead>
<tr>
<th>Period (s)</th>
<th>Period (s)</th>
<th>Period (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude (degrees)</td>
<td>Mass (# of washers)</td>
<td>String Length (cm)</td>
</tr>
</tbody>
</table>

### Applying what you know

Pendulum clocks were once among the most common ways to keep time. It is still possible to find beautifully made pendulum clocks for sale today. To make a pendulum clock accurate, the period must be set so a certain number of periods equals a convenient measure of time. For example, you could design a clock with a pendulum that has a period of 1 second. The gears in the clock mechanism would then have to turn the second hand 1/60th of a turn per swing of the pendulum.

a. Using your data, design and construct a pendulum that you can use to accurately measure a time interval of 30 seconds. Test your pendulum clock against the electronic stopwatch.

b. Mark on your graph the period you chose for your pendulum.

c. How many cycles did your pendulum complete in 30 seconds?

d. If mass does not affect the period, why is it important that the pendulum in a clock is heavy?

e. Calculate the percent error in your prediction of time from your pendulum clock. The percent error is 100 times the difference between your prediction and 30 seconds, divided by 30 seconds.

f. You notice in a magazine that a watch manufacturer advertises that its quartz watch loses no more than 5 seconds per month. Assume that the watch loses the maximum amount (5 seconds) in 31 days. Calculate the percent error of the quartz watch by comparing 5 seconds to the number of seconds in a month.
23B Natural Frequency and Resonance

What is resonance and why is it important?

The pendulum oscillated at only one frequency for each string length. The frequency at which objects vibrate is called the natural frequency. Almost everything has a natural frequency, and most things have more than one. We use natural frequency to create all kinds of waves, from microwaves to the musical sounds from a guitar. In this investigation you will explore the connection between frequency of a wave and its wavelength.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.10.18</td>
<td>Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.</td>
</tr>
<tr>
<td>SC.912.P.12.2</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
</tbody>
</table>

1 Setting up the experiment

Connect the Data Collector to the sound and waves generator as shown in the diagram. The telephone cord connects the Data Collector and wave generator. The black wire goes between the wave generator and the wiggler.

1. Attach the fiddle head to the top of the stand, as high as it goes.
2. Attach the wiggler to the bottom of the stand, as low as it goes.
3. Stretch the elastic string a little (5-10 cm) and attach the free end to the fiddle head. Loosen the knob until you can slide the string between any two of the washers. GENTLY tighten the knob just enough to hold the string.
4. Turn on the Data Collector and be sure to plug in the AC adapter.
5. Set the wave generator to WAVES using the button. The wiggler should start to wiggle back and forth, shaking the string.
6. Set the Data Collector to measure FREQUENCY. You should get a reading of about 10 Hz. 10 Hz means the wiggler is oscillating back and forth 10 times per second.
7. Try adjusting the frequency of the wiggler with the frequency control on the wave generator. If you watch the string, you will find that interesting patterns form at certain frequencies.
2 Resonances of a vibrating string

At certain frequencies the vibrating string will form wave patterns like those shown in the picture. Each of the patterns occurs at a resonance of the string. The resonances are called harmonics and they are described by the number of ‘bumps’ seen on the vibrating string.

The wavelength of each harmonic is the length of one complete wave. One complete wave is two “bumps.” Therefore, the wavelength is the length of two bumps. The string is 1 meter long. If you have a pattern of three bumps, the wavelength is 2/3 meter, since three bumps equal 1 meter and a whole wave is two of the three bumps.

3 Finding the standing waves

You noticed that the standing waves only occur at certain special frequencies. The wiggler applies a periodic force to the string. When the periodic force matches the natural frequency of the string, a large response develops (resonance).

1. Use the frequency control to find the first through the eighth harmonics of the string (at least).
2. Record the frequency and wavelength for each harmonic in Table 1. You should fine-tune the frequency to get the largest amplitude wave before recording the data. Look for harmonics 2 to 6 before looking for the first one. The first harmonic, also called the fundamental, is hard to find with exactness. Once you have the frequencies for the others, they provide a clue for finding the frequency of the first harmonic.

<table>
<thead>
<tr>
<th>Harmonic #</th>
<th>Frequency (Hz)</th>
<th>Wavelength (m)</th>
<th>Frequency times wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>6</td>
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</tbody>
</table>
4 Thinking about what you observed

a. In one or two sentences, describe how the frequencies of the different harmonic patterns are related.

b. Why is the word fundamental chosen as another name for the first harmonic?

c. Give an equation relating frequency ($f$) and wavelength ($\lambda$) that best describes your observations.

d. If the frequency increases by a factor of two, what happens to the wavelength?

e. Propose a meaning for the number you get by multiplying frequency and wavelength.

5 Frequency and energy

Waves are useful because they carry energy from one place to another. The energy of a wave can also carry information such as a voice signal from a cell phone or a TV picture.

1. Set up several wave patterns and measure the amplitude for each harmonic.

2. Measure at least 5 different harmonics, including the 6th or higher.

Table 2: Frequency vs. amplitude data

<table>
<thead>
<tr>
<th>Harmonic #</th>
<th>Frequency (Hz)</th>
<th>Amplitude (cm)</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

6 Thinking about what you observed

a. What happens to the amplitude of the waves as their frequency increases?

b. How does the energy of a wave depend on its frequency if the amplitude stays constant? How is your answer supported by your observations of the vibrating string?
Resonance

The diagram shows a useful way to think about pushing a swing. The person pushing applies a periodic force to the swing, just like the wiggler does to the vibrating string. Like the string, a swing is a system in harmonic motion. If the push is applied at the swing’s natural frequency, the amplitude grows large, like the standing wave on the string. The response of a swing to a periodic push is an example of *resonance*. The harmonics on the vibrating string are another example of resonance. Resonance happens when the force applied to a system matches its natural frequency. We use resonance to create waves with specific frequencies, such as in a musical instrument, cell phone, or microwave oven.
24A Properties of Sound

Does sound behave like other waves?

Sound is one of the most important of our senses. We use sounds to express the whole range of human emotion. Scientifically, sound is one of the simplest and most common kinds waves. Sound is a rich and beautiful palette from which musicians create works of joy, excitement and drama. In this investigation, you will listen to beats and show how they can be explained if sound is a wave, create interference of sound waves, and demonstrate resonance.

1. The teacher will set up two sound waves generated by one machine set to operate in “beat” mode. One sound wave will be at 440 Hz and the other will be at 445 Hz.
2. Listen to the 440 Hz sound by itself.
3. Listen to the 445 Hz sound by itself.
4. Listen to the combination of 440 Hz and 445 Hz together.
5. The teacher will keep one sound at 445 Hz and adjust the frequency of the other one between 444 and 430 Hz. Listen to the combination.
2 Thinking about what you observed

The oscillations of loud and soft you hear from the two sound waves are called **beats**. Beats are caused by small differences in frequency between multiple sounds heard at the same time.

Why we hear beats

Conduct experiments that can answer the following questions about beats.

a. What makes the beats get faster or slower? In your answer you should describe what you do to the frequencies to make the beats faster or slower.

b. Is the sound of beats pleasant to listen to, or unpleasant? The word *consonant* is used by musicians to describe sounds that fit smoothly together. The opposite of consonant is *dissonant*. Dissonant sounds tend to make people anxious and irritable. Describe the relationship between consonance, dissonance and beats.

c. How could you use beats to match one frequency to another frequency? This is done every day when musicians in an orchestra tune their instruments.

d. How much different do the two frequencies have to be before you do not hear any beats?

3 Interference

Beats are only one way sound waves interact with each other. Suppose you have two identical sound waves and you are standing where you can hear them both. For certain positions, one sound wave reaches your ear in the opposite phase with the other wave and the sound gets softer, like in beats. Move over a little and the two sound waves add up to get louder. These effects are called interference and are easy to demonstrate.
1. Set up one sound generator with two speakers. Place one speaker about 1/2 meter behind the other.
2. Set the frequency between 400 Hz and 800 Hz.
3. Stand 3 or 4 meters in front of one speaker and have your lab partner slowly move one of the two speakers away. You will hear the sound get loud and soft and loud again when the distance between speakers has changed by one wavelength.

When two speakers are connected to the same sound generator they both make the exact same sound wave. If you move around a room you will hear places of loud and soft whenever your distance from each speaker differs by one wavelength.

4 Thinking about what you observed
   a. Try to make an approximate measurement of the wavelength of sound by changing the separation of the two speakers. The speakers have been moved one wavelength when the sound heard by the observer has gone from loudest, to softest, and back to loudest again. For this to work you need to keep the observer and both speakers in the same line.
   b. Why do we not usually hear interference from stereos even though they have two speakers?

5 Resonance
Many objects that can create sound also demonstrate resonance. When struck, played, or rubbed, these objects produce a characteristic sound at their natural frequency. A tuning fork is a good example.

1. Select a tuning fork and tap it on your knee or another firm (but not hard) surface.
2. Listen to the sound. Does it change in frequency or do you hear a single frequency that does not change?
3. Use the sound generator and Data Collector to measure the frequency of the resonance by matching the frequency of the sound generator with the sound you hear from the tuning fork. The match is perfect when you no longer hear any beats.

4. Try several different size tuning forks and use the chart below to record the resonant frequency for each one.

Table 1: Resonant frequencies for tuning forks

<table>
<thead>
<tr>
<th>Tuning fork description</th>
<th>Measured resonant frequency (Hz)</th>
<th>Labeled resonant frequency (if any)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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</tbody>
</table>

Thinking about what you observed

a. Did you observe any relationship between the size (or shape) of the tuning fork and the frequency at which it was resonant?

b. What range of frequencies did you hear that seemed to match the frequency of the tuning fork? Give your answer in the form of a range written like 429 Hz–451 Hz.

c. Strike the tuning fork and hold the bottom end against a hard, thin surface, like a window. Does the sound get louder, softer, or remain unchanged? Explain what you hear by describing what might be happening between the tuning fork and the surface you touched.
24B Resonance in Other Systems

How can resonance be controlled to make the sounds we want?

Almost all objects show some kind of resonance. A good example is a wine glass. If you take a wine glass and rub a moistened finger around the rim you can hear a resonant sound. Music is a combination of sound and rhythm that we find pleasant. Some people like music with a heavy beat and strong rhythm. Other people like music where the notes rise and fall in beautiful melodies. In this investigation, you will create musical notes by choosing frequencies of sound, make a simple musical instrument called a straw kazoo, and learn the foundations of musical harmony.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.N.4.1</td>
<td>Explain how scientific knowledge and reasoning provide an empirically-based perspective to inform society’s decision making.</td>
</tr>
<tr>
<td>SC.912.P.10.18</td>
<td>Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.</td>
</tr>
</tbody>
</table>

1 Resonance in other systems

A - Wine Glass

1. Obtain a good quality wine glass, like the ones shown in the diagram.
2. Hold the glass firmly from its base and rub the rim with a moistened finger to hear the resonance.
3. Use the sound generator and Data Collector to match the frequency as close as you can to the sound of the glass.
4. Fill the glass to different heights with water and use the same technique to find the resonant frequency for each different height.
5. Use the table below to record the height of water and the resonant frequency you found for each different height.

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Water height</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
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<tr>
<td></td>
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</tr>
</tbody>
</table>
B - Tall Glass Bottle

1. Use a tall glass bottle, like the one in the diagram.
2. You can make a resonant sound by blowing over the open mouth of the bottle, as shown. This is a little tricky and you have to find the right angle for blowing air over the mouth of the bottle.
3. Fill the bottle to different heights of water and see how the sound changes.
4. Use the sound generator and Data Collector to estimate the frequency of the sound you get at different heights and write the results in the table below.

Table 2: Resonant frequencies of bottle of water

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Water height</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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</tr>
</tbody>
</table>

Thinking about what you observed

What was the relationship between the frequencies and the heights? In coming up with your answer, remember the waves on the vibrating string and how the frequency and wavelength were related. Do you see similar behavior with the sounds and heights from the glass and bottle? For each case, what might be the vibrating element that would explain your observed changes in frequency?

Making notes

Musical notes are different frequencies of sound. Over thousands of years people have found combinations of frequencies that sound good together. The frequencies are different enough to not make beats but not so different that they cannot make musical melodies that flow.

1. Set up your sound generator and Data Collector.
2. Turn down the volume so you cannot hear the sound but you can still read the frequency from the Data Collector.
3. Each group in the class will be given a different frequency to tune to. Tune your frequency using the Data Collector until you are within 1 Hz of the frequency you were given.
Your teacher will tell you to turn up and down different frequencies so they can be heard together. Don’t change the frequency, just adjust the volume up and down when you are asked.

**a.** Describe the sound of the three frequencies 264 Hz, 330 Hz, and 396 Hz when you hear them together. Which three notes are these? (Look at the diagram below.)

**b.** Describe the sound of the three frequencies 264 Hz, 315 Hz, and 396 Hz when you hear them together.

**c.** Contrast the two sounds. Does one sound more happy or sad compared with the other? Does one sound spookier than the other? Which combination reminds you more of spring, which of fall?

**d.** Describe the effect of adding a frequency of 528 Hz to each group of frequencies.

### C major Scale

<table>
<thead>
<tr>
<th>Note</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (Hz)</td>
<td>264</td>
<td>297</td>
<td>330</td>
<td>352</td>
<td>396</td>
<td>440</td>
<td>495</td>
<td>528</td>
</tr>
<tr>
<td>Ratio to C-264</td>
<td>$1/1$</td>
<td>$9/8$</td>
<td>$5/4$</td>
<td>$4/3$</td>
<td>$3/2$</td>
<td>$5/3$</td>
<td>$15/8$</td>
<td>$2/1$</td>
</tr>
</tbody>
</table>

#### Controlling frequency and wavelength

Most musical instruments use resonance. This means that when instruments are played the sounds they make are based on their natural frequencies. How do musical instruments make so many notes at different frequencies? Why does a guitar player use frets and a flute player use different fingerings?
These players are controlling the frequencies of their instruments by changing the wavelength of the vibrating string or column of air. If the wavelength is shorter, the frequency goes up. If the wavelength is longer, the frequency goes down. The chart on the previous page shows the ratios of frequency to make a musical scale. If the frequency goes up, the wavelength must go down proportionally. That means to double the frequency, the wavelength is reduced by half. To make the frequency 3/2 higher (to get the note E), the wavelength must be 2/3 because 
\[ \frac{2}{3} \times \frac{3}{2} = 1. \]

a. Make a straw kazoo and make some sound with it. Take a pair of scissors and cut off the end of the kazoo. What happens to the frequency of the sound it makes?

b. Take the scissors and cut a small hole exactly in the middle of your kazoo. Cover the hole with your finger. Blow through the kazoo and lift your finger to cover and uncover the hole. What happens to the sound? (Hint: What is vibrating in the straw is a length of air.)

c. Identify at least three musical instruments that use vibrating objects of different lengths.
25A Color

What happens when you mix different colors of light?

All the colors of visible light can be created artificially using a combination of three primary colors: red, blue, and green. In this investigation, you will use a white light source and color filters to discover what happens when you mix different colors of light. You will also learn how the filters work.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
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<tr>
<td>SC.912.N.3.5</td>
<td>Describe the function of models in science, and identify the wide range of models used in science.</td>
</tr>
<tr>
<td>SC.912.P.10.18</td>
<td>Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.</td>
</tr>
</tbody>
</table>

1 Sources of light

a. Compare the light from a light bulb with the light from the same bulb when seen in a mirror. In both cases, describe the path of the light from the source to your eyes.

b. Look at your clothes. Does the light reaching your eye from your clothes originate in your clothes? Or does the light originate somewhere else?

c. Turn off all the lights, and shade the windows so it is completely dark. Can you see your clothes in the dark? What does this experiment tell you about whether your clothes give off their own light or reflect light from somewhere else?

d. Turn on a television or computer screen in a dark room. Can you see the TV or computer screen in the dark? What does this experiment tell you about whether the TV or computer screen give off their own light or reflect light from somewhere else?

2 Making colors

1. Slide all three flashlights into their own light holder.

2. Connect the red and green flashlights by sliding their stands together using the rail and slot connectors on the side.
3. Place the blue flashlight on top of the red and green lights, making a small pyramid stack. Set the blue light on top of the other two with the holder on its side, so that the rail on the stand fits in the small groove created between the holders of the red and green lights. Turn the lights on.

4. Set the light blue lens just in front of the lights so they shine through it. Place the lens so the slotted side is facing up.

5. Set the white box that the Optics with Light & Color kit comes in on the opposite side of the paper from the lights. Fold the top of the box over to shade the area where the three colored lights are shining on the box.

6. Slowly move the lens away from the lights and toward the box until you see the three spots of color (red-green-blue) overlap on the screen.

3 Thinking about what you observed

a. What color do you see when red and green light mix?

b. What color do you see when red and blue light mix?

c. What color do you see when blue and green light mix?

d. What color is produced when all three colors of light equally mix?
**Table 1: Mixing primary colors of light**

<table>
<thead>
<tr>
<th>Color combination</th>
<th>Color you see</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red + Green</td>
<td></td>
</tr>
<tr>
<td>Green + Blue</td>
<td></td>
</tr>
<tr>
<td>Blue + Red</td>
<td></td>
</tr>
<tr>
<td>Red + Green + Blue</td>
<td></td>
</tr>
</tbody>
</table>

**e.** Research and explain the following terms from the diagram below: cone cells, rod cells, retina.

**f.** Research and explain how the eye sees white light in terms of the photoreceptors in the eye.

![Photoreceptors in the eye](image)

**4 How does a color filter work?**

A red laser can produce a single pure color of red which can be useful in some applications. For example, making three-dimensional images, called holograms, requires a very pure source of light which a laser can provide.

In the Optics with Light and Color kit, you have three different sources of colored light; but just how “pure” are these colors? In this part of the investigation you will examine the light produced by each colored light, and learn how a **color filter** works. You will use the diffraction glasses to make your observations.

1. Examine the red light with the diffraction glasses.
2. Using colored pencils, sketch what you see in the appropriate column of table 2.
3. Repeat steps 1 and 2 for the green and blue lights.
4. Remove one of the color filter from one of the color lights. Examine the light produced by the white LED and record your observations in the table.
5 Drawing conclusions

a. Compare the colors in the red light to those in the green light. What are the similarities and differences in the range of colors?

b. Compare the colors in the green light to those in the blue light. What are the similarities and differences in the range of colors?

c. How do the colors in the white light compare to the red, green, and blue lights combined?

d. The red light consists of a white LED covered with a red filter. What does the red filter do?

e. What do color filters do?

f. If you wanted to get yellow light, what part of the spectrum would the color filter have to absorb?

### Table 2: Examining colors

<table>
<thead>
<tr>
<th></th>
<th>Red light</th>
<th>Green light</th>
<th>Blue light</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White light</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
25B Reflection and Refraction

How does light behave when its path is changed?

Looking in a mirror we see a twin of ourselves reversed left-to-right. A fish underwater appears in a different place from where the fish really is. Both of these illusions are caused by the bending of light rays. This investigation explores reflection and refraction, two processes that bend light rays. You will also use refraction to calculate the focal point of a lens.

**Observing the law of reflection**

2. Set a sheet of graph paper on your lab table.
3. Slide the laser into a holder, turn the laser on and put it on the graph paper.
4. Align the laser so the beam follows one horizontal line across the paper.
5. To line up the beam with the horizontal line on the graph paper, place an index card on its side onto the paper. Keep its long side flat on the graph paper and slowly slide the card over until you can just start to see the beam on the very edge of the card. Follow the vertical edge of the index card down and make a mark on the paper. The mark tells you where the beam is, and you can use this method to trace the path of the beam in all the Optics with Light & Color activities.
6. Follow the beam as it moves across the graph paper and make sure it lines up with one of the horizontal lines on the paper.
7. Set the mirror on the graph paper so the light beam from the laser hits its shiny front at an angle. The mirror should be placed so its long side is down on the paper.
8. Draw a line on the graph paper marking the front face of the mirror.
9. Use a pencil and the index card to trace the light rays going toward and away from the mirror. Label it ray #1.

10. Draw small arrows every couple of inches indicating the direction the beam is traveling.

2 Thinking about what you observed

a. A diagram showing how light rays travel is called a **ray diagram**. Lines and arrows on a ray diagram represent rays of light.

b. Look at your ray diagram showing the surface of the mirror and the light rays before and after the mirror.

c. Which is the incident ray? Label it on your ray diagram.

d. Which is the reflected ray? Label it on your ray diagram.

3 The law of reflection

a. Move the laser and the mirror to a new location on the graph paper. Make sure the beam hits the mirror at a slightly different angle and repeat steps 7-10. Be sure to label each ray. Continue shining and tracing the beam from a total of 4 different locations. Label the rays 1–4.

b. For each ray diagram, draw a line perpendicular to the mirror surface at the point where the rays hit. This line is called the **normal line**.

c. Use a protractor to measure the angle between the normal and the incident and reflected rays. Record your measurements in Table 1.

d. Write down your own statement of the law of reflection, describing the relationship between the angles you measured.

e. A laser shines at a mirror at an angle of incidence of 75 degrees. Predict its angle of reflection. After predicting, test your prediction. Were you right?
Table 1: Angles of incidence and reflection

<table>
<thead>
<tr>
<th>Angle of incidence</th>
<th>Diagram #1</th>
<th>Diagram #2</th>
<th>Diagram #3</th>
<th>Diagram #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of reflection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 Light rays going through a prism

A prism is a solid piece of glass with polished surfaces. Prisms are useful for investigating how light bends when it crosses from one material into another, such as from air into glass or glass into air.

1. Flip your graph paper over and set the laser on the left side of the paper. Turn the laser on. Face the laser so it is shining horizontally across the paper.
2. Place the prism in the middle of the paper into the laser beam so the beam comes out the opposite short side.
3. Rotate the prism in the beam and observe where the beam comes out.
4. Keep rotating the prism until you can see the beam refracted and reflected at the same time.

5 Sketching what you observed

a. Draw at least one ray diagram showing a laser beam that is refracted after passing through the prism. The refracted ray is the ray that comes out of the prism at a different angle than it entered.

b. Draw a ray diagram showing a laser beam that is reflected.

c. Draw a ray diagram showing a laser beam that is both refracted and reflected.
6 Seeing reflection and refraction at the same time

Both refraction and reflection often occur when light hits a boundary between materials such as the boundary between glass and air. The amount of light reflected or refracted depends on the angle at which you are looking relative to the surface.

1. Take a piece of graph paper about the size of a business card and draw a line about 5 centimeters from one edge, dividing the rectangle in half. Draw the letter A on one side of the line and the letter B on the other side.
2. Fold the paper on the line and wrap it around one of the corners of the prism that is not a right angle.
3. Move your head up and down to change the angle at which you look into the prism.

7 Thinking about what you observed

a. Draw a diagram showing the path of the light when you see the letter A.

b. Draw a diagram showing the path of the light when you see the letter B.

c. Is the image in the prism always reflected or refracted or can there be both reflection and refraction at the same time?

8 Refracting light through a lens

1. Divide a new sheet of graph paper in half horizontally. For the first part of this activity use the top half of the new sheet of graph paper. Place the laser on the edge of the paper and shine the laser so it follows a horizontal grid line across the paper.
2. Place the light blue lens 10 cm to the right of the laser with the slot facing up. Line the lens up vertically using the grid lines on the graph paper. It is important that the beam is perpendicular to the lens. Make sure the beam of the laser is lined up with the middle of the lens. There are lines on the side of each lens indicating the middle of the lens.

3. Trace around the base of the lens so it can be removed and put back in place in case you need to move it to complete ray tracing.

4. Shine the laser through the lens so the beam passes off-center, almost at the very outer edge of the lens. Set the block with the mirror about 30 cm on the right side of the lens so the beam hits it after passing through the lens. Use the side of the block with the graph paper on it so you can clearly see where the beam hits the block.

5. Trace the laser beam before and after it passes through the lens. Be sure to always carefully mark the points that the beam exits the laser, enters the lens, exits the lens, and then hits the block. Connect all these points to see the path of the beam.

6. Realign the laser with a different horizontal grid line parallel to the original beam and closer to the center of the lens. Again, trace the path of the beam before and after it passes through the lens.

7. Realign the beam so it passes directly through the center and trace the beam again.

8. Trace two more beams passing through the lens on the other side of the center of the lens for a total of five beams. Label the beams 1-5 on both sides of the lens.

9. Repeat steps 1-8 with the dark blue lens using the bottom half of your graph paper.

**Thinking about what you observed**

a. Feel the glass surface with your fingers and note the shape of the lenses. How are they different?

b. Draw a quick sketch of the shape of each lens itself with no stand from a side view. Label each lens.

c. Describe the paths of the rays before and after they traveled through the light blue lens. Include the words refract, converge and diverge in your description.

d. What is the focal point of a lens? Mark the focal point on the first ray diagram.

e. What is the focal length of the lens? Measure the focal length of the light blue lens.

f. Describe the paths of the rays before and after they traveled through the dark blue lens. Include the words refract, converge and diverge in your description.

g. How are the two lenses different?

h. One lens is referred to as a diverging lens, and the other a converging lens. They are also sometimes referred to as convex or concave. Research these terms and explain which is which.
Making an image with a lens

Certain types of lenses can make an image of a distant light source. The image forms about one focal length away from a lens when the object is far away.

1. Find a wall at least 5 meters away from a lamp or sunlit window. Tape a piece of white paper to the wall to create a screen for seeing the image.
2. Get the light blue lens. Hold the lens at different distances parallel to your screen and window or light source. Try distances between 15 and 25 centimeters.
3. Move the lens until you see a sharp image of the lamp or window on the screen. An image is produced when your lens is about one focal length away from the screen.
4. Measure the distance from the lens to the wall and record in Table 2. Use this technique to determine the focal lengths for both lenses.

Images can be smaller or larger than the object that created them. Images can also be right side up or inverted.

a. Was the image created by the light blue lens smaller or larger than the object?

b. Was the image right side up or was it inverted?

Projecting an image with a lens

You can think about a lens as collecting a cone of light from each point on an object. For a perfect lens all the light in the cone is bent so it comes together at a point again to make the image. This is how movie projectors take an image on film and project it onto a screen.

