FLORIDA

Experience Chemistry®

Printable Lab Worksheets

SAVVAS

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

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APPENDIX B SAFETY IN THE LAB

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

Pre-Lab Preparation

1. Read the entire procedure before you begin. Listen to all of your teacher's instructions. When in doubt about a procedure, ask your teacher.

2. Do only the assigned experiments. Only do experiments when your teacher is present and has given you permission to work.

3. Know the location and operation of the following safety equipment: fire extinguisher, fire blanket, emergency shower, and eye wash station.

4. Know the location of emergency exits and escape routes. To make it easy to exit quickly, do not block walkways with furniture. Keep your work area orderly and free of personal belongings, such as coats and backpacks.

5. Protect your clothing and hair from chemicals and sources of heat. Tie back long hair and roll up loose sleeves when working in the laboratory. Avoid wearing bulky or loose-fitting clothing. Remove dangling jewelry. Wear closed-toe shoes at all times in the laboratory.

Proper Laboratory Practices

6. Even with well-designed and tested laboratory procedures, an accident may occur while you are working in the lab. Report any accident, no matter how minor, to your teacher.

7. Wear chemical splash goggles at all times when working in the laboratory. These goggles are designed to protect your eyes from injury. While working in the lab, do not rub your eyes, because chemicals are easily transferred from your hands to your eyes.

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

8. Always use the minimal amounts of chemicals specified for an experiment to reduce danger, waste, and cleanup.

9. Never taste any chemical used in the laboratory, including food products that are the subject of an investigation. Treat all items as though they are contaminated with unknown chemicals that may be toxic. Keep all food and drink that is not part of an experiment out of the laboratory. Do not eat, drink, or chew gum in the laboratory.

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

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

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

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

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

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

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

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

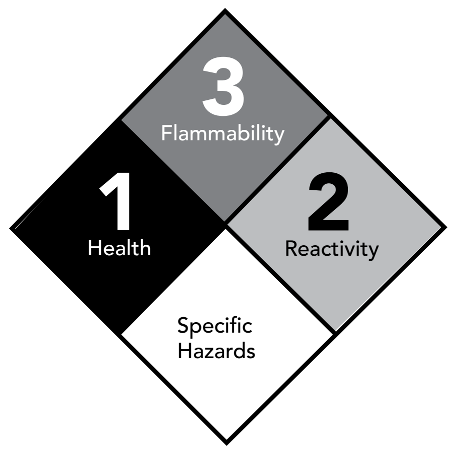
⚠ If, despite these precautions, a corrosive chemical gets on your skin or clothing, notify your teacher. Then wash the affected area with cold running water for several minutes.

Post-Lab Procedures

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

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

> A Materials Safety Data Sheet (MSDS) for a chemical describes any safety issues. A diagram summarizes risks related to flammability, health, and reactivity. A number scale indicates the level of risk.
>
> 0 Low
> 1 Slight
> 2 Moderate
> 3 High
> 4 Extreme



Safety Procedures

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

Eye Safety Wear safety goggles.

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

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

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

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

Flammable Substance Do not have a flame near flammable materials.

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

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

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

Thermal Burn Do not touch hot glassware or equipment.

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

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

Disposal Dispose of chemicals only as directed.

Hand Washing Wash your hands thoroughly with soap and water.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Elements: The Building Blocks of Matter

Matter is composed of atoms. Each atom corresponds to a specific element. If all the atoms within a specific material are the same then that material is also referred to as an element.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Aluminum strip
- Carbon rod
- Copper strip
- Copper(II) chloride solution, $CuCl_2$, 1*M*, 5 mL
- Hydrochloric acid, HCl, 1*M*, 5 mL
- Hydrogen peroxide, H_2O_2, 3%, 5 mL
- Iron strip
- Balance, 0.1 g precision
- Beaker, 150 mL
- Conductivity meter
- Pipet, beral-type
- Ruler
- Vernier calipers
- Wash bottle
- Water

Safety

Copper(II) chloride solution is a skin and eye irritant and is slightly toxic by ingestion. Hydrochloric acid solution is a corrosive liquid and is an eye and skin irritant. Hydrogen peroxide solution is an oxidizer and a skin and eye irritant. Wear chemical splash goggles, chemical-resistant gloves, and a lab coat or chemical-resistant apron. Please follow all normal laboratory safety guidelines and wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part I. Learning the Elements

NAME ______________________ DATE __________ CLASS __________

1. Locate each element name or symbol on the periodic table and complete the following table. The first one has been done for you.

Part I. Data Table — Learning the Elements		
Atomic Number	**Name**	**Symbol**
1	Hydrogen	H
2		
3		
4		
5		
7		
8		
9		
10		

Part II. Characteristics of Select Elements

2. In the Part II data table, record the general appearance of each element.
3. Measure the mass of each sample and record your results in the table.
4. Determine the volume of each sample (for the strips this will be length x width x height, for the rod it will be πr^2 x height) and record your results in the table.
5. Calculate the density of each sample and record your results in the table.
6. Test each element with the conductivity meter, and record your results in the table.
7. Try to bend each element, and record your results in the table.
8. Locate each element on the periodic table, and record its atomic number.

Part II. Data Table —Characteristics of Select Elements				
Element	**Aluminum**	**Carbon**	**Copper**	**Iron**
Appearance				
Mass (g)				
Volume (cm^3)				
Density (g/cm^3)				

NAME ______________________ DATE ____________ CLASS ____________

Conductivity				
Bend test				
Atomic number				

Part III. Reactions

9. **SEP Plan An Investigation** Devise an experiment to examine the reaction of the provided elemental samples with the solutions provided by your teacher. Show your procedure to your instructor before beginning any experimental work.

10. Record the results of your tests in the data table.

11. Dispose of all waste liquids and solids as directed by your instructor.

Part III. Data Table — Reactions			

NAME ______________________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Identify Patterns** Looking at your data table, do you notice any trends between atomic number and density? Do you think you have collected sufficient data to conclusively identify this trend?

2. **SEP Make Observations** Which element was the most reactive, and which was the least?

3. **SEP Plan an Investigation** Sometimes a layer of oxygen can form on the surface of certain elements. A student hypothesizes that this oxide layer could be preventing the elements from reacting. Describe how you could conduct and experiment to test this hypothesis.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Bean Bag Isotopes

What is an isotope? Are all atoms of an element the exact same? An element has multiple isotopes among which atoms of the same element can have different numbers of neutrons and the same number of protons. In this lab, you will model isotopes using dried beans.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Balance, centigram (0.01-g precision)
- "Bean bag" element, symbol Bg, approximately 50 g
- Labeling marker
- Weighing dishes, 4

Safety

Although the materials used in this activity are considered non hazardous, please observe all normal laboratory safety guidelines. The food-grade items that have been brought into the lab are considered laboratory chemicals and are for lab use only. Do not taste or ingest any materials in the chemistry laboratory. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Obtain a Bg sample element bag.

2. Observe the atoms in the "bean bag" element sample (Bg). What does each bean represent in element Bg?

NAME ______________________ DATE __________ CLASS __________

3. Determine the best method to count and weigh each group of beans from the materials provided.

4. Carry out your proposed experiment and determine the atomic mass of Bg.

Data Table — Isotopes		
Bg Isotope	**Number of Atoms**	**Total Mass of Atoms**
1. Lima		
2. Kidney		
3. Peas		
4. Navy		

NAME ______________________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Use Math** Determine the average mass of each Bg isotope.

2. **SEP Use Math** Calculate the percent abundance of each isotope.

3. **SEP Use Math** Calculate the atomic mass of element Bg.

NAME ________________________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Evaluate Atomic Spectra

What happens when white light passes through a prism or diffraction grating? What happens when light from a spectrum tube passes through the same grating? You get to be the scientist in the lab today and set up an experiment that will help you learn about electrons in the outermost energy level of atoms and their relationship with the beautiful colors emitted from the different lights.

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Light sources: flashlight, light bulb, street lamp, and novelty "neon" lamps
- Diffraction square
- Gas discharge (spectrum) tubes, such as hydrogen, helium, mercury, and neon
- Spectroscope
- Power supply

Safety

Power supplies and spectrum tubes operate at very high voltages and can produce a large electric shock. Do not touch the ends of the tube when the power supply is on. Do not touch the contacts on the transformer when the power is on. Always turn off the power supply before inserting, removing or adjusting the position of the spectrum tube. Spectrum tubes typically emit ultraviolet radiation, which is damaging to the eyes. Wear safety glasses or goggles that offer UV protection by filtering UV radiation. To extend the life of the tubes, do not leave the tubes on for more than 30–45 sec at a time. Cycle the power on and off as needed to complete the observations. Spectrum tubes may get very hot. Never touch a spectrum tube when the power is on. After turning off the power, allow the tube to cool before removing it from the power supply.

NAME ______________________ DATE ____________ CLASS ____________

Procedure

1. Using a diffraction grating observe an incandescent light bulb. Describe your observations.

2. With the power OFF, insert the hydrogen spectrum tube between the contacts on the power supply.
3. Hold the spectroscope so that it is about 3–5 cm away from the spectrum tube.
4. Turn on the power supply, and observe the atomic emission spectrum of hydrogen.
5. Turn OFF the power supply and remove the spectrum tube.
6. Repeat steps 2–5 for mercury spectrum tube and any additional spectrum tubes available for analysis.
7. Using the same spectroscope, observe the emission spectrum of other light sources, such as neon signs, streetlights, headlights, novelty lamps, etc.
8. Create your own data table to describe your observations. Record the number of lines, their colors, and their approximate wavelengths in your data table.

Analyze and Interpret Data

1. **SEP Identify Knowns** What colors from the visible region make up white light?

2. **SEP Analyze Data** What colors did you observe in the emission spectrum of both hydrogen and mercury?

3. **SEP Identify Knowns** What is the emitted particle called that is responsible for each color observed?

4. **SEP Interpret Data** Tungsten filament is the element found in light bulbs. Which subatomic particles surrounding the nucleus of tungsten are responsible for the continuous spectrum observed?

5. **SEP Identify Patterns** Assume that a Bohr model of an atom has a total of four possible energy levels. Applied energy results in excitation of its electrons. Based on your observations from this experiment, what happens when those electrons relax back down to their ground state?

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Evaluate the Bohr Model of the Atom

Where can we find the electron? In this lab activity, you will be modeling quantum mechanics with a few simple materials. Repeatedly drop a marble on a target. Imagine how this is analogous to quantum mechanics. Where did the marble land? How does this relate to our understanding of the probability of where the electron is located?

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Target Sheet, Waist-Level, carbonless 2-sheet set
- Target Sheet, Eye-Level, carbonless 2-sheet set
- Graphing analysis program
- Glass marble
- Pen or pencil, fine-lined

Safety

This laboratory activity is not considered hazardous. The only consideration would be the unlikely case of a cracked marble. If that happens, do not handle the glass shards with your hands. Use a dustpan and brush to clean up the pieces, and dispose of them properly in the receptacle indicated by the teacher.

Procedure

1. There are two available target sheets. Choose a target sheet type and collect a marble from your instructor.

NAME ________________________ DATE ____________ CLASS ____________

2. Drop the marble 100 times from the specified distance to the bullseye target.

3. The regions of space around the central bullseye are defined as Areas 1–6.

4. What is each entity below analogous to in relation to the structure of the atom?

   a. Bullseye

   b. Marble

   c. Region of spaces (Areas 1–6)

5. Carry out the investigation to determine the maximum probability of the marble anding in the specified areas on the target sheet. Record your investigation.

NAME ________________________ DATE ____________ CLASS ____________

6. Use the space or graphing software to make bar graph from your data.

Analyze and Interpret Data

1. **SEP Analyze Data** Which area on each target sheet (Areas 1–6) received the most hits?

2. **SEP Interpret Data** Why don't all the marbles dropped from a specified height land in the same spot?

3. **SEP Use a Model to Evaluate** As the distance from the nucleus (bullseye) increases, what happens to the probability of finding an electron (marble)?

4. **SEP Make Observations** What is the overall shape that the spots made on the target sheet? Compare with other groups. What differences can be seen between the waist-level target sheet and the eye-level target sheet?

5. **SEP Use Graphs** Compare the heights of the bars on the waist-level graph and the eye-level graph. Explain the shift in the heights of the bars toward or away from the origin (Area 1).

6. **SEP Identify Patterns** Is there any way to predict the exact location of any one marble drop on the target? Explain.

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Bean Bag Isotopes

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Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

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- "Bean bag" element, symbol Bg, approximately 50 g
- Labeling marker
- Weighing dishes, 4

Safety

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Procedure

1. Obtain a Bg sample element bag.

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Procedure

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NAME ______________________ DATE __________ CLASS __________

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Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

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- Target Sheet, Eye-Level, carbonless 2-sheet set
- Graphing analysis program
- Glass marble
- Pen or pencil, fine-lined

Safety

This laboratory activity is not considered hazardous. The only consideration would be the unlikely case of a cracked marble. If that happens, do not handle the glass shards with your hands. Use a dustpan and brush to clean up the pieces, and dispose of them properly in the receptacle indicated by the teacher.

Procedure

1. There are two available target sheets. Choose a target sheet type and collect a marble from your instructor.

2. Drop the marble 100 times from the specified distance to the bullseye target.

3. The regions of space around the central bullseye are defined as Areas 1–6.

4. What is each entity below analogous to in relation to the structure of the atom?

a. Bullseye

b. Marble

c. Region of spaces (Areas 1–6)

5. Carry out the investigation to determine the maximum probability of the marble anding in the specified areas on the target sheet. Record your investigation.

NAME ______________________ DATE __________ CLASS __________

6. Use the space or graphing software to make bar graph from your data.

Analyze and Interpret Data

1. **SEP Analyze Data** Which area on each target sheet (Areas 1–6) received the most hits?

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5. **SEP Use Graphs** Compare the heights of the bars on the waist-level graph and the eye-level graph. Explain the shift in the heights of the bars toward or away from the origin (Area 1).

6. **SEP Identify Patterns** Is there any way to predict the exact location of any one marble drop on the target? Explain.

NAME ____________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Model Electron Configuration

How do we know where the electrons are located around the nucleus of the atom? You and your partners have a task. A concert is happening tonight and your help is needed to seat all of the guests. This activity will help you understand how to assign an element's electron configuration with a concert seating chart analogy. Get ready to have some fun and stay engaged!

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations

Materials Per Group

- Seating chart
- Concert floor plan
- Pencil

Safety

All of the materials used in this activity are considered non hazardous. Practice all normal lab safety rules.

Procedure

1. Obtain a copy of the seating chart and a concert floor plan.
2. Notice the diagonal arrows on the seating chart. What do the diagonal arrows indicate?

3. Start with the endpoint of the top arrow (1s) and slide down the arrow. Is the 1s section completely filled before moving onto the next section?

4. When you reach the arrowhead, move to the endpoint of the next arrow and follow that arrow down, filling each section in the same manner. In your own words, describe the filling order on the seating chart.

5. There are four different sections in the amphitheatre—s, p, d, and f. Notice that section s has one box in each row, section p has three boxes in each row, section d has 5 boxes, and section f has 7 boxes. And each box has 2 seats, so each box can hold only 2 people and no more. (No exceptions!)

6. How many people can each row in section s hold?

How many people can each row in section p hold?

How many people can each row in section d hold?

How many people can each row in section f hold?

7. Here is a practice scenario: Seven people arrive for the concert at once and they need to be seated in the proper order.

8. Refer to the seating chart to decide where to start seating.

9. In addition to seating the guests, you will also need to record how many people are present at the event. Here is how the information should be recorded. After seating a guest, record the section number along with the total number of guests up to that point.

Analyze and Interpret Data

1. **SEP Use a Model to Evaluate** In what seat will the 5th person who arrives at the concert be seated? Relate this person to the elements in the periodic table. What is the “name” of the 5th “person” (element)?

2. **SEP Use a Model to Evaluate** In what seat will the 8th person be seated? What is the 8th person’s “name”?

3. **SEP Carry Out Your Investigation** Start from the beginning. If 24 people arrive for the concert, where will the people be seated? Draw the people in the correct places on the concert floor plan, and write the electron configuration (tally) below.

4. **SEP Carry Out Your Investigation** If 40 people arrive for the concert, where will the people be seated? Draw the people in the correct places on the concert floor plan, and write the electron configuration (tally) below.

5. **SEP Use a Model to Evaluate** If person X is seated in Row 3, Section p, and Seat 5, what is “person” X’s name?

6. **SEP Use a Model to Evaluate** If person Y is seated in Row 2, Section p, and Seat 6, what is “person” Y’s name?

NAME ____________________ DATE __________ CLASS __________

PERFORMANCE BASED ASSESSMENT

Evaluate Atomic Structure with Flame Tests

This two-part activity allows you to model and witness evidence that atoms of different elements have different electron structures. You are tasked with putting on a fireworks display at Homecoming. Perform flame tests as a small-scale analysis to determine which firework substances to use. How can the small-scale flame tests (and ultimately the fireworks display) help us understand the structure of the atom? Bingo chips and filter papers model the importance of an atom's outermost energy level. Get ready to observe some beautiful colors to understand one of the most complex topics in science!

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations

Materials Per Group

- Calcium chloride, $CaCl_2{\bullet}2H_2O$, 1–1.5 g
- Potassium chloride, KCl, 1–1.5 g
- Sodium chloride, NaCl, 1–1.5 g
- Strontium chloride, $SrCl_2{\bullet}6H_2O$, 1–1.5 g
- Beakers, 250 mL, 2
- Laboratory burner
- Watch glasses or weighing dishes, 5
- Wooden splints soaked in water, 5
- Water, distilled or deionized, 250 mL
- Bingo chips, red, blue, green and yellow, 120 ea., shared
- Energy level Diagrams, 14, shared

Safety 

Fully extinguish the wooden splints by immersing them in a beaker of water before discarding them in the trash, to avoid trash can fires. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

NAME ______________________ DATE __________ CLASS __________

Procedure

Part A

1. Obtain two 250 mL beakers, each filled with deionized or distilled water. The first beaker contains soaked wood splints.
2. There are four labeled watch glasses containing "$CaCl_2$", "NaCl", "KCl", "$SrCl_2$". Are these substances elements? How would you describe these substances? Make sure to provide a thorough answer and explain.

3. Dip the soaked end of one of the wooden splints into each substance, separately.
4. Ignite the laboratory burner flame.
5. If energy is required to excite the electrons in the substances, determine the step necessary to apply energy to the substance adhering to the wooden splint.

6. **SEP Collect Data** Construct a data table to organize your observations.

NAME ______________________________ DATE ____________ CLASS ____________

Part B

7. At each workstation, there is an energy level diagram, a symbol for a neutral atom or an ion, and chips representing electrons. Record the symbol for the neutral atom or ion in the data table.

Data Table — Electron Structure Activity							
Station	**Atom or Ion**	**Number of Protons**	**Number of Electrons**	**Number of Electrons Level 1**	**Number of Electrons Level 2**	**Number of Electrons Level 3**	**Number of Electrons Level 4**
1	He						
2	Na^{+}						
3	K						
4	B						
5	Cl^{-}						
6	H						
7	N						
8	Kr						
9	Al^{3+}						
10	Be						
11	Br						
12	N^{3-}						
13	O^{2-}						
14	O						

8. Determine the number of protons contained in the atom or the ion. (Refer to the Periodic Table.) Record this number in the data table.
9. Determine the number of electrons in the atom or ion. Record this number in the data table.

10. Count out this number of electrons (chips).
11. Fill the electron energy levels with the correct number of electrons, from lowest energy level to highest. Record the number of electrons in each energy level in the data table.
12. Remove the chips from the energy level diagram and proceed to the next workstation.

Analyze and Interpret Data

1. **SEP Carry Out Your Investigation** Describe your course of action in step 5 of the Procedure.

2. **SEP Use a Model to Evaluate** Based on the observations collected in the data table from your experiment, provide an explanation for the colors witnessed.

3. **SEP Identify Knowns** Typical fireworks display colors such as orange, violet, yellow, and red. Identify these based on your observations from Part A of this Procedure.

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4. **SEP Use Models** How are the energy levels filled with electrons for a phosphorus atom and an oxygen ion, O^{2-} from Part B of the Procedure?

5. **SEP Use a Model to Evaluate** If applied energy to the energy level diagrams resulted in the excitation of electrons, in your own words describe a phenomenon that could occur.

Investigation 2

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Develop a Periodic Table

How did the periodic table get its shape? Looking for patterns and developing models can help us to make sense of the world. In this activity you will make your own “periodic table of the animals” by applying scientific thinking and looking for patterns. Afterward you will play “periodic table solitaire” by arranging cards with real elemental data.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Plastic farm animals, 15
- Deck of element cards

Procedure

1. Assuming that the 15 plastic animals you have been given represent all the elements that exist, attempt to arrange them in an order that makes sense in a 3 x 5 grid on your desk. Make a record of your suggested model.

NAME ______________________________ DATE __________ CLASS __________

2. Assuming that there might be as-of-yet-undiscovered animals, arrange the figures in a 10 x 10 grid on your desk. You do not need to use all of the rows and columns. Make a record of your suggested model.

3. Take the deck of cards provided by your teacher and arrange them into a periodic table. You will need to identify patterns and decide on how many elements belong in each group and period.

NAME ______________________________ DATE __________ CLASS ___________

Analyze and Interpret Data

1. **SEP Identify Patterns** Describe the patterns that exist as you move down the groups of your 3 x 5 table.

2. **SEP Identify Patterns** Describe the patterns that exist as you move across the periods of your 3 x 5 table.

3. **SEP Identify Limitations of a Model** Identify any outliers within your table.

4. **SEP Identify Patterns** Describe the patterns that exist as you move across the periods of your 10 x 10 table.

5. **SEP Identify Patterns** Describe the patterns that exist as you move down the groups of your 10 x 10 table.

6. **SEP Identify Limitations of a Model** Identify any outliers within your table.

7. **SEP Use Models** How many color/animal combinations do you predict there are?

8. **SEP Compare Data** Ask another group about their estimate. If your estimates don't agree, what discovery accounts for the discrepancy?

NAME ____________________ DATE __________ CLASS __________

9. **SEP Identify Patterns** Looking at your arrangement of element cards, what trends exist for atomic radius?

10. **SEP Identify Patterns** Looking at your arrangement of element cards, what trends exist for ionization energy?

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Elemental Metals, Nonmetals, and Metalloids

Why are certain elements more metallic in nature and others more nonmetallic? In this lab, you will examine different elements and classify them as either metal, nonmetal, or metalloid. Then you will look at their position on the periodic table and attempt to identify trends associated with metallic character.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials for Procedure

- Aluminum, strip
- Carbon, rod
- Iron, nail
- Silicon, lump
- Sulfur, lump
- Tin, mossy
- Bar magnet
- Conductivity meter
- Paper

Safety

Silicon is slightly toxic by ingestion and can cause eye damage or irritation. Carbon and silicon are both flammable when powdered. Wear gloves and eye protection.

Procedure

1. Obtain a sample of each of the three elements from your teacher.
2. Locate each element on the periodic table, and record its atomic number on the following table.
3. Describe the appearance of each element in the table.
4. Test each element with the conductivity meter, and record your results in the table.
5. Think of at least three more tests to perform on your samples. Record the results of these tests in the table. **These tests are not to involve heating or reacting the samples!**

NAME ______________________ DATE __________ CLASS __________

Data Table — The Experiment					
Element	**Aluminum**	**Carbon**	**Silicon**	**Sulfur**	**Tin**
Atomic number					
Appearance					
Conductivity					

Analyze and Interpret Data

1. **SEP Interpret Data** Which elements would you characterize as metallic? Explain your reasoning.

2. **SEP Interpret Data** Which elements would you characterize as metalloids? Explain your reasoning.

3. **SEP Interpret Data** Which elements would you characterize as nonmetals? Explain your reasoning.

4. **SEP Develop Models** How would you describe the relative positions of these elements on the periodic table?

5. **SEP Use Models** From your results, what trend for metallic character can be inferred?

NAME ______________________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Periodic Trends and Properties

Why are certain elements more reactive than others? The periodic table contains many trends and patterns that enable scientists to predict the result of an experiment. In this lab we will examine the reactivity of the alkaline earth metals.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Aluminum foil, Al, 2 cm^2, 2
- Barium chloride, $BaCl_2$, 0.1 M, 3 mL
- Calcium turnings, Ca, 2 pieces
- Calcium chloride, $CaCl_2$, 0.1 M, 3 mL
- Hydrochloric acid, HCl, 0.5 M, 5 mL
- Magnesium ribbon, Mg, 1 cm piece, 2
- Magnesium chloride, $MgCl_2$, 0.1 M, 3 mL
- Potassium iodate, KIO_3, 0.2 M, 5 mL
- Sodium carbonate, Na_2CO_3, 1 M, 5 mL
- Sodium sulfate, Na_2SO_4, 1 M, 5 mL
- Strontium chloride, $SrCl_2$, 0.1 M, 3 mL
- Water, distilled or deionized
- 24-well reaction plate
- Beral pipet, 10
- Forceps
- Paper, one sheet of black and one sheet of white
- Red litmus paper
- Small beaker or weighing dish
- Thermometer

Safety

Wear safety goggles when performing this or any lab that uses chemicals or glassware. Calcium and magnesium are reactive, flammable solids and possible skin irritants. Use forceps or a spatula to handle these metals. Hydrochloric acid is toxic by ingestion and inhalation and is corrosive to skin and eyes; avoid contact with body tissues. Potassium iodate is moderately toxic and a strong irritant. Wear chemical-resistant gloves and avoid contact of all chemicals with eyes and skin. Wash hands thoroughly with soap and water before leaving the laboratory.

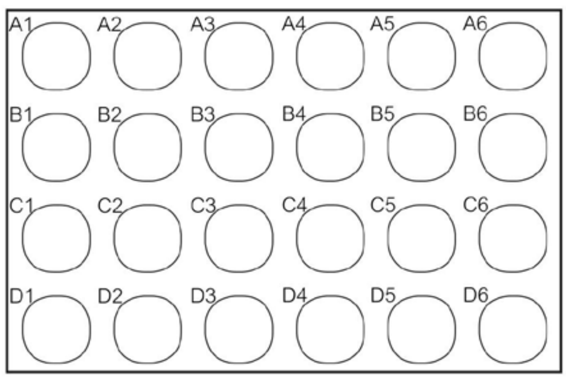
NAME ________________________ DATE ____________ CLASS ____________

Procedure

Part 1. Reactivity of metals

1. In a weighing dish or small beaker, obtain 2 small pieces of calcium turnings.
2. Obtain 2 small pieces of magnesium ribbon, approximately 1 cm each, and a short piece of aluminum foil.
3. Place a 24-well reaction plate on top of a sheet of white paper, as shown in the following figure. Note that each well is identified by a unique combination of a letter and a number, where the letter refers to a horizontal row and the number to a vertical column (Figure 1).

Figure 1



4. Use a pipet to add 20 drops of distilled water to wells A1–A3.
5. Test the water in wells A1–A3 with a piece of red litmus paper and record the initial color for this litmus test in Data Table A.
6. Use forceps to add one piece of calcium to well A1.
7. Use forceps to add one piece of magnesium ribbon to well A2.
8. Tear off a 2 cm piece of aluminum foil and roll it into a loose ball. Add the aluminum metal to well A3.
9. Observe each well and record all immediate observations in Data Table A. If no changes are observed in a particular well, write NR (No Reaction) in the data table.

NAME ____________________ DATE __________ CLASS __________

10. Test the water in wells A1–A3 with a piece of red litmus paper and record any color changes for this litmus test in Data Table A.

11. Continue to watch each well for 1–2 minutes. Record any additional observations comparing the rates of reaction in Data Table A.

12. Use a pipet to add 20 drops of 0.5 M HCl to wells C1–C3. Measure and record the initial temperature of the solutions in well C1–C3 in Data Table A.

13. Use forceps to add one piece of calcium turnings to well C1.

14. Use forceps to add one piece of magnesium ribbon to well C2.

15. Tear off a 2 cm piece of aluminum foil and roll it into a loose ball. Add the aluminum metal to well C3.

16. Observe each well and record all immediate observations in Data Table A. If no changes are observed in a particular well, write NR in the data table.

17. After 2 minutes, measure the temperature of each solution in wells C1–C3. Record the final temperature of each solution in Data Table A.

18. Is there evidence that a gas is being produced in wells C1–C3?

19. Continue to watch each well for 1–2 minutes. Record any additional observations comparing the rates of reaction in Data Table A.

20. Dispose of the well contents as instructed by your teacher. Rinse the reaction plate with distilled water before proceeding to Part 2.

Data Table A

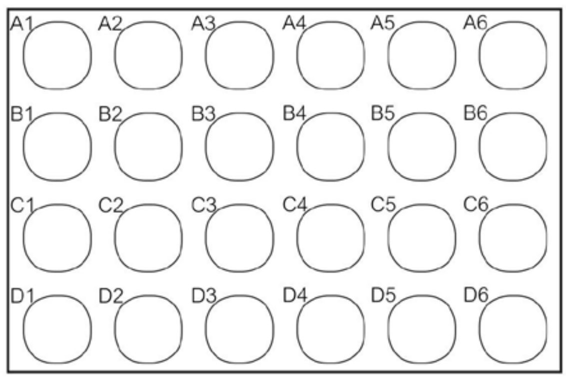
		Calcium	**Magnesium**	**Aluminum**
Reaction with H_2O	**Observations**			
	Litmus test			
Reaction with HCl	**Observations**	Initial temp___ Final temp___	Initial temp___ Final temp___	Initial temp___ Final temp___

NAME ______________________ DATE __________ CLASS __________

Part 2. Solubility of alkali earth metal salts

1. Place the 24-well reaction plate on top of a sheet of black paper. Note that each well is identified by a unique combination of a letter and a number, where the letter refers to a horizontal row and the number to a vertical column (Figure 2).

Figure 2



2. Devise a method to examine the solubility of various alkaline earth metal salts. Obtain your teacher's approval before commencing any experimental work.

3. Dispose of the contents of the reaction plate as instructed by your teacher.

Analyze and Interpret Data

1. **SEP Analyze Data** Rank the species (carbonate, chloride, iodate, and sulfate) from most to least soluble.

NAME ______________________ DATE __________ CLASS ____________

2. **SEP Analyze Data** Based on your observations are the magnesium or barium salts more soluble?

3. **SEP Identify Patterns** What trend, if any, exists for the solubility of group 2 metals?

4. **SEP Identify Patterns** Would you expect beryllium salts to be more or less soluble than strontium salts?

5. **SEP Analyze Data** Which group 2 metal, magnesium or calcium, is more active? Explain your reasoning.

6. **SEP Analyze Data** Which period 3 metal, magnesium or aluminum, is more active? Explain your reasoning.

7. **SEP Identify Patterns** What trend, if any, exists for the activity of group 2 metals?

NAME ______________________ DATE ____________ CLASS ____________

8. **SEP Analyze Patterns** What trend, if any, exists for the activity of period 3 metals?

NAME ________________________ DATE ____________ CLASS ____________

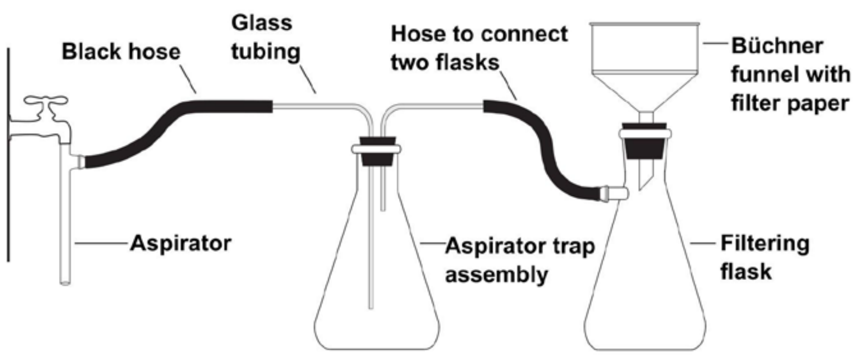
PERFORMANCE BASED ASSESSMENT

Gravimetric Analysis of Periodic Trends

Many trends exist within the periodic table of the elements, such as ionization energy, atomic radius, and metallic character. These trends result in predictable changes to the bulk properties of elements and their compounds. In this lab you will use gravimetric analysis to quantitatively investigate the solubility of sodium chloride, sodium bromide, and sodium iodide in methanol.

Gravimetric analysis is an analytical technique that permits quantitative determination of a property. Gravimetric analysis relies on making a mass measurement, which is then used to calculate the property of interest. In this experiment vacuum filtration (Figure 1) will be used to isolate the solid to be weighed. The use of a vacuum greatly increases the rate at which the solvent is drawn away from the solid. Additionally, when working with a volatile solvent, such as methanol (methyl alcohol), continuing to draw a current of air over the isolated solid helps to remove any remaining solvent and dry the sample.

Figure 1



The flow of water through the aspirator creates a partial vacuum in the flask

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

NAME ______________________________ DATE __________ CLASS __________

Materials Per Group

- Methanol, CH_3OH, 150 mL
- Sodium bromide, NaBr, 10 g
- Sodium chloride, NaCl, 10 g
- Sodium iodide, NaI, 10 g
- Balance, 0.01 g precision (shared)
- Beaker, 100 mL, 3
- Büchner flask, 250 mL
- Büchner funnel, 5.5 cm
- Büchner funnel rubber stopper, size 6
- Filter paper, quantitative, 5.5 cm, 3 pieces
- Graduated cylinder, 50 mL
- Spatula
- Magnetic stir bar
- Magnetic stir plate
- Vacuum filtration apparatus setup
- Watch glass, 75 mm, 3

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Methanol (methyl alcohol) is volatile, flammable, and toxic. Avoid breathing methanol fumes and do not use it around exposed flames. Sodium bromide, sodium chloride, and sodium iodide are all slightly toxic, and skin and eye irritants. Wear gloves at all times during the experiment. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. You need to fully plan out your experiment before starting any experimental work. Otherwise, you might neglect to keep key variables constant and invalidate your results.
2. Methanol is a volatile liquid (it readily evaporates). How can you minimize the amount of evaporation?

3. Classify each of the following as something that either needs to be kept constant between trials or can be permitted to vary: mass of solid, volume of methanol, speed of stirring, length of time stirred.

4. Write a detailed procedure and show it to your teacher for review. (Hint: When testing sodium iodide, use half the volume of methanol.)

NAME ______________________________ DATE ____________ CLASS ______________

5. Once your procedure has been approved, conduct your experiment. A blank data table has been provided for you to record your results.

Analyze and Interpret Data

1. **SEP Calculate** Use your data for NaCl to determine the amount of NaCl that dissolved in the methanol.

2. **SEP Use Math** Calculate solubility, in g/L, of NaCl in methanol.

3. **SEP Calculate** Use your data for NaBr to determine the amount of NaBr that dissolved in the methanol.

4. **SEP Use Math** Calculate solubility, in g/L, of NaBr in methanol.

5. **SEP Calculate** Use your data for NaI to determine the amount of NaI that dissolved in the methanol.

6. **SEP Use Math** Calculate solubility, in g/L, of NaI in methanol.

7. **SEP Identify Patterns** What trend exists for the atomic radius of fluorine, chlorine, bromine, and iodine.

8. **SEP Identify Patterns** Make a prediction for the solubility of NaF in methanol.

9. **SEP Evaluate and Communicate** Look up the accepted literature values for the solubility of NaF, NaCl, NaBr, and NaI. Compare these values with those you determined. What improvements could be made to your procedure to get a more reliable result?

Investigation 3

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Characteristics of Ionic Bonds

Chemical bonds are the forces that hold particles together in substances. The strengths of the bonds that hold the particles together in a compounds influence the compound's properties. For example, compounds with strong chemical bonds tend to have high melting points relative to compounds having weaker interparticle forces. Compounds with high melting points are useful for high-temperature applications, such as in spacecraft that must leave and re-enter Earth's atmosphere. In this lab, you will explore compounds' physical properties and sort the compounds based on bonding strength.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Dextrose, $C_6H_{12}O_6$, 2 g
- Potassium chloride, KCl, 2 g
- Sodium chloride, NaCl, 2 g
- Sucrose, $C_{12}H_{22}O_{11}$, 2 g
- Water, distilled or tap, 50 mL
- Balance (0.01-g precision)
- Butane safety lighter
- Metal ring with clamp
- Stirring rod, glass

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Allow samples to cool before touching or discarding them. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE __________ CLASS __________

Procedure

Develop a procedure to determine the relative strengths of the chemical bonds or interparticle forces in each of the compounds. Consider the following questions and points as you develop the procedure.

- **a.** How much of each solid is needed to conduct melting point tests?
- **b.** Should the amount of solid be controlled among compounds for the melting point tests?
- **c.** How much of each solid is needed to perform conductivity tests?
- **d.** Should the amount of solid be controlled among compounds for the conductivity tests?
- **e.** What type of glassware should be used in a conductivity test?
- **f.** Are quantitative data required to differentiate between bond strengths in compounds?

Use the area to record your detailed procedure, as well as any materials to be used.

NAME ____________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Analyze and Interpret Data** Based on your results, which of the compounds have the stronger chemical bonds or interparticle forces? Use data to support your answer.

2. **SEP Construct Explanations** Describe and explain one factor that you think affects the ability of a compound to conduct electricity in a solution of water.

Melting Point Data									
Compound	NaCl	KCl	RbCl	CsCl	MgF_2	$MgCl_2$	MgI_2	MgO	MgS
Melting Point, °C	800.7	771	724	646	1263	714	634	2825	2226

3. **SEP Construct Explanations** Discuss similarities between the compounds listed in this table that might account for their relatively high melting points. Also, describe and explain the trend in the melting point data for the compounds listed in this table.

4. **SEP Construct Explanations** Why do you think the melting points of MgO and MgS are significantly higher than the other compounds that contain Mg^{2+} as well as the alkali chlorides listed in the table?

5. **SEP Engage in Argument from Evidence** Imagine you are a scientist employed by a manufacturer of cookware like pots and pans. Which of the materials in the table would you use for a baking dish, and why?

NAME ____________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Investigate Metallic Bonds

The special properties of metals compared to nonmetals reflect their unique structure and bonding. Metals typically have a small number of valence electrons available for bonding. The valence electrons appear to be free to move among all of the metal atoms, which must exist therefore as positively charged cations. The purpose of this experiment is to study the physical properties of common solids and to investigate the relationship between the type of bonding in a substance and its properties.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Elements, two small pieces (or a few crystals) of each:
  - Aluminum
  - Carbon
  - Copper
  - Iodine
  - Magnesium
  - Silicon
  - Sulfur
  - Zinc
- Conductivity apparatus (optional)
- Hammer or other hard, solid object
- Nail
- Pencil or pen
- Periodic table
- Sheet of white paper, 8½" × 11"
- Spatula or forceps
- Test tubes, 8
- Test tube rack

Safety

Perform this lab activity in a well-ventilated laboratory. Iodine is toxic by ingestion and inhalation; it is corrosive to the skin, eyes, and the respiratory tract; avoid inhalation of iodine vapors by keeping the iodine bottle covered throughout the lab. Avoid contact of all chemicals with eyes and all body tissues. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE __________ CLASS __________

Procedure

Develop a procedure to classify the eight samples available to you into groups based on shared properties. Consider the following questions as you develop your procedure.

a. What physical properties can be used to distinguish between different types of elements?

b. What variables should be controlled in your tests of these physical properties?

Use the area to record your detailed procedure, as well as any materials to be used.

NAME ______________________ DATE ____________ CLASS ____________

Data Table						
Sample	**Chemical Symbol**	**Color**	**Luster**	**Other Physical Properties**	**Result of Tapping**	**Conductivity**
Aluminum						
Carbon						
Copper						
Iodine						
Magnesium						
Silicon						
Sulfur						
Zinc						

Analyze and Interpret Data

1. **SEP Analyze and Interpret Data** Review the data gathered for the eight elements. Sort the eight elements into groups based on similarities and differences in their physical properties.

NAME ____________________ DATE __________ CLASS __________

2. **SEP Construct Explanations** Are there any inconsistencies within the groups you made? Do any elements seem to have properties of multiple groups? Which? Explain.

3. **SEP Engage in Argument from Evidence** Look at the location on the periodic table of each of the eight elements tested in this lab. How do the properties of these elements compare to their general position on the periodic table?

4. **SEP Develop and Use Models** Predict the physical properties of the following elements not tested in this lab—selenium, calcium, and cobalt.

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Investigate Covalent Bonds

Covalent bonds are defined as the net attractive forces resulting from pairs of electrons that are shared between atoms (the shared electrons are attracted to the nuclei of both atoms in the bond). A group of atoms held together by covalent bonds is called a molecule. Covalent compounds have different physical properties than non-covalent compounds because the strength of the interactions between molecules are weaker than the strengths of the interactions between the particles that make up ionic compounds, for example. Also, when covalent compounds dissolve in water they do not break up into ions or atoms. They maintain their molecular structures. In this lab you are going to compare the strengths of the chemical bonds or interparticle forces present in two different types of compounds by observing some of their physical properties.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Dextrose, $C_6H_{12}O_6$, 2 g
- Potassium chloride, KCl, 2 g
- Sodium chloride, NaCl, 2 g
- Sucrose, $C_{12}H_{22}O_{11}$, 2 g
- Water, distilled or tap, 50 mL
- Aluminum evaporating dishes, 4
- Balance (0.01-g precision)
- Bunsen burner
- Butane safety lighter
- Metal ring with clamp
- Stirring rod, glass
- Support stand
- Test tubes, glass, 4
- Test tube clamp
- Test tube stand

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Allow samples to cool before touching or discarding them. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ____________________ DATE __________ CLASS __________

Procedure

Develop a procedure to determine the relative strengths of the chemical bonds or interparticle forces in each of the compounds. Consider the following questions and points as you develop the procedure.

- **a.** How much of each solid is needed to conduct melting point tests?
- **b.** Should the amount of solid be controlled among compounds for the melting point tests?
- **c.** How much of each solid is needed to perform conductivity tests?
- **d.** Should the amount of solid be controlled among compounds for the conductivity tests?
- **e.** What type of glassware should be used in a conductivity test?
- **f.** Are quantitative data required to differentiate between bond strengths in compounds?

Use the area to record your detailed procedure as well as any materials to be used.

NAME ____________ DATE ________ CLASS ________

Data Table		

Analyze and Interpret Data

1. **SEP Analyze and Interpret Data** Based on your results, which of the compounds have the weaker interparticle forces? What is the difference between the compounds with the weaker interparticle forces relative to the compounds with the stronger interparticle forces?

2. **SEP Construct Explanations** Describe and explain one factor that you think prevents $C_6H_{12}O_6$ and $C_{12}H_{22}O_{11}$ from conducting electricity strongly in a solution of water?

NAME ______________________ DATE ____________ CLASS ____________

Melting Point Data								
Compound	CH_4	C_2H_6	C_4H_{10}	C_5H_{12}	C_6H_{14}	C_7H_{16}	C_8H_{18}	C_9H_{20}
Melting Point, °C	-183	-172	-135	-130	-95	-91	-57	-54

3. **SEP Construct Explanations** Describe and explain the trend in the melting point data for the compounds listed in this table.

4. **SEP Engage in Argument from Evidence** Imagine you are a scientist employed by a manufacturer of cookware like pots and pans. What type of compound would you use to make a baking dish, and why?

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Intermolecular Forces

The forces that act between molecules, called intermolecular forces, play a significant role in many aspects of chemistry, from boiling point trends and the solubility of gases, liquids, and solids to the structure of DNA and proteins. In this experiment, you will develop a procedure to determine which compound has the stronger intermolecular forces—water or ethyl alcohol.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Plan and Carry Out Investigations
SEP 4 Analyze and Interpret Data
SEP 6 Constructing Explanations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Ethyl alcohol, anhydrous, C_2H_5OH, 30 mL
- Water, distilled or deionized, H_2O, 30 mL
- Buret, 50-mL
- Capillary tubes, 100 mm, 2
- Glass slides, 2
- Microspatulas, 2
- Petri dish, disposable
- Pipets, Beral-type, microtip, 2
- Polyethylene slides, 2
- Ruler

Safety

Ethyl alcohol is a dangerous fire risk; it is flammable. The addition of denaturants makes ethyl alcohol poisonous. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

NAME ______________________ DATE __________ CLASS __________

Procedure

Develop an experiment to determine which compound—water or ethyl alcohol—has the stronger intermolecular forces. Your experiment should measure or observe the following:

- **a.** The relative strengths of the interactions between each compound and glass and polyethylene (plastic) microscope slides.
- **b.** The height each liquid achieves by capillary action in a glass tube.
- **c.** The number of drops required to fill a microspatula.

Record your detailed procedure as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Data Table				
	Water		**Ethyl Alcohol**	
	Glass	Polyethylene	Glass	Polyethylene
Microscope Slide				
Drop Width (mm)				
Drop Height (mm)				
Force to Separate Slides	More/Less	More/Less		
Microspatula				
Number of Drops to Fill Microspatula				
Capillary Tube				
Capillary Rise (mm)				

Analyze and Interpret Data

1. **SEP Plan and Carry Out Investigations** Identify the independent, dependent, and control variables in your procedure(s).

2. **SEP Construct Explanations** Which liquid was least attracted to each of the surfaces? How could you tell that this was true?

NAME ______________________ DATE ____________ CLASS ____________

3. **SEP Engage in Argument from Evidence** Can you determine whether the polyethylene is made of polar or nonpolar molecules? Explain.