1. Place one of the lights near the edge of the graph paper. Put the “F” filter on the light. Shine it horizontally.
2. Take the light blue lens and set it on the graph paper 35 cm away from the light.
3. Shine the light at a distant light colored wall at least 5 meters away. If one is not available, affix a piece of paper to the wall as your projection screen. Slowly move the lens toward the light until you see a sharp image of the “F” on the wall or screen. Have one group member check the projected image closely while the lens is slowly moved to find the exact place the lens needs to be to make it come into focus.

At what distance from the light does the lens produce a sharply focused image?

4. Take a paper card and use it to block some of the light from the lens. The card should be 2–3 cm from the lens and on the same side as the light.

Observe the image on the wall or screen as you slowly cover and uncover the lens.

12 Thinking about what you observed

a. Describe the characteristics of the image formed by the lens. Characteristics include whether the image is right-side-up, inverted, larger, or smaller.

b. Discuss with your class why blocking part of the lens makes the image dimmer, even though you still see the entire image.

c. CHALLENGE; The thin lens formula is used to calculate the exact focal length of a lens. Calculate the focal length of your light blue lens using the thin lens formula. The distance of the object from the lens is 35 cm. You will need to measure the distance from the lens to your projection screen or wall where the image became sharply in focus. How does it compare with the other 2 focal lengths of the light blue lens you observed? Was the method from section 8 or 10 more accurate compared to the focal length you just calculated using the thin lens formula?
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<td>194</td>
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<td>18C</td>
<td>Nuclear Reactions</td>
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<td>19C</td>
<td>Solubility of CO2</td>
<td>203</td>
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<td>20C</td>
<td>Electric Charge</td>
<td>205</td>
</tr>
<tr>
<td>21C</td>
<td>Analyzing Circuits</td>
<td>207</td>
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<td>Electromagnetic Forces</td>
<td>210</td>
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<tr>
<td>23C</td>
<td>Waves in Motion</td>
<td>213</td>
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<td>Perceiving Sound</td>
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- Reaction Rate ................................................................................................................ 271
- Catalysts ......................................................................................................................... 275
- Doppler Effect ................................................................................................................ 279
1C Significant Digits

How do we make precise measurements?

We commonly make distance measurements in everyday life, whether to find the height of a person, the length of a rug, or the width of a doorway. In this investigation you will learn how to make precise measurements and to record your measurements using the correct number of significant digits.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
<td>Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.</td>
</tr>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1(6)</td>
<td>Define a problem and use tools to gather, analyze, and interpret data.</td>
</tr>
</tbody>
</table>

1 Significant digits and measuring length

Precise measurements are often required in science and engineering. A measurement that is a millimeter off could cause serious problems if you were designing parts for a computer, car engine, or space shuttle. Being careful when making measurements is important if you wish to be precise, but having the right tool for the job is also a key factor. Suppose you wanted to measure the mass of a quarter. Would you use a scale designed for people or a small digital scale?

When recording a measurement, you are only allowed to record the meaningful, or significant digits.

**Significant digits are those that you are certain of plus one additional estimated digit.**

Consider the length measurement shown to the right. The pencil looks to be a bit more than 7.5 centimeters long. Should it be recorded as 7 cm? 7.5 cm? 7.9 cm? 7.90 cm?

When the tip of the pencil is lined up with the ruler, you can definitely tell that the pencil is between 7.9 cm and 8.0 cm. You can therefore be sure of the 7 and 9 in your measurement, so these are both significant digits.

You can make the measurement more precise by estimating the last digit. The pencil tip may look like it’s on the 7.9 cm mark or right on the 8.0 cm mark, so the length falls between 7.90 and 8.00 cm. You might estimate the length to be 7.95 cm. It’s impossible to tell this last digit exactly, and someone else might record the length as 7.90 cm. However, you could not record the length as 7.950 cm because both the five and the zero would be estimated.

2 Making measurements

Use either a meterstick or small ruler to make the following measurements in centimeters using the correct number of significant digits.

a. The length of a sharpened pencil

b. The diameter of a pencil eraser

c. The length of a paper clip

d. The height of your desk or table

e. The length of your classroom
3 Analyzing the data

a. For which measurements did you use the meterstick? Why?
b. Which measurement was the most precise?
c. Which measurement was the least precise?
d. Describe two ways you could have made more precise measurements. You may include the use of tools you used other than the ruler and meterstick.
e. The distances you measured were relatively small. How could you measure a larger distance such as the length of a football field or the distance from your school to your house?

4 Another way to measure

Sometimes it is possible to use the tools we have to make measurements in a creative way to increase precision. You will need two different thick books such as textbooks or novels.

a. Suppose you wanted to measure the thickness of a single sheet of paper in each of the books. Can you do this with a ruler? Try it, and record your measurements using the correct number of significant digits.
b. According to your measurements, are the thicknesses significantly different from each other?
c. Discuss a better way to measure the thickness of a sheet of paper with your group members. Describe the steps you follow to make your measurements. Record your data and show any calculations you make. Use the correct number of significant digits to express your answers.
d. How many significant digits do your thickness measurements have now? How does this compare to the number of significant digits in your measurements from question a?
e. According to your measurements using your more precise method, are the thicknesses significantly different?
f. Describe another measurement you could make using a similar method to the one you used in step c.
# 2C Thickness of Aluminum Foil

**What is the thickness of aluminum foil?**

In this investigation you will be challenged to determine the thickness of aluminum foil. It is obviously much too thin to measure its thickness with a ruler, so how will you achieve your goal? You will use your knowledge of density, volume and area to arrive at a value and compare it to the findings of your classmates.

## 1 Doing the experiment

1. Obtain an aluminum cylinder from your teacher and record its mass in Table 1.
2. Measure 20 mL of water in the graduated cylinder and record the volume in Table 1.
3. Carefully place the aluminum cylinder in the graduated cylinder and record the combined volume in Table 1.
4. Cut out a 20 cm × 20 cm piece of aluminum foil and record its mass in Table 1.

## 2 Stop and think

Is the density of the aluminum cylinder and the aluminum foil the same?

## 3 Analyzing your data

a. What is the volume of the aluminum cylinder as calculated by water displacement?

b. What is the density of the aluminum cylinder?

c. Using the density of the aluminum cylinder calculated above, and the mass of the aluminum foil, what is the volume of the foil in mL?

d. What is the volume of foil in cm³ (1 mL = 1 cm³)?

e. What is the area of the aluminum foil (cm²)?

f. Calculate the thickness of the aluminum foil by dividing the volume by the area.

### Table 1: Aluminum data

<table>
<thead>
<tr>
<th>Mass of aluminum cylinder (g)</th>
<th>Volume of water (mL)</th>
<th>Volume of water and aluminum (mL)</th>
<th>Mass of aluminum foil (g)</th>
<th>Dimensions of aluminum foil (cm x cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

## Code

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
<td>Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.</td>
</tr>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences are drawn from scientific observations and provide examples.</td>
</tr>
<tr>
<td>SC.912.P.8.2</td>
<td>Differentiate between physical and chemical properties and physical and chemical changes in matter.</td>
</tr>
</tbody>
</table>
4 Thinking about what you observed

a. How does your answer compare with those of other students in the class?

b. Research aluminum foil. Is it pure aluminum? Be sure to cite your sources.

c. Do you think it is reasonable to use the density for the aluminum cylinder for your aluminum foil calculation?

d. A very thin layer of gold plating was placed on a metal tray that measured 25.22 cm by 13.22 cm. The gold plating increased the mass of the tray by 0.0512 g. Find the thickness of the plating. The density of gold is 19.3 g/cm³.
Looking for Significant Differences

Do you really need photogates to study the motion of the Energy Car, or is a stopwatch good enough?

People often ask if electronic timing is really necessary when conducting classroom motion experiments. Isn’t a stopwatch good enough? To explore this question, you will compare travel times for the Energy Car with and without a homemade “sail”. You will collect time data with photogates and with a simple stopwatch. Keep in mind that significant differences are differences that are much larger than the estimated uncertainty (or error) in the results. That means two results are “the same” UNLESS their difference is much greater than the estimated error.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
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</thead>
<tbody>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.N.1.3</td>
<td>Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.</td>
</tr>
<tr>
<td>SC.912.P.12.2</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
</tbody>
</table>

1 Predicting

You will compare travel times for the Energy Car as it rolls down a gentle slope with and without a “sail”. You will collect travel times using photogates and a stopwatch.

a. Write your hypothesis for how the sail will affect the travel time of the car.

b. Write your hypothesis for how the photogate times will compare to the stopwatch times for the same types of trials.

2 Setting up the experiment

1. Assemble a straight track and attach it to the first hole from the bottom of the stand.
2. Place one stop at the top of the track and one at the bottom; place a lump of clay on the plunger at the end of the track (so the car won’t bounce back through the photogate).
3. Attach the photogates as shown. Put photogate A at the top of the ramp.
4. Put 1 steel marble in the center of the Energy Car.
5. Place the Energy Car at the top of the track so it rests against the stop’s plunger. Adjust the plunger so the light beam is just about to be broken by the tab sticking straight up on the car; as you change the plunger position, the tab on the car will move in and out of the beam. Watch the photogate’s green/red light indicator. The light should be green, but about to become red as soon as you release the car.

3 Doing the experiment
1. Run the car down the track five times and record the time from A to B ($t_{AB}$) for each trial in Table 1.
2. Use stopwatch mode in the Data Collector’s timer function to time the car from when it is released until the tab passes through the second photogate. It is a good idea for the person operating the stopwatch to call out “1, 2, 3, GO!” and start the stopwatch as he or she says “go”. The car operator should release the car on “go”. Then, the stopwatch operator should look straight on at photogate B and stop the stopwatch when the car’s tab passes through the second photogate. Record times for five different trials in Table 1.
3. Tape a tongue depressor to the flag on the side of the car. Tape a paper plate to the tongue depressor. Use enough tape to make sure it is securely attached. You may need to slightly adjust photogate A so it isn’t blocked by the tongue depressor which is just a little wider than the car’s tab.
4. Repeat steps 1 and 2 and record the times in Table 1.
5. Find the average times and record in Table 1.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Without Sail</th>
<th>With Sail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>photogate time A to B (s)</td>
<td>stopwatch time A to B (s)</td>
</tr>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>5</td>
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<tr>
<td>average</td>
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</tbody>
</table>

4 Thinking about the results
a. Can you tell from the average times whether the sail had a significant effect on the car’s motion? Why or why not?

b. How do your average times compare to your hypotheses from part 1?
Analyzing the data

1. To find the estimated error in your measurements find the difference between the average photogate time for the car without the sail and each of the individual trial times. Record absolute values (drop negative signs) in Table 2.

2. Calculate the average estimated error.

3. Repeat steps 1 and 2 for the stopwatch times for the car without the sail, and the times from the photogates and stopwatch for the car with the sail.

Table 2: Analyzing Time Data

<table>
<thead>
<tr>
<th>Trial</th>
<th>Without Sail</th>
<th>With Sail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated Error</td>
<td>Estimated Error</td>
</tr>
<tr>
<td></td>
<td>photogate</td>
<td>stopwatch</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
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<tr>
<td>5</td>
<td></td>
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<tr>
<td>average estimated error</td>
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</tbody>
</table>

Now you can compare estimated error with average times to see if the sail had a significant effect.

a. Find the difference between the average photogate times for the car with and without the sail. Compare this difference to the average estimated error for the photogate times with and without the sail. If the time difference is at least 3 times greater than the estimated error, you can conclude that the sail did change the motion of the car significantly. Did the sail change the motion of your car significantly, according to photogate times?

b. Find the difference between the average stopwatch times for the car with and without the sail. Compare this difference to the average estimated error for the stopwatch times with and without the sail. Is the time difference at least 3 times greater than the estimated error? Did the sail change the motion of your car significantly, according to stopwatch times?

Drawing conclusions

a. Re-read the key question for this lab. Answer the key question and refer to evidence you collected in this lab to justify your answer.

b. Describe at least one way you could improve this experiment so you can be even more sure that the change in the car’s motion is due to air friction from the sail, and not some other effect.
4C Studying Two-part Motion

What happens to the Energy Car as it travels down a hill and across a flat section of track?

In the previous chapter 3 investigations, you explored the motion of the car on a flat track and again on a hill. This time, you will put the track together so it has both a hill and a flat section. What will the speed vs. time graph look like? You will soon find out!

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.12.02</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration (with respect to a frame of reference) as functions of time.</td>
</tr>
</tbody>
</table>

1 Predicting

You will set up the track so it has the steeper hill and flat section joined. What will the speed vs. time graph look like?

a. Draw a sketch of what you think the speed vs. time graph will look like. Put time on the x-axis and speed on the y-axis.

2 Setting up the experiment

1. Join the steeper hill with the flat track and attach it to the 4th hole from the bottom.
2. Place a stop at the top of the track with the plunger all the way back so the end is flush with the stop.
3. Place the other stop at the bottom of the track; put a lump of clay on the plunger so the car won’t bounce back through photogate B when it is near the end.
4. Attach photogate A as shown in the photo, and leave it there.
5. Photogate B will be placed every five centimeters, as shown in the photo.
6. Make sure the flat part of the track is level. Use the leveling feet on the physics stand base and on the bottom stop.
7. Place the Energy Car at the top of the track so it rests against the stop’s plunger. Put 1 marble in the center of the car. Photogate B should be 5 cm from photogate A.
3 Doing the experiment

1. Release the car and record the time through A, the time through B, the time from A to B, and the distance traveled in Table 1.
2. Move the photogate to the next 5-cm mark and repeat step 1. Do this all along the track until you reach the last mark possible. You will not be able to take time measurements at 35, 40, or 45 cm away from photogate A.

<table>
<thead>
<tr>
<th>Distance A to B (cm)</th>
<th>Time A (s)</th>
<th>Time B (s)</th>
<th>Time AB (s)</th>
<th>Speed A (cm/s)</th>
<th>Speed B (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
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<td>10</td>
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<td>75</td>
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</tbody>
</table>

4 Finding the speeds

a. Find the speed at A and speed at B for each trial and record in Table 1. Remember: to find the speed of the car, use the width of the flag (1.00 cm) for the distance, and the time through the photogate for the time. \( s = \frac{d}{t} \)

b. Look at the A speeds. What does this data tell you in general about the experiment?

c. Look at the B speeds. What does this data tell you in general about the motion of the car as it moved down and across the track?

5 Graphing the data

a. Create a speed vs. time graph for the data. Put time AB (s) on the x-axis and speed at B (cm/s) on the y-axis. Draw a best fit line.

b. How does the graph compare to your prediction? Explain.

6 Thinking about what you observed

a. Where is the car accelerating? Justify your answer with evidence from the experiment.

b. Where is the car moving at a constant speed? Justify your answer with evidence.
Gravity and Falling Objects

How does gravity affect the motion of falling objects?

Gravity causes objects to accelerate as they fall. An object is in free fall if it is moving under the influence of only gravity. For example, when you drop a ball, it is in free fall from the time it leaves your hand until it hits the ground. In this investigation, you will compare the motion of objects with different masses that are in free fall.

### Benchmark

<table>
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</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>SC.912.P.12.2</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
<tr>
<td>SC.912.P.12.4</td>
<td>Describe how the gravitational force between two objects depends on their masses and the distance between them.</td>
</tr>
</tbody>
</table>

### Setting up the experiment

1. This investigation should be done with the physics stand on the floor and with the pole as perfectly vertical as you can make it. Tape the steel marble to a piece of string to make a plumb bob. Hold the string at the top of the physics stand and adjust the leveling feet until the string hangs down the center of the pole.

2. Attach photogate A near the top of the stand. The bottom of the “U” of the photogate should be against the pole.

3. Attach photogate B so it is 50 cm (10 holes) below photogate A.

4. Plug both photogates into the Data Collector, then remove the tape and string from the steel marble.

### Collecting data

1. Examine the photogates and find the two small rectangular openings where the infrared light beam is emitted and detected. Hold the steel marble so it is above the top photogate, centered just above the openings.

2. Carefully drop the marble without giving it a push. Allow it to fall to the bottom of the stand where one group member should catch it. The marble should fall straight through the center of the two photogates. This may take some practice.

3. Record the time through photogate A ($t_A$), the time through photogate B ($t_B$), and the time from A to B ($t_{AB}$) in Table 1.

4. Repeat for a total of three trials with the steel marble.

5. Repeat with the plastic marble.
Gravity and Falling Objects

3 Calculating acceleration

1. Calculate the speed of the marble through each photogate. The distance a marble moves when passing through the photogate is its diameter, 0.019 meter.

2. Use the two speeds and the time A to B to calculate the acceleration for each trial.

Table 2: Speed and acceleration data

<table>
<thead>
<tr>
<th>Marble</th>
<th>speed through A (m/s)</th>
<th>speed through B (m/s)</th>
<th>acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>steel</td>
<td></td>
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<tr>
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<td>steel</td>
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<td>plastic</td>
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<tr>
<td>plastic</td>
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</tbody>
</table>

4 Analyzing the data

a. Calculate the average acceleration for your three trials for the steel marble. Use the average from each group in your class to find the class average for the steel marble’s acceleration.

b. Calculate your average and the class average for the plastic marble’s acceleration.

c. How do the accelerations compare? Are they about the same, or are they very different?

d. Which marble has the greater weight, and is therefore pulled on by a stronger force of gravity?

e. Suppose you wanted to move the steel and plastic marbles across the floor with the same acceleration. Which would require more force to accelerate?

f. Use your answers from questions d and e to explain why the accelerations of the two marbles in free fall compared as they did.

g. Why was it important to drop the marbles straight through the center of the photogate beam?
6C Collisions

Why do things bounce back when they collide?
Newton’s third law tells us that when two objects collide, they exert equal and opposite forces on each other. However, the effect of the force is not always the same. What happens when you collide two Energy Cars that have unequal masses?

### Code | Benchmark
--- | ---
SC.912.N.1.1 | Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.
SC.912.N.1.3 | Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.
SC.912.N.1.6 | Describe how scientific inferences are drawn from scientific observations and provide examples from the content being studied.
SC.912.P.12.03 | Interpret and apply Newton’s three laws of motion.

1. **Making a collision**

   ![Launching the car](image)

   Rest your palm on the wood and pull the car against the screw with your finger on the tab nearest the far end of the car.

2. Set up the long straight track with a rubber band on one end and a clay ball on the other end. Use the bubble level to set the track level.
3. Place one steel marble in each car.
4. Wrap the thick rubber band around the moving car. Place both cars on the track so their noses are pointed toward the rubber band launcher.
5. Place the target car near the center of the track. Use the screw to launch the car using the same deflection of the rubber band each time. This means the same force is applied to each launch. You will use this car to create the collision.
6. To make a collision, release the moving car from the rubber band launcher. It will speed down the track, and hit the target car. This is an efficient way to produce collisions on the track.
a. Does the **moving** car bounce back after the collision?

b. Does the **moving** car keep going forward after the collision?

c. Does the **moving** car stop at the collision?

d. How does the target car behave?

### 2 Thinking about what you observed

a. Describe in words the motion of the two cars before and after the collision.

b. The target car must exert a force on the moving car to stop it. How strong is this force relative to the force the moving car exerts on the target car to get it moving? How could you use the photogates to provide evidence for your answer?

### 3 Gathering evidence

1. Try the experiment again, but now use two photogates to collect time data.
2. Place two photogates on the square marks near the middle of the track.
3. Put the target car on the track so it is near photogate beam B.
4. Release the moving car from the rubber band launcher as before and make a collision.
5. Repeat several times and record trial times in Table 1.

#### Table 1: Collision Times

<table>
<thead>
<tr>
<th>Collision Trial</th>
<th>Time for moving car to pass through A before collision (s)</th>
<th>Time for target car to pass through B after collision (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
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</tbody>
</table>
a. Newton’s third law tells us that when the moving car exerts a force on the target car, the target car exerts an equal and opposite force on the moving car. Does your data provide evidence for this? Explain.

b. You can compare times through A and B for each individual trial. How can using these times show there are equal and opposite forces at work?

### 4 Changing the masses

<table>
<thead>
<tr>
<th>Target car</th>
<th>Four combinations</th>
<th>Target car</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 marbles</td>
<td></td>
<td>0 marbles</td>
</tr>
<tr>
<td>2 marbles</td>
<td></td>
<td>2 marbles</td>
</tr>
</tbody>
</table>

2. Try the experiment with the four combinations of mass shown above. You do not need to use photogates for this part of the investigation. If you want to use photogates, you will have to use the memory button for several of the collisions. This is explained in the teacher’s guide, and your teacher can provide guidance.

### 5 Applying what you have learned

a. Describe the motion of the two cars when the target car has more mass than the moving car.

b. Describe the motion of the two cars when the target car has less mass than the moving car.

c. Explain how your observations support the idea that there are action and reaction forces.

d. If the action and reaction forces are equal in strength, why does one car move at a different speed after the collision than the other car when the masses are unequal? Hint: the answer involves the Newton’s second law.
7C Energy and Efficiency

How well is energy changed from one form to another?

All processes that involve energy exchanges lose small amounts of energy to friction and heat. Efficiency is a measure of how well energy is transformed from one kind to another or transferred from one object to another. A process that is 100% efficient is one in which no energy is “lost” or converted to forms such as heat or sound.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.10.1</td>
<td>Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.</td>
</tr>
<tr>
<td>SC.912.P.10.2</td>
<td>Explore the Law of Conservation of Energy by differentiating among open, closed, and isolated systems and explain that the total energy in an isolated system is a conserved quantity.</td>
</tr>
</tbody>
</table>

1 Setting up the experiment

1. Set up the long straight track so it is level with rubber bands on both ends. The rubber bands should be twisted so they make an X in the middle.

2. Measure the mass of the empty car in kilograms and record it in the first row of Table 1.

3. Place the car so it is at one end of the track, just touching the rubber band. Position a photogate so the car’s flag will break the light beam right after the car moves away from the rubber band.

4. Place the car at the opposite end of the track from the photogate. Use the rubber band to launch the car toward the photogate. Measure the time the car takes to pass through the photogate before and after the car bounces off the rubber band. You will need to use the memory button to display the “before” time. Catch the car after the bounce.

5. Perform a couple of practice launches until you get consistent times. Record the before and after times and calculate the average speeds before and after hitting the rubber bands.

6. Change the mass of the car by adding a marble and repeat the procedure for a total of four trials.

<table>
<thead>
<tr>
<th>Table 1: Bounce data for different masses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of the car (including any marbles) (kg)</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>
2 Thinking about what you observed

a. Describe the energy flows that occur from when the car is launched until after it bounces off the rubber band.

b. If the transformation of energy were perfect (100% efficiency) what would you expect the speed of the car to be before and after the bounce with the rubber band?

c. Calculate the kinetic energy of the car before and after bouncing off the rubber band for each trial. Record your answers in Table 2.

d. Calculate the efficiency of the process of bouncing the car off a rubber band for each trial. Record your answers in Table 2.

e. Did the efficiency change when mass was added to the car?

3 Changing a different variable

In the first part of the experiment, you investigated the effect of changing the car’s mass on the efficiency. However, changing the mass also had the effect of changing the car’s launch speed. In this part of the experiment, you will keep the mass constant and only change the car’s speed.

1. Adjust the thumb screw so the rubber band only stretches back a small amount before touching the metal stopper. This will cause the car to launch at a slow speed. Launch the empty car and record its time before and after the bounce with the rubber band at the other end of the track.

2. Twist the thumb screw so the rubber band will stretch back a slightly greater distance. You will be doing four more launches, so adjust the screw so the stopper moves approximately 1/4 of the way back toward the wooden bumper. Launch the car and measure the times. Record your readings in Table 3.

3. Continue until you have a total of five launches at different speeds. Use the recorded time data to calculate the speeds of the car and record your calculations in Table 3.
4 Thinking about what you observed

a. Calculate the kinetic energy and efficiency of the rubber band for the different speeds you tested. Record the values in Table 4.

Table 4: Energy and efficiency data

<table>
<thead>
<tr>
<th>Speed before bounce (m/s)</th>
<th>Speed after bounce (m/s)</th>
<th>Kinetic energy before bounce (J)</th>
<th>Kinetic energy after bounce (J)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

b. Plot a graph showing the efficiency on the vertical (y) axis and the speed before the bounce on the horizontal (x) axis. Does the speed of the car affect the efficiency?
8C People Power

What’s your work and power as you climb a flight of stairs?

When you walk up a flight of stairs, you do work to lift your body against the force of gravity. If you know your weight and the vertical distance you climb, you can calculate the work you do. Measuring the time it takes to climb the stairs allows you to also calculate your power.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.P.10.03</td>
<td>Compare and contrast work and power qualitatively and quantitatively.</td>
</tr>
</tbody>
</table>

### Collecting the data

1. You will be doing this activity as a class. Choose several students as volunteers who will be climbing a flight of stairs as other students measure the time.

2. Use a bathroom scale to measure the weight of each volunteer. Convert each weight to newtons using the conversion factor: 1 pound = 4.448 newtons. Record each person’s weight and name in Table 1.

### Table 1: Stair climbing data

<table>
<thead>
<tr>
<th>Name</th>
<th>Weight (N)</th>
<th>Stair height (m)</th>
<th>Time 1 (s)</th>
<th>Time 2 (s)</th>
<th>Time 3 (s)</th>
<th>Average time (s)</th>
</tr>
</thead>
<tbody>
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</table>

3. Choose three students who will be timekeepers and two students who will be stair height measurers. These should not be the same students who are climbing the stairs.

4. Locate an empty stairwell with one or two flights of stairs. The stair height measurers should measure the total vertical distance a person climbs when going from the top to the bottom. The easiest way to do this is to measure the height of one stair, count the number of stairs, and multiply.

5. Have each person listed in Table 1 climb the stairs once as the three timekeepers measure the time. Record all of the times in Table 1. Calculate the average time for each person.
2 Calculating work and power

1. Calculate the work done by each person. The force for each person is his or her weight. Record the work in Table 2.
2. Use each person’s average time to calculate the power. Record each power in Table 2.

<table>
<thead>
<tr>
<th>Name</th>
<th>Work (J)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

3 Analyzing the data

a. Who did the most work? What do you notice about this person’s weight?
b. Who did the least work? What do you notice about this person’s weight?
c. Who had the greatest power? Must this be the person with the fastest time?
d. Who had the least power? Must this be the person with the slowest time?
e. Calculate the average work for the students.
f. The Calorie is also a unit of work. One Calorie equals 4186 joules. Calculate the average number of calories of work done by the students. You may be surprised at how small the answer is!
g. Calculate the average power of the students.
h. A typical bright light bulb has a power of 100 watts. How does this compare to the average power of the students?
i. Imagine that two people of equal weights climb the same flight of stairs. One runs, and the other walks. Do they burn the same number of calories? Do they have the same power? Explain.
j. Juan’s weight is twice the weight of his little sister Anna. They climb the same set of stairs and find that they have the same power. Explain how this can be possible.
9C Mechanical Advantage

What is mechanical advantage, and how do ropes and pulleys give you mechanical advantage?

Ropes and pulleys create large output forces from small input forces - but how large can the output forces be? What is the trade-off? In this investigation you will explore the mechanical advantage of different rope and pulley setups. You will soon discover a quick and easy way to determine the mechanical advantage of any rope and pulley system.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.1.2</td>
<td>Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.10.2</td>
<td>Explore the Law of Conservation of Energy by differentiating among open, closed, and isolated systems and explain that the total energy in an isolated system is a conserved quantity.</td>
</tr>
<tr>
<td>SC.912.P.10.3</td>
<td>Compare and contrast work and power qualitatively and quantitatively.</td>
</tr>
<tr>
<td>SC.912.P.12.3</td>
<td>Interpret and apply Newton’s three laws of motion.</td>
</tr>
</tbody>
</table>

1 Setting up the experiment

1. Attach four weights to the bottom block. Use a spring scale to measure the weight (N) of the bottom block and record it in Table 1 as the output force.

2. Attach the top block near the top of the physics stand.

3. Thread the yellow string over one or more of the pulleys of the top and bottom pulley blocks. The yellow string can be clipped to either the top block or the bottom block.

4. Build combinations with 1, 2, 3, 4, 5, and 6 strands directly supporting the bottom block, so you always pull down on the string to raise the block. (Hint: 1, 3, and 5 have the string clipped to the bottom block. 2, 4, and 6 have the string clipped to the top block)

5. Attach the spring scale to the cord stop as shown in the photo. This way of sliding the spring scale hook over the cord stop on the string will give the best force measurement. If you insert the hook into the hole of the cord stop, you will have some friction interfering with the measurement.

6. Use a force scale to measure the force needed to slowly lift the bottom block for different combinations of supporting strings.

Safety Tip: Don’t pull sideways, or you can tip the stand over!
2 Mechanical Advantage

a. Mechanical Advantage refers to the number of times effort force is multiplied in a simple machine like ropes and pulleys. The ratio of output force to input force equals the mechanical advantage, so divide output force by input force for each trial and record in Table 2. *Mechanical advantage has no unit; it is a ratio.*

b. What is the relationship between number of supporting strands and mechanical advantage?

c. The mechanical advantage for your first trial is 1. Since any number multiplied by 1 equals the same number, your effort force is not multiplied. What, then, could the advantage be for using one supporting strand? HINT: this arrangement is often used to raise a flag on a flagpole.

d. A windjammer is a large sailing ship that was popular in the 1700s and 1800s. Now, tourists enjoy sailing on reproductions like the one in the photo. Rope and pulley systems (called block and tackle) are used to lift the sails, which can require a lot of force in a strong wind! What is the mechanical advantage of a windjammer’s rope and pulley system for one of its sails if there are 5 supporting lines?

### Table 1: Rope and Pulley Force Data

<table>
<thead>
<tr>
<th>Number of supporting strings</th>
<th>Input force (N)</th>
<th>Output force (N)</th>
<th>Output force ÷ Input force</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 Input and output distances

Rope and pulley systems with a mechanical advantage greater than 1 will reduce the amount of force you have to put into the machine to make it work. However, this multiplied effort force comes at a “cost”. What is the trade-off?

1. Use the marker stop (cord stop) to mark where the string leaves the top pulley.
2. Choose a distance that you will lift the bottom pulley during each trial of the experiment. This is the output distance. Your output distance should be at least 20 centimeters.
3. Pull the yellow string to lift the block your chosen distance.
4. Measure how much string length you had to pull to lift the block. This is the input distance.
5. Measure the input and output distances for each of the different configurations (1, 2, 3, 4, 5, and 6). The table only shows two of the data rows.

### Table 2: Rope and Pulley Distance Data

<table>
<thead>
<tr>
<th>Mechanical advantage</th>
<th>Input distance (cm)</th>
<th>Output distance (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Study the data in Table 2. What is the “cost” for having mechanical advantages greater than 1?

b. You can calculate mechanical advantage using the input and output distances instead of forces. Study the data in Table 2 and figure out a new way to calculate the mechanical advantage of a rope and pulley system.

c. Windjammers usually have 2 or more masts with sails. Suppose one sail weighs 3000 N, and it is rigged with a rope and pulley system that has 5 supporting lines. The sail must be raised 35 meters. How much line will be needed to make this system work?
Freezing Point of a Stable Mixture

What is the freezing point of a unique ice cream topping?

Have you ever put “shell” topping on a frozen desert like ice cream? The topping is a liquid in the plastic bottle, but when you put it on ice cream, it hardens very quickly to form a shell or crust over the desert. The ice cream topping contains lecithin, a substance that stabilizes the mixture, so it acts like a pure substance when heated or cooled. In this investigation, you will compare the freezing points of different shell topping brands.

A

Doing the Experiment

1. Fill a foam cup about 3/4 full with ice water.
2. Shake the bottle of ice cream topping well, and pour about 15 mL into the test tube. This step might already have been completed for you.
3. Place the temperature probe in the test tube.
4. Connect the temperature probe to the Data Collector and set up a new experiment. Choose a sample rate of 5 seconds per sample (5 sec/sample). This means temperature data will be taken and placed in the table every 5 seconds.
5. Start the Data Collector. Place the test tube into the ice water bath. Use the temperature probe to gently stir the mixture while the temperature data is collected. Continue until the topping is a solid, and you can’t move the thermometer any more. When the topping is a solid, continue collecting data until the temperature reaches 4 or 5 °C (the temperature of the ice water bath).
6. Save the Data Collector experiment and make a note of the file name.
7. Follow your teacher’s instructions for cleanup.

B

Analyzing the data

Go to the graph screen on your data collector. The graph should show temperature on the y axis and time on the x-axis. If this is not the case, select the correct variable for each axis. Study the graph and answer the questions below.

a. As you cooled the mixture, what happened to the temperature at first?

b. At some point in the cooling process, you will see that the line on the graph is relatively flat (this is called a plateau). What does this tell you about the temperature during this time period?

c. What is happening to the ice cream topping during this point in the cooling process?

d. Did the temperature drop again after the plateau? Discuss.

e. On a piece of graph paper, make a sketch of the graph you have on the Data Collector. You do not have to use numbers, but you should label each axis with the correct variable. On your sketch, label the area of the graph where freezing occurred, and make a note of the average temperature (freezing point). Or, you can download the data to a spreadsheet and create a graph to print and place in your lab notebook.
3 Thinking about what you observed

Different brands of shell ice cream topping have similar ingredients, but they are not all identical mixtures. Are their compositions different enough to affect the freezing point? You will compare results with other groups to find out.

a. Based on your data analysis, at what temperature did your brand or type of ice cream shell topping freeze?

b. Compare your freezing point with other groups that used the same brand. Is the temperature similar? Discuss.

c. Compare your freezing point with other groups that used a different brand or type of topping. Is the temperature similar? Discuss.

d. Based on your observations, if your teacher gave you an unknown brand of shell topping, would you be able to identify the brand or type by finding its freezing point? Explain your answer.

4 Applying your knowledge

a. When the topping was in the ice water bath, thermal energy was transferred away from the topping. At first, the temperature dropped rapidly, and then the temperature stalled. Why?

b. What would shell topping be like if the freezing point was 20 °C?

c. What would shell topping be like if the freezing point was 0 °C?

d. Pure substances have unique freezing/melting points, but mixtures generally do not. Shell ice cream topping is a mixture that does freeze and melt at a certain temperature range. Why does the ice cream topping act like a pure substance?
11C Mass Determination Without a Balance

Can the mass of an object be determined without the use of a balance?

The mass of an object is the amount of matter in that object. This physical property can easily be measured with the use of a common piece of laboratory equipment: a balance. How could you determine the mass of a pure substance if the lab balance was out of order?

The following table of specific heat values will be useful:

<table>
<thead>
<tr>
<th>Name of Substance</th>
<th>Specific Heat, J/g°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.899</td>
</tr>
<tr>
<td>Brass</td>
<td>0.38</td>
</tr>
<tr>
<td>Copper</td>
<td>0.38</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.443</td>
</tr>
<tr>
<td>Iron</td>
<td>0.46</td>
</tr>
<tr>
<td>Steel</td>
<td>0.46</td>
</tr>
<tr>
<td>Water</td>
<td>4.18</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.388</td>
</tr>
</tbody>
</table>

1 **Stop and think**

a. When choosing a material to serve as an insulator, should a material with a high specific heat or a low specific heat be chosen? Explain your answer.

2 **Doing the Experiment**

1. Heat 200 mL of water in the beaker using the hot plate until the water boils. Gently lower the metal sample into the beaker using the tongs. Allow the sample to settle in the boiling water for 2 to 3 minutes so its temperature will be equal to that of the boiling water.

2. While the metal is warming up in the boiling water, begin to set up the calorimeter.

3. Measure exactly 100.0 mL of room temperature water in a graduated cylinder and pour the water into the Styrofoam cup. Record this volume in the Table 1.

4. Measure and record the stabilized temperature of the water in Table 1.

5. After the 2 to 3 minutes have passed, measure the temperature of the boiling water with the temperature probe and record this value in Table 1.
6. Using the tongs, carefully remove the metal from the boiling water and quickly transfer it to the calorimeter.

7. Stir the water in the calorimeter carefully with the temperature probe.

8. Watch the temperature reading as you stir. When the temperature reaches a plateau (no longer increases), record the temperature of the metal-water system in Table 1, stop stirring, and remove the metal.

9. Repeat the procedure for trial 2 replacing the water in the calorimeter with fresh water.

### Table 1: Determining mass data

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{H_2O}$ in calorimeter (mL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_i$ of H$_2$O in calorimeter ($^\circ$C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_i$ of metal in hot water ($^\circ$C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_f$ of system ($^\circ$C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of metal (g)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Analyzing the Data

**A. Calculate the heat absorbed by the water.**

1. Find the mass ($m_1$) of the original volume of water using $V_{H_2O}$ and density
2. Find the change in temperature of the water using $\Delta T = T_f - T_i$
3. Find the energy ($E$) absorbed by the water using $Q_{H_2O} = mC_p\Delta T$

**B. Calculate the mass of the metal.**

1. Find the change in temperature of the metal using $\Delta T = T_f - T_i$
2. Find the heat released by the metal ($Q_{metal}$) using $-Q_{metal} = Q_{H_2O}$
3. Find the mass of the metal ($m$) using $Q_{metal} = mC_p\Delta T$
4. Perform all calculations up to this point for both trial 1 and trial 2, then average your two mass predictions and use your average value for the calculation in step 6.
5. Use the balance to measure the mass of your metal sample.

6. Percent error, where $\text{% error} = \frac{\text{experimental} - \text{real}}{\text{real}} \times 100$
4 Thinking about what you observed

a. A sample of nickel is found to absorb 4.25 kJ as it is heated from 15.0 °C to 37.5 °C. What is the mass of this piece of nickel?

b. Predict how your results would differ if you allowed your metal to stay in the boiling water for only 2 minutes. Explain.

c. Name two possible sources of error for this experiment. How would they affect your data? How would they affect your results?
12C Density of Fluids

What is the maximum load a boat can hold before sinking? How is the maximum load affected by the density of the water in which the boat floats?

In Investigation 12B, you designed and created clay boats that floated in water. You learned that the density of the boat should be equal or less than the water in order to float. You also saw that altering the shape of the clay changed its ability to float. In this investigation, you will work to see what element of boat design increases the maximum load that your boat can handle before sinking and how this is all related to the density of water.

### Stop and think

a. What element of design do you think will affect the ability of your boat to hold more or less weight without sinking? Explain.

### Finding the apparent density of your clay boat

1. Form your clay into a floating boat like the one you used for Investigation 12B.

2. Find the total volume of the clay boat. This means the sum of the volume of the clay itself and the empty air space of the boat. Record your values in Table 1.
   a. Measure the volume of your clay boat by displacement.
   b. Measure the volume of empty air space of your boat. Start by filling a 100 mL graduated cylinder with water up to the 100 mL line. Pour water from the cylinder into your boat until it completely fills up. Once it is full, see how much water is left in the graduated cylinder. Subtract that amount from the 100 mL you started with to determine the volume of air space of your boat.
   c. Calculate the total volume of the clay boat.

3. Measure the mass of the boat.

4. Calculate the apparent density of your clay boat (Mass/Total Volume)
Table 1: Volume, mass, and density data

<table>
<thead>
<tr>
<th>Volume of clay used in boat (mL)</th>
<th>Volume of empty space (mL)</th>
<th>Total volume of clay boat (mL)</th>
<th>Mass of boat (g)</th>
<th>Apparent density of your boat (g/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

3 Predicting the maximum load of the boat

The boat will sink once it becomes denser than the water. You are going to predict what the maximum load should be for your boat based on the data you collected in Table 1. To do this, you will come up with a mathematical relationship that enables you to solve for the maximum load. Start by looking at your boat’s apparent density, and the density it must remain less than to stay afloat.

a. What was the mass of your boat?
b. What was the total volume of your boat?
c. What was your boat’s apparent density?
d. What is the maximum apparent density your boat can attain and still remain afloat?
e. Where would the additional mass of the load your boat carries enter into the apparent density calculation for your boat?
f. Write an equation to calculate the apparent density of your boat when carrying a load.
g. Solve your equation for maximum load. What is your calculated maximum load?

4 Testing the theoretical value

1. Place your boat in the water.
2. Record your calculated maximum load in Table 2.
3. Add one washer at a time to your boat. Once the boat starts to sink, stop adding washers and measure the total mass of all the washers your boat successfully carried. Record this value in Table 2.
4. Find the percent error and record this value in Table 2.
5. Who in the class was able to achieve the largest load? Look at his/her design and others. What design characteristics do the most successful boats share?

Table 2: Maximum load data for fresh water

<table>
<thead>
<tr>
<th>Calculated maximum load (g)</th>
<th>Measured maximum load (g)</th>
<th>Percent error of calculated maximum load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>
Changing the density of the liquid

The Dead Sea is located in the Middle East, between Jordan on its east bank and Israel and the West Bank on its west. It is known for its dense salt water. Would your boat have the same capacity for a maximum load if it were in very salty water with a much higher density than the fresh water you’ve used so far?

1. You will need to find the density of the salt water. Find the mass of 100 mL of the salt water solution by using a graduated cylinder. Record the mass in Table 3.
2. Calculate the density of the salt water sample. Record the density in Table 3.
3. Use your equation from part 3 to calculate the maximum load for your boat in the saltwater solution. Record this value in Table 3.
4. Test the maximum load in the salt water solution. Record the value in Table 3.
5. Find the percent error and record in Table 3.

<table>
<thead>
<tr>
<th>Mass of salt water sample (g)</th>
<th>Density of salt water sample (g/mL)</th>
<th>Calculated maximum load (g)</th>
<th>Measured maximum load (g)</th>
<th>Percent error of calculated maximum load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

Thinking about what you observed

a. In order to load more on a boat, what element of the design needs to be changed? Explain.

b. With a greater water density, can the boat hold fewer or more weights? Why?

c. For both the freshwater and saltwater, explain why you think the percent errors were as you found.

d. In an estuary, salt water from the ocean and fresh water from a river meet. What would you expect to happen in the estuary itself with these waters? Would there be any stratification?

e. Find out what the average density is of a typical sample of ocean water. How does its density compare to fresh water and to the sample you used that modeled the Dead Sea? Would your boat hold more or less washers in fresh water and typical ocean water compared to the Dead Sea water?
13C Charles’s Law

What is the relationship between the volume and temperature of a gas?

Jacques Charles (1746–1823) determined the relationship between temperature and volume for an enclosed gas. In this simple investigation, you will measure the volume of air in a balloon, heat the system, and observe and collect temperature and volume data as the system cools. From this data, you will be able to derive Charles’s Law.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.N.1.3</td>
<td>Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking.</td>
</tr>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences are drawn from scientific observations and provide examples.</td>
</tr>
<tr>
<td>SC.912.P.12.10</td>
<td>Interpret the behavior of ideal gases in terms of kinetic molecular theory.</td>
</tr>
</tbody>
</table>

1 Thinking about temperature and volume

a. If you inflate a balloon and leave it on a sunny windowsill, what do you think will happen to the balloon?

b. Make a hypothesis about the relationship between volume and temperature of an enclosed gas. (Hint: When temperature increases, what do you think happens to the volume?)

2 Setting up the experiment

1. To begin making the plunger assembly, use the weights base that comes with the equipment kit. Remove all the steel weights (you won’t need them).

2. Cut a styrofoam cup so that it is 12 cm high and then make a small hole in the side of the cup.

3. Poke a hole in the bottom of the cup using one of the posts and leave the cup attached to the weights base as shown in the photo. You will use this plunger assembly to submerge the balloon in the displacement tank.

4. Blow up a balloon but don’t tie it. Allow it to deflate. Repeat this process three times. This will stretch the balloon so it is easier to use in experiment.

5. Blow up the balloon with enough air that it will fit easily in the displacement tank. It should not fit snugly (approximately 12-cm in diameter).
3 Doing the experiment

1. Place the displacement tank on a tray or dish pan. Add 1250 mL of ice water to the displacement tank.
2. Submerge the balloon by pushing down on it with the plunger assembly. Be sure that it is completely submerged. Water will flow out of the tank. If it does not, add water until some runs out of the spout into the pan.
3. Place the temperature probe in the displacement tank. Wait one minute. If the water level has decreased and is no longer on the verge of overflowing, fill the tank with the same temperature water as used in that trial until it just starts to overflow.
4. Remove the weights base/styrofoam cup assembly and balloon.
5. Record the displaced volume of water. There is a measured scale down the side of the displacement tank labeled “Displaced Volume”. Record the values in Table 1.
6. Empty the displacement tank until the water level reads 750 mL. Then add warm water until the level again reaches 1250 mL.
7. Check the temperature of the tank water. It should be about 10 - 15 degrees warmer. Adjust the water temperature if necessary by adding ice or warm water.
8. Repeat Steps 2–7, until you have at least four data points.
9. Find the volume of the balloon for each trial by subtracting the tank volume from 1900 mL (which is the total tank volume). Record in Table 1.
10. Convert Celsius temperatures to Kelvin temperatures and record in Table 1.

<table>
<thead>
<tr>
<th>Tank volume (mL)</th>
<th>Volume of the balloon and plunger as read from tank (mL)</th>
<th>Temperature (°C)</th>
<th>Temperature (Kelvin)</th>
<th>V<em>T (mL</em>K)</th>
<th>V/T (mL/K)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>
4 Graphing the data

Use your data to make a graph of volume vs. temperature.

a. Does the graphical model support your hypothesis? Explain your answer.

b. What happens to the volume of an enclosed gas when the temperature increases?

5 Finding a relationship between volume and temperature

a. Divide the volume and temperature values for each trial and record the answers in Table 1. Remember to use appropriate numbers of significant figures.

b. Multiply the volume by the temperature for each trial and record the values in Table 1. Again, use the correct number of significant figures.

c. There is a mathematical relationship between volume and temperature that always equals a constant value. Based on your calculations, is that relationship $V/T$ or $V \times T$?

d. According to your data, what is the constant value? (You can record an average.)

6 Using Charles’s Law to make a prediction

a. Using your constant value, calculate what the volume of the balloon and plunger assembly would be when the temperature is 290K. (Or a similar temperature if this is already one of your data points.)

b. Using your graph, what is the volume that corresponds to 290K? How does this compare to your calculated value?

c. How would you use the experiment setup to test your predicted volume value for 290K?

7 Thinking about what you observed

a. If you do this experiment with much hotter water (such as 60 °C), the balloon/plunger volume measurements should increase, but they don’t. Why do you think this happens? (Hint: think about the way the experiment is set up.)

b. Go back to your answer to question 1a. Would you answer the question the same way now? Explain.
14C Energy and the Quantum Theory

How do atoms absorb and emit light energy?

The electrons in an atom are organized into energy levels. You can think of energy levels like a staircase where the electrons can be on one step or another but cannot exist in-between steps. When an electron changes levels, the atom absorbs or emits energy, often in the form of light. This investigation will teach you a challenging and fun game that simulates how atoms exchange energy through light. The process is fundamentally how a laser works.

1. The neon atom
   1. Build a neon atom with 10 each of protons (red or green marbles), neutrons (blue marbles) and electrons (yellow marbles).
   2. Set the electrons in the lowest spaces possible.
   3. Find the following cards in the Photons and Lasers can
      - Pump 1 (red)
      - Pump 2 (yellow)
      - Laser 1 (red)

2. How atoms exchange energy
   a. Explain the meaning of the term “ground state” when applied to an atom.
   b. Can the second energy level of neon hold any more electrons? How does this affect neon’s chemical properties and position on the periodic table?
   c. Take the red “pump 1” card from your hand and put it on the atom board. Move one electron from level 2 to level 3. Explain what this sequence of actions represents in a real atom.
   d. Take the yellow “pump 2” card from your hand and put it on the atom board. Move any one electron up 2 levels. Explain what this sequence of actions represents in a real atom.
   e. Take the red “laser 1” card from your hand and put it on the atom board. Move any one electron down one level. Explain what this sequence of actions represents in a real atom.
3 The photons and lasers game

1. The first player to reach 10 points wins the game.
2. Each player starts with 5 cards and plays one per turn. Draw a new card to maintain a hand of 5.
3. Playing a pump card allows the player to advance one electron up by the number of levels shown on the card (1 - 4). No points are scored by playing pump cards.
4. Playing a laser card allows the player to drop electrons from one level to a lower level. The player scores one point per electron per level. For example, moving 2 electrons down 2 levels scores 4 points.
5. Rules for playing laser cards:
   - Electrons can only be moved down if there are empty states for them to move to.
   - Electrons can only be moved from one level in a turn.
   - If the card says “laser 2” then each electron must move 2 levels.

4 Thinking about what you learned

a. What does the term “excited state” mean with respect to energy and atoms?

b. What physical principle prevents two electrons from moving into the same state?

c. In order of increasing energy, arrange the following colors of light: blue, red, green, yellow.

d. Could an atom emit one photon of blue light after absorbing only one photon of red light? Explain why or why not.

e. Suppose a real atom had energy levels just like the game. Could this atom make blue-green light with an energy in between blue and green? Explain what colors this atom could make.
15C Activity Series of Metals

How reactive are different metals?

An activity series is a list of elements arranged from most reactive to least reactive. When you place a solid piece of metal in contact with a solution, there may or may not be a reaction. In order for a reaction to proceed, the solid metal that is touching the solution must be more reactive than the metal that is part of the ionic compound (solute) dissolved in the water. In this investigation, you will examine several metals and rank them from most to least active based on how many reactions take place for each metal.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.8.2</td>
<td>Differentiate between physical and chemical properties and physical and chemical changes of matter.</td>
</tr>
<tr>
<td>SC.912.P.8.5</td>
<td>Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.</td>
</tr>
<tr>
<td>SC.912.P.8.7</td>
<td>Interpret formula representations of molecules and compounds in terms of composition and structure.</td>
</tr>
<tr>
<td>SC.912.P.8.8</td>
<td>Characterize types of chemical reactions.</td>
</tr>
</tbody>
</table>

**1 Stop and think**

Based on the metals given in the materials list, which do you think will be the most reactive?

**2 Doing the experiment**

1. You will need a 5x5 well plate. It will be arranged similar to the layout of Table 1. With an eyedropper, place 7 drops of each solution into each of four wells. For example, place 7 drops of Cu(NO₃)₂ solution in each of four wells across the top of the well plate.

2. If you are using a clear plastic well plate, place a sheet of white paper underneath the it. It will allow you to see evidence of a potential chemical reaction more easily.

3. Place one sample of each metal into each solution. For example, place one sample of copper in the first well of the row containing the Cu(NO₃)₂ solution. Then place a sample of copper into the first well of the row containing Zn(NO₃)₂, and so on until the first well in each row has a sample of copper in it. Repeat this process with one sample of zinc placed in each of the second wells in each row, lead in the third, and magnesium in the fourth.

4. After 15 minutes, use forceps to examine each metal. Be sure to turn the metal over and look at the underside for evidence of a chemical reaction.
5. Place an “X” in any square of the data table where a reaction occurs.
6. Clean up according to your instructor’s directions and be sure to wash your hands.
7. Add up the number of “X’s” for each metal and write the total in the second data table.

**Table 1: Reactivity data**

<table>
<thead>
<tr>
<th>Metal</th>
<th>Cu</th>
<th>Zn</th>
<th>Pb</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu(NO₃)₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn(NO₃)₂</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pb(NO₃)₂</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mg(NO₃)₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AgNO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Reactions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. **Thinking about what you observed**

   a. What evidence did you observe to indicate a chemical reaction had taken place in this experiment?

   b. Rank the solid metals used in the experiment from most reactive to least reactive.

   c. Even though silver solid was not used in this experiment, make a judgement as to where it would rank compared to the other metals. Explain.

   d. Compare the activity series you just constructed with one provided by your teacher. How do they compare?
16C Carbon and its Chemistry

What are some common molecules that contain carbon?