4. **SEP Construct Explanations** Which liquid required the most drops to fill the microspatula? What does this indicate about the size of the drops? How does the size of the drop relate to the attraction of the molecules to each other?

5. **SEP Analyze and Interpret Data** When you compare the size of the molecules of water and ethyl alcohol, which are bigger? How does this compare to the size of the drops?

6. **SEP Analyze and Interpret Data** Which liquid has weaker intermolecular attractions, and which has stronger intermolecular attractions?

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Chemical Names and Formulas

In the first part of this experiment, you will name and write chemical formulas of ionic and covalent compounds. In the second part of this experiment, you will develop a procedure that uses a chemical reaction to confirm the formula of an ionic compound.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 6 Constructing Explanations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Copper(II) chloride solution, 0.1 *M*, $CuCl_2$, 25 mL
- Iron(III) nitrate solution, 0.1 *M*, $Fe(NO_3)_3 \cdot 9H_2O$, 25 mL
- Sodium hydroxide solution, 0.1 *M*, NaOH, 25 mL
- Sodium phosphate solution, 0.1 *M*, $Na_3PO_4 \cdot 12H_2O$, 25 mL
- Envelope
- Ion Formula Chart
- Marking pen or wax pencil
- Metric ruler
- Models of Anions
- Models of Cations
- Pipets, Beral-type, thin-stem, 4
- Scissors
- Test tubes, 10 × 75 mm, 8
- Test tube rack
- Wood splints, 8

Safety

This activity requires the use of hazardous components and/or has the potential for hazardous reactions. Sodium hydroxide solution is corrosive and may cause skin burns. Iron(III) nitrate, copper(II) chloride, and sodium phosphate solutions may be skin/tissue irritants. All of these chemicals are toxic by ingestion. Avoid all body tissue contact when working with these chemicals. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE __________ CLASS __________

Procedure

Part A - Ionic Compounds

1. Working in teams or individually, separate the cations from the anions.
2. Observe carefully the ion cards. What do you notice about the height of the cards? What is the relationship between the height and the ion charge?
3. From the cation and anion cards, locate ion cards for the first two combining ions listed in the first column of the data table. The first two, for example, are the aluminum cation and chloride anion. Copy the ionic formula for each ion into the second column of the data table.
4. Put the cards for the two combining substances together on a flat surface, adding more cards of the same ion until the heights of the cation and anion column are equal. For example, every aluminum cation needs three chloride anions.
5. Count the number of each ion necessary for the heights to be equal (i.e., for the compound to form). For example, one aluminum cation combines with three chloride anions. Record the number of each ion used in columns 3 and 4 of the data table. Notice that the numbers recorded in columns 3 and 4 are the subscripts in the chemical formula of the compound.
6. Determine the total positive charge of the cation card(s) and the total negative charge of the anion card(s) used in forming the compound. For example, the total positive charge is +3 (from one aluminum with a +3 charge), and the total negative charge is –3 (from three chlorides, each with a –1 charge). Record the ionic charges in columns 5 and 6 of the data table.
7. Write the formula for the ionic compound, using subscripts to indicate the number of each kind of ion used (from columns 3 and 4). Follow the rules for writing ionic formulas listed in the *Background* material. In our example, the formula is $AlCl_3$. Record the chemical formula for the ionic compound in column 7 of the data table.

8. Write the name of the ionic compound following the rules for naming ionic compounds discussed in the *Background* information. In our example, the name of the compound is aluminum chloride. Record the name for the ionic compound in the last column of the data table.

9. Repeat steps 3–8 for each set of combining ions in the data table.

10. Gather the ion cards. Place them in an envelope, and return the ion cards to the instructor.

Data Table - Part A

Combining Ions	Ion Formulas	Number of Cations	Number of Anions	Total + Charge	Total – Charge	Formula	Name of Compound
Aluminum and Chloride							
Copper(II) & Hydroxide							
Ammonium & Carbonate							
Copper(I) & Phosphate							
Iron(III) & Oxide							
Aluminum & Sulfide							

NAME ______________________ DATE __________ CLASS __________

Part B - Covalent Compounds

11. Write the names of the covalent compounds to the right of the chemical formulas in the following data table.

12. Write the chemical formulas for the covalent compounds to the left of the chemical names in the data table.

Data Table - Part B	
Formula	**Name of Compound**
CO_2	
	Phosphorus trichloride
NO_2	
	Tetraphosphorus decasulfide
PCl_5	
	Dinitrogen pentoxide

Part C - Derive the Formulas of Two Ionic Compounds

13. Label four small test tubes 1–4 with a marking pen, and place them in a test tube rack.

14. When iron(III) nitrate and sodium hydroxide are mixed, a solid precipitate forms because Fe^{3+} ions combine with OH^- ions. The ratio of iron(III) nitrate to sodium hydroxide that will produce the most precipitate is the same ratio in which the Fe^{3+} and OH^- ions combine to form a neutral compound.

15. Fill a Beral-type pipet with 0.1 *M* iron(III) nitrate solution. Carefully add the number of drops indicated in the data table to each test tube. (*Note:* Exact volumes are crucial, so it is important to count accurately and hold the pipet vertically so the drop size is consistent and repeatable.)

16. Fill a different Beral-type pipet with 0.1 *M* sodium hydroxide solution. Again carefully add the number of drops indicated in the data table to each test tube. (*Note:* Exact volumes are crucial, so it is important to count accurately and hold the pipet vertically so the drop size is consistent and repeatable.)

17. Use wood splints to stir each of the mixtures in the tubes.

18. Let the tubes stand undisturbed for about 10 minutes to allow the precipitates to settle to the bottom of the tubes. During this time, determine the lowest whole-number ratio of drops of iron(III) nitrate to sodium hydroxide. Fill in this ratio in the data table.

19. Use a metric ruler to measure the height in millimeters of the precipitate in each test tube. Read from the top of the solid material to the bottom center of the test tube. It is important that you measure accurately so your results will be consistent. Record each height in mm in the data table.

20. Clean out the test tubes by pouring the solutions down the drain and dumping the solids in the solid waste disposal. Rinse out the tubes with plenty of water; use a test tube brush if necessary. Wash out the test tubes with soap and water for the next lab group.

21. Develop a procedure that uses copper(II) chloride and sodium phosphate to confirm that the formula of the solid formed by mixing these two compounds is $Cu_3(PO_4)_2$. Use the following space to record your procedure, as well as any materials to be used.

NAME ________________ DATE ________ CLASS ________

Data Table - Part C				
Test Tube	**1**	**2**	**3**	**4**
# drops 0.1 *M* $Fe(NO_3)_3$	4	8	11	16
# drops 0.1 *M* NaOH	28	24	22	16
Ratio of $Fe(NO_3)_3$ to NaOH				
Height of precipitate (mm)				

Analyze and Interpret Data

1. **SEP Construct Explanations** Why is it necessary to use roman numerals when naming ionic compounds that contain cations that can have more than one charge?

2. **SEP Construct Explanations** What is the purpose of the subscripts in a chemical formula?

3. **SEP Construct Explanations** Why is it necessary to place parentheses around a polyatomic ion before applying a subscript to the polyatomic ion?

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4. **SEP Construct Explanations** Why is it incorrect to name the chemical compound P_2O_5 as diphosphorus pentaoxide?

5. **SEP Construct Explanations** Why is it incorrect to name the chemical compound Fe_2S_3 as diiron trisulfide?

6. **SEP Engage in Argument from Evidence** Do the results of your experiments in Part C confirm that the formulas of the compounds formed by combining Fe^{3+} and OH^- and Cu^{2+} and PO_4^{3-} are $Fe(OH)_3$ and $Cu_3(PO_4)_2$, respectively? Explain.

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PERFORMANCE BASED ASSESSMENT

Qualitative Analysis and Chemical Bonding

Looking for patterns in the properties of solids can help us understand how and why atoms join together to form compounds. What kinds of forces hold atoms together? How do these forces influence the properties of materials? Use your knowledge of the relationship between chemical bonding type and the properties of substances to determine the identity of mystery solids.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 6 Construct Explanations

Materials Per Group

- Copper(II) sulfate, pentahydrate $CuSO_4 \cdot 5H_2O$, 2 g
- Dextrose monohydrate, $C_6H_{12}O_6 \cdot H_2O$, 2 g
- Ethyl alcohol, CH_3CH_2OH, 20 mL
- Hexane, C_6H_{14}, 20 mL
- Hydrochloric acid solution, HCl, 0.1 *M*, 20 mL
- Paraffin wax, C_nH_{2n+2} (n = 20–40), 2 g
- Sodium hydroxide solution, NaOH, 0.1 *M*, 20 mL
- Water, distilled or deionized, 20 mL
- Unlabeled samples, 6, 3 g of each
- Zinc, Zn, 2 g
- Aluminum dish
- Beaker, 100-mL
- Bunsen burner
- Conductivity meter or tester
- Hot plate
- pH paper
- Stirring rod
- Test tubes, 6
- Test tube holder
- Test tube rack
- Thermometer
- Tongs

NAME ________________________ DATE ____________ CLASS ______________

Safety

Hexane and ethyl alcohol are flammable organic solvents and dangerous fire risks. Keep away from flames, heat, and other sources of ignition. Cap the solvent bottles and work with hexane and ethyl alcohol in a fume hood or designated work area. Addition of a denaturant makes ethyl alcohol poisonous; it cannot be made nonpoisonous. Copper(II) sulfate is a skin and respiratory tract irritant and is toxic by ingestion. Graphite powder is a fire and inhalation risk. Dilute sodium hydroxide and acid solutions are irritating to skin and eyes. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab. Please follow all laboratory safety guidelines.

Procedure

Part A—Identifying Properties of Chemical Bonds

1. Four representative chemicals are provided for preliminary testing to identify physical and chemical properties that can be used for development of a classification scheme. The chemicals and the type of bonding in each are the following:

   Copper(II) sulfate—ionic bonding

   Dextrose—polar covalent bonding

   Paraffin wax—nonpolar covalent bonding

   Zinc—metallic bonding

2. Observe the color and appearance of each solid, and perform the following qualitative tests on each: (a) solubility in water, solubility in hexane, and solubility in alcohol; (b) high or low melting point; (c) conductivity of solid and conductivity of aqueous solution; (d) pH of solution; (e) reaction with acid (0.1 *M* HCl); and reaction with base (0.1 *M* NaOH). Note that a total of 2 g of each solid and 20 mL of each solvent are provided for testing.

3. To test the melting point of a substance, first place a small amount of each solid in separate locations in an aluminum evaporating dish. Hold the dish above a boiling water bath with tongs, and observe whether the solids melt at <100°C.

4. If the substance did not melt at <100°C, place a pea-size amount of solid in a borosilicate glass test tube. Heat the test tube in a medium burner flame for 1–2 minutes. Record observations.

5. Record the results of qualitative testing in a data table.

Part B—Development of a Classification Scheme

6. From your test data, list general properties that can be associated with each type of bonding in a solid.

7. Using yes−no logic, build a flowchart that can be used to characterize an unknown solid as ionic, polar covalent, nonpolar covalent, or metallic.

8. If given a white solid, what test results would help you identify the solid as polar covalent?

9. Each group will be given four unknown solids to evaluate. Using the flowchart as a guide, write a procedure to test the solids and to identify the type of bonding in each. Include the materials and equipment that will be needed, safety precautions that must be followed, amounts of chemicals to use, etc.

10. Carry out the flow chart tests on the four unknowns, and record the results of each test in an appropriate data table.

11. Share your group's data with a group that analyzed the other four unknowns.

12. Perform any additional tests as needed to verify the identities of any remaining chemicals that are still unknown. Match each unknown to one of the following chemicals: adipic acid, aluminum, calcium carbonate, dodecyl alcohol, glycine, graphite powder, iron(III) oxide, iron powder, potassium nitrate, salicylic acid, silicon, and sodium carbonate.

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Data Table - Part A				
Physical Property	**Copper(II) Sulfate, $CuSO_4$**	**Dextrose, $C_6H_{12}O_6$**	**Paraffin Wax**	**Zinc, Zn**
	Ionic	**Polar Covalent**	**Nonpolar Covalent**	**Metallic**
Color, Texture				
Solubility in Water				
Conductivity—Solid				
Conductivity—Solid in Water				
pH of Solution in Water				
Solubility in Hexane				
Solubility in Ethyl Alcohol				
Melting Point ≤100℃				
Melting Point 100–500℃				
Reaction with 0.1*M* HCl				
Reaction with 0.1*M* NaOH				

NAME ____________________ DATE __________ CLASS __________

Data Table - Part B					
Unknown Sample	**Solid Conductivity**	**Melting Point**	**Solubility in Water**	**Solution Conductivity**	**Type of Bonding**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

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Analyze and Interpret Data

1. **SEP Analyze and Interpret Data** Based on your results, identify the type of bonding in each compound. Use data to support your answer.

Melting Point Data									
Compound	NaCl	KCl	RbCl	CsCl	MgF_2	$MgCl_2$	MgI_2	MgO	MgS
Melting Point, °C	800.7	771	724	646	1263	714	634	2825	2226

2. **SEP Construct Explanations** Describe and explain the trend in the melting point data for the alkali chlorides listed in the Melting Point Data table.

3. **SEP Construct Explanations** Why are the melting points of MgO and MgS significantly higher than those of the other compounds that contain Mg^{2+} as well as the alkali chlorides listed in the table?

4. **SEP Construct Explanations** In order for a substance to conduct electricity, it must have free-moving charged particles.

   a. Explain the conductivity results observed for ionic compounds in the solid state and in aqueous solution.

   b. Would you expect molten sodium chloride to conduct electricity? Why or why not?

   c. Using what you have learned about the structures of metals, explain why metals conduct electricity.

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5. SEP Construct Explanations Why are the melting points of ionic compounds generally higher than the melting points of molecular compounds?

Investigation 4

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INQUIRY LAB – OPEN

Correlate Material Properties and Bond Type

Why do different materials have different properties? One way to approach this question is to look at the types of bonds within the material and identify trends. This enables us to predict bulk microscopic properties from the microscopic interactions that occur within different materials. In this activity you will be examining seven different liquids and five different solids and relating their properties to their bonds.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Aluminum granule, Al, 0.5 g
- Ethanol, C_2H_5OH, 2 mL
- Hexane, C_6H_{14}, 5 mL
- Methanol, CH_3OH, 2 mL
- Oil, canola, 5 mL
- Silicon dioxide, SiO_2, 0.2–0.3 g
- Sodium chloride, NaCl, 0.2–0.3 g
- Stearic acid, $C_{18}H_{36}O_2$, 0.2–0.3 g
- Sucrose, $C_{12}H_{22}O_{11}$, 0.2–0.3 g
- Water, distilled or deionized, in a wash bottle
- Balance, 0.01 g precision
- Beaker, 150 mL
- Boiling stone
- Bunsen burner
- Conductivity tester
- Hot plate
- Marking pen
- Pipette, Beral-type, 5
- Spatula
- Stirring rod
- Test tubes, small, 7
- Test tube rack
- Test tube holder (clamp)
- Weighing dishes, 5

Safety

Hexane, methanol, and ethanol are flammable organic solvents and a dangerous fire risk. Keep away from flames, heat, and other sources of ignition. Cap the solvent bottles and work with them in a fume hood or designated work area. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the lab.

NAME ______________________ DATE __________ CLASS __________

Procedure

Part 1. Liquids

1. Place seven small test tubes in the test tube rack. Label the test tubes as oil/hex, meth/hex, eth/hex, H_2O/hex, oil/H_2O, meth/H_2O, eth/H_2O.
2. Add 1 mL of the first listed liquid into each of the seven test tubes.
3. Add 1 mL of hexane to each of the first four test tubes.
4. Add 1 mL of distilled water to the final three test tubes.
5. Carefully agitate each test tube and record your observations in the data table.

Liquids						
oil/hex	**meth/hex**	**eth/hex**	**H_2O/hex**	**oil/H_2O**	**meth/H_2O**	**eth/H_2O**

Part 2. Solids

6. Prepare a boiling water bath: Half-fill a 150 mL beaker with water, add a boiling stone, and heat the beaker on a hot plate at a medium setting.

7. Label five weighing dishes for the five solid samples and measure 0.2–0.3 g samples of each solid in the appropriate weighing dish. Record the color and appearance of each solid in your data table. The five samples are: aluminum, silicon dioxide, sodium chloride, stearic acid, and sucrose.

8. **SEP Plan An Investigation** Devise at least five additional tests to characterize the provided samples. These tests should not involve any reactions. Record your detailed procedure, as well as any materials to be used.

9. Record the results of your tests in the data table.

10. Dispose of all waste liquids and solids as directed by your instructor.

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Physical Properties of Five Solids					
Physical Property	**Aluminum**	**Silicon Dioxide**	**Sodium Chloride**	**Stearic Acid**	**Sucrose**
Color and Appearance					
Bonding Type					

Analyze and Interpret Data

1. **SEP Form a Hypothesis** Why do you think some of the liquids in Part 1 formed one layer when mixed, while others formed two?

2. **SEP Identify Patterns** Both stearic acid and sucrose are molecular substances. Compare and contrast their observed properties, then propose and explanation for any observed differences.

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3. **SEP Identify Patterns** In order for a substance to conduct electricity, it must have free-moving charged particles.

   a. Explain the conductivity results observed for sodium chloride in the solid state and when dissolved in water.

   b. Would you expect molten sodium chloride to conduct electricity? Why or why not?

4. **SEP Develop Models** Use your observations to determine the general properties of the different types of solids.

Properties of Different Types of Solids				
General Properties	**Covalent-network**	**Ionic**	**Metallic**	**Molecular**
Melting Point			Low to high	
Solubility				Variable ability to dissolve
Conductivity of Solid		Nonconductors		

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INQUIRY LAB – OPEN

Measure the Energy of a Phase Change

What kind of energy changes are associated with the melting process of a substance? By careful examination of objects at the macroscopic level we can begin to understand the processes that occur at the molecular level. In this lab you will record the heating and cooling curves for an organic solid.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Organic solid (choose one)
    - Cetyl alcohol, $C_{16}H_{33}OH$, 6 g
    - Lauric acid, $C_{11}H_{23}CO_2H$, 6 g
    - Stearic acid, $C_{17}H_{35}CO_2H$, 6 g
- Beakers, 250 and 400 mL
- Digital thermometers or temperature probes, 2
- Graph paper or graphing software
- Hot plate or hot water bath
- Paper towels
- Polystyrene foam cups, 2
- Support stand and clamp
- Spatula
- Stopwatch or timer
- Test tube, 20 mm x 150 mm
- Test tube clamp
- Weighing dish

Safety

Read the entire procedure before beginning the experiment. Work carefully to avoid scalding yourself with hot water. Cetyl alcohol is slightly toxic by ingestion. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Part A. Cooling curve

1. Prepare a hot water bath by filling a 400 mL beaker two-thirds full with hot tap water. Heat the water to about 80°C on a hot plate.
2. Obtain about 6 g of the chosen organic solid in a weighing dish and transfer the solid to a clean and dry test tube.
3. Add about 100 mL of cold tap water (15–20°C) to a polystyrene foam cup and nest the cup inside a second polystyrene foam cup. Place the nested polystyrene foam cups in a 250 mL beaker and set the beaker on the support stand.
4. **SEP Plan a Procedure** Devise a method to record a cooling curve for your chosen organic solid. As you develop your procedure, consider the following:
    - How will you heat/cool the sample?
    - How will you record the temperature?
    - How often will you record the temperature?
    - How can you ensure that your reading is indicative of the bulk temperature and not of just one spot?

    Record your detailed procedure as well as any materials to be used.

NAME ______________________ DATE ____________ CLASS ____________

Cooling Curve	
Time (s)	**Temperature (°C)**

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Part B. Heating curve

5. Check that the temperature of the hot water bath is between 75°C and 80°C. Do not let the temperature rise above 80°C. Add cold water if necessary to adjust the temperature.

6. **SEP Plan a Procedure** Devise a method to record a heating curve for your chosen organic solid. As you develop your procedure, consider the following:

    - How will you heat/cool the sample?
    - How will you record the temperature?
    - How often will you record the temperature?
    - How can you ensure that your reading is indicative of the bulk temperature and not of just one spot?

    Record your detailed procedure, as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

7. Dispose of the sample as directed by the instructor.

Heating Curve	
Time (s)	**Temperature (°C)**

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Use Graphs** Prepare a graph of temperature on the y-axis versus time on the x-axis. Use graphing software or the space to plot the data from Parts A and B as two series of points, using different colors or different shapes to distinguish the points of Part A from those of Part B. Add a continuous curve through the plotted points for each series of data.

2. **SEP Interpret Data** What happens to the temperature of a pure substance while it is freezing or melting? Estimate the freezing point and the melting point of the organic solid from the cooling curve and the heating curve, respectively. Does the freezing point/melting point depend on the direction in which the phase change takes place?

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3. **SEP Interpret Data** Based on your observations, what do you estimate the melting point of your organic solid is?

4. **SEP Obtain Information** Look up and record the melting point of your organic solid.

5. **SEP Evaluate and Communicate** What changes could be made to the experimental procedure to improve the quality of the data collected?

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INQUIRY LAB – OPEN

Melt Ionic and Covalent Compounds

Why do different materials have different melting points? Is it possible to relate the type of bonding within a substance to its melting point? When chemicals melt, the molecules break out of their ordered structure and begin to move freely.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Acetic acid, glacial, $C_2H_3O_2H$, 5 mL
- Ammonium acetate, $NH_4C_2H_3O_2$, 5 g
- Sodium acetate, anhydrous, $NaC_2H_3O_2$, 5 g
- Sodium chloride, NaCl, 5 g
- Balance
- Beaker, 250 mL
- Bunsen burner
- Ice water
- Test tubes, heavy walled, 16 mm x 125 mm, 3
- Test tube holder
- Thermocouple
- Weighing dish, 3

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Glacial acetic acid is corrosive and has a strong odor; do not open the sealed sample. Ammonium acetate can break down to produce acetamide (a suspected carcinogen) when heated; only heat in a fume hood or well ventilated area and avoid breathing any fumes released. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Half fill a 250 mL beaker with ice water.

2. Place the sealed sample of acetic acid into the ice water and record your observations.

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3. Measure the temperature of the ice water and the room. Report this temperature range as the melting point of acetic acid.

4. **SEP Plan an Investigation** Design an experiment to determine the melting points for the remaining three materials. Two things to consider are how long to heat a sample for, and when to record the temperature. Use the area to record your detailed procedure, as well as any materials to be used. Show your teacher your procedure before starting any experimental work.

Data Table — Melting Points	
Sample	**Melting Point**
Acetic acid	
Ammonium acetate	
Anhydrous sodium acetate	
Sodium chloride	

NAME ______________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Obtain Information** Look up the structures of acetic acid and ammonium acetate. Classify each as either a covalent molecule or ionic compound.