Living organisms are made up of a great variety of molecules, but the number of different elements involved is very small. Organic chemistry is the science of molecules that contain carbon and these are the ones most important to living organisms. This investigation will introduce you to some small organic molecules.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA.910.4.2.2</td>
<td>The student will record information and ideas from primary and/or secondary sources accurately and coherently, noting the validity and reliability of these sources and attributing sources of information.</td>
</tr>
<tr>
<td>SC.912.N.1.4</td>
<td>Identify sources of information and assess their reliability according to the strict standards of scientific investigation.</td>
</tr>
<tr>
<td>SC.912.N.1.6</td>
<td>Describe how scientific inferences are drawn from scientific observations and provide examples.</td>
</tr>
<tr>
<td>SC.912.P.8.5</td>
<td>Relate properties of atoms and their position in the periodic table to the arrangement of their electrons.</td>
</tr>
<tr>
<td>SC.912.P.8.7</td>
<td>Interpret formula representations of molecules and compounds in terms of composition and structure.</td>
</tr>
</tbody>
</table>

1 The chemistry of carbon

Carbon is the central element in the chemistry of living things. This is because carbon can make complex molecules. Each carbon atom can make four bonds because carbon has four electrons in the outer energy level, which can hold a total of eight. Carbon can also form double and triple bonds by sharing two or three electrons with a single atom. Because of carbon’s flexible bonding ability, many molecular structures are possible.

[Diagrams of straight chains, branched chains, and rings]

Propane
\[ \text{C}_3\text{H}_8 \]
iso-octane
\[ \text{C}_8\text{H}_{18} \]
Benzene
\[ \text{C}_6\text{H}_6 \]

2 Single carbon molecules

[Diagrams of carbon dioxide, methyl alcohol, and methane]

1. Build the three carbon molecules above using the periodic table tiles.
2. Build a model of carbonic acid: \( \text{H}_2\text{CO}_3 \).

3 Stop and think

a. Research and describe at least one use of methyl alcohol.

b. Research and describe the use and production of methane.
4 Molecules with two carbon atoms

Once there are two carbon atoms, the structures get more complicated. The carbon atoms may share a single, double, or triple bond between them.

1. Build the 2-carbon molecules above using the periodic table tiles.
2. Build a model of ethyl alcohol (ethanol): C₂H₅OH.
   (Hint: Each carbon atom makes 4 bonds and the oxygen atom makes two bonds)
3. Build a model of acetylene: C₂H₂.
   (Hint: there is a triple bond between the two carbon atoms)

5 Stop and think

a. Research and describe where acetic acid is found.
b. Research and describe at least one use of ethyl alcohol.

6 Biological molecules

Living organisms are constructed mainly of proteins, which are very large carbon-based molecules, such as hemoglobin (right). A single protein may contain 10,000 or more atoms. Proteins themselves are constructed of simpler units called amino acids. For example, the hemoglobin molecule contains 584 amino acids.

Use the periodic table tiles to build models of the three smallest amino acids.

7 Stop and think

a. What is similar about all three amino acids?
b. Is the chemical in the diagram on the right an amino acid? Explain why you think your answer is correct.
17C Classifying Chemical Reactions

How can you predict the products of a chemical reaction?

In a previous investigation, you learned to balance chemical equations. You may have noticed some patterns in those reactions. For example, you balanced some reactions in which a carbon compound reacted with oxygen gas to produce carbon dioxide and water. In this investigation, you will explore patterns like these and learn how they can help you predict the products of a chemical reaction.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.8.7</td>
<td>Interpret formula representations of molecules and compounds in terms of composition and structure.</td>
</tr>
<tr>
<td>SC.912.P.8.8</td>
<td>Characterize types of chemical reactions, for example: redox, acid-base, synthesis, and single and double replacement reactions.</td>
</tr>
</tbody>
</table>

1 Addition reactions

When two substances combine to form one new substance, we call the reaction an *addition reaction*. The general formula for an addition reaction looks like this: \( A + B \rightarrow AB \). The sodium-chlorine addition reaction built using the Periodic Table Tiles looks like this:

![Na] + [Cl] → [NaCl]

2 Decomposition reactions

In other chemical reactions, you may find one substance is broken down into two substances. This is called a *decomposition reaction*. Water, for example, can be broken down into the elements hydrogen and oxygen: \( 2H_2O \rightarrow 2H_2 + O_2 \). The general formula for a decomposition reaction is \( AB \rightarrow A + B \).

![H2O] → [H] + [O]
3 Single-displacement reactions

A third type of reaction, called a *single-displacement reaction*, occurs when one element replaces a similar element in a compound. If you put an iron nail into a beaker of copper chloride, you will see reddish copper forming on the nail.

Iron replaces copper in the solution, and copper falls out of the solution as a metal: \( \text{CuCl}_2 + \text{Fe} \rightarrow \text{FeCl}_2 + \text{Cu} \). The general formula for a single-displacement reaction is \( AX + B \rightarrow BX + A \).

4 Double-displacement reactions

A *double-displacement* reaction occurs when ions from two compounds in a solution switch places to form two new compounds. This happens in the reaction between hydrochloric acid and sodium hydroxide: \( \text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O} \). The general formula for a double-displacement reaction is \( AB + CD \rightarrow AD + CB \).
Combustion reactions

A fifth type of chemical reaction occurs when something burns. We call these reactions combustion reactions. You are probably familiar with combustion reactions in which a carbon compound is burned to produce carbon dioxide and water.

For example, methane (natural gas) is burned to heat homes:

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]

The general formula for a carbon combustion reaction is:

\[ \text{Carbon compound} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

Summary of types of reactions

<table>
<thead>
<tr>
<th>Type</th>
<th>General Equation</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>addition</td>
<td>A + B \rightarrow AB</td>
<td>2Na + Cl\text{\textsubscript{2}} \rightarrow 2NaCl</td>
</tr>
<tr>
<td>decomposition</td>
<td>AB \rightarrow A + B</td>
<td>2H\text{\textsubscript{2}}\text{O} \rightarrow 2H\text{\textsubscript{2}} + O\text{\textsubscript{2}}</td>
</tr>
<tr>
<td>single-displacement</td>
<td>AX + B \rightarrow BX + A</td>
<td>CuCl\text{\textsubscript{2}} + Fe \rightarrow FeCl\text{\textsubscript{2}} + Cu</td>
</tr>
<tr>
<td>double-displacement</td>
<td>AB + CD \rightarrow AD + CB</td>
<td>HCl + NaOH \rightarrow NaCl + H\text{\textsubscript{2}}\text{O}</td>
</tr>
<tr>
<td>combustion</td>
<td>carb cpd + O\text{\textsubscript{2}} \rightarrow CO\text{\textsubscript{2}} + H\text{\textsubscript{2}}\text{O}</td>
<td>CH\text{\textsubscript{4}} + 2O\text{\textsubscript{2}} \rightarrow CO\text{\textsubscript{2}} + 2H\text{\textsubscript{2}}\text{O}</td>
</tr>
</tbody>
</table>

Predicting the products of a chemical reaction

Using the table above, predict the products of these chemical reactions:

- **a.** The addition of magnesium and iodine: Mg + I\text{\textsubscript{2}} \rightarrow ?
- **b.** The decomposition of mercury oxide: HgO \rightarrow ?
- **c.** In potassium nitrate, the potassium is replaced by lead: KNO\text{\textsubscript{3}} + Pb \rightarrow ?
- **d.** The reaction between hydrochloric acid and potassium hydroxide: HCl + KOH \rightarrow ?
- **e.** The combustion of liquid hexane: C\text{\textsubscript{6}}H\text{\textsubscript{14}} + O\text{\textsubscript{2}} \rightarrow ?
Balancing equations given only the reactants

Use the periodic table tiles to help you complete and balance the following chemical equations:

a. \text{Al} + \text{Br}_2 \rightarrow

b. \text{KBr} + \text{Cl}_2 \rightarrow

c. \text{HCl} + \text{K}_2\text{SO}_3 \rightarrow

d. \text{C}_2\text{H}_6 + \text{O}_2 \rightarrow

e. \text{Al}_2\text{O}_3 \rightarrow

f. \text{ZnSO}_4 + \text{SrCl}_2 \rightarrow

g. \text{Mg} + \text{HCl} \rightarrow

h. \text{CaCl}_2 \rightarrow

i. \text{C}_5\text{H}_{12} + \text{O}_2 \rightarrow

j. \text{Sb} + \text{I}_2 \rightarrow
How do we model nuclear reactions?

You would be very surprised to see a bus spontaneously transform into three cars and a motorcycle. But radioactive atoms do something very similar. If left alone, a radioactive atom eventually turns into another kind of atom, with completely different properties. This investigation looks at some basic concepts behind radioactivity.

1 Radioactivity

1. Place 50 pennies in a paper cup, shake them and dump them on the table. Each penny represents an atom of carbon-14.
2. Separate the pennies that land tails-up. Count the heads-up pennies and tails-up pennies and record the number of each in Table 1 in the row for the first toss.
3. Put only the pennies that landed heads-up back in the cup. Put the tails-up pennies aside. Shake the cup again and dump the pennies on the table.
4. Record the number of heads-up pennies in the row for the second toss.
5. Repeat the experiment using only the pennies that landed heads-up until you have one or no pennies left.

<table>
<thead>
<tr>
<th>Table 1: Coin toss decay simulation</th>
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<tbody>
<tr>
<td>Heads</td>
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<tr>
<td>Start</td>
</tr>
<tr>
<td>First toss</td>
</tr>
<tr>
<td>Second toss</td>
</tr>
<tr>
<td>Third toss</td>
</tr>
</tbody>
</table>
Thinking about what you observed

a. Make a graph showing the number of heads-up pennies on the y-axis and the number of tosses on the x-axis (0, 1, 2, 3,...).

b. On average, what percentage of pennies are lost on each toss? “Lost” means they came up tails and were removed.

c. How does the concept of half-life relate to the experiment with pennies? What does one half-life correspond to?

Build a radioactive atom

Build a carbon-14 atom (C\textsuperscript{14}). This isotope of carbon is radioactive.

1. Take one neutron out and replace it with a proton and an electron. This is what happens in radioactive decay of C\textsuperscript{14}.

Thinking about what you did

a. Research what happens to C\textsuperscript{14} when it decays. What element does it become? What particles are given off?

b. What is the average time it takes for 50% of the C\textsuperscript{14} atoms in a sample to decay?

c. Suppose you have 50 atoms of C\textsuperscript{14} and you watch them for a very long time. How do the results of your penny-flipping experiment describe the number of C\textsuperscript{14} atoms?

d. We actually find C\textsuperscript{14} in the environment. Research where it comes from.

e. Describe two other types of radioactivity and give an example of each.

f. (Challenge) You cannot predict when any one atom will decay, just as you cannot predict whether a penny will come up heads or tails. Why can you predict that 50% of the C\textsuperscript{14} atoms will decay every half-life?
Introduction to Nuclear Reactions

If you were to add one, two or four extra neutrons to lithium-7 you would have created lithium-8, lithium-9, and lithium-11, respectively. Each of these isotopes of lithium is radioactive. These means that the atomic force in the nucleus (called strong nuclear force) is not strong enough to hold these atoms together. The nuclei of these atoms fly apart.

The goal of Nuclear Reactions is to earn points by creating atoms that are stable (not radioactive) and neutrally charged (not ions). Remember that ions are atoms that have different numbers of protons and electrons so they have a charge.

Each player starts with 8 protons, 8 electrons, and 8 neutrons in their pocket of the Atomic Building Game board. The game will last for about a half-hour. The first player to 20 points wins.

Playing Nuclear Reactions

To begin play, each player is dealt five cards from the deck of Nuclear Reactions cards. These are held and not shown to anyone else.

Players take turns, choosing which card to play each turn, and adding or subtracting particles from the atom as instructed on the card. For example, playing an “Add 2 Electrons” card would mean you place two yellow marbles in the atom.

Sub-atomic particles that are added or subtracted from the atom must come from, or be placed in your own pocket. You may not play a card for which you do not have the right marbles. For example, a player with only 2 protons left cannot play an “Add 3 Protons” card.

Each time you play a card, draw a new card from the deck so you always have five cards. Played cards can be shuffled and re-used as needed.
7 Scoring points

The number of points scored depends how many of the conditions below are satisfied by the atom you create. You can use the periodic table to determine strategy and points. In particular it is useful to know which cards to play to get to stable isotopes, neutral atoms, or stable and neutral atoms.

1. You score 1 point if your move creates or leaves a stable nucleus. For example, you score 1 point by adding a neutron to a nucleus with 6 protons and 5 neutrons. Adding a neutron makes a carbon 12 nucleus, which is stable. The next player can also score a point by adding another neutron, making carbon 13. Points cannot be scored for making a stable nucleus by adding or subtracting electrons, because electrons do not live in the nucleus! To get the nucleus right you need to satisfy conditions #1 and #2.

2. You score 1 point for adding or taking electrons or protons from the atom if your move creates or leaves a neutral atom. A neutral atom has the same number of electrons and protons. Getting the electrons and protons to balance satisfies condition #3.

3. You score 3 points (the best move) when you add or take particles from the atom and your move creates a perfect, stable and neutral atom. Both adding and subtracting can leave stable, neutral atoms. For example, taking a neutron from a stable, neutral carbon 13 atom leaves a stable, neutral carbon 12 atom, scoring 3 points. You get 3 points if your turn makes an atom that meets all 3 conditions.

**Condition #1:** The number of protons (red or green marbles) matches the atomic number.

**Condition #2:** The number of protons (red or green marbles) plus the number of neutrons (blue marbles) equals one of the correct mass numbers for the element of Rule #1. This creates a stable nucleus.

**Condition #3:** The number of electrons (yellow marbles) equals the number of protons (red or green marbles). This creates a neutral atom.
8 Miscellaneous rules

Taking a turn
When it is your turn you must either
1. Play a card and add or subtract marbles from the atom.
2. Trade in your cards for a new set of five.

Trading in cards
You may trade in all your cards at any time by forfeiting a turn. You have to trade all your cards in at once. Shuffle the deck before taking new cards.

Using the periodic table
All players should be allowed to use the special periodic table of the elements in the course of the game.

The marble bank
You may choose to play two versions of the marble bank.

Version 1: Players may take marbles from the bank at any time so they have enough to play the game.
Version 2: Players must lose a turn to draw marbles from the bank, and may draw no more than 5 total marbles (of any colors) in one turn.

9 Applying what you learned

a. There are two basic kinds of nuclear reactions, fission and fusion. Fission splits heavy elements up into lighter elements. Fusion combines lighter elements to make heavier elements. Both can release energy, depending on which elements are involved. What element do you get when you fuse lithium six and boron 11 together? It is stable or radioactive?

b. Write down a nuclear reaction using only two elements that would allow you to build Fluorine 19 starting with Boron 10.

c. Suppose you split a uranium 238 atom. If you have to break it into two pieces, name two elements that could be formed. Be sure that your two elements use up all the neutrons and protons in the uranium. Are either of your two elements stable or is one (or both) radioactive?
**19C Solubility of CO₂**

*How is the solubility of a gas affected by temperature?*

The carbonation from a soda is carbon dioxide gas that is dissolved in solution. The can is pressurized with carbon dioxide gas in order to maximize the amount of the gas dissolved in the beverage. As you have probably experienced, once you open the can, the carbon dioxide begins to escape and eventually the soda will taste “flat.” The purpose of this investigation is to examine the solubility of carbon dioxide gas in solution.

### Code Benchmark

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.L.17.20</td>
<td>Predict the impact of individuals on environmental systems and examine how human lifestyles affect sustainability.</td>
</tr>
<tr>
<td>SC.912.N.4.1</td>
<td>Explain how scientific knowledge and reasoning provide an empirically-based perspective to inform society’s decision making.</td>
</tr>
<tr>
<td>SC.912.P.8.2</td>
<td>Differentiate between physical and chemical properties and physical and chemical changes of matter.</td>
</tr>
<tr>
<td>SC.912.P.10.5</td>
<td>Relate temperature to the average molecular kinetic energy.</td>
</tr>
</tbody>
</table>

**1** Stop and think

Based on what you know about carbonated drinks, how will the mass of carbon dioxide dissolved in solution change over time? When heated?

**2** Doing the experiment

**Part A: Solubility of Carbon Dioxide vs. Time**

1. Dry the outside of a room temperature unopened can of soda.
2. Carefully open the can and place it on the balance immediately. Record the mass in Table 1.
3. Record the mass every 3 minutes until 15 minutes have elapsed.
4. Don’t discard the soda. Your teacher may have you record the mass one more time just before the period ends so be sure to note the time you first opened the soda.

**Part B. Temperature vs. Solubility**

1. Using a 600 mL beaker, measure out approximately 150 mL of water. Place a thermometer in the beaker.
2. Place the beaker on a hot plate and heat it until the temperature is between 55–60 °C. you will maintain this temperature during the experiment.
3. Once the temperature of the water bath is reached, open a can of soda and quickly measure its mass and record the value in Table 2.
4. Use the temperature probe and Data Collector to measure the temperature of the opened soda and record it in Table 2.
5. Carefully, place the opened can of soda into the warm water. Place the temperature probe into the can and select a new experiment on the Data Collector. Use the meter mode. When the temperature reaches 25 °C, remove the can, dry it, and measure its mass. Record the value in Table 2.
6. Repeat step five after every five degrees until the temperature of the soda reaches 50 ºC.

<table>
<thead>
<tr>
<th>Table 1: Time and mass data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (minutes)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Temperature and mass data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (celsius)</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>Starting temp:</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>45</td>
</tr>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

3 Data analysis

a. Make a graph of the data in Table 1. Place time on the x-axis. Put in a best-fit straight line through the data if the relationship looks linear.

b. Make a graph of the data in Table 2. Place temperature on the x-axis.

4 Thinking about what you observed

a. What does the first graph show?

b. Examine the data in Table 2. What effect did a rise in temperature have on the mass of carbonated beverage in the opened can? Explain this result.

c. What does your second graph indicate about the relationship between temperature and the solubility of a gas (carbon dioxide)?

d. In the summertime, there is a risk that large populations of fresh-water fish sometimes die-off. Explain this observation.
20C Electric Charge

What is static electricity?

Have you ever felt a shock when you touched a metal doorknob or removed clothes from a dryer? A tiny imbalance in either positive or negative charge on an object is the cause of static electricity. In this investigation, you will cause objects to have charge imbalances, and then observe what happens when different objects interact. Remember: positive and negative charges attract, while like charges repel.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
</table>

### 1 Observing electric charge

1. Cut out two small “leaves” of aluminum foil and use a paperclip to make a hole in the top of each leaf. You can hold the leaf against a pencil as you poke the hole with the paperclip.
2. Suspend one leaf from a thread that you hold up in one hand.
3. Rub an inflated balloon against your hair and move it towards the foil leaf.
4. Touch the rubbed part of the balloon to something metal then bring it close to the leaf.
5. Bring other objects near the leaf before and after they are rubbed with different materials such as silk, fleece, or fur.

### 2 Thinking about what you observed

a. Describe what happens to the aluminum foil leaf as you move the balloon closer.

b. Explain the reaction of the leaf to the rubbed balloon using the concepts of positive and negative charge.

c. Explain why touching the balloon to a metal object changed its effect on the leaf.
3 Making an electroscope

1. Cut a piece of insulated copper wire so it is about 10 cm long.
2. Strip about 2 cm of the insulation from the wire at both ends. Be careful not to break the wire.
3. Bend the wire over the edge of the glass beaker as shown in the photo. It helps to place a small bit of clay on the side so you can anchor the wire by pressing it into the clay.
4. Make the electroscope as shown in the photo by hanging two leaves on the end of the wire that is inside the beaker.
5. Rub an inflated balloon against your hair and move it towards the end of the wire sticking out of the beaker.
6. Touch the balloon to the wire then remove it.
7. Touch the end of the wire with your finger or a metal object.
8. Bring the plastic rod near the wire. Then rub the plastic rod with the fleece and bring it near the wire again.

4 Thinking about what you observed

a. Describe what happens to the aluminum foil leaves as you move the rubbed balloon closer.

b. Give a reason why the leaves stay apart after the balloon is removed.

c. Explain what happens when you touch the wire with your hand or a metal object.

d. “Charge” the electroscope by touching it with a balloon that has been rubbed against your hair. Then touch the rubbed side of the balloon to something metal and bring it close to the electroscope again. Describe what happens.

e. Why does the plastic rod cause the leaves to move only after it has been rubbed with the fleece?

f. What causes the leaves of the electroscope to move apart?
21C Analyzing Circuits

How do you build and analyze a network circuit?

When both series and parallel circuits are combined into one circuit, a network circuit is created. In this investigation, you will build and analyze network circuits. After determining the resistance of the colored resistors in the Electric Circuits kit, you will use these to build your network circuits.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.2</td>
<td>Describe and explain what characterizes science and its methods.</td>
</tr>
<tr>
<td>SC.912.P.10.15</td>
<td>Investigate and explain the relationships among current, voltage, resistance, and power.</td>
</tr>
</tbody>
</table>

1 Determining the resistance of each resistor

You will use three different colored resistors in this investigation. Use tape to label the green resistors R1 and R2, the blue resistor R3, and the red resistor R4.

Use the multimeter to measure the resistance of each resistor and enter the results in Table 1.

**Table 1: Measured resistance values**

<table>
<thead>
<tr>
<th>Resistance (Ω)</th>
<th>R1 (green)</th>
<th>R2 (green)</th>
<th>R3 (blue)</th>
<th>R4 (red)</th>
</tr>
</thead>
</table>

2 Building a network circuit

1. Use a battery, resistors 1, 2, and 3, and as many wires as necessary to construct the network circuit shown in the diagram at right.

2. Measure the voltage across the battery. This is the total circuit voltage. Then measure the voltage across each of the resistors. Record your measurements in Table 2.

3. Measure the current through each resistor. Record your measurements in Table 2. You have to break the circuit temporarily to insert the meter and make each current measurement. Be sure the meter is set to DC amps.
3 Analyzing the circuit

Table 2: Voltage and current measurements

<table>
<thead>
<tr>
<th>Voltage (volts)</th>
<th>Battery (total circuit)</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (amps)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Which of the two resistors is connected in parallel?
b. Which resistor is in series with the other two?
c. How does the voltage across the parallel resistors \( R_2 \) and \( R_3 \) compare?
d. How does the voltage across the parallel resistors relate to what you learned about voltages in a parallel circuit in a previous investigation?
e. How does the current flowing through \( R_1 \) compare with the current through \( R_2 \)?
f. How does the current coming out of the battery compare with the sum of the currents flowing through \( R_2 \) and \( R_3 \)? Explain this relationship.
g. Use what you know about series and parallel circuits to calculate the theoretical total resistance of the circuit. The formulas for finding the total resistance are:

<table>
<thead>
<tr>
<th>Series circuit</th>
<th>Parallel circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{\text{tot}} = R_1 + R_2 )</td>
<td>( \frac{1}{R_{\text{tot}}} = \frac{1}{R_1} + \frac{1}{R_2} )</td>
</tr>
</tbody>
</table>

h. Now calculate the total resistance of the circuit using Ohm’s law, the battery voltage, and the total circuit current you measured.
i. How does the total resistance calculated using Ohm’s law compare with the theoretical total resistance found above?

4 Predicting the effect of changing a resistor

a. Replace the 10-ohm resistor \( R_3 \) with the 20-ohm resistor \( R_4 \). Use what you have learned about network circuits to predict the total circuit resistance and total circuit current. Show the process you used to make your predictions.
b. Measure the voltage across the battery and each resistor and the total current in the circuit. Use Ohm’s law to find the total circuit resistance. You will need to make a data table similar to Table 2.
c. How did the predicted values compare with the measured ones?
A circuit puzzle

Build this circuit

1. Build the circuit shown in the diagram above with 2 batteries, a switch, and three bulbs.
2. Turn the switch on and observe the brightness of each bulb.
3. Temporarily interrupt the current to bulb B by disconnecting one wire from the terminal post.
4. Observe how the brightness of the other two bulbs changes.

e. When bulb B is disconnected, does bulb A get dimmer, brighter, or stay the same?

f. When bulb B is disconnected, does bulb C get dimmer, brighter, or stay the same?

g. Use what you know about series and parallel circuits to propose an explanation for what you observed.

Challenge: Analyze a four-resistor network circuit

a. Build the circuit shown in the diagram at right.

b. Use what you have learned about network circuits to predict the total circuit resistance and current. Show the process you used to make your predictions.

c. Use the meter to measure the voltage across the battery and each resistor and the total circuit current. Use Ohm’s law to find the total circuit resistance.

d. How did the predicted values compare with the measured ones?
How does an electric motor work?

Electric motors are found in many household devices, such as a hair dryer, blender, drill, and fan. In this investigation, you will build a simple electric motor and see how it works. The concepts you learn with the simple motor also apply to other electric motors.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA.912.S.3.2</td>
<td>Collect, organize, and analyze data sets, determine the best format for the data and present visual summaries.</td>
</tr>
<tr>
<td>SC.912.N.1.1</td>
<td>Define a problem, conduct systematic observations, plan investigations, and use tools to gather, analyze, and interpret data.</td>
</tr>
<tr>
<td>SC.912.P.10.18</td>
<td>Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.</td>
</tr>
<tr>
<td>SC.912.P.10.15</td>
<td>Investigate and explain the relationships among current, voltage, resistance, and power.</td>
</tr>
</tbody>
</table>

Making the base

1. Bend the two paper clips so they look like the photo.
2. Fasten them with rubber bands so they contact the positive and negative terminals of the battery.
3. Break off a small lump of clay from the 1/2 stick. Set the battery on the small clay lump so it stays in one place without rolling around.
4. Use a tiny piece of clay to stick a magnet to the top of the battery.
5. Your motor base is complete!
2 Making the coil

1. Cut 1 meter of magnet wire (also called varnished magnet wire). This wire has a painted insulation layer on the surface.
2. Wrap the wire around the square form of the modeling clay with one end sticking out 4 cm or so.
3. Keep wrapping until you have only 4-5 cm left.
4. Remove your coil from the form and wrap the ends of the wire a few turns around the sides of the coil to keep things together. There should be about 3 cm of wire on each side of the coil.
5. Take some sand paper and sand off all the varnish on one wire.
6. Sand off the varnish on ONE SIDE ONLY of the other end of the wire.
7. Adjust the wires until the coil balances as well as you can get it.
8. Your coil is done!

3 Making the motor work

1. Set the coil into the paper clips so it is free to spin.
2. Adjust the height of the paper clips until the coil rotates just above the magnet.
3. The motor should spin! Adjust the balance by bending the wires or paper clips.

Troubleshooting - the main problem areas to watch out for are:

- unbalanced coil
- poor connections
- improperly sanded coil ends
- dead D-cell
4 Thinking about what you observed

a. When electricity runs through the coil of wire, what type of force is created around the coil?

b. What is the purpose of the permanent magnet?

c. What interactions cause the coil of wire to spin?

d. Try adding a second magnet. Does this make the motor go faster, slower, or about the same? What observations did you make that support your answer?

e. What else might make the motor spin faster? With your teacher’s approval, try it!

5 Challenge

See if you can hold a photogate so the spinning coil breaks the light beam. With the Timer mode set on frequency, you will know how many breaks per second the spinning coil makes.

a. Describe how you set up the experiment to get frequency readings from the Timer/photogate equipment.

b. How did your spinning coil measurements compare to other groups’ data?

c. Repeat the last 2 steps in the previous section (4d and 4e). Record your data.

d. Does the spinning coil data support your answers to 4d and 4e? Explain.

e. The basic parts of any simple DC motor like the one you made are: electromagnet, permanent magnet, commutator, and energy source. Draw a diagram of your simple motor and label these parts.
23C Waves in Motion

How do waves move?
Waves are oscillations that move from one place to another. Like oscillations, waves also have the properties of frequency and amplitude. In this investigation, you will explore waves on strings and in water. What you learn applies to all other types of waves as well.

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.N.3.5</td>
<td>Describe the function of models in science, and identify the wide range of models used in science.</td>
</tr>
<tr>
<td>SC.912.P.10.18</td>
<td>Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.</td>
</tr>
<tr>
<td>SC.912.P.12.2</td>
<td>Analyze the motion of an object in terms of its position, velocity, and acceleration as functions of time.</td>
</tr>
</tbody>
</table>

1 Making a transverse wave pulse

2. It takes two students to do this experiment. Each student takes one end of the spring.
3. Bring the spring down to the floor. Stretch it to a length of about 3 meters while keeping the spring on the floor.
4. One student should jerk one end of the spring rapidly to the side and back, just once. Make sure both ends of the spring are held tight and do not move once the wave is in motion. A wave pulse should travel up the spring.
5. Watch the wave pulse as it moves up and back. Try it a few times.

2 Thinking about what you observed

a. How is the motion of a wave pulse different from the motion of a moving object such as a car? (HINT: What is it that moves in the case of a wave?)

b. What happens to the wave pulse when it hits the far end of the spring? Watch carefully. Does the pulse stay on the same side of the spring or flip to the other side? Use the word “reflect” in your answer.

c. Imagine you broke the spring in the middle. Do you think the wave could cross the break? Discuss the reasoning behind your answer in a few sentences.

d. Why does the wave pulse move along the spring instead of just staying in the place you made it?
3 Making a longitudinal wave pulse

1. Just like the wave you made in Part 1, each student takes one end of the spring.
2. Bring the spring down to the floor. Stretch it to a length of about 3 meters while keeping the spring on the floor.
3. One student should jerk one end of the spring rapidly forward and back, just once. Make sure both ends of the spring are held tight and do not move once the wave is in motion. A wave pulse should travel up the spring.
4. Watch the wave pulse as it moves up and back. Try it a few times.

4 Thinking about what you observed

a. How is the motion of the longitudinal wave pulse different from the transverse wave pulse you made in Part 1? (HINT: How is the motion of the spring itself different?)

b. What happens to the wave pulse when it hits the far end of the spring? Does it behave like the transverse wave, or much differently? Use the word “reflect” in your answer.

c. Why do you think longitudinal waves are also sometimes called “compressional waves”?

d. Do you think a wave can be made by only stretching the Slinky® instead of compressing it? Make a prediction then try it and see if you were right.
Waves in water

1. Fill a flat tray with about one-half centimeter of colored water. The color helps you see the waves.

2. Roll the wave tube forward about 1 cm in a smooth motion. This launches a nearly straight wave called a **plane wave** across the tray.

3. Next, poke the surface of the water with your fingertip. Disturbing a single point on the surface of the water makes a **circular wave** that moves outward from where you touched the water.

4. Arrange two wood blocks so they cross the tray leaving a 1 cm opening between them.

5. Make a plane wave that moves toward the blocks. Observe what happens to the wave that goes through the opening.

**Thinking about what you observed**

a. Draw a sketch that shows your plane wave from the top. Also on your sketch, draw an arrow that shows the direction the wave moves.

b. Is the wave parallel or perpendicular to the direction the wave moves?

c. Draw another sketch that shows the circular wave. Add at least four arrows that show the direction in which each part of the wave moves.

d. At every point along the wave, are the waves more parallel or perpendicular to the direction in which the circular wave moves?

e. Sketch the shape of the wave before and after passing through the 1 cm opening.

f. Does the wave change shape when it passes through the opening? If you see any change, your answer should state into what kind of shape the wave changes.

g. Are the waves you made in the water transverse or longitudinal waves, and why?
24C Perceiving Sound

What is sound and how do we hear it?

The ear is a very remarkable sensor. Sound waves that we can hear change the air pressure by one part in a million! Because sound is about perception, and people are different, we will have to use some very interesting techniques to make experiments reliable. In this investigation, you will learn about the range of frequencies the ear can detect and also how small a difference in frequency we can perceive.

How high can you hear?

The accepted range of frequencies the human ear can hear ranges from a low of 20 Hz to a high of 20,000 Hz. Actually, there is tremendous variation within this range, and people’s hearing changes greatly with age and exposure to loud noises.

Connect your sound generator to a Data Collector set to measure FREQUENCY. Connect a speaker to the sound generator. When you turn the Data Collector on, you should hear a sound and the Data Collector should measure a frequency near 440 Hz.

There are two knobs for frequency and volume control. Try adjusting the frequency and see how high and low it will go.

See if you and your group can agree on a frequency where you hear the sound as low, medium, high, and very high frequency. Write frequencies of sound that you think sound low, medium, high, and very high in Table 1. Don’t try to be too exact, because the words “low,” “medium,” and “high” are themselves not well defined. It is difficult to agree exactly on anything that is based completely on individual human perception.

<table>
<thead>
<tr>
<th>Description</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Very high</td>
<td></td>
</tr>
</tbody>
</table>
2 Testing the upper frequency limit of the ear

To start with a simple experiment, your teacher has a sound generator that can make frequencies up to 20,000 Hz. When the teacher asks, raise your hand if you can hear the sound. Don’t raise your hand if you can’t hear. Someone will be appointed to count hands and survey the class to see what fraction of students can still hear the sound.

a. The objective of the test is to see what fraction of people can hear a particular frequency. Once the frequency gets too high, no one will be able to hear it, or at least no humans. Cats, dogs, and other animals can hear much higher frequencies than people. Do you think the method of raising your hands is likely to give a good result? Give at least one reason why you think the method is either good or bad.

b. Make a bar graph showing how your class responded to frequencies between 10,000 and 20,000 Hz. You should have six bars, each one for a frequency range of 2,000 Hz. The height of each bar is the number of people who could hear that frequency of sound. If someone could hear the frequency they are counted as a positive response in the graph. This kind of graph is called a histogram.

3 Doing a more careful experiment

Another way to do the experiment is with a hidden ballot. The researcher running the experiment will ask if anyone can hear a certain frequency of sound and you check yes or no on a piece of paper. The researcher may play or not play the sound. Each frequency will be played five times, and the five repetitions will be all mixed up so there is less chance for error. Every one in the class does one response survey.

Collect the data from the survey sheets and record it in Table 2.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Frequency</th>
<th>Key</th>
<th>Played</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1</td>
<td>12,000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td># 2</td>
<td>14,000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td># 3</td>
<td>16,000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td># 4</td>
<td>18,000</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td># 5</td>
<td>20,000</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 2: Frequency survey data

<table>
<thead>
<tr>
<th># Right</th>
<th>10,000 Hz</th>
<th>12,000 Hz</th>
<th>14,000 Hz</th>
<th>16,000 Hz</th>
<th>18,000 Hz</th>
<th>20,000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Plot another histogram showing only those people whose choices matched the yes/no on the key for all five times at each frequency. It is hard to fake a response or get it right by chance because you have to choose correctly five times for each frequency. This kind of experiment is called a double-blind test since neither you nor the researcher can see anyone else’s response. The results from a double-blind experiment are much more reliable that other forms of surveys. Doctors use the double-blind method to test new medicines.

4 Perceiving differences in frequency

Can you tell the difference between a sound with a frequency of 400 Hz and a sound at 401 Hz? The next experiment on hearing is to test people’s ability to distinguish if one sound has higher frequency than another. In this experiment the researcher will play two frequencies and you mark which one is higher.

To analyze the results you need to know how many people got the right answer for each frequency range. Make a data table like the example below that is large enough to hold all of your results.

<table>
<thead>
<tr>
<th>Frequency A (Hz)</th>
<th>Frequency B (Hz)</th>
<th>Frequency difference (Hz)</th>
<th>Percent difference</th>
<th># of correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>995</td>
<td>5</td>
<td>0.5%</td>
<td>1</td>
</tr>
<tr>
<td>1,000</td>
<td>1,050</td>
<td>50</td>
<td>1%</td>
<td>15</td>
</tr>
<tr>
<td>1,000</td>
<td>1,001</td>
<td>1</td>
<td>.1%</td>
<td>0</td>
</tr>
</tbody>
</table>

a. Calculate the percent difference in frequency for each test.
b. There are two ways to look at sensitivity. In one way, we hear *absolute* differences in frequency. If the ear was sensitive to absolute differences, we would hear a 5 Hz difference no matter if the two frequencies were 500 Hz and 505 Hz, or 5,000 Hz and 5,005 Hz.

The second possibility is that we hear relative differences. We might be able to hear a 1 percent difference which would be 5 Hz at 500 Hz. But we could not hear the difference between 5,000 Hz and 5,005 Hz because the percentage difference is only 0.1 percent. To hear a similar difference at 5000 Hz, Frequency B would have to be 5,050 Hz, which is 1 percent higher.

Which model does the data support?

## 5 Chance and experiments

A very good way to ensure accurate results in a survey test is to make it improbable that anyone could get the correct response by guessing. A single test is almost never enough to rule out this possibility. Consider that on each test you have a 50 percent chance to guess right. That means one out of every two times you could get the right response just by guessing. This is not very reliable!

### The advantage of doing multiple trials

The diagram shows a decision tree for an experiment with multiple trials. There is only one path with no mistakes. With each additional trial, the total number of possible outcomes increases by 2. With two trials you have one right path out of 4 choices. That means there is only a 1 in 4 chance someone could guess twice correctly. With three trials there is only a 1 in 8 chance of guessing. With four trials the chance of guessing is down to 1 in 16.

a. What is the chance of guessing correctly with five trials?

b. If 100 people did a test with five trials, and everybody guessed, how many people would be likely to make five correct choices in a row?
25C Magnification and Mixing Pigments

How is the magnification of a lens determined? What happens when you mix different colors of pigments?

In optics, lenses are optical devices that use refraction to bend light. Some lenses can be used to produce images that are larger than the object they are collecting light from. This process is called magnification and it is used in equipment like microscopes and telescopes to investigate objects that are difficult to see with the naked eye. In this investigation you will look at how distance can affect magnification, and also how mixing materials colored by pigments, paints, or dyes are different than mixing different colors of light.

**Finding the magnification of a lens**

1. Set your light blue lens directly on the graph paper and count the number of *unmagnified* squares that cross the diameter of the lens. In the example, the lens is 10 squares wide.

2. Next, examine a section of graph paper with your lens held above the paper. Move the lens closer and farther away until you have the biggest squares you can still see clearly in the lens.

3. Count the number of *magnified* squares that cross the diameter of the lens. For example, the picture shows 4 1/2 squares across the lens.

4. The magnification can be calculated by dividing the number of *unmagnified* squares by the number of *magnified* squares. In the example, you see 10 *unmagnified* squares and 4.5 *magnified* squares. The magnification is 10 / 4.5, or 2.22.

5. Try the experiment again using a ruler to measure the distance between the lens and the paper. Notice that the magnification changes with different distances.

6. Fill in the table by measuring the magnification of your lens for at least four different distances. The number of squares on the graph paper will be the same for all distances.

<table>
<thead>
<tr>
<th>Distance to paper</th>
<th># of squares on graph paper (unmagnified squares)</th>
<th># of squares in lens (magnified squares)</th>
<th>Magnification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Magnification of a lens**

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA.910.4.2.2</td>
<td>The student will record information and ideas from primary and/or secondary sources accurately and coherently.</td>
</tr>
<tr>
<td>SC.912.N.1.4</td>
<td>Identify sources of information and assess their reliability according to the strict standards of scientific investigation.</td>
</tr>
<tr>
<td>SC.912.P.10.18</td>
<td>Explore the theory of electromagnetism by comparing and contrasting the different parts of the electromagnetic spectrum in terms of wavelength, frequency, and energy, and relate them to phenomena and applications.</td>
</tr>
<tr>
<td>SC.912.P.12.7</td>
<td>Recognize that nothing travels faster than the speed of light in vacuum which is the same for all observers no matter how they or the light source are moving.</td>
</tr>
</tbody>
</table>
2 Thinking about what you observed

a. Is the image in a magnifying glass inverted or upright?

b. At what distances will the lens act like a magnifying glass? What happens when the object is more than one focal length away?

c. Describe something that looks completely different under a magnifying glass than when seen with the un-aided eye.

d. Try the same activity with the dark blue lens. What happens to the image in the lens when you lift it up from the paper?

3 The subtractive color model (CMYK)

1. You have three colors of clay: cyan, magenta, and yellow. Take a portion the size of your fingertip of the both cyan and the magenta. Mix them together. What color do you get?

2. Mix equal amounts of cyan and yellow. What color do you get?

3. Mix equal amounts of yellow and magenta. What color do you get?

The subtractive color model (CMYK)

<table>
<thead>
<tr>
<th>Absorbs</th>
<th>Cyan</th>
<th>Magenta</th>
<th>Yellow</th>
<th>Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Green</td>
<td>Blue</td>
<td>Red, Green, Blue</td>
<td></td>
</tr>
</tbody>
</table>

| Reflects | Cyan, Green | Blue, Red | Red, Green | None               |

Mix equal amounts of the three subtractive primary colors (two colors at a time)
4 Thinking about what you observed

a. Explain how the mixture of magenta and cyan makes its color when seen in white light.

b. Explain how the mixture of cyan and yellow makes its color when seen in white light.

c. Explain how the mixture of yellow and magenta makes its color when seen in white light.

d. Why don’t the mixed colors produce full red, green, or blue?

e. What color would you see if you looked at a mixture of magenta and cyan under a lamp that only made blue light?

f. Research how printers make colors. Do they use red, green, and blue (RGB) or cyan, magenta, yellow, and black (CMYK)? Explain why printed pictures need to use one or the other.

g. Research how computer monitors and televisions make colors. Do they use red, green, and blue (RGB) or cyan, magenta, yellow, and black (CMYK)? Explain why TV’s and computer screens need to use one or the other.

h. Explain why mixing the primary colors of light is referred to as the “Additive Color Mixing Process”, while mixing materials colored with pigments, paints or dyes is referred to as the “Subtractive Color Mixing Process”.

People sometimes confuse the terms astronomy and astrology, much to the dismay of scientists. *Astronomy* is the scientific study of celestial objects such as stars, planets, comets, and galaxies. Astronomers study the physics, chemistry, meteorology, and motion of celestial objects. *Astrology* is completely different. Astrology is not a scientific field of study. Astrology is a group of traditions and beliefs that say the positions of celestial objects can provide information about human personalities and daily life. An astrologer might write a horoscope like the one shown at left. As you can see from this sample horoscope, the general statements could be true and helpful for anyone, not just the reader and the particular birth star she is “born under.” Astrology is not a science, it is a *pseudoscience*. It is important to be able to distinguish between pseudoscience and science.
Pseudoscience

Professor Rory Coker of the Physics Department at the University of Texas offers an entire college course devoted to distinguishing science from pseudoscience. “The word pseudo means fake,” says Professor Coker, “and the surest way to spot a fake is to know as much as possible about the real thing, in this case science itself.” Coker goes on to say:

“When we speak of knowing science, we do not mean simply knowing scientific facts (e.g., the distance from Earth to Sun, the age of Earth, etc.). We mean that one must clearly understand the nature of science itself—the criteria of valid evidence, the design of meaningful experiments, the weighing of possibilities, the testing of hypotheses, and the establishment of useful theories. These are the many aspects of the methods of science that make it possible to draw accurate, reliable, meaningful conclusions about the phenomena of the physical universe.”

Scientific theories

In everyday language, the word “theory” means a vague idea that may or may not be right. You might say “I have a theory to explain why my dog hides when I get out the vacuum cleaner.” In this statement, you are using the everyday meaning of theory. In science, the word theory is used differently. A scientific theory is a comprehensive, well-tested description of how and why a process in nature works the way it does. Usually, one or more natural laws fit into a single comprehensive theory. For example, the classical theory of motion includes Newton’s three laws as well as conservation laws for energy and momentum. It is a common mistake for someone to carry the everyday meaning of theory into a discussion of scientific theory. Don’t be the one to make this mistake!

Questions science can answer

If a question is scientifically testable, science can attempt to answer it. Suppose you have a toy car and a ramp. A scientific question might be “What happens to the speed of the car as it rolls down the ramp?” This question is scientific, because you can collect scientific evidence to answer it. Another question might be “Is this toy car fun to use?” This question does not fit with what science can answer. It is not scientifically testable, since the answer would be based on opinions. Many questions posed in marketing campaigns such as “Which toothpaste is the best?” or “Which soda tastes better?” are not scientific questions. The answers to those questions are based on subjective measures, not on scientific evidence.
Comparing science and pseudoscience

If you know what characterizes true science, if you know what types of questions science can and cannot answer, and if you have carefully read the parts of your science text that cover the scientific method, you are well on your way to distinguishing science from pseudoscience. Dr. Rory Coker offers a direct comparison, feature by feature, between science and pseudoscience. Study the comparisons listed below so you can further understand the difference between science and pseudoscience.

*Science vs. Pseudoscience*

<table>
<thead>
<tr>
<th>Science</th>
<th>Literature is written for scientists, with peer review and rigorous standards for honesty and accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudoscience</td>
<td>Literature is written for general public with no review, standards, or demand for accuracy</td>
</tr>
<tr>
<td>Science</td>
<td>Reproducible, reliable results are demanded and experiments are precisely described</td>
</tr>
<tr>
<td>Pseudoscience</td>
<td>Results cannot be reproduced or verified</td>
</tr>
<tr>
<td>Science</td>
<td>Failures are searched for and studied closely</td>
</tr>
<tr>
<td>Pseudoscience</td>
<td>Failures are ignored, excused, hidden, and avoided</td>
</tr>
<tr>
<td>Science</td>
<td>As time goes on, more and more is learned about the physical processes under study</td>
</tr>
<tr>
<td>Pseudoscience</td>
<td>No actual physical phenomena or processes are found, noticed, or studied</td>
</tr>
<tr>
<td>Science</td>
<td>Convinces by appeal to evidence</td>
</tr>
<tr>
<td>Pseudoscience</td>
<td>Convinces by appeal to faith and belief</td>
</tr>
<tr>
<td>Science</td>
<td>No conflicts of interest; scientist has no personal financial stake</td>
</tr>
<tr>
<td>Pseudoscience</td>
<td>Conflicts of interest; pseudo-scientist generally earns money by selling pseudoscientific services</td>
</tr>
</tbody>
</table>

*used with permission from https://webspace.utexas.edu/cokerwr/www/index.html/distinguish.htm*
Science or pseudoscience?

1. Sir Ian Wilmut, an English scientist, led a research group that in 1996 cloned a sheep. Is this good science or pseudoscience? Do some research to find out. Be sure to cite your sources. Also, list at least three qualities of Sir Ian Wilmut’s work that justify your choice.

2. In 1989, two chemists from the University of Utah, Pons and Fleischmann, discovered cold fusion (an inexpensive way to create a nuclear fusion reaction to produce energy). Is this good science or pseudoscience? Cite your sources and list at least three qualities of Pons and Fleischmann’s work that justify your choice.

3. Your friend visited a fortune-teller. Every prediction the fortune-teller made turned out to be correct. Is this good science or is it an example of pseudoscience? Justify your answer.

4. The Loch Ness monster, Sasquatch, ESP, and flying saucers are all subjects that people have tried to study for years. Even some notable scientists have studied these and similar subjects. However, all of these things qualify as pseudoscience. Why are these topics considered myths or pseudoscience?

5. Study the following questions. Indicate which questions can be answered by science. Justify your choices.
   a. Is there life after death?
   b. How long is a day on Mars?
   c. Does one diet cola taste better than another?
   d. How many atoms are in a sample of 23 grams of sodium chloride?
   e. What is the weather like on Jupiter?
   f. Which animal has the longest migration range on Earth?
   g. Is there gravity on the Moon?
   h. Are red colors easier to see in a painting than blue colors?

6. Dr. Rory Coker, the physics professor mentioned earlier in this tutorial, states on his website: “It is vital for each citizen to distinguish carefully between science and pseudoscience.” Why is it vital for people to distinguish between science and pseudoscience? Support your answer with an example.
**Inverse square relationships**

If you stand one meter away from a portable stereo blaring your favorite music, the intensity of the sound may hurt your ears. As you back away from the stereo, the sound’s intensity decreases. When you are two meters away, the sound intensity is one-fourth its original value. When you are ten meters away, the sound intensity is one-hundredth its original value. The sound intensity decreases according to the **inverse square law**. This law says that the intensity decreases as the square of the distance increases. If you triple your distance from the stereo, the sound intensity decreases to one-ninth of its original value. The intensity of light from a small source such as a light bulb follows an inverse square law also, because its intensity diminishes as the square of the distance increases.

Gravitational and electrical forces also decrease with distance according to the inverse square law. Doubling the distance between two masses or charges reduces the force to one-fourth its original strength. Tripling the distance reduces the force to one-ninth the strength.

If you know the masses of two objects and the distance between their centers, you can calculate the gravitational force between them. Similarly, you can calculate the electrical force between charges if you know the distance between charges and the strength of each charge.
Calculating gravitational force with the law of universal gravitation

The force between two masses \( m_1 \) and \( m_2 \) that are separated by a distance \( r \) is given this way:

When the masses \( m_1 \) and \( m_2 \) are given in kilograms and the distance \( r \) is given in meters, the force has the unit of newtons. The distance \( r \) corresponds to the distance between the center of gravity of one object and the center of gravity of the other object. For example, the gravitational force between two spheres that are touching each other, each with a radius of 0.3 meter and a mass of 1,000 kilograms, is given by the equation below:

The force of gravity between everyday objects is very weak because the gravitational constant (\( G \)) is so small. There is a gravitational force between your pencil and this paper, but it is too weak to feel. We notice gravitational forces only when at least one of the objects has a huge mass. You notice the force of gravity between your pencil and Earth because Earth’s mass is so large. Newton’s law of universal gravitation explains these relationships.

Calculating electrical force with Coulomb’s law

The electrical force between two charges is described by Coulomb’s law. This law is very similar to the law of universal gravitation. Mass is replaced by charge, and the gravitational constant (\( G \)) is replaced by an electrical constant (\( k \)). The electrical force between two charged objects, such as a proton and an electron, is much stronger than the gravitational force. If you compare the two constants you will notice that \( k \) is many times larger than \( G \).

While gravitational forces only attract, electrical forces can attract or repel. When the two charges have the same sign (positive or negative), the force between them is repulsive because like charges repel. When the two charges have opposite signs, the force between them is attractive because unlike charges attract.

The example below shows how to use Coulomb’s law to calculate the strength of the force between two charges.

Question: A 0.001 coulomb charge and a 0.002 coulomb charge are 2 meters apart. Calculate the force between them.

Given

The charges have magnitudes of 0.001 C and 0.002 C.
The charges are 2 m apart.

Looking for

The force between the charges.

Relationships

\[ F = k \frac{q_1 q_2}{r^2} \]

Solution

\[ F = \frac{(9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2) \times (0.001 \text{ C})(0.002 \text{ C})}{(2 \text{ m})^2} \]

\[ F = 4,500 \text{ N} \]

The force is 4,500 newtons.
Practice using inverse square laws (show all work)

1. The gravitational force between two objects depends on their masses. What is the analogous quantity that determines the electrical force between two objects?

2. Two protons have an attractive gravitational force and a repulsive electrical force. Will the net force be attractive or repulsive? Why?

3. What happens to the electrical force between two charges if the distance between them is tripled?

4. What happens to the gravitational force between two masses if the distance between them is quadrupled?

5. What happens to the gravitational force between two masses if the distance between them is cut in half?

6. What happens to the electrical force between two charges if the magnitude of one charge is doubled?

7. What happens to the electrical force between two charges if the magnitude of both charges is doubled?

8. What happens to the gravitational force between two objects if both of their masses double and the distance between their centers is doubled?

9. What happens to the electrical force between two charges if the magnitude of both charges is doubled and the distance between them is cut in half?

10. Calculate the gravitational force between two objects that have masses of 70 kilograms and 2,000 kilograms and are separated by a distance of 1 meter.

11. A man with a mass of 90 kilograms weighs 146 newtons on the Moon. The radius of the Moon is $1.74 \times 10^6$ meters. Find the mass of the Moon.

12. The distance between Earth and the Moon is $3.84 \times 10^8$ meters. Earth’s mass $m$ is $= 5.9742 \times 10^{24}$ kilograms and the mass of the Moon is $7.36 \times 10^{22}$ kilograms. What is the force between Earth and the Moon?

13. A satellite is orbiting Earth at a distance of 35 kilometers. The satellite has a mass of 500 kilograms. What is the force between the planet and the satellite? (Hint: Convert kilometers to meters.)

14. The mass of the Sun is $1.99 \times 10^{30}$ kilograms and its distance from Earth is 150 million kilometers ($150 \times 10^9$ meters). What is the gravitational force between the Sun and Earth?

15. A person is $6.36 \times 10^6$ meters from Earth’s center. What is the person’s mass if the gravitational force on her is 490 newtons? Earth’s mass is $5.9742 \times 10^{24}$ kilograms.