2. **SEP Identify Patterns** From your data, what can be inferred about the degree of ionic character for the other two chemicals tested?

3. **SEP Obtain Information** Look up and draw the structures of the ammonium ion, acetate ion, chloride ion, and sodium ion.

4. **SEP Construct an Explanation** Based on your results and the structures you drew in question 3, propose a reason for why different compounds have differing degrees of ionic character.

5. **SEP Plan an Investigation** Propose an experiment that you could conduct to test your hypothesis from question 4. Include examples of chemicals that could be tested.

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INQUIRY LAB – OPEN

Modeling Metals, Ceramics, and Polymers

What gives different materials their properties? The modern materials that we encounter on a daily basis are tailored to their applications. By constructing models we can start to understand why specific properties arise and how to more efficiently develop new materials. In this activity you will make models of metals as well as nonmetallic ceramics and polymers.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations

Materials Per Group

- Bamboo skewers, 10
- Beaker, 50 mL
- Chenille wires, 30
- Expanded polystyrene balls, 1 in., 14
- Graduated cylinder, 50 mL
- Plastic tub, approximately 10 cm x 10 cm x 5 cm
- Scissors
- Water

Procedure

Part 1. Metals

1. Place an expanded polystyrene ball into the beaker. This ball represents a metal atom.
2. Add 20 ml of water to beaker. This represents the metal atom's delocalized electrons.
3. Pour the contents of the beaker into the plastic tub.
4. Repeat steps 1–3 until either all the balls are in the plastic tub, or there is no more room for a ball to sit on the water's surface.

5. Push one of the balls along the water's surface. How does this affect the other balls? Record your observations.

Part 2. Ceramics

6. Remove the balls from the plastic tub and dry them.
7. First we will make a model of a layered material, such as graphite or sedimentary rock.
8. Cut or break the bamboo skewers roughly into thirds.
9. Use the pieces of the bamboo skewers to connect and make a layer of 7 balls. They should be in a 2-3-2 pattern.
10. Repeat step 8 to make a second layer of balls.
11. Place one layer on top of the other. The balls should nestle into the gaps of the lower layer.
12. Pick up the two layers and hold them in one hand, then push down on them with you other hand. Record your observations.

13. Now push the back end of the top layer, in such a way that the force is parallel to the plane. Record your observations.

14. Disconnect all of the balls. Then reconnect them in such a way that each ball is connected to at least three other balls in a three-dimensional network. This network should have a regular repeating pattern.

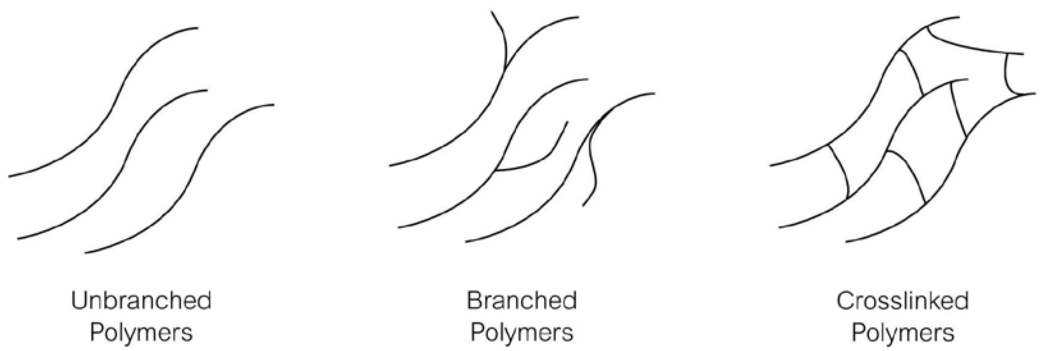
15. Push and pull the three-dimensional network along different axes. Record your observations.

NAME ______________________ DATE ____________ CLASS ____________

Part 3. Polymers

16. Devise ways to represent straight chain polymers, branched polymers, and crosslinked polymers (**Figure 1**) using the chenille wires. You may wish to cut some of the wires into shorter lengths. Record your detailed procedure as well as any materials to be used in the box.

Figure 1



NAME ________________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Use Models** If a small hole was drilled just above the water level of the plastic tub and more water was poured in, what would happen, and what would this represent?

2. **SEP Use Models** If a ceramic material was made of atoms assembled in layers, what do you predict its physical properties will be?

3. **SEP Use Models** If a ceramic material was made of atoms assembled in a three-dimensional network, what do you predict its physical properties will be?

4. **SEP Develop Models** How did you represent the flexibility of polymers in your model?

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5. **SEP Use Models** Take the unbranched polymers and group them together so that they are roughly aligned. Gently toss them a couple of times in your hands and then place them on the table. Attempt to carefully remove a wire from the center of the bundle. How easy was this to do?

6. **SEP Use Models** Take the branched polymers and group them together so that they are roughly aligned. Gently toss them a couple of times in your hands and then place them on the table. Attempt to carefully remove a wire from the center of the bundle. How easy was this to do?

7. **SEP Use Models** Take the crosslinked polymers and gently toss them a couple of times in your hands and then place them on the table. Attempt to carefully remove a wire from the center of the bundle. How easy was this to do?

8. **SEP Use a Model to Evaluate** What do you predict the relative properties of plastics made with unbranched, branched, and crosslinked polymers to be?

9. **SEP Compare** How do the properties of plastics compare with those of metals?

NAME ______________________ DATE ____________ CLASS ____________

10. SEP Analyze Costs and Benefits You are asked to design a drink bottle for use by a five-year-old. What material would you recommend making it out of and why?

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Investigate Surface Tension

How are water strider insects able to walk on water? In this lab you will investigate the way that water interacts with other objects.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations

Materials Per Group

- Paper clip
- Water, tap
- Soap
- Pennies, 3
- Pipet, beral, 1
- Petri dish
- Cotton swab
- Paper towel
- Paraffin wax

Procedure

Part 1. Floating a paperclip

1. Fill the petri dish ¾ full with tap water.
2. Hold the paper clip along its long axis, between the tips of your thumb and forefinger.
3. Carefully lower the paper clip so that it just contacts the surface of the water. (The body of the paper clip should be parallel to the surface of the water).
4. Release the paper clip. It should float on the surface of the water. If the paper clip sinks, remove it from the water and dry it with the paper towel before trying again.

5. Carefully observe the surface of the water where the paper clip touches it. Record your observations.

6. Apply soap to one end of the cotton swab.

7. Insert the soap-free end of the cotton swab into the water about 2 cm away from the paper clip. Wait for 5 seconds and record your observations.

8. Remove the cotton swab from the water.

9. Insert the soaped end of the cotton swab into the water about 2 cm away from the paper clip. Wait for 5 seconds and record your observations.

10. Remove the paper clip from the water and dry it. Pour the water down the drain. Discard the cotton swab and paper towel. Return all materials to your teacher.

NAME ______________________ DATE __________ CLASS __________

Part 2. Water on a penny

1. Devise a procedure to explore the effects on water tension of different coatings on the surface of pennies. Record your detailed procedure as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Develop Models** Propose an explanation for why the paper clip floated on the water.

2. **SEP Use Models** Propose an explanation for what happened when the clean end of the cotton swab was inserted into the water.

3. **SEP Use Models** Propose an explanation for what happened when the soaped end of the cotton swab was inserted into the water.

4. **SEP Develop Models** What did you observe when water was first added to the face of each penny?

5. **SEP Use Models** Propose an explanation for your results in Part 2.

NAME ______________________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Aqueous Solutions

What kind of changes occur when something dissolves? Is there a limit to a substance's solubility?

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Copper(II) sulfate, $CuSO_4 \cdot 5H_2O$, 25 g
- Glucose, $C_6H_{12}O_6$, 25 g
- Balance, 0.1 g precision
- Beaker, 100 mL
- Conductivity meter
- Spatula
- Stirring rod
- Weighboat
- Water, distilled, 50 mL

Safety 

Wear safety goggles when performing this or any lab that uses chemicals or glassware. Copper(II) sulfate is a skin irritant and toxic by ingestion. Wear gloves and wash your hands with soap and water before leaving the lab.

NAME ______________________ DATE __________ CLASS ____________

Procedure

1. In this laboratory you will investigate observable changes in the bulk properties of a solution as substances dissolve. You will do this using two different solids. The first solid is copper(II) sulfate and the second solid is glucose. Record your detailed procedure; it should involve using all of the provided solid. Have your teacher approve your procedure before starting any experimental work.

2. Dispose of your solutions as directed by your instructor.

NAME ______________________ DATE ____________ CLASS ____________

Data Table—Copper(II) Sulfate	

Data Table—Glucose	

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Develop Models** What evidence was there that the copper(II) sulfate was dissolving?

2. **SEP Identify Patterns** What happened to the color of the solution as the copper(II) sulfate dissolved?

3. **SEP Make Observations** Was there a limit to the amount of copper(II) sulfate that dissolved? If not why do you think that is?

4. **SEP Make Observations** What evidence was there that the glucose was dissolving?

5. **SEP Identify Patterns** What happened to the color of the solution as the glucose dissolved?

NAME ______________________ DATE __________ CLASS ___________

6. **SEP Make Observations** Was there a limit to the amount of glucose that dissolved? If not why do you think that is?

7. **SEP Make Observations** How did the conductivity of the copper(II) sulfate solution compare with the conductivity of the glucose solution? Propose an explanation for any observed differences.

8. **SEP Construct an Explanation** Propose an explanation for what happens when a material dissolves that explains your answers to questions 1–7.

NAME ______________________ DATE ____________ CLASS ____________

PERFORMANCE BASED ASSESSMENT

Road Deicers

During winter months many states use deicers to remove ice from roadways and to improve traction. These deicers are granular solids spread by snowplows. Three compounds commonly found in road deicers are sodium chloride, calcium chloride, and silicon dioxide. In this laboratory you will make predictions about the effectiveness of each of these compounds before designing and conducting an experiment to evaluate these predictions.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Calcium chloride, $CaCl_2$, 10 g
- Silicon dioxide, SiO_2, 10 g
- Sodium chloride, NaCl, 10 g
- Balance, 0.1 g precision
- Beaker, 50 mL, 4
- Beaker, 600 mL
- Ice, crushed, 200 g
- Stopwatch
- Thermometer

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Calcium chloride and sodium chloride are slightly toxic, and skin and eye irritants. Wear gloves at all times during the experiment. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. **SEP Plan an Investigation** You need to fully plan out your experiment before starting any experimental work. Otherwise, you might neglect to keep key variables constant, and that will invalidate your results.

NAME ______________________ DATE ____________ CLASS ____________

2. Classify the bonding in each of the following as either ionic or covalent: sodium chloride, calcium chloride, silicon dioxide, water.

3. **SEP Plan an Investigation** Write a detailed procedure and show it to your teacher for review. Don't forget to explain how you will assess the effectiveness of the deicers.

4. Which substance do you predict will be the most effective deicer? Explain your reasoning.

NAME ______________________ DATE __________ CLASS __________

5. Once your procedure has been approved, conduct your experiment. A blank data table has been provided to record your results.

Data Table — The Experiment			

Analyze and Interpret Data

1. **SEP Analyze Data** Which substance did you determine to be the most effective road deicer?

2. **SEP Use Evidence** How did your results compare to your prediction? Propose an explanation for any discrepancies.

3. **SEP Analyze Costs and Benefits** 2 kg of sodium chloride costs $8.80, 2 kg of calcium chloride costs $17.05, and 2 kg of silicon dioxide costs $9.60. Use this information to make a recommendation about which material should be used as a road deicer.

Investigation 5

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Describe Small-scale Matter Using the Mole

How big is a mole? The number is so large, it's almost impossible to imagine. The following activity will help you visualize the size of a mole and better understand its use as a tool to count matter on very small scales, such as the atomic scale.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Aluminum foil
- Balance, 0.01-g precision
- Navy beans
- Rice
- Weighing Dishes, 4

Procedure

Part A - Counting with the Mole

1. "Counting by weighing" is used in chemistry and other applications to deal with small things. A hardware store, for example, may sell nails in packages of 500. Similarly, the office supply store probably carries boxes that contain 100 paper clips. Do you think someone counts out by hand every nail or paper clip in these products?

NAME ______________________________ DATE ____________ CLASS ____________

2. The average mass of one paper clip is 0.39 g. What is the expected mass of 100 paper clips?

3. Develop a procedure that uses the "counting by weighing" method that will allow you to predict the mass of one hundred grains of rice with a degree of accuracy that results in a percent error less than 5%. Your procedure must include the steps necessary to calculate the percent error. Record your detailed procedure, as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Part B - Conceptualizing the Mole

4. Review the mass and size of an atom. A typical hydrogen atom, for example, has a mass of 1.66×10^{-24} g. Imagine how big a number we would need to describe the number of atoms in a real-life sample of an element. Could we somehow measure or handle a dozen or a ream of atoms?

5. The mass of a single aluminum atom is about 4.5×10^{-23} g. Tear a 218 cm-long piece of aluminum foil from a roll that is 12 inches wide. Note that this will be a fairly large piece of Al foil, about 7 ft in length. Fold the piece of Al foil enough times such that it can be weighed on a balance. Measure and record its mass. Calculate how many aluminum atoms are present in that single piece of aluminum foil. The result of your calculation is Avogadro's number, which represents the number of Al atoms in 1 mole of Al atoms!

6. Write out Avogadro's number in longhand, and then in scientific notation.

7. Imagine you have a mole of dollar bills. Assuming you can spend a million dollars a second, how many years would you be able to spend the money at this rate before the mole of dollar bills has been spent?

NAME ______________________ DATE ____________ CLASS ____________

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Develop and Use Models** Describe how your procedure accounts for the effects of mass variability in rice grains.

2. **SEP Use Mathematics and Computational Thinking** What method is necessary to guarantee 100% accuracy, or zero percent error, in determining the mass of 100 grains of rice?

3. **SEP Use Mathematics and Computational Thinking** Predict the mass of 1,000,000 grains of rice.

4. **SEP Develop and Use Models** Why is it often necessary, when working in the chemistry lab, to describe matter in terms of "moles."

5. **SEP Develop and Use Models** Write a short paragraph explaining how a chemist would count the number of atoms in a piece of aluminum wire.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Mole Ratios

The single replacement reaction of copper wire with silver nitrate in aqueous solution shows chemistry in action. Delicate silver crystals grow on the wire surface and the blue color of copper(II) ions gradually appears in solution. The amount of silver crystals that grow on the copper wire is related to the amount of copper wire that transforms into copper ions.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 7 Engage in Argument from Evidence

Materials Per Group

- Acetone, CH_3COCH_3
- Copper wire, Cu, 25 cm
- Nitric acid, HNO_3, 3 M, 3 drops
- Silver nitrate, $AgNO_3$, 1.5 g
- Balance, centigram (0.01-g precision)
- Labeling or marking pen
- Beakers, 50- and 100-mL 250-mL
- Erlenmeyer flask, 125-mL
- Spatula
- Stirring rod
- Wash bottle and distilled or deionized water
- Wooden splint

Safety 

Nitric acid is a corrosive liquid and a strong oxidizer. Silver nitrate is a corrosive solid and is toxic by ingestion; it will stain skin and clothes. Acetone is a flammable liquid; avoid contact with flames and other sources of ignition. Avoid contact of all chemicals with eyes, skin, and clothing. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

When copper wire is immersed in an aqueous solution of silver nitrate (solid silver nitrate dissolved in water), a single replacement reaction occurs. As the reaction progresses, the copper metal is converted to copper ions and the silver ions are converted to silver metal that forms on the copper wire. Because the copper metal is converted to copper ions, the mass of copper changes. Develop a procedure to determine the mole ratio of silver:copper in the reaction between copper metal and silver nitrate. Consider the following questions as you develop your procedure.

a. What mass of copper wire should be used?

b. How much solid silver nitrate should be dissolved in water?

c. How long must the reaction be allowed to progress?

NAME ______________________ DATE __________ CLASS __________

Record your detailed procedure as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Use Math** Calculate the number of Ag atoms formed in your experiment.

2. **SEP Use Math** Calculate the number of Cu atoms used in your experiment.

3. **SEP Engage in Argument from Evidence** Explain how your empirical and qualitative data support the idea that matter such as atoms are not created or destroyed in a chemical reaction, but converted from one form to another. If your data does not support this idea, explain why.

4. **SEP Analyze and Interpret Data** Why is it necessary to dry the solids recovered from the reaction prior to massing them?

5. SEP Planning and Conducting Investigations Write a brief, 2–3 sentence procedure that outlines how you would experimentally determine the molar relationship between aluminum and copper in the equation that represents the reaction between aluminum and aqueous copper(II)nitrate.

6. SEP Construct Explanations Is it possible to know for sure, given the information you have in this lab, what reactant or product is responsible for the blue color that the solution takes on as the chemical reaction progresses?

7. SEP Developing and Using Models What do you think will happen if an iron nail is placed in a solution of $CuCl_2$?

NAME ______________________ DATE __________ CLASS ___________

INQUIRY LAB – OPEN

Determine an Empirical Formula

Empirical formulas are chemical formulas that show the simplest ratio of elements in a compound. Through experimentation and careful measurements, you can determine the empirical formula of an unknown binary compound. In this lab, your group will be given an unknown binary compound to analyze. Each group's compound has the general formula D_xE_y. When heated, the compound decomposes and E becomes a gas.

$$D_xE_y(s) \rightarrow xD(s) + yE(g)$$

To calculate the empirical formula of a compound, you need to know the percent or mass of each element in the compound. These masses, once converted to moles using molar mass values, reveal the mole ratios of the constituent elements to each other in the compound.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Unknown Binary Compound in vial, 34 g
- Balance, milligram (0.001-g precision)
- Bunsen burner
- Clay triangle
- Crucible and crucible lid
- Crucible tongs
- Support Stand and ring clamp
- Wire gauze with ceramic center

NAME ______________________ DATE __________ CLASS __________

Safety

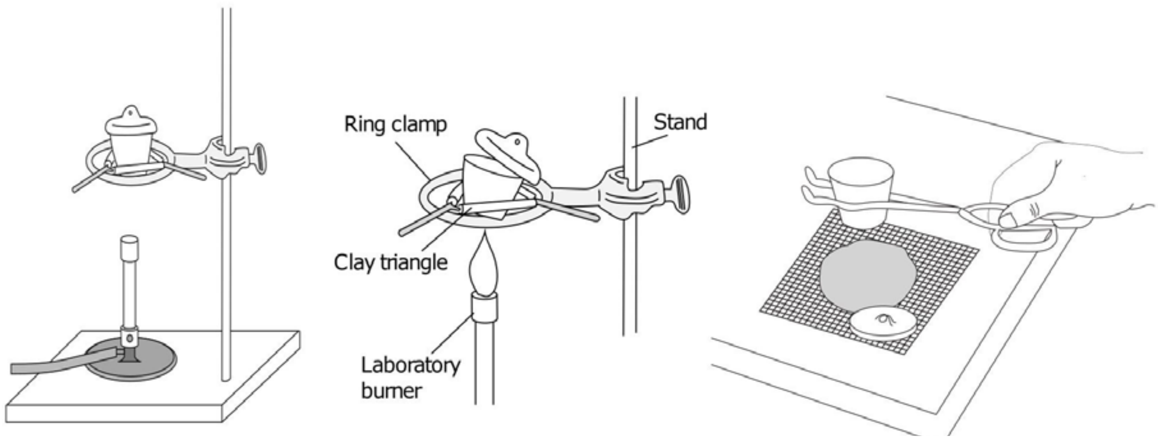
The unknown compounds are toxic if swallowed and harmful if inhaled. Avoid breathing dust or fumes. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Handle the hot crucible and its lid only with tongs. Do not touch the crucible with fingers or hands—remember that a hot crucible looks exactly like a cold one. Please follow all laboratory safety guidelines.

Procedure

Figure 1 below provides an illustrative guide on how to set up a crucible and Bunsen burner to heat a solid material to the point that it decomposes into a solid and a gas. Use this information along with the information in the Introductory video to develop a simple procedure for determining the empirical formula of your unknown compound. Record your detailed procedure as well as any materials to be used.

NAME ____________________ DATE __________ CLASS __________

Figure 1



Analyze and Interpret Data

1. **SEP Use Mathematics and Computational Thinking** What is the mass of D and E in your unknown sample?

NAME ________________ DATE ________ CLASS ________

2. **SEP Use Mathematics and Computational Thinking** What are the moles of D and E in your sample?

3. **SEP Use Mathematics and Computational Thinking** Using the moles of D and E, determine the empirical formula of your unknown.

4. **SEP Analyze and Interpret Data** What is the empirical formula of a compound that is 39.95% carbon, 13.44% hydrogen and 46.5% nitrogen?

5. SEP Construct Explanations If you ran a similar experiment to this one with 10.0 g $CuCl_2$•$2H_2O$ and heated the compound at a low temperature to remove the water in the chemical formula, what would the post-heating mass be?

6. SEP Construct Explanations Which of the following statements about the experiment you performed is more accurate? Explain.

a. When we heated our unknown samples we destroyed the atoms.

b. When we heated our unknown samples we converted the atoms from one form to another form.

NAME ________________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Preparation of Solutions

Chocolate milk is an example of a solution, in which a solute (chocolate syrup) is dissolved in a solvent (milk). If you like a lot of chocolate syrup in your milk you prefer concentrated chocolate milk. If you prefer only a little bit of chocolate syrup in your milk you like dilute chocolate milk. How can we relate this idea to chemistry? We would not use terms like “dilute” and “concentrated” to describe chocolate milk. We’d probably say we like it chocolatey or not too chocolatey. But when we are dealing with matter that is really small we need to describe quantities differently.

For example, the molarity, *M*, of a solution is the number of moles of solute in one liter of solution. To determine the molarity of a solution, the following equation can be used:

$$Molarity\ (M) = \frac{moles\ of\ solute}{liters\ of\ solution\ (V)}$$

In conjunction with the molecular weight of a solute, this equation is used to determine the number of grams of solute needed to prepare a given volume of a solution with a specific concentration.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Copper(II) sulfate, $CuSO_4 \cdot 5H_2O$
- Balance
- Beaker, 250-mL
- Beral-type pipets, 2
- Funnel
- Marker, waterproof
- Paper towels
- Spatula
- Volumetric flask, 100-mL, 2
- Wash bottle filled with water
- Wax pencil or labeling tape
- Weighing dish

NAME ______________________ DATE __________ CLASS __________

Safety

Copper(II) sulfate is moderately toxic by ingestion and inhalation and is a skin and respiratory irritant. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Prepare 100 mL of a 0.10 M solution of $CuSO_4$ using water as the solvent. First, calculate the number of grams of copper(II) sulfate pentahydrate, $CuSO_4•5H_2O$, required to prepare 100 mL of a 0.10 M solution.

2. Once your calculation has been approved by your instructor, weigh out the required amount of copper(II) sulfate on a balance in a clean, dry weighing dish.

3. Transfer the solid to a clean, dry beaker. Use a wash bottle filled with distilled or deionized water to rinse any remaining solid from the weighing dish into the beaker. Dissolve the solid in the beaker in a minimum amount of distilled or deionized water.

4. Transfer the solution to a 100-mL volumetric flask using a funnel. Rinse the beaker with distilled or deionized water using a wash bottle. Pour the rinse water through the funnel and into the volumetric flask so that every bit of solid copper(II) sulfate or solution is transferred to the volumetric flask. Rinse the beaker, running the rinse water through the funnel several times to thoroughly rinse both the beaker and the funnel.

5. Slowly continue adding distilled or deionized water to the volumetric flask until the flask is one-half to two-thirds full.

6. Continue filling the flask until the liquid level is almost to the 100-mL mark. Fill to the mark with a pipet or wash bottle drop-by-drop so that no water splashes up on the sides of the flask.

7. Fill until the bottom of the meniscus is exactly at the 100-mL mark.

8. Cap the volumetric flask and invert it 10–15 times to make a completely homogeneous solution.

9. Develop a procedure to make 100 mL of 0.1 M $CuSO_4$, using the 0.5 M $CuSO_4$ you prepared in steps 1–8. Record your detailed procedure as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Develop and Use Models** Draw a model of the dilute solution and a model of the concentrated solution. Comment on their similarities and differences.

2. **SEP Develop and Use Models** How does the scale of matter you are working with prevent you from drawing a model that is 100 percent reflective of the contents in the two solutions you prepared?

3. **SEP Analyze and Interpret Data** How can you tell that the 0.5 M solution you prepared is more concentrated than the dilute, 0.1 M solution you prepared?

NAME ______________________________ DATE __________ CLASS ____________

4. **SEP Use Mathematics and Computational Thinking** Do you think the masses of the two $CuSO_4$ solutions you prepared are the same or different? Explain.

5. **SEP Develop and Use Models** Why does 100 mL of a 0.1 M solution of NaCl require a different amount of solid than 100 mL of a 0.1 M solution of $CuSO_4$?

6. **SEP Planning and Carrying Out Investigations** If you needed the $CuSO_4$ you used to prepare the solutions back to run a different experiment, how could you separate the water from the solid?

NAME ______________________ DATE __________ CLASS __________

PERFORMANCE BASED ASSESSMENT

Analysis of Basic Copper Carbonate

There are two different formulas for basic copper carbonate. To determine the correct formula, a two-part experiment is conducted.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Basic copper carbonate, 2 g
- Copper(II) sulfate stock solution, $CuSO_4$, 0.20*M*, 40 mL
- Hydrochloric acid solution, HCl, 2*M*, 15 mL
- “Unknown” basic copper carbonate solution (U), 10 mL
- Water, distilled or deionized
- Balance, 0.01-g precision
- Erlenmeyer flask, 125-mL
- Graduated cylinder, 10-mL
- Graduated cylinder, 25-mL
- Marker, permanent
- Paper towels
- Pipets, Beral-type, 4
- Reaction plate
- Test tube rack
- Test tubes, 13 × 100 mm, 7
- Weighing dish
- White paper, 8.5″ × 11″, 2 sheets

Safety

Hydrochloric acid solution is toxic and corrosive to eyes and skin tissue. Copper carbonate is slightly toxic by ingestion and inhalation. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

NAME ________________________ DATE ____________ CLASS ____________

Procedure

Develop a two-part procedure to determine whether the formula of your unknown copper carbonate is $Cu_2(OH)_2CO_3$ or $Cu_3(OH)_2(CO_3)_2$. In one part, describe a method for determining the mass percent of CO_2 in the unknown. In another part, describe a method for determining the mass percent of Cu in the unknown. With respect to the percent copper determination, you will be given a solution made by dissolving 1.30 g of the unknown solid into a 100 mL solution, and a solution that has a copper concentration of 0.20*M*. Consider the following questions and points as you develop your procedure.

a. Think about how you can use the concept of molarity, or solution concentration, together with the fact that copper(II) ions appear blue in solution to determine the amount of Cu in your unknown solution.

b. How can you take advantage of the fact that when copper carbonate reacts with hydrochloric acid, CO_2 gas is released?

c. How much unknown copper carbonate is necessary to determine the mass percent of CO_2 in the unknown? Explain.

d. How can you use your experimental data to determine the probable formula of your unknown copper carbonate?

NAME ______________________ DATE ____________ CLASS ____________

Part A

1. **SEP Plan a Procedure** Record your detailed procedure as well as any materials to be used to determine the mass percent of CO_2 in the unknown

2. **SEP Collect Data** Review the data table. Revise it to meet your plan.

Data Table – Mass Loss, CO_2	
Mass of clean and dry Erlenmeyer flask	
Mass of flask and copper carbonate sample	
Mass of copper carbonate sample	
Mass of cylinder and HCl	
Mass of cylinder after HCl was added to the reaction flask	
Mass of HCl added to flask	
Mass of flask + copper carbonate sample + HCl	
Mass of flask + final solution after CO_2 loss	
Mass of released CO_2	
Percent CO_2 in copper carbonate sample	

NAME ____________________ DATE __________ CLASS __________

Part B

3. **SEP Plan a Procedure** Record your detailed procedure as well as any materials to be used to determine the mass percent of Cu in the unknown.

SEP Collect Data Review the data table. Revise it to meet your plan.

Data Table – Color Comparison, Cu							
Test Tube	**1**	**2**	**3**	**4**	**5**	**6**	**Unknown**
Volume of $CuSO_4$ Stock Solution (mL)							1.30 g copper carbonate diluted to 100.0 mL
Final volume of diluted solution (mL)							
Color comparison (lightest blue = 1 to deepest blue = 6)							
Cu^{2+} concentration (*M*)							

NAME ____________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Use Evidence to Construct an Argument** If you began with twice the amount of copper carbonate, would you expect your percent composition results to be the same or different? Explain.

2. **SEP Plan an Investigation** If you ran two additional trials of this experiment, one with 1.5 g of $CaCO_3$ and one with 1.5 g of $MgCO_3$, which compound would you expect to experience the greatest mass change? Explain.

3. **SEP Use Math** Would you say there are a lot of atoms of Cu in the sample you reacted with hydrochloric acid, or a small number of atoms? As part of your explanation, calculate the number of Cu atoms in a 0.55 g sample of $CuCO_3$, and discuss what that calculated value indicates about the scale of the mole.

4. **SEP Develop and Use a Model** Does the reaction you performed in this lab abide the Law of Conservation of Mass, or not? Explain.

5. **SEP Analyze and Interpret Data** Would you expect a solution formed by dissolving 0.01 g of the copper carbonate sample in 100 mL of an acidified aqueous solution to be light or dark in color? Explain.

Investigation 6

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Evaluate Chemical Reactions

How do we represent and understand chemical reactions? This lab begins with a bingo chip activity to solidify building molecules, balancing chemical equations, and visualizing how matter is conserved in a chemical reaction. Then you are the scientist in this lab. From a few chemicals to select, perform your own chemical reactions and make observations.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Bingo chips
- Aluminum foil, small piece
- Copper(II) chloride solution, $CuCl_2$, 0.05 M, 50 mL
- Copper(II) chloride solution, $CuCl_2$, 1.0 M, 50 mL
- Sodium phosphate solution, Na_3PO_4, 0.05 M, 50 mL
- Water, distilled or deionized, 500 mL
- Beakers, 100-mL, 4
- Graduated cylinder, 50mL
- Stirring rod

Safety 

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Allow charcoal sample to cool before touching or discarding it. Use a glass stirring rod to stir the liquid; never stir with a thermometer. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE __________ CLASS ____________

Procedure

1. Refer to the Data Table 1. Identify the atoms by element name, and provide a count of the atom type. Fill in your answers in the last column.

Data Table 1 — Identify Atoms in the Formula		
Name and Use	**Formula**	**Atoms in Formula**
Silicon dioxide (sand)	SiO_2	
Butane (lighter fluid)	C_4H_{10}	
Iron(III) oxide (rust)	Fe_2O_3	
Sulfuric acid (car batteries)	H_2SO_4	

NAME ______________________________ DATE __________ CLASS __________

2. Refer to the Data Table 2.

Data Table 2 — Model Chemical Reactions
_____ $PbCl_2$(aq) + _____ Na_2SO_4(aq) → _____ $PbSO_4$(s) + _____ NaCl(aq) Molecular representation:
_____ Si(s) + _____ Cl_2(g) → _____ $SiCl_4$(l) Molecular representation:
_____ Cl_2(aq) + _____ KBr(aq) → _____ KCl(aq) + _____ Br_2(aq) Molecular representation:
_____ Na(s) + _____ Cl_2(g) → _____ NaCl(s) Molecular representation:
_____ $NaHCO_3$(s) → _____ Na_2CO_3(aq) + _____ CO_2(g) + _____ H_2O(l) Molecular representation:

NAME ______________________ DATE __________ CLASS __________

3. Select a different color chip to represent each different atom (e.g., red for oxygen atoms, blue for hydrogen atoms).

4. Using the bingo chips reproduce the chemical equations in Data Table 2 and complete the entire table.

5. From the following chemical list, perform two chemical reactions: Compare your results with other classmates.

   a. Copper(II) chloride solution, 1.0 M, 40 mL

   b. Aluminum foil

   c. Copper(II) chloride solution, 0.05 M, 40 mL

   d. Sodium phosphate solution, Na_3PO_4, 0.05 M, 40 mL

Analyze and Interpret Data

1. **SEP Analyze Data** Describe how you started an atom inventory to balance the equations in Data Table 2 and how it relates to conservation of mass.

2. **SEP Interpret Data** Which chemicals did you choose to perform reactions from step 5 in the *Procedure*? Describe your observations and determine the overall balanced chemical reaction equations for each.

3. **SEP Use a Model to Evaluate** Explain how the outermost electron states of atoms or any trends in the periodic table, and our knowledge of the patterns of chemical properties, lead to the reactions from step 5 in the *Procedure*.

NAME ______________________ DATE __________ CLASS __________

4. **SEP Identify Patterns** Compare the concentrations of the two available solutions of copper(II) chloride (0.05 M vs 1.0 M). How do these different concentrations affect the rate of the reaction?

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INQUIRY LAB – OPEN

Types of Chemical Reactions

How do we know a chemical reaction has occurred, and how is the chemical reaction classified? Select your own set of chemicals to perform four given reaction types, and witness one reaction type performed by your instructor. Look for evidence that a chemical reaction has occurred in each case, and write the chemical equations for each reaction.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Calcium chloride solution, 0.5 M, $CaCl_2$, 3 mL
- Copper wire, Cu, 10 cm
- Magnesium metal ribbon, Mg, 2.5 cm
- Silver nitrate solution, 0.5 M, $AgNO_3$, 5 mL
- Sodium bicarbonate, $NaHCO_3$, 1 g
- Sodium carbonate solution, 0.5 M, Na_2CO_3, 3 mL
- Balance
- Bunsen burner
- Butane safety lighter
- Cobalt chloride test paper
- Graduated cylinder, 10-mL
- Pipets, Beral-type, 3
- Scoop or spatula
- Test tubes, borosilicate glass, 13 mm × 100 mm, 3
- Test tube clamp
- Test tube rack
- Tongs or forceps
- Wooden splint

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Avoid contact between silver nitrate and skin or clothing as it will readily stain skin and clothing brown. Ethyl alcohol is a flammable liquid and a dangerous fire risk. Addition of denaturant makes the alcohol poisonous—it cannot be made nonpoisonous. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________________ DATE __________ CLASS ___________

Procedure

Read the Open Procedure first before starting and report materials when prompted. Each chemical may only be utilized once.

Reaction 1: Decomposition

1. Select 1 g of a solid compound that will decompose in heat. Must be preapproved by the instructor and reported here.

2. Light the laboratory burner.
3. Holding the test tube with a test tube clamp, heat the solid in the test tube gently in the burner flame for about one minute.
4. While the solid is heating, light a wooden splint. While continuing to heat the solid, place the burning wooden splint in the mouth of the test tube.
5. While the solid is heating, place a piece of cobalt chloride test paper in the mouth of the test tube. Cobalt chloride test paper is blue when dry but turns pink when in contact with water or water vapor.
6. Turn off the burner.

Reaction 2: Synthesis

7. Select a metal solid, about five centimeters in length. This solid must be a main group metal. Must be preapproved by the instructor and reported here.

8. Light the laboratory burner.
9. Hold the piece with a pair of tongs.
10. Place the piece in the burner flame and allow it to burn. DO NOT LOOK DIRECTLY AT THE FLAME! The bright light emitted is UV light that can damage your eyes. Observe by looking slightly to one side and using peripheral vision.

11. When finished burning, place the remains in a watch glass.

12. Turn off the burner. Record observations in the data table.

Reaction 3 (Performed as a Demonstration by the Instructor): Combustion

Record observations in the data table.

Reaction 4: Double Replacement

13. Place a test tube in a test tube rack.

14. Add one pipet full of a metal solution with a concentration of 0.5 M to the test tube. Must be preapproved by the instructor and reported here.

15. Add one pipet full of a metal solution with a concentration of 0.5 M to the test tube. Must be preapproved by the instructor and reported here. Record observations in the data table.

Reaction 5: Single Replacement

16. Place a test tube in a test tube rack.

17. Fill the test tube about half full with a 0.5 M metal solution. Must be preapproved by the instructor and reported here.

18. Obtain a piece of metal about four inches in length. The metal must be a transition metal. Must be preapproved by the instructor and reported here.

19. Wrap it wire around a pencil so it forms a coil.

NAME ______________________ DATE __________ CLASS __________

20. Submerge the coiled metal into the solution. Observe for several minutes as the reaction proceeds.

21. Record observations in the data table.

Data Table — Chemical Reactions		
Observations	**Reaction 1**	
	Reaction 2	
	Reaction 3	
	Reaction 4	
	Reaction 5	
Balanced Chemical Equation	**Reaction 1**	
	Reaction 2	
	Reaction 3	
	Reaction 4	
	Reaction 5	
Type of Reaction	**Reaction 1**	
	Reaction 2	
	Reaction 3	
	Reaction 4	
	Reaction 5	

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Use Math** Balance each chemical equation performed in the experiment. Record your answers in the data table.

2. **SEP Identify Patterns SEP Identify Patterns** Consider the decomposition of water, $2H_2O \rightarrow 2H_2 + O_2$. Is energy released or absorbed in this reaction? Discuss bond energy in your answer.

3. **SEP Identify Patterns** As what did you classify reaction 4? Based on periodic patterns (the available electrons to form bonds), provide an explanation for the sodium chloride product formed.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Predict Chemical Reactions

Can we predict the products of net ionic equations in aqueous solutions? Predict and write the chemical reactions given and then set up the chemical reactions in the procedure. Based on your observations, make any necessary corrections to your written predictions.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Copper(II) sulfate solution, $CuSO_4$, 0.1 M, 5 mL
- Copper(II) chloride solution, $CuCl_2$, 1 M, 5 mL
- Sodium hydroxide solution, NaOH, 1 M, 5 mL
- Zinc metal shot, Zn, 1–2 pieces
- Aluminum foil, Al, 1 small piece
- Silver nitrate solution, $AgNO_3$, 0.1 M, 1 mL
- Sodium bicarbonate, $NaHCO_3$, 2 g
- Sodium chloride solution, NaCl, 1 M, 5 mL
- Balance (0.01 g precision)
- Test tubes, 5
- Test tube rack
- Test tube clamp
- Bunsen burner
- Pipet, graduated, 10
- Scoopula

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Do not come in contact with the silver nitrate solution as it will stain skin and clothing. Use caution when working with the Bunsen burner flame. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ________________________ DATE ____________ CLASS ______________

Procedure

1. Set up five test tubes on a test tube rack and label the test tubes 1 to 5 using a marker.

2. From the list, select five chemical combinations to perform five reactions. Your instructor should check your combinations before you perform the experiment.

List of Chemicals	
Copper(II) sulfate solution, $CuSO_4$, 0.1 M	Aluminum foil, Al
Copper(II) chloride solution, $CuCl_2$, 1 M	Silver nitrate solution, $AgNO_3$, 0.1 M
Sodium hydroxide solution, NaOH, 1 M	Sodium bicarbonate, $NaHCO_3$
Zinc metal shot, Zn	Sodium chloride solution, NaCl, 1 M

NAME ________________ DATE ________ CLASS ________

3. Predict the type of chemical reaction and equation for each of your five reactions.

Reaction Predictions			
Reactant Name	Reactant Name	Reaction Type	Predicted Equation

4. Perform each of your approved reactions, one in each test tube. Use the recommended amounts for each chemical in the Materials Per Group list. Record your observations in the data table.

Chemical Reactions Observations		
Reactant Name	Reactant Name	Observations

NAME ______________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Use Math** From your observations of reactants turning into products, were your predicted equations correct from step 3 in the Procedure? If not, correct the data table.

2. **SEP Plan Your Investigation** From your observations of reactants turning into products were your predicted reaction types correct from step 3 in the Procedure? If not, correct the data table.

3. **SEP Identify Patterns** Was a precipitation reaction performed? Refer to a solubility table in your textbook and discuss why the product is not soluble in water.

4. **SEP Identify Patterns** In all five reactions, why do the chemical reactions go to completion and form products?

NAME ______________________ DATE ____________ CLASS ____________

PERFORMANCE BASED ASSESSMENT

Identify Evidence of Chemical Reactions

Does a chemical reaction occur when two substances are mixed? What evidence is there that a reaction occurred? This lab's focus is on evidence of a reaction, the type of reaction occurring, balancing the reaction, and explaining why it occurred. Your challenge is to fill a balloon with gas and identify and write the balanced chemical equation.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Acetic acid, CH_3COOH, 2 M, 60 mL
- Calcium carbonate, 2–2.5 g
- Sodium bicarbonate, $NaHCO_3$, 2–2.5 g
- Sodium carbonate, 2–2.5 g
- Sodium chloride, 2–2.5 g
- Sucrose, 2–2.5 g
- Balance (0.01g precision)
- Balloons, 5
- Erlenmeyer flask, 125-mL, 5
- Funnel, powder, small
- Graduated cylinder, 25-mL
- Permanent maker
- Spatula
- Weighing dishes, 5

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Acetic acid is a skin and eye irritant. Avoid contact with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

NAME ______________________ DATE __________ CLASS __________

Procedure

1. With your group, discuss what evidence would indicate that a chemical reaction has occured when 2 M acetic acid is combined with any of the given five white solids.

2. Design a procedure for determining if a chemical reaction occurs between 2 M acetic acid the five white solids. Record your detailed procedure.

NAME ____________________ DATE __________ CLASS __________

3. Plan to record your observations in the data table. A sample data table is shown.

Data Table — Production of Gas	
Trial 1	
Trial 2	
Trial 3	
Trial 4	
Trial 5	

NAME ________________ DATE ________ CLASS ________

Analyze and Interpret Data

1. **SEP Make Observations** How did the five trials with 2 M acetic acid compare?

2. **SEP Interpret Data** Recall that your group had started out discussing *evidence* of a chemical reaction. Are any of the results of your investigation consistent with the evidence you had discussed? Explain.

3. **SEP Use Math** Did a chemical reaction occur between the acid and all white solids? Write a balanced chemical equation for the reactions that did occur.

4. **SEP Calculate** Review your procedure and the results. Did the procedure provide an accurate, useful test of evidence that a reaction occurred? Did you follow the procedure correctly, or were there errors? Are the results as expected? If not, what could explain the unexpected results?

Investigation 7

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Identify Unknowns Through Stoichiometry

How do chemists determine the identity of a compound? A variety of analytical techniques and procedures, ranging from instrumental methods like spectroscopy and chromatography to more classical processes, such as qualitative and gravimetric analysis, have been developed to accomplish that task. In this laboratory, the identity of a group 1 metal carbonate will be determined using two complementary methods—change in mass due to loss of CO_2 and acid–base titration.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Bromocresol green indicator solution, 0.04%, 2 mL
- Hydrochloric acid solution, HCl, 0.1 M, 60 mL
- Hydrochloric acid solution, HCl, 2 M, 20 mL
- Unknown A
- Unknown B
- Water, distilled or deionized, 500 mL
- Balance, 0.01 g precision
- Beaker, 50 mL
- Beaker tongs or heat-resistant gloves
- Buret, 50 mL
- Buret clamp
- Erlenmeyer flask, 500 mL
- Erlenmeyer flasks, 125 mL, 3
- Graduated cylinder, 25 mL
- Graduated cylinder, 50 mL
- Graduated cylinder, 500 mL
- Hot plate
- Ice bath
- Magnetic stirrer, with stir bar
- Ring stand
- Paper, white
- Weighing dishes, 2

Safety 

Hydrochloric acid solution is toxic and corrosive to eyes and skin tissue. Potassium carbonate is a body tissue irritant. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part 1. Gas Evolution Reaction

1. Measure the mass of a 125 mL Erlenmeyer flask on a balance, and record the value in the data table.

2. In a tared weighing dish, measure approximately 2 g of the unknown you were assigned on a balance.

3. Record the precise mass of the metal carbonate in the data table.

4. Develop a procedure to calculate the molar mass of the metal carbonate from the mass loss of CO_2. Enter any information needed in the blank spaces on the data table.

   Use the following area to record your detailed procedure as well as any materials to be used.

5. Repeat for a second trial if instructed to do so by the teacher.

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Part 2. Titration

6. Obtain approximately 1 g of the unknown group 1 metal carbonate sample in a tared weighing dish. This should be a different unknown than you were assigned in part 1. Measure and record the precise mass of the metal carbonate sample in the data table.The general formula for a group 1 metal carbonate is M_2CO_3, where M represents metal.

7. Transfer the metal carbonate sample to a 500 mL Erlenmeyer flask. Using a 500 mL graduated cylinder, add 500 mL of distilled or deionized water and a stir bar to the same flask, and mix the solution on a magnetic stirrer.

8. Obtain a clean 50 mL buret, and rinse it with two 5 mL portions of 0.10 M HCl solution.

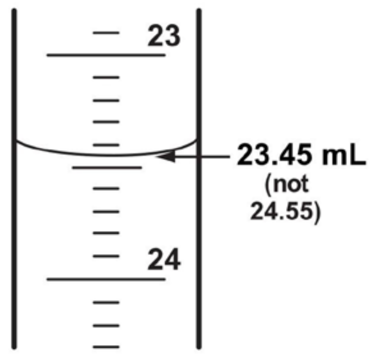
9. Use the buret clamp to secure the buret to the ring stand, and place the 50 mL beaker under the buret tip. Fill the buret to above the zero mark with the 0.10 M HCl solution. Open the stopcock to allow any air bubbles to escape from the tip. Close the stopcock when the liquid level in the buret is between the 0 and 5 mL marks.