16. Two particles, each with a charge of 1 coulomb, are separated by a distance of 1 meter. What is the force between the particles?

17. What is the force between a 3-coulomb charge and a 2-coulomb charge separated by a distance of 5 meters?

18. Calculate the force between a 0.006-coulomb charge and a 0.001-coulomb charge 4 meters apart.

19. Calculate the force between a 0.05-coulomb charge and a 0.03-coulomb charge 2 meters apart.
20. Two particles each have a charge of $5 \times 10^{-5}$ coulombs. What is the force between the charged particles if the distance between them is 2 meters?

21. The force between a pair of charges is 100 newtons. The distance between the charges is 0.01 meter. If one of the charges is $2 \times 10^{-10}$ coulombs, what is the strength of the other charge?

22. Two equal charges separated by a distance of 1 meter experience a repulsive force of 1,000 newtons. What is the strength in coulombs of each charge?

23. The force between a pair of 0.001-coulomb charges is 200 newtons. What is the distance between them?

24. The force between two charges is 1,000 newtons. One has a charge of $2 \times 10^{-5}$ coulombs, and the other has a charge of $5 \times 10^{-6}$ coulombs. What is the distance between them?

25. The force between two charges is 2 newtons. The distance between the charges is $2 \times 10^{-4}$ meters. If one of the charges is $3 \times 10^{-6}$ coulombs, what is the strength of the other charge?
After you woke up this morning, you probably had breakfast. If you didn’t, you probably became very tired and ran out of energy until you were able to eat lunch. Food is your source of energy. Without food, your body and brain get sluggish.

What is energy anyway? **Energy** is a quantity that describes the ability of an object to change or cause changes. For example, food energy allows you to change your motion or change your mind!

Like your body, devices such as cars and lights require energy. The engine of a car needs gas in order to run. The electric lights in your home require electricity to work. Electricity is provided by energy sources. And if you want your home and school to be heated or air conditioned, energy is required as well.

### Nonrenewable and renewable resources

Since our energy resources come from Earth and the Sun we call them **natural resources**. These resources are divided into two categories. A **nonrenewable resource** is a natural resource that is not replaced as it is used. A **fossil fuel** is an example of a nonrenewable resource. Fossil fuels include gasoline, natural gas, and oil. These resources are nonrenewable because they formed from the remains of dead organisms in Earth’s crust over millions of years. It would take millions of years to replace Earth’s supply of fossil fuels.

A **renewable resource** is a natural resource that can be replaced. The Sun’s energy is an example of a renewable resource. This energy is available in huge quantities and will not get used up any time soon.

### What are your state’s energy resources?

To answer this question, you will take on a role. In that role, you will research and present information about the energy resources that are used in your state. You may pick a role from the list on the next page. The one
you choose will determine your project for how to present your research findings.

<table>
<thead>
<tr>
<th>Role</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Politician</td>
<td>Campaign speech</td>
</tr>
<tr>
<td>Journalist</td>
<td>Article for state newspaper</td>
</tr>
<tr>
<td>Museum educator</td>
<td>One-hour class to a group of students visiting the museum</td>
</tr>
<tr>
<td>TV anchorperson</td>
<td>Segment for the evening news</td>
</tr>
<tr>
<td>Artist</td>
<td>Art installation or performance</td>
</tr>
</tbody>
</table>

**Your energy resources research**

1. Describe your role and your project.
2. Write down a plan for how you will go about answering the question “What are your state’s energy resources?” Come up with three methods. Possible methods include conducting interviews, doing library research, doing Internet research, visiting a power plant, and reading pertinent newspapers and magazines.
3. Before beginning your research, set up a research notebook.
   a. In your notebook, write one to two paragraphs that describe what you already know about your state’s energy resources. For example, does your state rely on renewable or nonrenewable resources?
   b. Write down at least three questions you want to answer regarding your state’s energy resources.
4. Now you are ready to begin your research. Be sure you use all three methods of research that you listed.
5. Once you have completed your research, create an outline in your notebook for how you will present your research. Note: Don’t forget that graphics and charts can help you present your findings. Show your outline to a friend or your teacher and get feedback.
6. Use the feedback to improve your outline. Then finish your project and present it to your class.

**Reflection questions**

7. How well did playing your role help you find the information you needed?
8. Would the role you chose be a good career choice for you? Why or why not?
9. Does your state depend on nonrenewable resources, renewable resources, or both? Give some examples.
10. List three things you learned about energy resources in your state.
11. Conservation of resources is an important topic. Write one to two paragraphs that describe how your state is working to conserve its energy resources.
12. List one question that you still have that you would like to answer. Discuss this question in class or with a friend.
You have learned that all matter is made up of atoms, and that atoms are made up of protons, neutrons, and electrons. But did you ever wonder how humans figured that out? It’s a fascinating story. It starts thousands of years ago, with ordinary people around the globe asking questions like these:

- How does a tree grow from a tiny seed, earth, and water?
- Is the tree made of earth and water?
- Does a tree turn back into earth when it burns?

In this tutorial, you’ll find out about how different cultures answered these questions. You’ll learn how their answers led to new questions that could be answered only through careful observation and experiments. The process of questioning, observing, and experimenting led to some remarkable discoveries about atomic structure. The process has also raised many new questions that we have yet to answer.
Early ideas about matter: India

In India, writings from the Samkhya-system of the sixth century BCE describe five elements: earth, water, fire, air, and ether, that form the sum and substance of the physical universe. The writings explain that the differences between objects such as stones, gold, silver, and trees, are neither permanent nor fundamental, because all objects are made up of the five elements. It goes on to explain that even these five elements are not totally separate things, but are five degrees of density of a basic “cosmic substance.”

Early ideas about matter: Greece

In Greece, philosopher Empedocles of Acragas (495–435 BCE) also attempted to answer questions about the basic building blocks of matter. He explained that everything we see is made up of four elements: fire, water, air, and earth. Each of these elements, said Empedocles, is particular (separate) and indestructible, and the amazing diversity of objects around us can be attributed to differences in the ratio of these elements present in each object.

In 350 BCE, another Greek philosopher, Aristotle, described Empedocles’ explanation as the best one by which to understand what makes up the physical world. Aristotle greatly influenced the western European understanding of matter for 1,500 years after his death.

While there are subtle differences among the ancient Chinese, Indian, and Greek teachings about matter, the similarities between these explanations are striking. Each culture independently asserted that everything we see is made of different proportions of a small number of elements, and that the amazing diversity of objects on Earth can be attributed to differences in the ratios of the elements they contain.

Think about it

1. The ancient Chinese, Indian, and Greek texts each list basic elements from which all things on Earth are made. Which elements are common to all three texts?

2. Based on your observations of the natural world, why do you think all three cultures included these
elements? Describe what the ancients thought accounted for different kinds of matter.

Beginnings of atomic theory

In 430 BCE, the Greek philosopher Leucippus and his pupil Democritus continued the discussion of matter and its building blocks. They theorized that an object can be divided into smaller and smaller pieces, to a certain point. However, an object cannot be divided infinitely, because if it could be, all matter could completely disintegrate and there would be nothing left of the world.

Instead, they reasoned, if an object is divided and divided, eventually it must end up as tiny, solid, indivisible particles. They called these particles atomos, which means “uncutable.” Leucippus and Democritus went on to suggest that there must be empty space—a void—between these particles so that they can move around. All changes in matter, they proposed, is due to rearrangement of these basic particles.

While the ideas of Leucippus and Democritus were never completely lost during the following 2,300 years, their atomic theory remained outside the mainstream of western philosophy and science until English scientist John Dalton revived the idea in 1803.

Early experiments: The Lavoisiers

The ideas of Leucippus and Democritus were just that: ideas. Their explanation that all matter is made up of tiny, indivisible, independent particles began to take hold again in the early 1800s because it helped make sense of observations and experiments. In the last half of the 1700s, the French scientist Antoine Lavoisier and his wife, Marie-Anne Paulze, were convinced that they could learn more about what happened when two substances combined in a chemical reaction if they could make better measurements. They invented an accurate balance.

Through experimentation and careful record-keeping, they discovered the law of conservation of mass: in a chemical reaction, the total mass of the reacting substances is equal to the total mass of all of the products formed. Their widely-read book, The Elementary Treatise on Chemistry, was immensely important not only because it explained the law of conservation of mass, but because it elevated the importance of evidence gained through careful, detailed, repeatable experiments.

Early experiments: Proust

In 1797, another French scientist, Joseph Proust, reported that for every reaction he studied, the reacting substances combined in a consistent ratio. For example, no matter how much copper, carbon, and oxygen he started with, the copper carbonate
compound that resulted when they reacted was 5.3 parts copper to 4 parts oxygen to 1 part carbon by weight. He called this the law of constant composition.

**Early experiments: Dalton**

When English Scientist John Dalton read and studied the works of these scientists, he began to think of ways to explain what was going on in their experiments. He concluded that the reacting elements must be made of tiny, indivisible, independent particles that can be rearranged in chemical reactions. These particles, he explained, combine in simple and predictable ratios. He used the Greek word atoms to describe these particles.

Dalton did some experimenting of his own and figured out that two elements can combine in a chemical reaction in different ways. For example, he found that nitrogen and oxygen can combine to form nitrous gas (one nitrogen atom + one oxygen atom), or nitric acid (one nitrogen atom + two oxygen atoms) or nitrous oxide (two nitrogen atoms + one oxygen atom).

Dalton showed that each combination resulted in the formation of a separate chemical. The law of constant composition held true for each individual chemical that was formed. From his work, Dalton derived the **law of multiple proportions**, which states that atoms of the same element can unite in more than one simple ratio with another element, but each ratio forms a separate chemical compound.

Dalton’s experiments provided further evidence that elements must be made of simple, indivisible particles that can combine, separate, or rearrange in different patterns during chemical reactions.

In 1808, Dalton published *A New System of Chemical Philosophy*, in which he explained his bold new atomic theory. It contained these main points:

- All matter is made of tiny, indivisible particles called atoms.
- All atoms of the same element have the same mass and are identical in every way.
- Each element is made of a different kind of atom. Atoms of different elements have different masses.
- In a chemical reaction, atoms are rearranged to form different kinds of molecules. No atoms are created or destroyed.
- Atoms of different elements combine in simple whole-number ratios, with more than one ratio being possible for a given set of elements.

Although scientists still accept much of Dalton’s theory, Dalton didn’t get everything right. Today we know that atoms are not indivisible, but are made of smaller particles. Atoms are not indestructible, but can be split. Not all of the atoms of a given element are exactly identical.

Dalton also proposed a “rule of greatest simplicity”, which stated that if only one compound formed from elements A and B, it had to be one A plus one B. If two compounds formed from elements A and B, the second compound could be two A’s and one B or two B’s and one A.

Dalton insisted, therefore, that since water was the only known compound formed by hydrogen and oxygen, it must be formed from one hydrogen and one oxygen.
An atomic puzzle: How do you make water?

However, experiments by other scientists, such as Frenchman Joseph Gay-Lussac and Amadeo Avogadro of Italy, were suggesting that Dalton was not completely right. Gay-Lussac proved that when hydrogen and oxygen combine to form water vapor, two volumes of hydrogen plus one volume of oxygen produce two volumes of water vapor.

Avogadro repeated these experiments and concluded that equal volumes of gas at the same temperature and pressure must contain the same number of molecules, no matter what kind of gas.

This idea made sense if hydrogen and oxygen existed not as single atoms, but as molecules of two atoms joined together. Then, it could be shown that two hydrogen molecules plus one oxygen molecule produce two water molecules. Therefore, the formula for water must be two hydrogen atoms + one oxygen atom.

Dalton thought that this arrangement was impossible, because he imagined that in a gas, atoms were stacked up like, in his words, “a pile of shot.” Since he had already concluded that different atoms had different weights, he figured that they must vary a lot in size, too. So if oxygen atoms were much bigger than hydrogen atoms, fewer oxygen atoms would fit into the same size container. He also didn’t think two atoms of the same element were likely to combine. Gay-Lussac and Avogadro, on the other hand, reasoned that there must be empty space between atoms or molecules in a gas. In this case, varying sizes wouldn’t make it impossible to have the same number in each container. Their evidence, they said, showed that two atoms of the same element did combine, at least in the case of hydrogen and oxygen.

Dalton’s insistence that there were no empty spaces between atoms or molecules and Avogadro’s reasoning that these empty spaces must exist became a disagreement that scientists wrestled with for over fifty years. After all, atoms and molecules can’t be seen. Their very existence can’t be directly observed, even today. Scientist puzzled over clues present in their experiments, tested hypotheses, and discussed their results.

Finally, in 1860, an Italian scientist named Stanislao Cannizzaro re-argued the position of Avogadro before a scientific convention in Karlsruhe, Germany, and the
scientific community largely came to favor the idea that hydrogen and oxygen molecules did exist in pairs and confirmed that the formula for water could be two hydrogen atoms + one oxygen atom. The possibility of empty spaces between atoms and molecules gained acceptance.

**Think about it**

3. How did Lavoisier and Paulze-Lavoisier’s invention contribute to our understanding of atoms as the building blocks of matter?

4. Dalton, Gay-Lussac, and Avogadro all tried to imagine how hydrogen and oxygen atoms combine to make water. Draw a picture to show how Dalton’s idea differed from that of Gay-Lussac and Avogadro.

**The puzzle of the inside of the atom**

In the years since 1860, scientists have continued to probe the nature of matter and have learned a great deal about what is inside an atom. Experimental evidence now leads us to conclude that not only is there space between atoms of a gas, but that atoms themselves are mostly empty space!

**The electron**

In 1897, an English physicist named J.J. Thomson observed that streams of particles carrying electricity could be made to come from different gases placed in tubes. Thomson identified a negatively charged particle he called the *electron*. These electrons must have come out of atoms, he reasoned. This was the first solid evidence that atoms were something different from the solid, featureless spheres that Dalton had described. Thomson proposed that the atom was a positive sphere with negative electrons embedded in it “like raisins in a bun.”

**Mysterious rays**

In that same year, a young Polish woman, Marie Curie, began working on her doctoral thesis at the University of Paris (also called the Sorbonne). For her research topic, she chose uranium rays, which had been discovered recently by French physicist Henri Becquerel. After reading Becquerel’s report that uranium compounds emitted some sort of ray that fogged photographic plates, Marie Curie decided to research the effect these rays had on the air’s ability to conduct electricity.

Marie Curie confirmed that the electrical effects of the uranium rays were similar to the photographic effects that Becquerel reported—both were present whether the uranium was solid or powdered, pure or in compound, wet or dry, exposed to heat or light. She concluded that the emission of rays by uranium was not the product of a chemical reaction, but could be something built into the very structure of uranium atoms. This idea was truly revolutionary, because most scientists still thought of atoms as tiny, featureless particles. As a result of this work, in 1903, Marie Curie became the first woman to share a Nobel Prize in Physics.
Back in England, J.J. Thomson was intrigued by Marie Curie’s work. He asked his research assistant, New Zealand native Ernest Rutherford, to investigate the nature of these mysterious uranium rays. Rutherford exposed the rays to a strong magnetic field. In 1898 he described two kinds of particles that made up these rays. The first kind was attracted to the negatively charged terminal, which suggested that it was positively charged. Rutherford called these alpha particles. The second kind of particle was attracted to the positively charged terminal. Rutherford called these beta particles. He found that they were very much like J.J. Thomson’s electrons. We now know they are electrons.

Later, a third type of ray was identified. It was not bent at all by the magnetic field. This mysterious type of ray was called a gamma ray. It is now known to be an emission of energy from an atom. Unlike alpha and beta rays, gamma rays don’t release subatomic particles.

In 1898, Rutherford accepted a professorship at McGill University in Montreal, Canada. It was there he proved that when alpha particles are emitted from a radioactive element, a piece of the atom is expelled, causing the element to decay into another kind of element. This finding was revolutionary. Atoms could change into other kinds of atoms! Rutherford received the Nobel Prize in Chemistry in 1908 for this work.

Rutherford returned to England in 1907, to Manchester University. There he used spectroscopy to figure out that the alpha particles were, in fact, helium ions. Thanks to the work of Thomson, Curie, Rutherford, and others, scientists now understood that atoms must be made of smaller particles. Atoms could emit electrons, and some atoms could even eject helium ions and decay into other kinds of atoms. However, little was known about how the inside of an atom was organized.

The nucleus

In 1909, Rutherford and two Manchester University students did an experiment to learn more about the internal structure of atoms. They launched alpha particles at a very thin gold foil. They expected most of the alpha particles to be deflected a little as they plowed through the gold atoms.

They found something unexpected. Most of the alpha particles passed right through the foil with no deflection at all. Even more surprising, a few bounced back toward the source! The unexpected result prompted Rutherford to remark, “It was as if you fired a fifteen-inch (artillery) shell at a piece of tissue paper and it came back and hit you in the head!”
The best way for Rutherford to explain the pass-through result was if the gold atoms were mostly empty space. If most of the alpha particles hit nothing, they wouldn’t be deflected. The best way to explain the bounce-back result was if nearly all the mass of a gold atom were concentrated in a tiny, dense core at the center. Further experiments confirmed Rutherford’s ideas, which he published in 1911. We now know that every atom has a tiny nucleus that contains more than 99 percent of the atom’s mass.

**The Bohr model**

In 1912, a Danish physicist named Niels Bohr went to England to study under Ernest Rutherford. Rutherford had recently published his new “planetary” model of the atom, which explained that an atom has a tiny dense core surrounded by orbiting electrons. Bohr began researching more about electrons. Bohr studied the quantum ideas of Max Planck and Albert Einstein as he sought to describe the electrons’ orbits. In 1913, he published his results. He proposed that electrons traveled only in specific orbits. The orbits are like rungs on a ladder, he said—electrons can move up and down orbits, but do not exist between the orbital paths. He explained that outer orbits could hold more electrons than inner orbits, and that many chemical properties of the atom were determined by the number of electrons in the outer orbit.

Bohr also described how atoms emit light. He explained that an electron needs to absorb energy to jump from an inner orbit to an outer one. When the electron falls back to the inner orbit, it releases that energy in the form of visible light.

**Inside the nucleus**

In 1917, Rutherford made another discovery. He bombarded nitrogen gas with alpha particles and found that occasionally an oxygen atom was produced. He concluded that the alpha particles must knock a positively charged particle (which he named the proton) from the nucleus of a nitrogen atom. He called this “playing with marbles,” but word quickly spread that he had become the first person to split an atom. But there still was a serious problem with this atomic model—protons could account for only about half the observed mass in the nucleus. This problem was solved in 1932 by British physicist James Chadwick, another of Rutherford’s students. Chadwick bombarded a thin sheet of beryllium metal with alpha particles. On the opposite side of the beryllium was a sheet of paraffin. Chadwick was able to detect that protons were being ejected from the paraffin, even though no charged particles (alpha or beta rays) seemed to be coming out of the beryllium. His experiment suggested the existence of a third type of subatomic particle, massive enough to push protons around, but with no electric charge. Chadwick called this particle the neutron. The nucleus’s missing mass could now be explained.

**Think about it**

5. What evidence did J.J. Thomson give for saying that Dalton was wrong when he described atoms as tiny, indivisible, featureless spheres?

6. What evidence did Ernest Rutherford have to back up his suggestion that J.J. Thomson was wrong when he described the atom as a positive sphere with negatively charged electrons embedded “like raisins in a bun”?
7. Describe how Rutherford split an atom. Which subatomic particle was discovered as a result?

Quantum theory
The Bohr model led to a new way of thinking about energy in systems as small as an atom. A quantum is an amount of something that cannot be divided any smaller. One electron is a quantum of matter because you can’t split an electron. Quantum theory says that when a particle (such as an electron) is confined to a small space (inside an atom), the energy, momentum, and other variables of the particle become quantized, which means they can have only certain specific values.

In 1925, Austrian physicist Erwin Schrodinger proposed the quantum model of the atom that we still use today. The quantum model is based on thought experiments and mathematical models rather than on laboratory experiments like those carried out by Rutherford and his associates. Still, the quantum model helps us to understand real-world phenomena, like why molecules form particular shapes.

The quantum model of an atom describes the nucleus as a tiny center of mass containing all of the protons and neutrons. However, instead of describing an electron as a particle moving around the nucleus, in the quantum model the electron dissolves into a fuzzy cloud of negative charge called a quantum state. The quantum state spreads the electron out into a three-dimensional cloud with a shape that depends on the electron’s energy level and location within its energy level. The second energy level has eight quantum states, one for each of the eight electrons that the level can hold.

The illustration above shows the shapes of these eight quantum states. These shapes are important because they determine the shape of molecules formed by the atom. According to the quantum model, two electrons can never be in the same quantum state at the same time. This rule is known as the Pauli exclusion principle after Austrian physicist Wolfgang Pauli. The exclusion principle explains why an electron cannot fall to a lower energy level if that level is already filled by other electrons. Once all the quantum states in the first energy level are occupied, the electron has to go into a higher energy level.

Think about it
8. How was the development of the quantum model of the atom different from the development of earlier models proposed by Dalton, Thomson, and Rutherford?

9. Give an example of how the quantum model can be used to help us understand something in the physical world.
Splitting an atom

In the 1920s and 1930s, amazing gains were made in our understanding of the atomic world. Schrödinger, Pauli, and others were using mathematical models and “thought experiments” to develop the quantum theory of atomic structure. Meanwhile, other European physicists continued to carry out laboratory experiments to deepen their understanding of the nucleus.

In 1934, an Italian scientist named Enrico Fermi wanted to see if he could create heavier isotopes of uranium. Ordinary uranium, called uranium-238, has 92 protons and 146 neutrons. Fermi tried bombarding uranium-238 with slow-moving neutrons. He reasoned that if the uranium nuclei captured the neutrons, he would create a new, heavier uranium isotope. However, he found the experimental results puzzling. It appeared that the bombardment resulted in two new products, but he couldn’t figure out what they were. They didn’t have the chemical characteristics of uranium.

At the Kaiser Wilhelm Institute for Chemistry in Berlin, an Austrian physicist named Lise Meitner collaborated with German chemists Otto Hahn and Fritz Strassmann to study radioactive substances. They were intrigued by Fermi’s experiment, and decided to perform some tests on the mysterious products. Their research was interrupted in 1938 when Nazi Germany annexed Austria and restrictions on “non-Aryan” academics tightened. Because of her Jewish heritage, Meitner was no longer safe in Berlin and she went into exile in Sweden. Meitner corresponded with her coworkers and suggested some new tests for them to try. When these tests showed that one product was barium, the group was puzzled. Barium was so much smaller than uranium. Otto Hahn wrote to Meitner that uranium “can’t really break into barium...try to think of some other possible explanation.”

Meitner worked with her nephew Otto Frisch, who was also in Sweden, on the problem. They proved that splitting the uranium atom was energetically possible. Using Niels Bohr’s model of the nucleus, they explained how the neutron bombardment could cause the nucleus to elongate into a dumbbell shape. Occasionally, they explained, the narrow center of the dumbbell could separate, leaving two nuclei. Meitner and Frisch called this process nuclear fission.

The nuclear age

By early 1939, scientists knew that neutron bombardment could split a uranium atom into barium and krypton atoms, and that this process also released one or more neutrons and a small burst of energy. It was soon evident to physicists that the neutrons released by one uranium atom could be used to split other uranium atoms, and their released neutrons could split more uranium atoms. With each split, more energy would be released. Once this “chain reaction” was started, a very powerful explosion could be created.
It was not an easy decision for these physicists to use their knowledge and skills to build something with such destructive capabilities. Einstein, Bohr, and Fermi all wrote about how they wrestled with the moral implications. Each felt that the creation of the atomic bomb was necessary in the face of the Nazi threat, but after World War II ended, they expressed concern about its future implications and supported disarmament efforts.

Since then, controlled fission reactions have been harnessed for a peaceful enterprise, as a source of electrical power production. But energy production from nuclear fission continues to be controversial because it leaves behind harmful radioactive waste. Researchers are currently exploring the possibility of creating nuclear fusion reactors. Instead of splitting atoms, fusion reactors would join two hydrogen isotopes into an isotope of helium.

These fusion reactions, which happen constantly in the Sun, produce a great deal more energy than fission reactions, without radioactive waste. However, on Earth we would need to generate temperatures of about 100 million degrees Celsius to create hydrogen fusion for energy production. The high temperature is necessary to overcome the difficulty of forcing positively charged protons together. With current technology, it simply takes too much energy to actually produce energy from nuclear fusion for human needs. But perhaps one day these challenges will be overcome.
Think about it

10. What surprising fact did Lise Meitner, Otto Hahn, and Fritz Strassmann find about a product of Fermi’s uranium experiment?

11. How did Meitner and her nephew Otto Frisch explain these surprising results?

12. What is produced when uranium is bombarded with slow-moving neutrons?

13. Define chain reaction.

14. How was nuclear fission used to create an atomic bomb?

15. Research: Like Einstein, Bohr, and Fermi, Lise Meitner and Otto Hahn also wrestled with the destructive potential of their discoveries. Write a paragraph that explains the position that these two scientists held concerning the development of the atomic bomb.

16. Research: Find out about one current nuclear fusion research project. What progress has been made? What challenges remain?
Oxidation-reduction reactions
When was the last time you used a battery? Many common devices and machines we use every day contain batteries: mobile phones, flashlights, automobiles, and watches are just some examples of things that are battery-powered. A battery transforms chemical energy into electrical energy. The chemical reactions that accomplish this are known as oxidation-reduction reactions, or redox reactions for short. Redox reactions are also responsible for combustion reactions, respiration and photosynthesis, electroplating reactions, and corrosion reactions. Let’s take a close look at how redox reactions work.