10. Obtain approximately 50 mL of distilled or deionized water in a 125 mL Erlenmeyer flask and add 5 drops of bromocresol green indicator.

11. Record the precise level (initial volume) of the 0.10 M HCl solution in the buret in the data table. *Note:* Volumes are read from the top down in a buret. Always read from the bottom of the meniscus, and remember to include the appropriate number of significant figures (see Figure 1).

Figure 1

NAME ______________________ DATE __________ CLASS __________



12. Place the flask containing distilled or deionized water under the buret so the tip of the buret is inside the mouth of the flask. Place a piece of white paper under the flask to make it easier to detect the color change of the indicator at the endpoint.

13. Carefully add the HCl solution one drop at a time to the flask. Swirl the flask after each drop is added. Stop when the solution color changes from blue-green to yellow-green with a single drop and does not dissipate after swirling. Record the buret volume in the data table. Save this "control" flask as a color standard for detecting the endpoint in step 17.

14. Using a 50 mL graduated cylinder, transfer 50.0 mL of the metal carbonate solution to a clean 125 mL Erlenmeyer flask. Record this volume in the data table. Add 5 drops of bromocresol green indicator solution to the flask.

15. Record the initial volume of the HCl solution in the buret. Titrate the carbonate solution with the HCl solution to an intermediate green or slightly aqua color.

16. Stop the titration, and place the flask on a hot plate. Heat the solution to a gently boil for two to three minutes. Use beaker tongs or heat-resistant gloves to remove the flask from the hot plate. Place the flask in an ice bath or under cold running water to cool the solution. *Note:* This step expels any dissolved carbon dioxide before the titration is completed.

17. When the solution has cooled back to room temperature, complete the titration of the carbonate solution to match the yellow-green endpoint obtained in step 13. Record the final volume of the HCl solution in the buret in the data table.

18. Repeat the procedure with a new 50 mL sample of the metal carbonate solution if instructed to do so by the teacher.

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19. Dispose of the waste solutions as instructed by the teacher.

Assigned unknown: ____________

Part 1. Gas Evolution Reaction		
	Trial 1	Trial 2
Mass of flask		
Mass of M_2CO_3		
Mass of cylinder empty		

NAME ______________________ DATE ____________ CLASS ____________

Part 2. Titration Analysis

Mass of solid M_2CO_3: ____________

Titration Analysis			
	Control	**Trial 1**	**Trial 2**
Volume of M_2CO_3 solution titrated			
Initial Volume of 0.10 M HCl			
Final Volume of 0.10 M HCl			
Volume of 0.10 M HCl added			

Analyze and Interpret Data

Part 1. Gas Evolution

1. **SEP Use Math** Using the data obtained, calculate the number of moles of carbon dioxide, CO_2, released by the reaction.

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2. **SEP Use Math** Calculate the molar mass of the unknown group 1 metal carbonate.

3. **SEP Interpret Data** Based on your answer in Question 2, what is the identity of your unknown carbonate compound?

4. **SEP Construct an Explanation** Calculate the percent error in the experimental determination of the molar mass. What adjustments can be made to the procedure to improve results?

Part 2. Titration Analysis

5. **SEP Use Math** Calculate the moles of hydrochloric acid used to neutralize the unknown group 1 metal carbonate dissolved in the 50 mL sample for each trial titration.

6. **SEP Use Math** For each trial, calculate the total moles of the unknown group 1 metal carbonate originally dissolved in the 500 mL of distilled or deionized water.

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7. **SEP Interpret Data** Calculate the molar mass of the unknown group 1 metal carbonate, and identify the metal.

8. **SEP Use Math** Calculate the percent error in the experimental determination of the molar mass.

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9. **SEP Construct an Explanation** How could your titration be modified to produce a titration curve? What kind of data can we learn from this?

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INQUIRY LAB – OPEN

Determination of Reaction Output

Industrial chemists need produce a specific amount of a chemical with minimal waste. In this lab, stoichiometry and a balanced chemical reaction will be used to determine the correct mass of reactants to add to produce a specific amount of product.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Assigned reaction mixture
- Water, distilled or deionized
- Balance, 0.01 g precision
- Beakers, 50 mL, 2
- Beaker, 150 mL
- Büchner funnel
- Filter flask, 250 mL
- Filter paper
- Oven
- Stirring rod

Safety

The compounds selected for this experiment have low to moderate toxicity, but avoid breathing the dust or getting any in your eyes or on your skin. Zinc sulfate is a skin and mucous membrane irritant and is mildly toxic. Sodium carbonate and potassium carbonate may be skin irritants. Magnesium sulfate irritates eyes and the respiratory tract. Calcium chloride is moderately toxic. Wear chemical splash goggles, chemical-resistant gloves, and chemical-resistant aprons.

NAME ______________________ DATE ____________ CLASS ____________

Procedure

Each precipitation reaction will follow this generic format:

$$A(aq) + B(aq) \rightarrow C(s) + D(aq) + H_2O(l)$$

1. Write a complete balanced chemical equation for your assigned reaction mixture. Which compound will form the precipitate?

2. Calculate the number of moles in 2.00 grams of the precipitated product.

3. Use dimensional analysis to determine the mass of each reactant required to make 2.0 grams of your precipitate. Calculate the mass of the other product(s) that will form. Have your teacher check your calculations before proceeding to the next step. Record the masses of each in the data table.

NAME ____________________ DATE __________ CLASS __________

4. Design and carry out an experiment to generate and collect your precipitate. Both of the reactants need to be dissolved in separate beakers using 25 mL of distilled water for each reactant. Then the two solutions need to be mixed together to form the precipitate. The precipitate will be recovered by filtration using a premassed piece of filter paper. The precipitate will be dried under a heat lamp or in a drying oven, and then the mass of the solid determined.

Use the following area to record your detailed procedure as well as any materials to be used.

NAME ______________________________ DATE ____________ CLASS ____________

Reaction # chosen: ____________

Data Table	
Mass of reactant A needed (g)	
Mass of reactant B needed (g)	
Mass of product C that should form (g)	
Mass of product D that should form (g)	
Mass of H_2O that should form (g)	
Mass of filter paper (g)	
Mass of filter paper + dried precipitate (g)	
Final mass of precipitate (g)	

Analyze and Interpret Data

1. **SEP Analyze Data** Were you able to produce 2.00 grams of the precipitate? If not, what errors could have led to the amount produced?

NAME ______________________ DATE __________ CLASS __________

2. **SEP Evaluate and Communicate** Describe what techniques are critical to the success of precipitate collection.

3. **SEP Interpret Data** How would the final results be affected if the reaction were not complete before filtering? What is a possible solution to this?

4. **SEP Use Math** Calculate your percent yield and percent error.

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Formation of Barium Iodate

If you have 12 bicycle frames, 15 handlebars, and 20 tires, how many bicycles can you make? This question may be simple, but it can help us learn about an important idea in chemistry—limiting reagents. In this lab, we will investigate the concept of limiting reagents.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Barium chloride solution, $BaCl_2$, 0.2 *M*, 40 mL
- Potassium iodate solution, KIO_3, 0.2 *M*, 40 mL
- Sodium bisulfite/starch indicator solution, 60 drops
- Sodium sulfate solution, Na_2SO_4, 0.1 M, 30 drops
- Labeling tape or pen
- Metric ruler, graduated to 1 mm
- Pipets, Beral-type, 5 (for extracting supernatant liquids)
- Reaction plate, 24-well (for testing excess ions)
- Syringes, 10 mL, 2
- Test tubes, 16 x 100 mm, 5
- Test tube rack
- Wood splints (for stirring), 5

Safety 

Barium chloride solution is toxic by ingestion. Avoid contact with all body tissues. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE __________ CLASS __________

Procedure

STAGE 1. Constant Iodate Volume

Part 1. Formation of Barium Iodate

1. Obtain two 10 mL syringes—label one syringe as $BaCl_2$ and the other as KIO_3.

2. Label five test tubes A–E. Place them in a test tube rack.

3. Fill the appropriately labeled 10 mL syringe with 0.2 M barium chloride solution. Fill the other labeled syringe with 0.2 M potassium iodate solution. Prepare syringes to deliver accurate volume by removing any air from the tips.

4. Following the data table, add the assigned volumes of $BaCl_2$ and KIO_3 to test tubes A–E. (*Note*: Add the larger volume of solution second to ensure efficient mixing. For example, if 1 mL of $BaCl_2$ solution is to be combined with 3 mL of KIO_3 solution, add the KIO_3 last.) Stir the contents of each test tube with a separate wood stick.

5. Once the reagents have been thoroughly mixed, allow the solid precipitates to settle for about 3–5 minutes. Tap the tubes very gently so the precipitates settle evenly.

6. After the precipitates in each of the five tubes have settled undisturbed, use a metric ruler to measure the height in millimeters of solid in each tube. Record the height of each precipitate in the data table.

Part 2. Testing the Supernatant Liquid for the Excess Reagent

7. Use a Beral-type pipet labeled A to extract a small amount of the clear liquid from the top of tube A. (*Note:* Be careful to avoid drawing any precipitate into the dropper.)

8. Add 3 drops of the liquid from pipet A to wells 1A and 1B in the 24-well reaction plate.

9. *Test for Excess Ba^{2+}:* Add 3 drops of 0.1 M sodium sulfate solution to well 1A and make observations. A cloudy white precipitate indicates that there are still barium ions in the solution. Determine whether there is excess Ba^{2+}, and record this result in the data table.

10. *Test for Excess IO_3^-:* Add 5 drops of sodium bisulfite/starch indicator solution to well 1B and make observations. An initial yellow followed by a dark blue color indicates that there are still iodate ions in the solution. Determine whether there is excess IO_3^-, and record this result in the data table.

11. Repeat both tests (steps 9 and 10) using pipet B and the liquid from the top of tube B. Use wells 2A and 2B.

12. Repeat both tests (steps 12 and 13) for tubes C–E.

13. Clean out the test tubes, reaction plates, and pipets by combining all rinse solutions in a barium waste container as provided by your instructor. Do not dump any solutions down the drain.

NAME ______________________ DATE ____________ CLASS ____________

STAGE 2.

14. Design a procedure to empirically prove the stoichiometric ratio of $BaCl_2$ to KIO_3 by finding the most efficient combinations of those two reactants. Use the space to record your detailed procedure as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Stage 1. Constant Iodate Volume					
Test Tube	**A**	**B**	**C**	**D**	**E**
Starting vol Ba^{2+} (mL)	1	3	5	7	9
Starting vol IO_3^- (mL)	3	3	3	3	3
Height of ppt (mm)					
Excess Ba^{2+} or IO_3^-?					
Starting mmol Ba^{2+}					
Starting mmol IO_3^-					
Expected mmol ppt					
Expected excess? (mmol)					
Limiting reagent					

Stage 2. Stoichiometric Ratio Determination					
Test Tube	**A**	**B**	**C**	**D**	**E**
Starting vol Ba^{2+} (mL)					
Starting vol IO_3^- (mL)					
Height of ppt (mm)					
Excess Ba^{2+} or IO_3^-?					
Starting mmol Ba^{2+}					
Starting mmol IO_3^-					
Expected mmol ppt					
Expected excess? (mmol)					
Limiting reagent					

NAME ______________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

Complete the following for both stages.

1. **SEP Use Math** Using the volume and concentration of each starting material, calculate the number of starting millimoles (mmol) of Ba^{2+} and IO_3^- that were combined. Record these values on the data table.

2. **SEP Use Math** Using the balanced chemical equation for the reaction of barium ions with iodate ions, calculate the mole ratio of each reactant and product?

$$Ba^{2+}(aq) + 2IO^{3-}(aq) \rightarrow Ba(IO_3)_2(s)$$

3. **SEP Interpret Data** Use the equation to calculate the number of millimoles of solid $Ba(IO_3)_2$ precipitate that are expected to form in each tube (A–E). Note which material is in excess and which is the limiting reagent (LR). Record the expected millimoles of precipitate in the data table. Also record which material is expected to be in excess and the amount of excess in mmol. Record the limiting reagent for each tube. [*Hint:* Review your data chart to determine which reagent was completely used up—the limiting reagent. Start with mmoles of that limiting reagent (from question 1) to calculate the mmoles of precipitate expected from the balanced equation.]

4. **SEP Construct an Explanation** Compare the calculated number of mmol of precipitate expected (from question 3) with the height ratios found in the tubes. Account for any patterns that are observed. Determine the point at which each chemical becomes the limiting reagent for the reaction.

NAME ________________________ DATE __________ CLASS __________

PERFORMANCE BASED ASSESSMENT

The Stoichiometry of Filling a Balloon

How much sodium bicarbonate does it take to fill a balloon? This lab uses the well-known reaction of sodium bicarbonate and acetic acid to illustrate the concepts of limiting and excess reactants. By comparing the amount of carbon dioxide generated when varying amounts of sodium bicarbonate react with a given amount of acetic acid, students will be able to immediately identify the limiting and excess reactant in each case.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Acetic acid, CH_3COOH, 2 *M*, 60 mL
- Sodium bicarbonate, $NaHCO_3$, 10.5 g
- Balance, 0.01 g precision
- Balloons, 6
- Erlenmeyer flasks, 125 mL, 6
- Graduated cylinder, 25 or 50 mL
- Permanent marker
- Powder funnel
- Spatula
- Weighing dishes, 6

Safety 

Students with asthma or other respiratory issues should alert their teacher and may not be able to complete the part of blowing up the balloon. Acetic acid is a skin and eye irritant. Avoid contact with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

NAME ____________________ DATE __________ CLASS __________

Procedure

1. Label six Erlenmeyer flasks 1–6. Using a graduated cylinder, add 10 mL of 2 *M* acetic acid to each flask.

2. Label six weighing dishes 1–6.

3. Calculate the mass of sodium carbonate needed for each flask to produce the moles of CO_2 gas listed in the following table. Show all work, and record your answers in the data table.

Theoretical CO_2 Production	
Flask	**Moles of CO_2 produced**
1	0.006
2	0.012
3	0.018
4	0.024
5	0.030
6	0.036

4. Stretch each balloon, and blow them up at least once. Then let out as much air as possible.

5. Use a powder funnel to add the first sodium bicarbonate sample (sample 1) to one of the balloons.

6. Flatten out the balloon to remove any extra air, and then carefully stretch the neck of the balloon over the mouth of Erlenmeyer flask 1. Do not allow the solid to drop into the flask at this time.

7. Repeat steps 5 and 6 with the other sodium bicarbonate samples (samples 2–6).

8. Line up flasks 1–6 from left to right. Lift each balloon in turn, and shake it to allow the solid to fall into the solution. Make sure the neck of each balloon stays firmly attached to the flask.

9. The reactions will be immediate and vigorous. The white solids will dissolve, the solutions will start to bubble and fizz, and the balloons will become inflated.

10. Allow the reactions to proceed until the bubbling stops. Swirl the flasks, if necessary. Compare the size of the inflated balloons and whether all the solid has dissolved in each case.

11. Calculate the moles of acetic acid used in the experiment, and identify the limiting reactant and the excess reactant in each case.

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Data Table						
Flask	Moles of CO_2 produced (theoretical)	Acetic Acid		Sodium Bicarbonate		Limiting Reagent
		Volume	Moles	Mass	Moles	
1	0.006	10 mL				
2	0.012	10 mL				
3	0.018	10 mL				
4	0.024	10 mL				
5	0.030	10 mL				
6	0.036	10 mL				

Analyze and Interpret Data

1. **SEP Identify Patterns** Were there any noticeable patterns as the balloons inflated? What explains the trend you observed?

2. **SEP Interpret Data** If you continued to increase the amount of sodium bicarbonate in the reaction while holding the amount of acetic acid constant, would the balloon continue to inflate? Why or why not?

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3. **SEP Design Your Solution** How could you measure the amount of CO_2 gas produced in the reaction to determine whether the reaction went to completion?

4. **SEP Identify Patterns** What if the experiment was carried out with sodium carbonate instead of sodium bicarbonate? Use a balanced equation in your answer.

Investigation 8

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INQUIRY LAB – OPEN

The Thermodynamics of Hand Warmers

How does energy change when chemical bonds break or form? What causes heat to be released or absorbed when a solid dissolves in water? From instant cold packs to hand warmers, the energy changes accompanying physical and chemical transformations have many consumer applications. Explore the energy changes that follow the formation of solutions using common laboratory salts, and apply the results to design a hand warmer that is reliable, safe, and inexpensive.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Ammonium chloride, NH_4Cl, 15 g
- Calcium chloride, $CaCl_2$, 15 g
- Sodium chloride, NaCl, 15 g
- Sodium hydroxide, NaOH, 15 g
- Water, distilled or tap
- Balance, 0.01 g precision
- Beaker, 250 mL
- Graduated cylinder, 100 mL
- Heat-resistant gloves
- Magnetic stirrer and stir bar, or stirring rod
- Paper towels
- Solution vessel (two nested polystyrene cups)
- Support stand and ring clamp
- Thermometer, digital
- Timer or stopwatch
- Weighing dishes

Safety 

Calcium chloride and ammonium chloride are slightly toxic. Sodium hydroxide is highly corrosive. Wear chemical safety glasses, heat-resistant gloves, and a chemical-resistant apron for good laboratory practice. Use a magnetic stirrer and stir bar, or a glass stirring rod to stir the liquid; never stir with a thermometer. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines.

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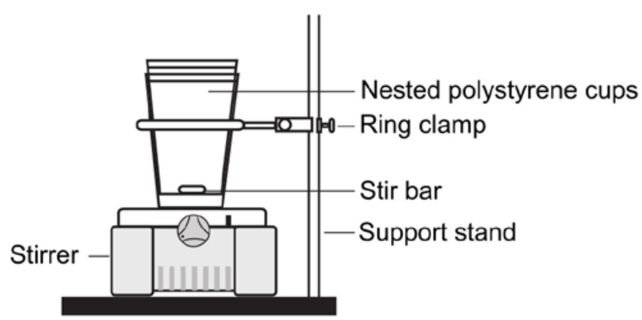
Procedure

Examine the heat energy change associated with the dissolution of the various salts above in water. Write the chemical equations that represent the dissolution of each salt in water, following the example:

$$NH_4Cl(s) \rightarrow NH_4^+(aq) + Cl^-(aq)$$

1. Measure a volume of distilled or tap water and transfer to the solution vessel (nested polystyrene cups).
2. Measure and record the initial temperature of the water.
3. Measure a mass of one of the solid salts in a weighing dish.
4. Set up and secure the solution vessel (nested polystyrene cups) on the stirrer plate as shown in **Figure 1**.
5. Dissolve the salt in the water contained in the solution vessel, and monitor the temperature of the solution.
6. Repeat steps 1–5 using the remaining salts.

Figure 1



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Data Table — Heat of Dissolution				
Salt	NH_4Cl	$CaCl_2$	NaCl	NaOH
Volume of water				
Density of H_2O				
Mass of H_2O				
Mass of salt				
Mass of solution (m)				
Initial temperature ($T_{initial}$)				
Final temperature (T_{final})				
Temperature change ($T_{final} - T_{initial}$)				
Heat of dissolution (Q)				

Analyze and Interpret Data

1. **SEP Use Math** Determine the change in temperature of the system after dissolution of the various salts in water.

2. **SEP Use Math** Determine the heat of dissolution/energy change (*Q*, in joules) for each one of the solutions prepared.

3. **SEP Use Math** Calculate the heat of dissolution per mole of solute (Q_{soln}, in kJ/mol) for each one of the ionic solids used. Use blank rows in the data table to accommodate any additional values needed to determine Q_{soln}.

4. **SEP Analyze Data** Based on these results, describe the heat energy changes that take place when each one of the salts used dissolves in water. Which ionic solids release heat when dissolved? Which ionic solids absorb heat when dissolved?

5. **SEP Construct an Explanation** Based on your responses to the previous two questions, which is stronger—the attractive forces between water molecules and Ca^{2+} and Cl^{-} ions, or the combined ionic bond strength of $CaCl_2$ and intermolecular forces between water molecules? Explain your reasoning.

6. **SEP Construct an Explanation** Similarly, which is stronger—the attractive forces between water molecules and NH_4^+ and Cl^- ions, or the combined ionic bond strength of NH_4Cl and intermolecular forces between water molecules? Explain your reasoning.

7. **SEP Apply Scientific Reasoning** Describe some of the critical characteristics an ionic solid must have to be used in the design of an effective hand warmer.

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8. **SEP Design Your Solution** Propose and test an experimental design, using any of the salts available, for an effective instant cold pack. Use the table and space below to record your detailed procedure as well as any materials to be used for the instant cold pack.

Data Table — The Instant Cold Pack	
Salt	
Volume of water	
Density of H_2O	
Mass of H_2O	
Mass of salt	
Mass of solution (m)	
Initial temperature ($T_{initial}$)	
Final temperature (T_{final})	
Temperature change ($T_{final} - T_{initial}$)	
Heat of dissolution (Q)	

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INQUIRY LAB – OPEN

Hess's Law and the Combustion of a Metal

How much energy is released when magnesium burns? The reaction of magnesium metal with air in a Bunsen burner flame is a dazzling demonstration of a combustion reaction. Magnesium burns with an intense flame that emits a blinding white light and a large amount of heat. In this experiment, you will apply Hess's Law to determine magnesium's heat of combustion in a practical and safe manner.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 5 Using Mathematics and Computational Thinking
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Hydrochloric acid, HCl, 1*M*, 60 mL
- Magnesium ribbon, Mg, 7 cm strip
- Magnesium oxide, MgO, 0.4 g
- Balance, 0.01 g precision
- Calorimeter, small scale
- Digital thermometer or temperature sensor
- Forceps
- Graduated cylinder, 25 or 50 mL
- Metric ruler, marked in mm
- Scissors
- Spatula
- Stirring rod
- Wash bottle and water
- Weighing dish

Safety

Wear safety goggles, chemical-resistant gloves, and a lab coat when performing this or any lab that uses chemicals, heat, or glassware. Hydrochloric acid is toxic by ingestion and corrosive to skin and eyes. Magnesium metal is a flammable solid. Do not handle magnesium metal with bare hands. Use a glass stirring rod to stir liquids; never stir with a thermometer. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Record all data for parts 1 and 2 in the Data Table.

Part 1. Reaction of Magnesium with Hydrochloric Acid

1. Carefully cut the magnesium ribbon into two pieces of unequal length, roughly 3 and 4 cm each. *Note:* Handle the magnesium ribbon using forceps.
2. Measure the exact length of each piece of magnesium ribbon to the nearest 0.1 cm.
3. Multiply the length of each piece of Mg ribbon by the conversion factor (in g/cm) provided by your teacher to obtain the mass of each piece of Mg.
4. Measure the mass of a clean, dry calorimeter to the nearest 0.01 g.
5. Using a graduated cylinder, add 15 mL of 1*M* hydrochloric acid to the calorimeter and measure the combined mass of the calorimeter and acid solution.
6. Using a digital thermometer or a temperature sensor, measure the initial temperature of the hydrochloric acid solution to the nearest 0.1°C.
7. Add the shorter piece of magnesium ribbon to the acid solution and stir until the magnesium has dissolved and the temperature of the solution remains constant.
8. Record the final temperature of the solution to the nearest 0.1°C.
9. Rinse the contents of the calorimeter down the drain with excess water.
10. Dry the calorimeter and mass it again to the nearest 0.01 g.
11. Repeat steps 5–9 using the larger piece of magnesium ribbon.

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Part 2. Reaction of Magnesium Oxide with Hydrochloric Acid

12. Design a procedure to measure the heat of reaction for a mixture of MgO and 1 *M* HCl. Use the procedure of Part 1 to guide yourself, and perform two trials. You may use similar volumes of 1*M* HCl as those used in Part 1, and approximately 0.2–0.3 g of MgO in each trial. Use the area below to record your detailed procedure as well as any materials to be used.

13. Pour the reaction mixture down the drain with excess water.

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Data Table – Calorimetry				
Reaction	**Part 1 ($Mg + 2HCl \rightarrow MgCl_2 + H_2$)**		**Part 2 ($MgO + 2HCl \rightarrow MgCl_2 + H_2O$)**	
Trial	**1**	**2**	**1**	**2**
Mass of solid reactant				
Mass of calorimeter				
Mass of calorimeter + HCl solution				
Initial temperature ($T_{initial}$)				
Final temperature (T_{final})				

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Analyze and Interpret Data

Summarize your calculations for each reaction and trial in the Results Table.

1. **SEP Use Math** Calculate the heat absorbed by the solution (Q) in joules. *Note:* $Q = m \times c \times T$, where m is the total mass of the reactants (solid and liquid), c is a constant value intrinsic to the solution (here we will use c = 4.18 J/g·°C), and ΔT is the change in temperature of the solution.

2. **SEP Use Math** Calculate the number of moles of magnesium and magnesium oxide used in Part 1 and 2, respectively.

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3. **SEP Use Math** Calculate the enthalpy change for each reaction (ΔH = $-Q$/*moles of solid*) in kilojoules per mole of solid reactant (kJ/mol).

4. **SEP Use Math** Calculate the average enthalpy change (ΔH_{avg}) for reactions in Part 1 and 2, respectively.

5. **SEP Develop Models** Review chemical Equations 1–4. Arrange Equations 2, 3, and 4 so that their sum is equal to Equation 1.

Equation 1: $Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$ + heat, light

Equation 2: $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

Equation 3: $MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$

Equation 4: $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$

6. **SEP Use Models** Apply Hess's Law to calculate the heat of reaction for Equation 1 (ΔH_{rxn}), the enthalpy of formation for MgO. The heat of reaction for Equation 1 is equal to the appropriate algebraic sum of the heats of reaction for Equations 2, 3, and 4. The heat of reaction for Equation 4 is equal to the standard heat of formation of water, which is −285.83 kJ/mol. *Note:* The heat of formation of a compound is defined as the enthalpy change for the preparation of one mole of a compound from its respective elements in their standard states at 25 °C.

7. **SEP Interpret Data** Based on the calculated ΔH_{rxn}, is the formation of MgO exothermic or endothermic? Is this the outcome you expected?

8. **SEP Engage in Argument** Consider the setup used in this experiment. Some of the heat generated in reactions performed in Part 1 and 2 might be lost to the air right above the solution mixture. Likewise, the calorimeter holding the solution might absorb some of the heat produced by these reactions. Think of experimental strategies to minimize the potential effects of these side processes on the quality of your measurements. Write down your ideas in the space below.

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Data Table – Enthalpies of Reaction				
Reaction	**Part 1 ($Mg + 2HCl \rightarrow MgCl_2 + H_2$)**		**Part 2 ($MgO + 2HCl \rightarrow MgCl_2 + H_2O$)**	
Trial	**1**	**2**	**1**	**2**
Heat of reaction ($Q = m \times c \times \Delta T$)				
Moles of solid reactant				
Enthalpy change (ΔH)				
Average enthalpy change (ΔH_{avg})				
Reaction	**$Mg + ½O_2 \rightarrow MgO$**			
Enthalpy of reaction (ΔH_{rxn})				

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INQUIRY LAB – OPEN

The Heat of Melting Ice

What energy changes accompany the formation of ice? Water freezes to form ice at a temperature of 0°C and an atmospheric pressure of 1 atm. On the other hand, ice melts when exposed to heat under the same conditions of temperature and pressure. In this lab you will determine the heat of fusion of ice by applying basic calorimetry, and you will investigate the flow of energy during ice growth.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Ice cubes
- Sodium chloride, NaCl, 30 g
- Water, distilled (preferred) or tap
- Balance, 0.01 g precision
- Beaker, 500 mL
- Calorimeter (two nested polystyrene cups)
- Erlenmeyer, 250 mL
- Graduated cylinder, 100 mL
- Paper towels
- Spatula
- Stirring rod
- Support stand and ring clamp
- Test tubes, 2, 16 mm × 100 mm
- Test tube clamp
- Thermometer
- Timer or stopwatch
- Weighing dishes/paper

Safety 

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

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Procedure

Part 1. The Heat of Fusion of Ice

1. Measure the mass of a clean, dry calorimeter (two nested polystyrene cups) to the nearest 0.01 g and record this mass in the data table.

2. Measure 100 mL of water using a graduated cylinder. Pour the water into the clean, dry calorimeter.

3. Measure the mass of the calorimeter containing the 100 mL of water to the nearest 0.01 g. Record this value in the data table.

4. Place the calorimeter containing the water on a ring clamp attached to the support stand.

5. Use a thermometer to measure the temperature of the water in the calorimeter to the nearest 0.1°C. Wait a few minutes for the temperature to stabilize before writing it down in the data table. Leave the thermometer in the water.

6. Grab 2–3 ice cubes and place them on a paper towel. Use the paper towel to dab dry the ice cubes to remove any liquid water from their surface.

7. Gently drop the ice cubes into the calorimeter to avoid splashing water. If any water is lost from the calorimeter at this point, you must start over from step 1.

8. Observe the change in temperature of the water in the calorimeter. The temperature should begin to drop rapidly as soon as you drop the ice cubes into it. Gently and consistently stir the water with the stirring rod.

9. Once all the ice has melted, record the final temperature of the water before it starts to increase. This is the equilibrium temperature of ice melting.

10. Remove the thermometer from the calorimeter and mass the calorimeter and its contents (initial water and melted iced water). Include this mass value in the data table.

11. Pour the calorimeter contents down the drain.

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Data Table – Part 1	
Mass of empty calorimeter	
Mass of calorimeter plus water	
Mass of water (m_w)	
Initial temperature of water ($T_{initial}$)	
Final temperature of water plus melted ice (T_{final})	
Change in temperature ($\Delta T = T_{final} - T_{initial}$)	
Mass of calorimeter plus water plus melted ice	
Mass of melted ice (m_{ice})	
Heat lost by water in calorimeter (Q_w)	
Heat required to warm ice (Q_{ice})	
Heat required to melt ice (Q_L)	
Energy required to melt ice (L)	

Part 2. The Freezing Curve of Water

12. Prepare an ice-salt-water bath by putting ice cubes in a 500 mL beaker up to the 200 mL mark, adding approximately 15 g of NaCl, and cold tap water to barely cover the ice cubes. Stir the bath contents using the stirring rod. The temperature of the bath will drop down to approximately −6°C.

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13. Measure and record a volume of distilled water, and transfer into a clean test tube.

14. Insert a thermometer into the test tube to measure the temperature of the water. Wait a few minutes for the temperature of the water to stabilize and then record it in the data table.

15. Carefully lower the test tube into the ice-water bath (keeping the thermometer in the tube) and begin to record the temperature of the water. Record the temperature values in the data table as a function of time. Gently stir the water in the test tube until it is not possible because of solidification. Continue to record the temperature of the water when it becomes stable.

16. Remove the test tube from the ice-water bath, and pour the contents down the drain. Do not get rid of the ice-water bath yet.

17. Design an experiment to measure the freezing curve of an aqueous solution containing an ionic compound available in the lab. Use the area to record your detailed procedure as well as any materials to be used.

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Data Table – Part 2			
Trial 1 (pure water)		**Trial 2 (ionic solution)**	
Time	**Temperature (°C)**	**Time**	**Temperature (°C)**

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Analyze and Interpret Data

Part 1. The Heat of Fusion of Ice

1. **SEP Use Math** Determine the heat lost by the water in the calorimeter to the ice cubes (Q_w, in Joules) and record it in the data table. *Note:* The heat absorbed by the ice cubes is given by the expression $Q_w = m_w \times c \times \Delta T$, where m_w is the initial mass of water in the calorimeter, c is equal to 4.18 J/g·°C, and ΔT is the change in temperature of the system.

2. **SEP Use Math** Determine the heat needed to warm the ice cubes (Q_{ice}, in Joules) and record it in the data table. *Note:* The heat required to warm the ice cubes is given by the expression $Q_{ice} = m_{ice} \times c \times (T_{final} - 0)$, where m_{ice} is the mass of ice added to the calorimeter, c is equal to 4.18 J/g·°C, and T_{final} is the final temperature of the system.

3. **SEP Use Math** Determine the heat needed to melt the ice cubes (Q_L, in Joules) by subtracting Q_{ice} from Q_w, and record it in the data table.

4. **SEP Use Math** Knowing the value of Q_L and m_{ice}, determine how much energy (in joules) is required to convert 1 gram of ice to 1 gram of liquid water for each trial. Record it in the data table. *Note:* The heat required to melt the ice cubes is given by the expression $Q_L = m_{ice} \times L$, where m_{ice} is the mass of ice added to the calorimeter, and L is the energy required to melt ice.

5. **SEP Construct an Explanation** Write an equation that relates Q_w, Q_{ice} and Q_L.

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6. **SEP Use Models** Your water bottle has 500 g of water (m_w) at 22°C ($T_{initial}$). Calculate the mass of ice (m_{ice}, in grams) you need to add to your water bottle to cool it down to 5°C (T_{final}). *Note:* Remember that $Q_w = Q_{ice} + Q_L$; the equations for each of these heat values are provided in previous questions; use the value of L calculated in question 4, and $c = 4.18$ J/g·°C.

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Part 2. The Cooling Curve of Water

7. **SEP Use Graphs** Use graphing software or draw a graph that plots temperature on the *y*-axis versus time on the *x*-axis. Plot the data collected in the data table for part 2. Draw a smooth (continuous) curve through the plotted points on each graph.

8. **SEP Construct an Explanation** Describe what happens with the temperature over time when the water and the ionic solution in their respective test tubes are immersed in the ice-water bath.

9. **SEP Construct an Explanation** The freezing points of the liquids in the test tubes used in trials 1 and 2 correspond to the temperatures at which a solid-liquid phase equilibrium is established. At the freezing point, the temperature of the system becomes constant. From your plots above, estimate the freezing points of pure water and water containing the ionic compound.

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10. SEP Construct an Explanation What is the effect of adding the ionic compound on the freezing point of water, if any?

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PERFORMANCE BASED ASSESSMENT

Enthalpy of a Neutralization Reaction

Some chemical reactions give off heat, and some need heat to proceed. How much heat is released during an acid-base (neutralization) reaction? In this lab you will determine the change in enthalpy of a reaction widely used in analytical chemistry labs and numerous industrial processes—the neutralization of hydrochloric acid with sodium hydroxide.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Hydrochloric acid solution, 1.0*M*, HCl, 100 mL
- Sodium hydroxide solution, 1.0*M*, NaOH, 50 mL
- Sodium hydroxide flakes, NaOH, 8 g
- Water, distilled or deionized
- Balance, 0.01 g precision
- Beaker, 400 mL
- Graduated cylinder, 2, 50 mL
- Polystyrene cups, 2
- Spatula or scoop
- Thermometer
- Weighing dishes or paper

Safety 

Hydrochloric acid solution is toxic by inhalation, ingestion, and it is severely corrosive to all body tissues. Sodium hydroxide, both as a solid and in solution, is corrosive and may cause burns to skin and eyes. A large amount of heat is evolved when sodium hydroxide is added to water. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron or a lab coat. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

NAME ______________________ DATE __________ CLASS __________

Procedure

Part 1. Reaction between HCl(*aq*) and NaOH(*aq*)

1. Nest one polystyrene cup inside another. Mass the two nested cups to the nearest 0.01 g. This assembly will serve as your “calorimeter” to measure the heat change of the reaction mixture.

2. Place the nested cups inside a dry, clean 400 mL beaker for support.

3. Use a graduated cylinder to measure 25 mL of 1.0*M* hydrochloric acid solution. Record the exact volume, to the nearest 0.1 mL, in the data table. Pour this solution into the calorimeter.

4. Rinse the graduated cylinder with plenty of distilled or deionized water. Fill it up with 25 mL of 1.0*M* sodium hydroxide solution. Do not pour this solution into the calorimeter. Record the exact volume, to the nearest 0.1 mL, in the data table.

5. Measure the initial temperature of the HCl solution ($T_{\text{initial HCl}}$) in the calorimeter, and of the NaOH solution ($T_{\text{initial NaOH}}$) in the cylinder to the nearest 0.1°C. Record the temperatures in the data table. *Note:* Be sure to rinse the thermometer between measurements.

6. Carefully pour the NaOH solution into the calorimeter. Stir the reaction mixture very gently with the thermometer. (Caution: Hold the thermometer at all times; do not allow the thermometer to stand up in the calorimeter, as it may tip over.) Record the highest or lowest temperature (final temperature T_{final}) that the solution reaches.

7. Mass the calorimeter (without the beaker and thermometer) with the solution to the nearest 0.01 g, and record this mass in the data table as the mass of solution after reaction.

8. Rinse the neutral solution down the drain with water. Thoroughly rinse and dry the cups for use in part 2.

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Data Table — Part 1	
Mass of empty calorimeter	
Volume of HCl solution before reaction	
Volume of NaOH solution before reaction	
Moles of NaOH added	
Mass of calorimeter plus solution after reaction	
Mass of solution after reaction (m)	
Initial temperature of HCl before mixing ($T_{\text{initial HCl}}$)	
Initial temperature of NaOH before mixing ($T_{\text{initial NaOH}}$)	
Average initial temperature (T_{initial}) before mixing	
Final temperature of solution after reaction (T_{final})	
Change in temperature ($\Delta T = T_{\text{final}} - T_{\text{initial}}$)	
Heat released ($Q = -m \times c \times \Delta T$)	
Enthalpy of neutralization ($\Delta H = Q$/moles of NaOH added)	

Part 2. Reaction between HCl(*aq*) and solid NaOH

9. Mass the nested two cups to the nearest 0.01 g.

10. Use a graduated cylinder to measure 50 mL of 1.0*M* hydrochloric acid solution. Record the exact volume, to the nearest 0.1 mL, in the data table. Pour this solution into the calorimeter.

11. Mass the calorimeter and its contents to the nearest 0.01 g and record this mass in the data table. Handle the calorimeter carefully to avoid acid spills.

12. Place the nested cups inside a dry, clean 400 mL beaker for support.

13. Measure the initial temperature of the HCl solution ($T_{\text{initial HCl}}$) in the calorimeter to the nearest 0.1 °C. Record this temperature in the data table.

14. Tare a weighing dish/paper and add approximately 2.0 g of NaOH flakes. Record the exact mass of NaOH added to the nearest 0.01 g.

15. Carefully pour the NaOH flakes into the calorimeter. Stir the reaction mixture gently with the thermometer to fully dissolve the NaOH flakes in the acid solution. (Caution: Hold the thermometer at all times; do not allow the thermometer to stand up in the calorimeter, as it may tip over.) Record the highest or lowest temperature (final temperature T_{final}) that the solution reaches.

16. Mass the calorimeter (without the beaker and thermometer) with the solution to the nearest 0.01 g, and record this mass in the data table as the mass of solution after reaction.

17. Rinse the neutral solution down the drain with water. Thoroughly rinse and dry the cups for use in part 3.

NAME ______________________________ DATE ____________ CLASS ____________

Data Table — Part 2	
Mass of empty calorimeter	
Volume of HCl solution before reaction	
Mass of calorimeter plus HCl solution before reaction	
Mass of HCl solution before reaction	
Mass of NaOH flakes	
Moles of NaOH flakes	
Mass of solution after reaction (m)	
Initial temperature of HCl before mixing with NaOH ($T_{\text{initial HCl}}$)	
Final temperature of solution after reaction (T_{final})	
Change in temperature ($\Delta T = T_{\text{final}} - T_{\text{initial HCl}}$)	
Heat released ($Q = -m \times c \times \Delta T$)	
Enthalpy of neutralization ($\Delta H = Q$/moles of NaOH added)	

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Part 3. Dissolution of NaOH(*s*) in H_2O(*l*)

18. Develop a procedure to determine the enthalpy of dissolution of NaOH in water. Record all values of mass, volume, and temperature in a data table for part 3. Record your detailed procedure as well as any materials to be used.

19. Return the solution to the instructor to be disposed of properly. Thoroughly rinse and dry the cups.

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Data Table — Part 3	

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

Answer the following questions regarding experiments done in Parts 1 and 2. Show all your work.

1. **SEP Use Math** Calculate the moles of NaOH added, the change in temperature (ΔT), the heat released (Q, in joules), and the enthalpy of the neutralization reaction (ΔH, in kilojoules per mol of NaOH), and record the results in the respective data table.

2. **SEP Interpret Data** Classify the reaction as endothermic or exothermic and explain your reasoning.

3. **SEP Develop Models** Write the balanced chemical equations for the reactions that took place in Parts 1 and 2, including heat on the appropriate side of the equation and the abbreviations that describe the state/phase of reactants and products.

Answer the following questions regarding the experiment done in Part 3:

4. **SEP Use Math** Calculate the moles of NaOH added, the change in temperature of the system (ΔT), the heat released (Q, in joules), and the enthalpy of dissolution of NaOH (ΔH, in kilojoules per mol of NaOH). Record the results in the respective Data Table.

5. **SEP Interpret Data** Classify this process as endothermic or exothermic and explain your reasoning.

6. **SEP Develop Models** Write the balanced chemical equation for the dissolution that took place in Part 3, including heat on the appropriate side of the equation and the abbreviations that describe the state/phase of reactants and products.

7. **SEP Use Models** What chemical equation results from adding the equations for the processes in Parts 1 and 3? Write down this equation and compare it to the three equations written for Parts 1, 2, and 3.

NAME ____________________ DATE __________ CLASS __________

8. **SEP Use Math** What enthalpy value results from adding the enthalpies determined for the processes studied in Parts 1 and 3? Calculate this value and compare it to the three enthalpies obtained in Parts 1, 2, and 3.

9. **SEP Use a Model to Evaluate** Write your observations about the results of the calculations done in questions 7 and 8. What does this tell you about adding chemical equations and their respective enthalpies?

Investigation 9

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Compressibility

The kinetic molecular theory (KMT) tells us that gases are in constant, random motion and that the volume of gas particles is very small relative to the volume of the container in which the gas is held. This means that there is a significant amount of empty space between gas particles in a container of gas. In this experiment, you will explore how the compressibility of a gas compares to the compressibility of a liquid and a solid.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing explanations and Designing Solutions

Materials Per Group

- Beaker, 50 mL or greater
- H_2O, liquid
- Syringe apparatus, 1
- Freezer access

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. When pressing a syringe plunger into the barrel when the barrel is capped, take care to orient the apparatus away from labmates so that if the cap pops off it does not strike them. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE ____________ CLASS ____________

Procedure

1. **SEP Plan Your Investigation** Develop a procedure to compare the compressibilities of the three states of matter: gas, liquid, and solid. Include a description of the variables you will control. Identify your independent and dependent variables. Adapt the data table as needed. Record your detailed procedure as well as any materials to be used. Show your plan to your instructor before you begin.

Data Table	

NAME ______________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Construct Explanations** Which sample was the easiest to compress? Explain why you think one state of matter is easier to compress than another.

2. **SEP Construct Explanations** Explain what you think would happen if you tried to compress the sample of air if it was heated.

3. **SEP Evaluate Your Plan** Discuss limitations of this experiment. For example, what variable could be controlled that was not controlled in the experiment as written? Would you expect to get a different result if you controlled this variable?

NAME ______________________________ DATE ____________ CLASS ______________

INQUIRY LAB – OPEN

Relationships Between Gas Variables

The four variables used to describe a gas—pressure, volume, temperature, and moles—are closely related. As one or more change, one or more of the others also change, in direct or inverse relation. This investigation explores relationships between gas variables.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Sodium chloride, NaCl, 20 g
- Ice cubes
- Petroleum jelly, foilpac, 5 g
- Water, tap or distilled
- Balance, 0.1 g precision
- Beakers, 600 mL, 4
- Beaker tongs, 1
- Beral-type pipet, 1
- Heat-resistant gloves
- Various masses, such as small books (5–8)
- Hot plate
- Stirring rod, glass, 1
- Spatula or scoop
- Syringe tip cap, 1
- Syringe, disposable, 35 mL, 1
- Thermometer or temperature sensor
- Weighing dish or paper, 1
- Wooden base with large (23-mm diameter) pre-drilled hole
- Wood splint

Safety

Hot objects and escaping steam can cause severe burns. Handle hot objects with beaker tongs and do not place your hands in the steam. Do not use a thermometer as a stirring rod. Wear chemical splash goggles when working with chemicals, heat, or glassware in the laboratory. Wash hands with soap and water before and after leaving the laboratory.

NAME ______________________ DATE __________ CLASS __________

Procedure

Part I. The Pressure-Volume Relationship

1. **SEP Plan Your Investigation** Design an experiment that uses the apparatus provided to explore the relationship between a gas's pressure and the volume of the container in which it is held. Use the following questions to guide you as you design your experiment.
   - **a.** What are the two gas variables you will be measuring and plotting on a graph?
   - **b.** How can you apply a measurable pressure, or calculate the pressure, applied to the syringe plunger?
   - **c.** How can the experimental volume change be measured as the pressure exerted on the plunger changes?

d. According to the kinetic molecular theory of gases, very fast compressions of a gas from large volumes to small volumes cause significant temperature changes. Why then, for the purpose of this investigation—to determine the mathematical relationship between the gas variables pressure and volume—is it necessary to compress the gas in the syringe slowly?

2. Use the space to record your detailed procedure as well as any materials to be used. Use the data table to record your observations about pressure and volume. Show your procedure to your instructor before you begin.