What is a redox reaction?
All reactions in which a substance undergoes an increase in oxidation number, such as by gaining electrons. The loss of electrons by one substance and the simultaneous gain by another substance makes up an oxidation-reduction pair, also known as a redox reaction. It is often necessary and helpful to figure out which substance in a redox reaction is the one being oxidized, and which one is being reduced. How do you figure this out? Here is an example:

\[ 2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO} \]

In the reaction above, magnesium reacts with oxygen to form magnesium oxide. Each magnesium atom loses 2 electrons to become a magnesium ion (\(\text{Mg}^{2+}\)). Each oxygen atom gains two electrons and becomes an oxide ion (\(\text{O}^{2-}\)). You can figure this out by looking at magnesium’s place on the periodic table. Elements in group 2 tend to lose 2 valence electrons to become (2+) ions. Elements in oxygen’s group tend to gain two valence electrons to become (2-) ions. Thus, magnesium is oxidized, and oxygen is reduced in this redox reaction. To determine which substance in a redox reaction is oxidized and which is reduced, you need to learn how to assign oxidation numbers. The
next section will review that process and some helpful rules.

Determining oxidation numbers

These rules will help you assign oxidation numbers to substances in simple redox reactions so you can determine which substance is oxidized and which is reduced. Knowing what is oxidized and what is reduced in a redox reaction is a first step in being able to eventually figure out whether two substances are likely to react with each other, and if so, how they will react. Analyzing redox reactions is important to chemists who are designing reactions for batteries that convert chemical energy to electrical energy, as in electrochemical cells. Study the oxidation number assignment rules below, and refer to these rules when you are working through the practice problems in this tutorial.

ASSIGNING OXIDATION NUMBERS

1. The oxidation number of an atom in a molecule of an element is 0. The oxidation number of oxygen in O₂ is 0.

2. The oxidation number of a monoatomic ion is the charge on the ion. The oxidation number of a calcium ion is 2+.

3. Conventionally assigned oxidation numbers for atoms combined in common chemical compounds (there are exceptions) are:
   a. Oxygen = 2–
   b. Hydrogen = 1+
   c. Group 1 elements = 1+
   d. Group 2 elements = 2+
   e. Group 17 elements in binary compounds = 1–

4. When needed, use charges on polyatomic ions as shown in Table 1.

5. The sum of positive and negative oxidation numbers in a compound is 0. So, a single oxidation number of a single unknown atom in a compound is determined by:
   a. Assigning a common oxidation number (see rules 1–3) to all but the unknown atom.
   b. Adding the total oxidation numbers of all but the unknown atom. Don’t forget to multiply oxidation numbers by subscripts when necessary.

The oxidation number of the unknown atom is the charge which must be assigned to make the overall compound have a zero charge.

<table>
<thead>
<tr>
<th>Ion</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₄</td>
<td>2–</td>
</tr>
<tr>
<td>OH</td>
<td>1–</td>
</tr>
<tr>
<td>NO₂</td>
<td>1–</td>
</tr>
<tr>
<td>NO₃</td>
<td>1–</td>
</tr>
<tr>
<td>CO₃</td>
<td>2–</td>
</tr>
</tbody>
</table>

Sample analysis

You can find examples of redox reactions almost every time you have a reaction that is used as a source of heat. Many people heat their homes with natural gas. When natural gas undergoes combustion, the following redox reaction occurs:

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]

Which reactant is reduced and which is oxidized? To find out, you need to see how the oxidation number for each substance changes. The one that undergoes an increase in oxidation number is oxidized. The one that undergoes a decrease in oxidation number is reduced. You can see in the illustration below that oxygen is reduced and the methane (natural gas) compound is oxidized. There is a lot of heat energy produced with this redox reaction.
Everyday redox reactions

We encounter redox reactions regularly in daily life. The chemical reactions in our bodies that metabolize sugar and fat are redox reactions. The tarnish that forms on silver metal and rusty iron is the result of redox reactions. Photosynthesis, the important energy-producing process in plants, involves a series of redox reactions. Any reaction in which at least one type of atom has a change in oxidation state is a redox reaction.

Practice identifying oxidation states (be sure to have a periodic table for reference)

1. Fill in the table below with the correct oxidation states. Each blank box should have an element symbol and its oxidation state next to it.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Atom 1</th>
<th>Atom 2</th>
<th>Atom 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al$^{3+}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N$_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_3^-$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FeCl$_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N$_2$O$_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO$_4^-$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H$_2$SO$_4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HNO$_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Study this reaction and answer the questions that follow:

\[2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}\]

a. In this reaction, the oxidation state of magnesium changes from _________ to _________.

b. Is magnesium reduced or oxidized? ____________________.

c. In this reaction, the oxidation state of oxygen changes from _________ to _________.

d. Is oxygen reduced or oxidized? ____________________.
3. Study this reaction and answer the questions that follow:

\[ 4\text{Li} + \text{O}_2 \rightarrow 2\text{Li}_2\text{O} \]

a. In this reaction, the oxidation state of lithium changes from _________ to _________.
b. Is lithium reduced or oxidized? ____________________.
c. In this reaction, the oxidation state of oxygen changes from _________ to _________.
d. Is oxygen reduced or oxidized? ____________________.

Types of redox reactions (be sure to have a periodic table for reference)

4. One of the simplest types of redox reactions is a combination reaction. When the elements are combined to form a compound, one element is reduced and the other is oxidized. One example of an interesting combination reaction happens in a hydrogen fuel cell. This fuel cell can produce electricity from fuel in a tank. Researchers are working to see whether they can replace a vehicle’s internal combustion engine that runs on gasoline with an environmentally friendly fuel cell that powers an electric car. The simple fuel cell reaction combines hydrogen and oxygen. The products are energy and water.

\[ 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{energy} \]

a. In this reaction, the oxidation state of hydrogen changes from _________ to _________.
b. Is hydrogen reduced or oxidized? ____________________.
c. In this reaction, the oxidation state of oxygen changes from _________ to _________.
d. Is oxygen reduced or oxidized? ____________________.

5. Another type of redox reaction is a decomposition reaction, in which a compound is decomposed into its constituent elements (not all decomposition reactions involve a change in oxidation state of the atoms involved; those that do not would not be classified as redox). Water can be decomposed into hydrogen and oxygen gas when an electric current is provided. This process is known as electrolysis of water. This energy-intensive process can be used to produce hydrogen gas that is needed for other purposes, but most of the hydrogen used worldwide is produced from fossil fuels.

\[ 2\text{H}_2\text{O} + \text{energy} \rightarrow 2\text{H}_2 + \text{O}_2 \]

a. In this reaction, the oxidation state of hydrogen changes from _________ to _________.
b. Is hydrogen reduced or oxidized? ____________________.
c. In this reaction, the oxidation state of oxygen changes from _________ to _________.
d. Is oxygen reduced or oxidized? ____________________.
6. In a *displacement reaction*, an element takes the place of another element in a compound. An interesting and popular example of a displacement reaction that your teacher might demonstrate for you is the redox reaction between silver nitrate and copper. If you place a copper wire in a silver nitrate solution, the copper will displace the silver, and you will be able to see the solution change color. You will end up with copper nitrate and silver.

\[
Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag
\]

da. In this reaction, is copper oxidized or reduced? _______________________________

db. Explain how you arrived at your answer for the previous question.

**Putting it all together**

7. Study each reaction and fill in the table with the missing information. For “type of reaction,” choose combination, decomposition, or displacement.

<table>
<thead>
<tr>
<th>Redox Reaction</th>
<th>Substance reduced</th>
<th>Substance oxidized</th>
<th>Type of reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2KClO_3 \rightarrow 2KCl + 3O_2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2HCl + Zn \rightarrow ZnCl_2 + H_2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fe_3O_4 + 4CO \rightarrow 3Fe + 4CO_2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2HgO \rightarrow O_2+ 2Hg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2Ba + O_2 \rightarrow 2BaO)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4Ag + 2H_2S + O_2 \rightarrow 2Ag_2S + 2H_2O)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Research

There are many examples of redox reactions that occur in daily life.

8. Choose one of the reactions below and list it here: ____________________________________________
   
   electrochemical, dry cell battery reaction, corrosion, combustion, metabolism, bleaching, or photosynthesis

   a. What is a chemical equation that describes the process you chose?
   b. What is oxidized, and what is reduced in this process?
   c. Does this process involve one chemical reaction or a series of reactions? Explain.
   d. Describe how this redox reaction works, and how it is useful for daily living.
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**The discovery of nuclear fission**

In the early 1900s, many scientists throughout the world were conducting research to discover the inner workings of the atom. New Zealander Ernest Rutherford was one of these early pioneers. In 1911 he came up with the planetary model of the atom. He described the atom as having most of its mass concentrated in the positive nucleus that is orbited by negative electrons, similar to the way planets orbit the Sun. Rutherford performed many experiments with atoms and is credited with being the first person to observe the splitting of a nucleus. He succeeded in 1917 when he knocked a proton out of a nitrogen atom.

Two of Rutherford’s students, Ernest Walton and John Cockcroft, performed the first controlled experiment to split a nucleus, in 1932. They designed equipment that allowed them to use fast-moving protons to split lithium atoms to create helium.

Enrico Fermi, an Italian physicist, conducted experiments in the 1930s that involved bombarding different elements with slow-moving neutrons. These experiments created elements with higher atomic numbers than the original elements. At this time, uranium (atomic number 92) was the largest element that had been discovered. In 1934, Fermi decided to conduct his experiment with uranium as the target. He hoped to create an element with an atomic number greater than uranium, called a **transuranic element**. After performing the experiment, he was not able to fully prove that he had created an element with an atomic number above 92. However, many scientists at the time believed that he had achieved his goal.

German chemist Ida Noddack criticized Fermi’s analysis of his results. She believed that instead of creating a larger atom, Fermi might have split the uranium atom apart, a process later named **nuclear fission**. Scientists at this time believed it was impossible to knock more than a single proton out of a nucleus, so most did not take Noddack’s argument seriously.

Austrian Lise Meitner and German Otto Hahn met in
Berlin in 1907 and had been doing research on atoms for 30 years. They read Noddack’s paper and thought she might be correct. Along with Hahn’s assistant Fritz Strassman, they repeated Fermi’s uranium experiment. In 1938 they began to believe they had split uranium atoms apart, as Noddack had suggested.

Meitner was of Jewish ancestry, and she knew it was not safe to remain in Germany once the Nazis took power. Two Dutch physicists helped her escape to Holland in July of 1938. She eventually made it to Stockholm, Sweden, where she found a position in a physics laboratory and so could continue her work.

In November of 1938, Hahn and Meitner secretly met in Copenhagen, Denmark, to exchange data and plan further experiments for Hahn and Strassman to carry out. They corresponded through letters as they analyzed data from the new experiments. Hahn believed barium (atomic number 56) was one of the products created when a uranium atom was struck by a neutron and split apart. Meitner’s nephew, physicist Otto Robert Frisch, was living in Copenhagen at the time. He and Meitner met at the end of 1938 and worked together to explain the results of the uranium experiment. Frisch also repeated the experiment and confirmed that barium was created.

The political situation made it impossible for Meitner and Hahn to publish the results together. Hahn and Strassman wrote an article focusing on their experimental procedure and the proof that barium had been created from uranium. Their article appeared in the German journal *Naturwissenschaften* on January 6, 1939. Meitner and Frisch published a separate article that explained the physics behind the experiment and first used the term nuclear fission. It appeared in the British journal *Nature* on February 11, 1939.

In 1944, Hahn was awarded the Nobel Prize in Chemistry for discovering nuclear fission. Many believe that Meitner should have shared the prize with Hahn. In 1966, Meitner, Hahn, and Strassman were awarded the Enrico Fermi Award, a prestigious prize given by the U.S. government to scientists who have made achievements in the field of energy.

The physics of nuclear fission

A fission reaction splits a large nucleus into smaller pieces. For elements heavier than iron (atomic number 26), breaking up the nucleus into smaller pieces releases nuclear energy. For certain atoms, the amount of energy released is huge. For example, a kilogram of uranium can release approximately 123 trillion joules (TJ) of nuclear energy!

The graph above shows how the energy of an atom’s nucleus is related to its atomic number. A fission reaction splits the uranium nucleus into two pieces, both with a smaller atomic number and less energy than the original atom. It also releases a single neutron. For example, one possible result of splitting a uranium-235 atom is the creation of a molybdenum-99 atom, a tin-135 atom, and a neutron. If a kilogram of uranium-235 atoms are split, the total energy contained in the nuclei of the resulting molybdenum-99 and tin-135 atoms is only 25 trillion joules. The fission of a kilogram of uranium releases the difference in energies, or 98 trillion joules. This amount of energy from a golf-ball-sized piece of uranium is enough to drive an average car 19 million miles!
A fission reaction typically happens when a neutron hits a nucleus with enough energy to make the nucleus unstable. Fission breaks the nucleus into two smaller pieces and often releases one or more extra neutrons. Some of the energy released by the reaction appears as gamma rays and some as kinetic energy of the smaller nuclei and the extra neutrons. For example, a possible fission reaction for uranium-235 is shown in the diagram above.

Mass and energy are conserved together but not separately in nuclear reactions, because nuclear reactions can convert mass into energy. If you could take apart a nucleus and separate all of its protons and neutrons, the separated protons and neutrons would have less mass than the nucleus does when it is all together. This bizarre fact is explained by Einstein’s formula \( E = mc^2 \), which tells us that mass \( (m) \) can be converted to energy \( (E) \). The mass of a nucleus is reduced by the energy that is released when the nucleus breaks apart.

A chain reaction occurs when the fission of one nucleus triggers fission of many other nuclei. In a chain reaction, the first fission reaction releases two (or more) neutrons. The two neutrons hit two other nuclei and cause fission reactions that release four neutrons. The four neutrons hit four new nuclei and cause fission reactions that release eight neutrons. The number of neutrons increases rapidly. The increasing number of neutrons causes more nuclei to have fission reactions and releases an enormous amount of energy. The chain reaction stops only when all the original material is used up.

In a conventional nuclear power plant, the uranium-235 fission reaction is used to generate electricity. The process of getting electricity from nuclear reactions takes many steps. Nuclear reactions with uranium produce heat in the reactor core. The heat from the core boils water and makes steam that turns a turbine. The turbine is connected to an electric generator that makes electricity.
Practice applying fission concepts

1. Why was Rutherford’s model of the atom called the *planetary model*?

2. What did Ida Noddack believe about the results of Fermi’s uranium experiment?

3. Hahn determined that barium (atomic number 56) was one of the elements created when a uranium atom (atomic number 92) split. Use a periodic table to determine the other element that was created during this process.

4. How was the paper published by Meitner and Frisch different from the one published by Hahn and Strassman?

5. Use the graph on the second page of the reading and a periodic table to arrange the following elements in order of increasing energy of their nuclei.
   a. carbon (C)
   b. iron (Fe)
   c. magnesium (Mg)
   d. lithium (Li)
   e. lead (Pb)
   f. krypton (Kr)

6. An experiment is performed in which a uranium atom splits, creating a zirconium atom and an unknown atom. Use a periodic table to determine the name and atomic number of the unknown atom.

7. Where does the energy created in a fission reaction come from?

8. How does Einstein’s formula explain what happens in a fission reaction?

9. Describe what occurs during a fission chain reaction.

10. Four transuranic elements are named after scientists mentioned in the reading. Use a periodic table to find the element names and atomic numbers.
How has Earth changed over the past millions of years? Occasionally, Earth’s history has been interrupted by catastrophes such as massive volcanic eruptions or asteroid impacts. These events have played a big role in shaping Earth’s surface and in the evolution of life. When scientists want to estimate how long ago various events occurred, they use fossil records and dating techniques. Relative dating provides information about a sequence of events in Earth’s history. It doesn’t give you the exact age of an event or object. Relative dating uses clues to sequence the order of events that occurred. For example, study the illustration at left. This illustration shows three events: a footprint, a tire track, and a snowfall. Which event happened first? Sequencing these events in the correct order is a form of relative dating. You don’t know exactly when the events occurred, but you do know the sequence in which the events occurred. In contrast, absolute dating is a method of estimating the age of a fossil or other sample in years. Absolute dating requires the use of a natural “clock.” That clock is the radioactive decay of certain naturally occurring elements such as uranium and carbon. This tutorial will help you understand the role nature’s clocks play in helping scientists determine a geologic and evolutionary time scale.
In 1898, Ernest Rutherford, a scientist working with J.J. Thomson in England, described two different kinds of particles emitted from radioactive atoms, calling them alpha and beta particles. He also coined the term \textit{half-life} to describe the amount of time for radioactivity to decrease to half its original level. Half-lives range from fractions of a second to billions of years. In a sample of uranium-238, it takes 4.5 billion years for half of the uranium atoms to transform into lead atoms. By comparison, the half-life of carbon-14 is about 5,700 years.

**Carbon dating**

Living things contain a large amount of carbon. The isotope carbon-14 is used by scientists to determine age. We find carbon-14 in the environment because it is constantly being produced in the upper atmosphere by cosmic rays (high-energy particles from the Sun), and elsewhere in the universe. The ratio of carbon-14 to carbon-12 in the environment is determined by the balance between production and decay of carbon-14. As long as an organism is alive, it constantly exchanges carbon with the environment. The ratio of carbon-14 to carbon-12 in an organism stays the same as the ratio of carbon-14 to carbon-12 in the environment. When a living organism dies, it stops exchanging carbon with the environment. All the carbon-12 in the organism remains, because carbon-12 is a stable isotope and does not undergo radioactive decay. Almost no new carbon-14 is created in the organism because most cosmic rays do not reach the ground. As the carbon-14 decays, the ratio of carbon-14 to carbon-12 slowly gets smaller with age. By measuring this ratio, an archeologist can tell how much time has passed since the organism was alive.

Carbon dating works reliably up to about 10 times the half-life, or 57,000 years. After 10 half-lives there is not enough carbon-14 left to measure accurately. Carbon dating works only on material that has once been living, such as bone or wood, or on material that once contained living organisms. The sand beneath human footprints discovered in Nicaragua in 1874 has been carbon dated and scientists report that the footprints are about 6,000 years old.

![Ancient footprints of Acahualinca, carbon-dated to be about 6,000 years old](image-url)
Studying Earth’s history

Something drastic happened about 65 million years ago; the fossil evidence shows that clearly. At the end of the Cretaceous Period, almost all of Earth’s large vertebrates (including dinosaurs) and most of the oceans’ plankton became extinct. In fact, 60 to 70 percent of all plant and animal species disappeared. Scientists have studied the fossil record and have used both relative and absolute dating techniques to verify when the mass extinction occurred. Carbon and uranium dating help scientists understand that there may have been five mass extinctions in Earth’s history. Each time, biodiversity eventually returned, but with new dominant plant and animal species. As a result, scientists hypothesize that mass extinctions play an important role in evolution. Relative and absolute dating give scientists helpful evidence as they study Earth’s history, but how do they learn more about how groups of organisms diverged evolutionarily after the mass extinction? This is where molecular clocks become useful.

Nature’s clocks

Carbon and uranium decay rates are natural “clocks” that help scientists determine age and event sequences. Carbon and uranium dating help connect the fossil record to real time events in Earth’s history. Nature provides yet another tool for estimating Earth’s time scales: molecular clocks. “Molecular” refers to the DNA and protein sequence blueprints contained in the cells of all living and once-living organisms.

DNA comparisons

All species of organisms have DNA as their hereditary material. Scientists compare the DNA base sequences of different species to determine evolutionary relationships. Do cattle and sheep share a common ancestor? Evolutionary biologists have discovered that the genetic code of these animals is very similar, and does suggest a common ancestor.

The diagram above compares the DNA base sequences in the gene that codes for hemoglobin in vertebrates. The greater the number of differences in base sequences, the farther the evolutionary distance from humans.

Molecular clock model

Establishing genetic relationships among organisms is important, but it is also helpful to know when these organisms diverged evolutionarily from one another. The molecular clock model can help establish an evolutionary time scale. DNA and protein sequences evolve at a rate that is relatively constant over time and among different organisms. Scientists hypothesize that the genetic difference between any two species is proportional to the time since these species last shared a common ancestor. This hypothesis is the idea behind how the molecular clock model is used. But using molecular clocks as a research tool is quite complicated, and reliable techniques are still under development. The molecular clock model has helped scientists learn that cattle and sheep share a common ancestor that lived probably no more than 20 million years ago—a relatively short time on the evolutionary time scale.
Discuss the use of dating techniques and molecular clocks

1. What is meant by the term molecular clock?

2. What is meant by the term half-life and how is half-life important to carbon-14 dating techniques?

3. Study the illustration at the bottom of this tutorial’s first page. Explain exactly what this illustration shows about carbon-14 dating.

4. No land animal larger than a cat survived the mass extinction of 65 million years ago. However, small mammals fared amazingly well. A few species evolved into many newer species and eventually into the many species we know today. How does the molecular clock model play an important role in our understanding of how Earth’s biodiversity eventually grew from early post-extinction levels?

5. There are many theories about what caused the mass extinction of 65 million years ago. Use the Internet or a library to find out about at least two possible causes. Write a paragraph about each possible cause.
Rosalyn Sussman Yalow and her research partner, Solomon Berson, developed radioimmunoassay (RIA). This important biomedical diagnostic tool uses radioactive isotopes to trace hormones, enzymes, and medicines that exist in such low concentrations in blood that they were previously impossible to detect using other laboratory methods.

Encouraged and inspired

Rosalyn Sussman Yalow and her research partner, Solomon Berson, developed radioimmunoassay (RIA). This important biomedical diagnostic tool uses radioactive isotopes to trace hormones, enzymes, and medicines that exist in such low concentrations in blood that they were previously impossible to detect using other laboratory methods.

A wartime opportunity

However, as the United States began drafting large numbers of men in preparation for war, universities began to accept women rather than close down. In the fall of 1941, Sussman arrived at the University of Illinois with a teaching assistantship in the School of Engineering, where she was the only woman. There, she specialized in the construction and use of devices for measuring radioactive substances. By January 1945 she had earned her doctorate, with honors, in nuclear physics, and married Aaron Yalow, a fellow student.

From medical physics to radioimmunoassay

From 1946 to 1950, Sussman, who now went by Yalow, taught physics at Hunter College, which had
only introduced it as a major her senior year and which now admitted men. In 1947, she also began working part time at the Veterans Administration Hospital in the Bronx, which was researching medical uses of radioactive substances.

In 1950 she joined the hospital full time and began a research partnership with Solomon A. Berson, an internist. Together they developed the basic science, instruments, and mathematical analysis necessary to use radioactive isotopes to measure tiny concentrations of biological substances and certain drugs in blood and other body fluids. They called their technique radioimmunoassay, or RIA.

RIA helps diabetes research
One early application of RIA was in diabetes research, which was especially significant to Yalow because her husband was diabetic. Diabetes is a condition in which the body is unable to regulate blood sugar levels. Regulation of blood sugar levels is normally accomplished through the release of a hormone called insulin from the pancreas. Using RIA, Yalow and Berson showed that adult diabetics did not always lack insulin in their blood, and that, therefore, something must be blocking their insulin’s normal action. They also studied the body’s immune system response to insulin injected into the bloodstream.

Commercial applications, not commerce
RIA’s current uses include screening donated blood, determining effective doses of medicines, detecting foreign substances in the blood, testing hormone levels in infertile couples, and treating certain children who had growth hormone deficiencies. Yalow and Berson changed theoretical immunology and could have made their fortunes had they chosen to patent RIA. But instead, Yalow explained, “patents are about keeping things away from people for the purpose of making money. We wanted others to be able to use RIA.” Berson died unexpectedly in 1972; Yalow had their Veterans Administration hospital research laboratory named after him, and lamented later that his death had excluded him from sharing the team’s greatest recognition.

A rare Nobel winner
Yalow was awarded the Nobel Prize in Physiology or Medicine in 1977. She was only the second woman to win in that category, for her work on radioimmunoassay of peptide hormones.

Reflection questions
1. Rosalyn Yalow has said that Eve Curie’s biography of her mother, Marie Curie, helped spark her interest in science. Compare the lives of these two scientists.
2. Describe radioimmunoassay in your own words.
3. What information about adult diabetes was discovered using RIA?
4. Find out more about the role of patents in medical research. Do you agree or disagree with Yalow’s statement? Why?
Earth has a limited amount of water. About 97% of this water is salt water found in oceans. Approximately 2% of Earth’s water is frozen at the North Pole and South Pole and on mountaintops. The remaining 1% is fresh water and available for humans, plants, and animals to consume. Fortunately, the water cycle makes this limited amount of water available to living things. The water cycle is a set of processes energized by the Sun that keeps water moving from place to place on Earth.

Processes in the water cycle
The main processes of the water cycle involve the evaporation of water, the release of water from plants, the formation of water droplets from water vapor (called condensation), and precipitation. The process of condensation happens on your bathroom mirror when you take a shower. Warm water vapor from your shower forms droplets of water that collect on the cooler mirror surface. Condensation also happens in the atmosphere to form clouds and precipitation like rain, snow, sleet, and hail.

Watersheds, groundwater, and surface water
The U.S. Environmental Protection Agency (EPA) has a web page called “Surf your Watershed.” By typing your zip code on this web page, you can find out where your water comes from. You can even find out the names of citizen groups that volunteer to protect your local watershed. But what exactly is a watershed?

A watershed is an area of land that catches precipitation and surface runoff. The boundaries of a watershed are often steep mountain ridges. Acting like a funnel, a watershed collects water flowing downhill into a body of water such as a river. Rivers, ponds, oceans, and reservoirs are examples of surface water. A reservoir is a protected artificial or natural lake that stores water.

Some of the surface runoff collected in a watershed becomes groundwater. Groundwater is fresh water that infiltrates (absorbs into) the soil and collects underground. This water represents our most abundant, available water supply.
Water resources research

In this guided tutorial you will learn about your state’s water resources. To complete this tutorial, form a water resources investigation team. Keep track of your findings in a team notebook. When you have completed the tutorial, write up your findings in a report and make a poster to hang in your classroom.

1. Information about you and your team:
   a. What is the name of your team?
   b. List the names of all team members.
   c. What is your city and state?

2. Information about your state’s water resources (you will have to do Internet research or other kinds of research to answer these questions):
   a. List the names of the main bodies of water in your state (lakes, rivers, and ocean if your state has a coastline).
   b. What is your state’s average annual rainfall?

3. Find the U.S. EPA “Surf Your Watershed” website online. Use the search phrase “surf your watershed.” What is the name of the watershed for your zip code?

4. At the “Surf Your Watershed” website, click on the link for the citizen-based groups that work to protect your watershed. List the name of one organization.
   a. What does this organization do?
   b. Visit the organization’s website if it has one. List three things you learned about the organization from your visit to the website.

5. Use the name of your state and the phrases “water resources” and “USGS” to find the U.S. Geological Survey (USGS) web page that focuses on your state’s water resources. Find the menu for “Real-time data.”
   a. List the types of real-time data that are provided at this website.
   b. Why do you think it is important for the USGS to collect each of these types of data?
   c. When you click on the “Precipitation” link, what kind of information do you find?

6. The National Institutes for Water Resources (NIWR) is a collection of 54 centers, one for each U.S. state or territory. Visit the website for the National Institutes for Water Resources. Find the website using an Internet search engine. Click on your state on the large U.S. map on the NIWR website.
   a. Where is your state’s water resources center located?
   b. List three things you learned about the research performed by this center.

7. Your state government has one or more departments that focus on water use and conservation. Visit your state’s government website to find the answers to these questions:
   a. What is the name of the organization that studies and protects water resources?
   b. What does this organization do to conserve and protect your state’s water resources?

8. Locate the website for the department in your city that is involved in managing water quality and treatment.
   a. What does your city do to monitor water quality?
   b. What does your city do to treat water?
   c. Why is water treatment important?
   d. From the website, what is the quality of your city’s drinking water?

9. List one question that your team has about your state’s water resources. Find the answer to this question by doing research or by interviewing an expert. Write up your findings in a short essay.

10. Your research is complete! Write up your findings in a report. Then, create a poster that colorfully and graphically illustrates your findings.
Relative motion

The motion of any object must be defined relative to or compared to a specific frame of reference. A frame of reference is a coordinate system or set of axes that sets an origin. The position and motion of an object are measured according to a frame of reference. For example, suppose you are standing on a bus that is moving at 10 m/s. If you compare yourself to the frame of reference of the ground outside, you are moving at 10 m/s. But if you compare yourself to the frame of reference of the bus, your speed is 0 m/s. Relative to the bus, you are at rest. The speed of an object in one frame of reference can be different from its speed in another frame of reference.

Suppose your friend is waiting at a bus stop one block in front of the bus. You are on the bus. You throw a ball from the back of the bus toward the front at 5 m/s. Relative to you, the ball is moving at 5 m/s. But relative to your friend, the ball is moving at 15 m/s—the speed of the bus relative to the ground (10 m/s) added to the speed of the ball relative to the bus (5 m/s).

Einstein considered the same situation using light instead of a ball. If you were to shine a flashlight toward the front of the bus, you would expect the light to approach your friend at 10 m/s plus the speed of light (3 x 10^8 m/s). That is not what happens. The light comes toward your friend at a speed of 3 x 10^8 m/s no matter how fast the bus moves!
A similar experiment was done in 1887 by Albert A. Michelson and Edward W. Morley. They used the Earth itself as the “bus.” The Earth moves with an orbital speed of 29,800 m/s. Michelson and Morley measured the speed of light parallel and perpendicular to the orbital motion of the Earth. They found the speed to be exactly the same! This result is not what they expected, and it was confusing to everyone. Like all unexpected results, it forced people to rethink what they thought they already knew.

The speed of an object, such as a person or a ball, can be different in different frames of reference. Your speed relative to the floor of a moving bus is not the same as your speed relative to the ground outside. But light follows a different set of rules. The speed of light in a vacuum (empty space) is $3 \times 10^8$ m/s when compared to any frame of reference!

**Einstein’s theory of special relativity**

For objects moving at slow speeds, Newton’s laws describe the motion of the objects. Einstein thought about what this new idea about light meant for everything else in physics. Einstein’s theory of **special relativity** describes what happens to matter, energy, time, and space at speeds close to the speed of light. Special relativity does not affect ordinary experience because objects need to be moving faster than 100 million m/s before the effects of special relativity become obvious.

One of the strangest results of special relativity is that time itself changes depending on the motion of an observer. Einstein’s conclusion about the flow of time is totally revolutionary, and completely changed our understanding of how physics works.

Einstein thought about a clock that measures time by counting the trips made by a beam of light going back and forth between two mirrors. The clock is on a moving spaceship. A person standing next to the clock sees the light move straight up and down. Rearranging the formula $v = \frac{d}{t}$ for time, we find that the time it takes to make one trip is the distance between the mirrors divided by the speed of light ($t = \frac{d}{v}$).

To someone who is not moving, the path of the light is not straight up and down. The light appears to make a zigzag because the mirrors move with the spaceship. The observer on the ground sees the light travel a longer path. This would not be a problem, except that the speed of light must be the same to all observers, regardless of their motion.
Suppose it takes light 1 s to go between the mirrors. The speed of light must be the same for both people, yet the person on the ground sees the light move a longer distance! How can this be?

![Image](https://via.placeholder.com/150)

The only way the situation reconciles itself is if one second on the ground is not the same as one second on the spaceship. The speed of light is the distance traveled divided by the time taken. If one second of “ship time” is longer than one second of “ground time,” then the problem is resolved. (Both people measure the same speed for light of $3 \times 10^8$ m/s. The difference is that one second of “ship time” is longer than one second of “ground time.”)

The consequence of the speed of light being constant is that passage of time is not the same in all frames of reference. If you move fast enough, the change in the flow of time is enormous. For a spaceship traveling at 99.9 percent of the speed of light, 22 years pass on Earth for every year that passes on the ship. The closer the spaceship’s speed is to the speed of light, the greater the difference in the time.
Practice applying speed of light concepts (show all work)

1. You are riding on a plane that is flying east at 200 m/s. A child is sitting in the seat in front of you. He throws a ball toward the front of the plane at a speed of 3 m/s.
   a. What is the speed of the ball relative to the plane?
   b. What is the speed of the ball relative to a person on the ground?
   c. What is the speed of the ball relative to a person who is walking toward the front of the plane at a speed of 3 m/s?
   d. What is the speed of the ball relative to a person who is walking toward the front of the plane at a speed of 2 m/s?
   e. What is the speed of the ball relative to a person who is walking toward the back of the plane at a speed of 2 m/s?

2. Explain what is special about the speed of light.

3. Suppose that the child in question 1 shines a flashlight toward the front of the plane. How would your answers to questions 1a through 1e for the speed of light compare to your answers for the speed of the ball? Explain your reasoning.

4. Steve and Juan are both 30 years old. Steve stays on Earth, while Juan spends a year traveling on a spaceship traveling at 99.9 percent of the speed of light. How old is each person when Juan returns from his trip?

5. Describe an experiment that could be done to prove that Einstein’s theory about the passage of time in different frames of reference is correct. What results would support the theory?

6. People are constantly moving while walking, biking, and riding in cars, buses, trains, and planes. Explain why we don’t we notice a difference in the passage of time as we travel at different speeds in our everyday lives.

7. In 1969, Neil Armstrong and Buzz Aldrin were the first people to land a lunar module on the Moon. You may have heard Armstrong’s famous phrase, spoken when he stepped out of the module onto the Moon’s surface: “That’s one small step for a man, one giant leap for mankind.” When he spoke, he was not heard immediately on Earth because of the moon’s distance, 384,400,000 meters from Earth. How long did it take the radio waves to travel to Earth so that those words could be heard by millions of viewers? (Hint: Radio waves travel at the speed of light.)
What are biofuels, and how are they made?

Fossil fuel dependency and environmental problems are propelling a trend toward finding new, environmentally friendly and renewable fuels. This investigation is about one possibility: biofuels.

Materials List

- Access to the Internet
- Soybean products: a soybean plant, soybean oil, soy milk, tofu, etc.
- Sample of algae from a freshwater pond
- Microscope
- Sketch paper and pencils

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.L.17.11</td>
<td>Evaluate the costs and benefits of renewable and nonrenewable resources, such as water, energy, fossil fuels, wildlife, and forests.</td>
</tr>
<tr>
<td>SC.912.L.17.15</td>
<td>Discuss the effects of technology on environmental quality.</td>
</tr>
<tr>
<td>SC.912.L.17.19</td>
<td>Describe how different natural resources are produced and how their rates of use and renewal limit availability.</td>
</tr>
<tr>
<td>SC.912.L.17.20</td>
<td>Predict the impact of individuals on environmental systems and examine how human lifestyles affect sustainability.</td>
</tr>
<tr>
<td>SC.912.N.4.2</td>
<td>Weigh the merits of alternative strategies for solving a specific societal problem by comparing a number of different costs and benefits, such as human, economic, and environmental.</td>
</tr>
<tr>
<td>SC.912.P.10.1</td>
<td>Differentiate among the various forms of energy and recognize that they can be transformed from one form to others.</td>
</tr>
</tbody>
</table>

Building knowledge: biofuels vs. fossil fuels

With a partner, explore and build your knowledge of biofuels and fossil fuels.

1. Fill in the table on the next page using what you already know about these fuels.
2. Next, research biofuels and fossil fuels, fill in the rest of the table, and make corrections to your information as needed. The U.S. Department of Energy website at www.energy.gov/ will be helpful.
**Biofuels**

*Your carbon footprint* is an indicator of how much greenhouse gas emissions are produced as a result of your activities, both directly and indirectly.

### 2 Biodiesel from land or water

For the rest of this investigation, the focus will be on one type of biofuel: biodiesel. Biodiesel can be used as a fuel in a diesel vehicle engine. Oil from soybean plants is commonly used to make biodiesel. Oil from algae that grow in freshwater ecosystems is also a possible source for making biodiesel. However, algae are not yet a reliable resource for large-scale biodiesel production.

1. Soybeans: Examine soybean products such as soybean oil, fresh or packaged soybeans, and even tofu or soy milk. Find out how much fat (oil) is in these products. Then, examine a soybean plant. Make a sketch of this plant.
   a. What is the original source of energy for both soybean plants and algae? Both soybean plants and algae use this energy to make sugar, starch, and oil molecules needed for growth.
   b. Study the information in the table on the next page. Next, write a paragraph that describes the pros and cons of using soybean plants or algae as a source for biodiesel.

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<table>
<thead>
<tr>
<th>Biofuels</th>
<th>Fossil fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples</td>
<td></td>
</tr>
<tr>
<td>Sources</td>
<td></td>
</tr>
<tr>
<td>Renewable or nonrenewable?</td>
<td></td>
</tr>
<tr>
<td>Where is it used?</td>
<td></td>
</tr>
<tr>
<td>Efficiency of vehicles when used</td>
<td></td>
</tr>
<tr>
<td>Relative cost to produce</td>
<td></td>
</tr>
<tr>
<td>Greenhouse gas emissions produced?</td>
<td></td>
</tr>
<tr>
<td>Role in global warming</td>
<td></td>
</tr>
<tr>
<td>How its use affects your carbon footprint*</td>
<td></td>
</tr>
</tbody>
</table>

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*Your carbon footprint* is an indicator of how much greenhouse gas emissions are produced as a result of your activities, both directly and indirectly.
Making biodiesel

Once you have oil from a source such as soybeans or algae, making biodiesel is possible using a chemical reaction. The reactants are as follows:

- fat or oil, commonly referred to as the “feedstock”
- an alcohol, such as methanol
- a catalyst (sodium hydroxide)

The reaction to make biodiesel is called transesterification. The products of the reaction are organic compounds called esters (this is the biodiesel) and glycerol. Interestingly, the glycerol produced in this reaction can be used as is or purified and used for pharmaceutical or cosmetic products.
Here is the reaction:

\[
\begin{align*}
\text{Plant oils or fats} & \quad \text{Alcohol (Methanol)} & \quad \text{Catalyst (Sodium hydroxide)} & \quad \text{Esters (Biodiesel)} \quad \text{Glycerol} \\
\text{CH}_3\text{O} - \text{C} - \text{R} & \quad \text{CH}_3\text{OH} \quad \text{OH}^- & \quad 3\text{CH}_2\text{O} - \text{C} - \text{R} & \quad \text{CH}_2\text{OH} \quad \text{CH}_2\text{OH} \\
\end{align*}
\]

a. This reaction uses a catalyst. What is the purpose of a catalyst in a chemical reaction?

b. This reaction can be considered toxic because methanol is toxic if inhaled or absorbed through the skin and sodium hydroxide can burn skin. Write out the detailed safety instructions you would follow if you were to perform this reaction in your school laboratory, including how you would dress.

c. Once the reactants are combined with the catalyst and heated, a solution forms that is then poured into a separatory funnel. This special funnel allows you to see that the mixture forms two layers after it stands for a period of time. Speculate the answers to these questions: (i) What is the difference between the “organic layer” and the “aqueous layer”? (ii) How do these layers compare in terms of density? (iii) How is this mixture like oil and vinegar salad dressing?

d. Find out about biodiesel blends and how they are used. In particular, find out about B20.
Defining reaction rate and making predictions

The reaction rate for a chemical reaction can sometimes be determined by observing the rate of disappearance of a reactant or the appearance of a product. Throughout this investigation, you will be observing relative rates of reaction by seeing how long it takes a reactant to disappear.

The first reaction you will investigate is between two active ingredients in an effervescent antacid tablet—sodium bicarbonate and citric acid. Since both ingredients are solids, it is difficult for them to react together within the tablet. By dissolving the tablet in water, the ingredients are able to move freely, collide, and react. Sodium citrate, carbon dioxide, and water are the products in this reaction.

\[
\text{sodium bicarbonate (s) + citric acid (s)} \rightarrow \text{sodium citrate (aq) + carbon dioxide (g) + water (l)}
\]

\(s = \text{solid; aq = aqueous solution; g = gas; l = liquid}\)

1. For this reaction, you will need to determine how you will know when the reaction has completed. To figure out a method that works easily, first look at the list of materials for the investigation. What tools are available? Are there any other tools you could use to help you measure the rate of reaction?

2. Drop one effervescent antacid tablet into a cup of water. Record your observations of what happens.
3. Now, use your observations and brainstorm with your group how you will measure the rate of this reaction. Write down your procedure for measuring the rate of the reaction. Show it to your teacher for approval.

2 Making predictions

Now, make predictions about how surface area and temperature might affect the rate of the reaction of the two active ingredients in the effervescent antacid tablet.

a. You can increase the surface area of a tablet by breaking it into pieces or by crushing it into a powder. How might increasing the surface area of the tablet affect reaction rate? Explain your answer.

b. You can increase the temperature of the reaction by changing the water temperature. How might cold water affect the reaction? Hot water?

3 Experiment #1: Surface area

1. Grind one effervescent antacid tablet into a fine powder by placing it in the large teaspoon and crushing it with the back of the smaller teaspoon. Use a blunt knife to carefully cut a second tablet in four pieces and a third tablet in half. Fill in Table 1 below with your thoughts on how surface area compares for each.

2. Add 100 mL of water at room temperature to each of four cups numbered 1 to 4.

3. Review your procedure for determining the completion of the reaction.

4. Then, all at the same time, add the powdered tablet to cup #1, the four pieces to cup #2, the two half pieces to cup #3, and a whole tablet to cup #4. You will need to work together with your lab partner(s) to accomplish this.

5. Record the time to complete the reactions in Table 1. Then answer the questions below.

6. Discard the solution and rinse and dry each cup.

<table>
<thead>
<tr>
<th>Cup number</th>
<th>Description of added tablet</th>
<th>Amount of surface area</th>
<th>Time to complete reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Which cup had the fastest reaction rate? Why?

b. Which cup had the slowest reaction rate? Why?
Experiment #2: Temperature

1. Obtain ice water, hot water, and room temperature water from your teacher.
2. Add 100 mL of each temperature of water to each of three cups numbered 1 to 3.
3. Measure and record the temperature of each cup of water in Table 2.
4. Add a tablet to each of the containers at the same time.
5. Record the time to complete the reactions in Table 2. Then, answer the questions below.

<table>
<thead>
<tr>
<th>Cup number</th>
<th>Temperature (°C)</th>
<th>Time to complete reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Which cup had the fastest reaction rate? Why?
b. Which cup had the slowest reaction rate? Why?

Experiment #3: Concentration

To test the effect of concentration on reaction rate, we will use a different type of antacid tablet. This time, we will use a calcium carbonate (non-effervescent) tablet and react it with vinegar (acetic acid).

\[
\text{calcium carbonate (s) + acetic acid (aq) } \rightarrow \text{calcium acetate (aq) + carbon dioxide (g) + water (l)}
\]

\[s = \text{solid; aq = aqueous solution; g = gas; l = liquid}\]

You will use different concentrations of vinegar to see how different concentrations of this reactant affect reaction rate. Your teacher has either already prepared the different vinegar solutions or will help you prepare them.

1. Add 200 mL of each vinegar solution (5%, 4%, 3%, and 2.5%) to each cup, numbered 1 to 4.
2. At the same time, add a 500-mg antacid tablet (calcium carbonate) to each cup. You will need to work together with your lab partner(s) to accomplish this.
3. Record the time to complete the reactions in Table 3. Then answer the questions below.

**Table 3: Concentration**

<table>
<thead>
<tr>
<th>Cup number</th>
<th>Vinegar solution</th>
<th>Time to complete reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>2.5%</td>
<td></td>
</tr>
</tbody>
</table>

a. Which cup had the fastest reaction rate? Why?

b. Which cup had the slowest reaction rate? Why?

6 **Summarizing your results**

Now that you have completed these three experiments, write one to two paragraphs that summarize your results. Be sure to state whether or not your results were as you expected.

7 **Pressure and catalysts**

a. If the reactants in a reaction are gases, increased or decreased pressure can affect the reaction rate. Why do you think this is? Hint: Find a definition for pressure and then answer this question.

b. A catalyst is a special molecule that helps bring reactant molecules together so that they can react. The catalyst is not affected by or used up by the reaction. It can keep interacting with the reactant molecules until the reaction is complete. For example, your body is full of catalysts called enzymes that help you do things like digest food in a timely manner. Based on this information, explain how catalysts affect reaction rate and why they can be crucial in a reaction.

8 **Applying your knowledge**

You are surrounded by chemical reactions. Pick one and develop a controlled experiment to find out the reaction rate for the reaction and determine how it can be increased or decreased. Write up your procedure below. Get your teacher’s permission before conducting any experiments. Examples of chemical reactions are:

- the ripening of fruit
- the spoiling of milk
- the combustion of wood
- the rusting of iron
How does a catalyst work?

Various factors affect the rate of chemical reactions. These factors include the concentrations of reactants and temperature. As long as the supply of reactants is available, a reaction can continue. Reactions occur faster at higher rather than lower temperatures because atoms and molecules have more energy to move, collide, and react. Another important factor in reactions is the presence of catalysts. A catalyst is a molecule that increases reaction rate without getting used up in the process. In this investigation, you will observe a catalyst in action and design an experiment to investigate the factors that influence the rate of reactions.

Materials List

- Potato, 100 g, cut into pieces 5 mm on each edge
- Distilled water
- Blender
- Hand-operated pump
- Distillation flask
- 2 Beakers and 2 droppers
- Funnel and filter paper
- Glucose-1-phosphate
- Iodine tincture or Lugol’s solution
- 2 Spot plates
- Timer or stopwatch
- 2 Pipettes
- Safety goggles, gloves, and apron

Thinking about what you know

A catalyst affects chemical reaction rates by interacting with one or more reactant molecules. By bringing together molecules so that they can react, catalysts lower the activation energy needed for a reaction to take place, and speed up the rate of the reaction. Once one reaction happens, the catalyst is available to “catalyze” another.

You will observe a catalyst in action for the reaction involving glucose described on the next page. Glucose is a simple, single sugar molecule, whereas starch is a polysaccharide composed of many glucose molecules. Starch phosphorylase is an enzyme that creates bonds between glucose molecules to make starch.
a. Potatoes are a good source of the enzyme starch phosphorylase. Why might this be so?

b. Iodine solutions stain purple in the presence of a form of starch called amylose. Look at the materials list for this investigation. Write a short paragraph that predicts how these materials will be used to show that starch phosphorylase makes starch (amylose) from glucose over time.

c. Based on your answer to question b, describe a control you could use in this experiment.

2 Setting up and conducting the experiment

1. Be sure to wear eye protection.
2. Place the pieces of potato in a blender with 100 mL of distilled water. Blend until you get a soupy liquid.
3. To set up the filtration apparatus: Fold the filter paper into a cone shape and place it in the funnel. Place the funnel in the distillation flask. Attach one end of the soft rubber tubing to the distillation flask as shown in the photo, and connect the other end to the outlet of the pump that will create negative pressure (suction). Operate the hand pump to pull the liquid, leaving the potato residue behind.
4. Label one spot plate “Enzyme only” and the other “Enzyme plus glucose.” Use a permanent marker to number eight wells on each spot plate 0, 2, 4, 6, 8, 10, 12, and 14. The numbers correspond to the number of minutes passed during the experiment.
5. Once the potato residue is separated from the liquid, test it with the iodine solution. It will stain for starch. Then, test the liquid to make sure it is free of starch. Is it?
6. Pour at least 20 mL of the liquid into each of two beakers. The liquid will be a pinkish brown color (this is normal). Place a pipette in each beaker.
7. Label one beaker “Enzyme only.”
8. Label the other beaker “Enzyme plus glucose.” When you are ready to begin timing for the experiment, add a few milligrams of glucose powder (i.e., two dashes) to this beaker and stir.
9. Start your timer. Begin by placing three drops from each beaker into the “0” well on the associated spot plate. Then clean the dropper and place a drop of iodine solution into each of these wells. Stir the mixture. Describe the color of the reaction in each well in Table 1. Place the spot plates on a piece of plain white paper so the color changes are easier to see.

10. Repeat step 8 at 2-minute intervals for 14 minutes. Fill in the last column of Table 1 after step 10.

Table 1: Reaction Results

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Color of reaction</th>
<th>Starch present?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Enzyme only</td>
<td>Enzyme plus glucose</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
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<tr>
<td>8</td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Did you detect the presence of starch in this experiment? If so, for which beaker of liquid and after what period of time?

b. In this investigation, you are told that the potato juice has starch phosphorylase. What might be a control to prove that an enzyme really exists in the liquid and the glucose molecules aren’t just making starch on their own?
Designing your own experiment

1. Various factors affect the rate of chemical reactions. In addition to the presence of a catalyst, these factors include concentration of the reactants and the temperature at which the reaction occurs.

2. Design an experiment to test how one of these two factors influences reaction rate. Be sure to include a control in your experiment. What is your hypothesis?

3. Challenge: Have your teacher approve your experiment. Then perform your experiment and write up your results as a formal lab report.

Applying your knowledge

a. Liquid hydrogen peroxide (H₂O₂) is broken down by the enzyme catalase, which is common in the cells of living things. Predict the products of this reaction.

b. Think about times when you have used hydrogen peroxide. What might be the evidence that this molecule is being catalyzed?
How does an object’s motion affect the frequency of its sound?

You may have noticed that the sound of an ambulance siren changes as the vehicle creating the sound moves toward or away from you. The change in a sound’s frequency as its source moves relative to the listener is called the Doppler effect. Your perception of the pitch of a sound is related to its frequency, so your ears sense a change in pitch as a siren moves past you.

1. **Setting up**
   1. Use a rubber band to attach the buzzer to the battery. Do not connect any wires yet.
   2. Use scissors to make a small slice in the foam ball. The opening should be just large enough so the buzzer and battery can fit in the center of the ball.

2. **Making observations**

   You need a large open area such as a gym, hallway, or outdoor field to do this part of the investigation. Do not throw or twirl the ball too quickly.

   1. Connect the buzzer wires to the battery terminals and insert it in the foam ball. Use a piece of tape to cover the opening.
   2. Choose two people from your group to play catch with the ball. The thrower and catcher should stand approximately 3—5 meters away from each other. The other group members should stand beside the thrower or catcher.

Materials List (per group)

- Electric buzzer
- 9-volt battery
- Rubber band
- Foam ball
- Scissors
- String
- Duct tape

<table>
<thead>
<tr>
<th>Code</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC.912.P.10.21</td>
<td>Qualitatively describe the shift in frequency in sound or electromagnetic waves due to the relative motion of a source or a receiver.</td>
</tr>
</tbody>
</table>
3. Toss the ball back and forth. Observe the sound of the buzzer as the ball is moving toward and away from you. Pay close attention and listen for a change in pitch. The loudness will also change, so you must listen carefully to distinguish between the two changes in sound. Record your observations in the first two rows of Table 1.

**Table 1: Pitch of Moving Buzzer**

<table>
<thead>
<tr>
<th>Motion</th>
<th>Observations about pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tossed ball moving away from you</td>
<td></td>
</tr>
<tr>
<td>Tossed ball moving toward you</td>
<td></td>
</tr>
<tr>
<td>Ball moving with you</td>
<td></td>
</tr>
<tr>
<td>Swinging ball moving toward, past, and away from you</td>
<td></td>
</tr>
</tbody>
</table>

4. Now you will observe the sound of the buzzer as you are moving along with it. Each person should take a turn holding the ball with the buzzer while running at a steady speed. Observe the sound of the buzzer as you are moving with it. Record your observations in Table 1.

5. Tie a piece of string around the foam ball as shown in the picture. The string should be tightly and securely wrapped around the ball, and a piece of tape should be covering the opening. The loose end of the string should be at least 2 meters long.

6. Have one student stand in the center of an open area and swing the ball in a circle. The rest of the group members should be outside of the circle’s radius. **Note: The speed of the ball should be greater than it was when it was being thrown, but not so fast that someone could be harmed if the string were to break.**

7. Observe the sound of the ball as it moves toward you, past you, and away from you. Record your observations in Table 1.

8. Repeat steps 6 and 7 with another group member swinging the ball so the first swinger can observe the sound.
Thinking about what you observed

a. What is the relationship between pitch and frequency?

b. What happened to the pitch of the sound when the buzzer was moving toward you and away from you?

c. Does the speed at which the buzzer is moving relative to you affect the pitch of the sound you hear? Explain.

d. Sound waves are made of compressions and rarefactions of air molecules. A compression is the region where the molecules are squeezed close together, and a rarefaction is where the molecules are far apart. The frequency at which you hear a sound wave is the frequency of the compressions hitting your eardrum. Which person in the diagram is hearing a higher frequency and therefore a higher pitch?

e. What happens to the wavelength of a sound wave if the source of the sound is moving toward you? What happens to the wavelength if the source is moving away from you?