NAME ______________________ DATE ____________ CLASS ____________

Part I. Data Table — Pressure-Volume Relationship			
Mass (kg)	**Pressure (kPa)**	**Volume (mL)**	**1/Volume**

Part II. The Volume-Temperature Relationship

3. Use the 600 mL beakers to prepare four water baths for this activity. Use the information in the data table to help you choose a temperature range for each water bath. Record the actual range in the data table for each bath. Dissolve sodium chloride in an ice-water bath to prepare the salt-ice water bath. *Note: Do not use thermometers as stirring rods.*

Part II. Data Table — Water Baths Conditions	
Water Bath	**Temperature Range (°C)**
Salt-ice water	
Ice-water	
Room temperature	
Hot water	

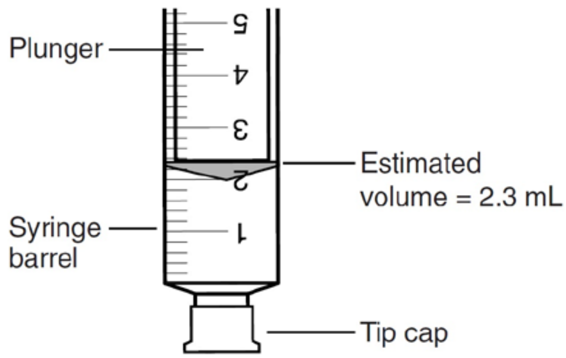
4. **SEP Plan Your Investigation** Use the available materials to design an experimental procedure that tests the volume-temperature relationship of gases. Use air as your sample gas. Use the following recommendations when designing your procedure. Record your procedure. Show your procedure to your instructor before you begin.

NAME ________________________________ DATE __________ CLASS ___________

A. Remove the plunger from the syringe and cover the black rubber gasket with a thin layer of petroleum jelly. Spread petroleum jelly on the surface of the gasket using a wood splint.

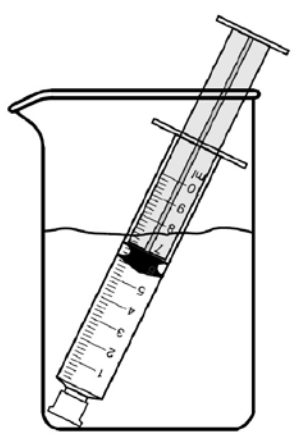
B. Measure and record the precise volume of air in the syringe at room temperature in a data table. Note: Measure the volume at the black insert rubber seal, not at the inverted V-like projection, as shown in Figure 1.

Figure 1



C. Place the syringe in the water baths and submerge the syringe just to the bottom of the plunger as shown in Figure 2.

Figure 2



NAME ______________________ DATE __________ CLASS __________

Record your detailed procedure.

Part II. Data Table — Volume-Temperature Relationship for Air					
Water Bath	**Temperature, T (°C)**	**Volume of Air in Syringe, V (mL)**			

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

Part I.

1. **SEP Construct Graphs** Use graphing software or the space to construct a graph or graphs from the data you collected on the pressure and its volume of a gas.

2. **SEP Analyze Graphs** Look at your graph(s). Identify any relationship you notice between the pressure and volume of gases.

NAME ______________________ DATE __________ CLASS __________

3. **SEP Consider Limitations** Describe two sources of error and the effects each had or may have had on your experimental data.

Part II.

4. **SEP Identify Variables** Identify the independent and the dependent variables in this experiment.

5. **SEP Construct a Graph** Use graphing software or the space to plot a graph of the dependent variable on the y-axis versus the independent variable on the x-axis. Choose a suitable scale for each axis so that the data points fill the graph space. Label each axis, including the units, and give the graph a title.

NAME ______________________________ DATE __________ CLASS ___________

6. **SEP Use Math** Based on your graph, describe the mathematical relationship between the temperature and volume of a gas.

7. **SEP Analyze Data** For each of the four temperatures in this experiment, calculate the value of the volume/temperature (V/T in mL/°C) ratio, and write these values in the data table. How do these ratios compare with one another?

8. **SEP Analyze Data** Convert each of the temperature measurements in this experiment to absolute temperature in kelvins (K), and write these values in the data table. Calculate the value of the volume/absolute temperature (V/absolute temperature in mL/K) ratio for each of the four temperatures in this experiment, and write these values in the data table as well. How do these ratios compare with one another?

9. **SEP Identify Patterns** Which volume/temperature ratio (in mL/°C or mL/K) appears to be more constant? Why?

NAME ______________________ DATE __________ CLASS __________

10. SEP Apply Scientific Reasoning According to the kinetic-molecular theory (KMT), the volume of the gas particles is extremely small compared to the volume that the gas occupies—most of the volume of gas is “empty space.” Based on this theory, would the results in this experiment have been different if different gases had been used in the syringe? On the amount of gas in the syringe? Explain in terms of the KMT and the amount of empty space in a gas.

NAME ______________________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

The Ideal Gas Law

The four variables used to describe a gas—pressure, volume, temperature, and moles—are closely related. As one or more change, one or more of the others also change, in direct or inverse relation. This investigation explores relationships between gas variables by examining the ideal gas law. The ideal gas law is a mathematical equation that relates the four gas variables to each other: $PV = nRT$, where P = pressure, V = volume, n = moles, R = ideal gas constant, and T = temperature.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Copper wire, Cu, 18 gauge, 12 cm long
- Hydrochloric acid, HCl, 2*M*, 20 mL
- Magnesium ribbon, Mg, 1 cm pieces, 2
- Water, distilled or deionized
- Water, ice
- Balance, electronic, 0.001 g
- Barometer
- Beaker, 600 mL
- Graduated cylinder, 25 mL
- Metric ruler
- Rubber stopper, one-hole, size 0 or 1
- Pencil
- Scissors or wire cutter
- Thermometer
- Wash bottle

Safety

Hydrochloric acid is a corrosive liquid; it will cause skin burns and eye damage. Avoid contact with eyes and skin and clean up all spills immediately. Magnesium metal is a flammable solid. Keep away from flames and other sources of ignition. Wear chemical splash goggles, chemical-resistant gloves, and a lab coat or chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE __________ CLASS __________

Procedure

1. **SEP Plan Your Investigation** Use the available materials to plan a procedure that determines an experimental value for the ideal gas constant. Keep in mind these points as you design your procedure:

   A. You should include a process for generating hydrogen gas and measuring its volume.

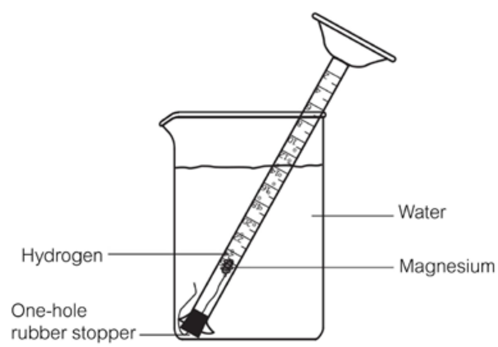
   B. You should carry out two separate trials using different masses of Mg in each.

   C. Your set-up should resemble the one shown in the figure.

   D. Use the copper wire to build a cage to contain the magnesium.

   E. Your calculation should take into account the barometric pressure as well as the vapor pressure of water.

   F. You will need to observe values of *n*, *P*, *T*, and *V*, in order to calculate *R.*



NAME ______________________ DATE __________ CLASS __________

2. Record your detailed procedure as well as any materials to be used. Show your procedure to your instructor before beginning.

NAME ______________________ DATE __________ CLASS __________

Data Table		
	Trial 1	**Trial 2**
Length of Mg ribbon		
Mass of Mg		
Moles Mg		
Evidence of chemical reaction		
Volume of H_2 gas		
Moles H_2 gas		
Temperature of water bath		
Barometric pressure		

Analyze and Interpret Data

1. **SEP Construct Explanations** Compare the volumes of hydrogen gas generated in trials 1 and 2. Why is the volume in one of the trials greater than the volume in the other?

2. **SEP Use Math** The ideal gas constant, *R*, can be determined by rearranging the ideal gas equation, $PV = nRT$. Rearrange the equation to solve for *R*, and explain why *R* should remain constant regardless of the amount of Mg used in this experiment.

3. **SEP Construct Explanations** In setting up this experiment, if a bubble of air leaked into the graduated cylinder when it was inverted in the water bath, would the calculated ideal gas law constant, *R*, be too high or too low as a result of this error? Explain.

4. **SEP Use Math** Your instructor wants to scale up this experiment for demonstration purposes and would like to collect the gas in an inverted 50 mL buret (a cylindrical glass tube) at room temperature. Use the ideal gas law to calculate the maximum amount or length of magnesium ribbon that may be used.

NAME ______________ DATE ______________ CLASS ______________

NAME ________________ DATE ________ CLASS ________

INQUIRY LAB – OPEN

Gas Diffusion

Gas particles move from areas of high concentration to areas of low concentration. This process is called diffusion. The rate at which gas particles diffuse can be affected by temperature and the size of the particles. In this investigation you will explore factor(s) that affect diffusion rates and use the things you learn about gas diffusion to better understand wind.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Ammonium hydroxide, concentrated 14.7*M*, NH_4OH, 4 mL
- Hydrochloric acid, concentrated, 12.1*M*, 2 mL
- Phenolphthalein solution, 1%, 4 mL
- Thymol blue solution, 0.04%, 2 mL
- Beral-type pipets, 2
- Bunsen burner
- Cotton balls, 12
- Distilled water and wash bottle
- Glass diffusion tubes, 14-mm wide by 30-cm long, 2
- Forceps
- Medicine droppers, glass, 2
- Ring stands and clamps, 2
- Rubber stoppers, size 00, 4

Safety

Concentrated ammonium hydroxide and hydrochloric acid are toxic and corrosive and will cause severe burns. Their vapors are extremely irritating, especially to the eyes and respiratory tract. Dispense these reagents in a hood and exercise caution. Do not handle the soaked cotton balls with bare hands. Use forceps and wear chemical-resistant gloves. Phenolphthalein indicator solution contains alcohol and is flammable. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling and disposal information.

NAME ______________________ DATE __________ CLASS __________

Procedure

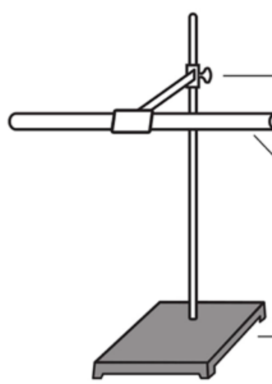
1. **SEP Plan Your Investigation** Develop a procedure to test how the diffusion rate of a gas varies with molecular mass, and how the diffusion rate of a gas varies with temperature. Keep the following in mind as you develop your procedure.

   A. Use the apparatus described in Figure 1 to study the diffusion of hydrochloric and ammonia gases.

   B. Use phenolphthalein-soaked cotton balls to indicate the presence of ammonia gas and thymol-blue soaked cotton balls to indicate the presence of hydrochloric acid vapor. In both cases, the cotton balls will change color when they interact with one of the gases.

   C. You may use a Bunsen burner to heat the glass diffusion tubes, but be sure to use a very gentle flame. *Do not overheat—the diffusion tube is made of soft, flint glass.*

Figure 1



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

NAME ______________________ DATE __________ CLASS __________

NAME ________________ DATE ________ CLASS ________

Analyze and Interpret Data

1. **SEP Construct Explanations** Which gas, ammonia or hydrochloric acid, diffuses at a faster rate, and why?

2. **SEP Engage in Argument from Evidence** Would you expect the pressure on the ground to be higher or lower on a relatively warm day than the pressure on a relatively cold day? Explain.

3. **SEP Construct Explanations** Explain why sea breezes, in which winds blow from the water to the land, occur during the day when the adjacent land area heats more rapidly than water.

NAME ______________________ DATE ____________ CLASS ____________

PERFORMANCE BASED ASSESSMENT

Cartesian Divers

Whether an object floats or sinks in a fluid depends on the object's density compared to the density of the fluid. Density = mass/volume ($D = m/v$). Gas densities can change because gases are compressible. In this activity you will use what you know about the properties of gases to make Cartesian divers that descend in predictable orders.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Developing and Using Models

Materials Per Group

- Beaker, 600 mL
- Hex nuts, 100
- Paper towel
- Pipette, Beral-type, disposable plastic, 100
- Plastic soda bottle, 1 L
- Tap water

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Wash hands thoroughly with soap and water before leaving the laboratory.

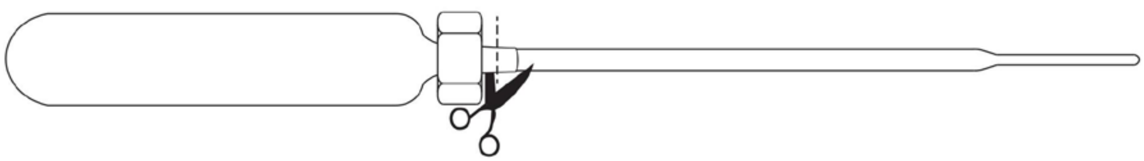
NAME ______________________ DATE __________ CLASS __________

Procedure

Part I. Making a Cartesian Diver

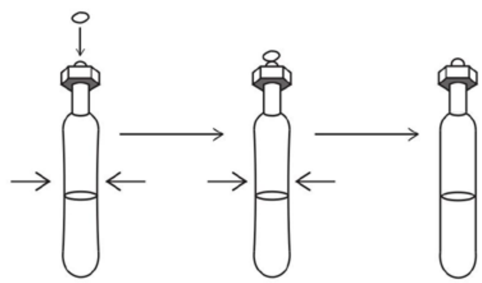
1. Fill the 600 mL beaker approximately 4/5 full with tap water.
2. Screw the hex nut securely onto the pipet stem. The hex nut will form its own threads as it turns. Cut off the remaining pipet stem as shown in Figure 1.

Figure 1



3. Place the pipet-nut diver assembly into the 600 mL beaker of water and observe that it floats in an upright position with the hex nut acting as ballast.
4. Squeeze out some of the air from the bulb and draw some water up into the pipet. Now check the buoyancy. If you draw up too much water, the diver will sink. If this happens, simply lift it out of the water, squeeze out a few drops of water, and let air back in to replace the water.
5. Using this technique, adjust the amount of water in the diver so that it just barely floats in the beaker.
6. Remove the diver from the beaker and squeeze out one or two drops of water. Using a paper towel, pat dry the inside rim of the open stem.
7. Holding the bulb with the stem end upward, squeeze the bulb very slightly to expel a very small amount of air. Hold the squeeze while carefully placing a drop of hot, melted glue in the stem opening of the diver and then relax the squeeze. The drop of hot glue will be pulled into the stem as shown in Figure 2.

Figure 2



8. Wait 1–2 minutes for the drop of glue to harden and seal the mouth of the diver.

9. Place the diver assembly in the plastic 1 L bottle completely filled with water and screw on the cap securely. Squeeze the bottle and observe what happens to the diver.

NAME ______________________ DATE __________ CLASS __________

Part II. Inquiry Challenge

10. SEP Develop Models Design a set of three divers that descend in a specific order. Consider the following questions.

A. How will the final design be tested? What data will be recorded?

B. What variables are going to change with each diver? Why?

C. What variables will be held constant? Why?

D. What criteria make for a successful design?

11. Use the area to record your detailed procedure as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Construct Explanations** Why does a Cartesian diver sink when the 1 L bottle it is contained in is squeezed, and then float to the surface when the squeeze is released?

2. **SEP Construct Explanations** Which of the three Cartesian divers (first sinker, second sinker, or third sinker) must contain the most air? Explain.

3. **SEP Construct Explanations** If Part II of the experiment was repeated in every way, except the Cartesian divers were heated prior to placing them in the 1 L bottle, would you expect the amount of external pressure needed to sink the divers to increase, decrease, or stay the same? Explain.

NAME ______________________ DATE ____________ CLASS ____________

4. **SEP Communicate Scientific Information** How are the activities conducted in this lab a demonstration of Boyle's law?

Investigation 10

NAME ____________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Feedback and Climate Change

Earth's atmosphere is a mixture of several gases, including nitrogen, oxygen, carbon dioxide, and water vapor. Gases like carbon dioxide and water vapor trap some of the radiation emitted by Earth. This allows our planet to stay warm and sustain life. Recently the amount of carbon dioxide in our atmosphere has been increasing, enhancing the warming effect. What happens to temperature in a system if carbon dioxide levels increase? How will that affect glaciers and sea ice?

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions
SEP 8 Obtaining, Evaluating, and Communicating Information

Materials Per Group

- Antacid effervescent tablets, 4
- Clear plastic bottles, 1 L, 2
- Chunk of modeling clay, 2
- Graduated cylinder, 100 mL
- Light/heat source, 100 W
- Marker
- Tap water, 50 mL
- Thermometer, 2
- Ruler
- Crushed ice, 300 g
- Balance
- Pencil

Safety

Carbon dioxide in the bottle may be under pressure. Wear safety goggles. Wear plastic gloves. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________________ DATE ____________ CLASS ____________

Procedure

1. **SEP Plan and Carry Out an Investigation** Using the materials provided, design an experiment to test if atmospheric carbon dioxide accelerates the rate at which ice melts. Use the space provided to record your detailed procedure as well as any materials to be used. Show your procedure to your teacher before you start.

NAME ______________________ DATE __________ CLASS __________

Temperature Change in Bottles		
Time (minutes)	Temperature: Control Bottle (°C)	Temperature: CO_2 Bottle (°C)
Initial		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
Total Temperature Difference		

NAME ______________________ DATE __________ CLASS __________

Volume of Ice Melted	
Bottle	Volume of Liquid (mL)
Control Bottle	
Carbon Dioxide Bottle	

1. **SEP Construct Graphs** After collecting all the data, use graphing software or draw a graph that shows temperature (*y*-axis) vs. time (*x*-axis) for each bottle.

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Evaluate and Communicate** Which bottle had the greatest volume of melted ice? What factor contributed to the difference?

2. **SEP Apply Scientific Reasoning** How would adding additional antacid tablets affect the feedback mechanism observed in this investigation?

3. **SEP Apply Scientific Reasoning** What modifications could be made to introduce a balancing feedback into the experimental bottle?

4. **SEP Construct an Explanation** How does the reduction of sea ice and glaciers promote the reinforcing feedback mechanism associated with climate change?

NAME ______________________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Energy in the Atmosphere

Energy from the sun shapes Earth's global climate system. The atmosphere is a key component of this system, and the flow of energy that produces different climates in different regions of the world depends on the overall motion of the gases that make up the atmosphere. Understanding how different gases move as they absorb energy is an essential step in understanding weather, climate, and the numerous feedbacks that affect them.

In this investigation you will explore factor(s) that affect particle movement in the atmosphere and use the things you learn to better understand weather and climate.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Ammonium hydroxide, concentrated 14.7*M*, NH_4OH, 4 mL
- Hydrochloric acid, concentrated, 12.1*M*, 2 mL
- Phenolphthalein solution, 1%, 4 mL
- Thymol blue solution, 0.04%, 2 mL
- Beral-type pipets, 2
- Bunsen burner
- Cotton balls, 12
- Distilled water and wash bottle
- Glass diffusion tubes, 14-mm wide by 30-cm long, 2
- Forceps
- Medicine droppers, glass, 2
- Ring stands and clamps, 2
- Rubber stoppers, size 00, 4

Safety

Concentrated ammonium hydroxide and hydrochloric acid are toxic and corrosive and will cause severe burns. Their vapors are extremely irritating, especially to the eyes and respiratory tract. Dispense these reagents in a hood and exercise caution. Do not handle the soaked cotton balls with bare hands. Use forceps and wear chemical-resistant gloves. Phenolphthalein indicator solution contains alcohol and is flammable. Wear chemical splash goggles, chemical-resistant gloves, and a *chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling and disposal information.*

Procedure

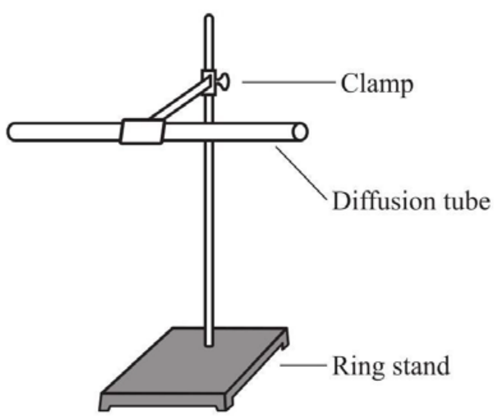
1. **SEP Plan Your Investigation** Develop a procedure to test how the diffusion rate of a gas varies with molecular mass, and how the diffusion rate of a gas varies with temperature. Keep the following in mind as you develop your procedure.

   A. Use the apparatus described in Figure 1 to study the diffusion of hydrochloric and ammonia gases.

   B. Use phenolphthalein-soaked cotton balls to indicate the presence of ammonia gas and thymol-blue soaked cotton balls to indicate the presence of hydrochloric acid vapor. In both cases, the cotton balls will change color when they interact with one of the gases.

   C. You may use a Bunsen burner to heat the glass diffusion tubes, but be sure to use a very gentle flame. *Do not overheat—the diffusion tube is made of soft, flint glass.*

Figure 1



NAME ______________________ DATE ____________ CLASS ____________

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

Analyze and Interpret Data

1. **SEP Construct Explanations** Which gas, ammonia or hydrochloric acid, diffuses at a faster rate, and why?

2. **SEP Engage in Argument from Evidence** The composition of Earth's atmosphere has changed significantly over time. Currently, air consists almost entirely of nitrogen and oxygen in a 4:1 ratio (with trace amounts of other gases). Based only on the data you collected, write a hypothesis about the potential effect that reversing this ratio might have on warm and cold climates. Explain.

3. **SEP Construct Explanations** Explain why sea breezes, in which winds blow from the water to the land, occur during the day when the adjacent land area heats more rapidly than water.

4. **SEP Construct Explanations** As moist air warms above the ocean near the equator, where the sun shines intensely, it becomes less dense. As the air becomes less dense, it rises and cools. As the air cools water particles in the air condense to form clouds, and rain. Describe the flow of electromagnetic energy throughout this process and explain why this process occurs repeatedly and predictably near the equator.

5. **SEP Construct Explanations** Why does severe weather, including strong winds, sometimes occur when warm air masses and cold air masses collide?

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Albedo and Composition of Earth's Surface

How does the composition of Earth in a specific region affect the temperatures in that region? The temperature of Earth's surface varies from a low of –89°C in the vast ice domain of Antarctica to a high of 58°C in the desert of Africa. Surface albedo, which is a function of the composition of the surface materials and the angle at which the Sun's rays strike Earth, contributes to the temperature variations observed on Earth. The purpose of this investigation is to compare how similar amounts of infrared radiation affect the temperature of geological materials.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Water, deionized, 70 mL
- Light source, or infrared heat lamp
- Petri dishes, 4
- Sand, black, 100 g
- Sand, white, 100 g
- Soil, black, 100 g
- Thermometers, 4

Safety 

Use extreme caution while using heating equipment in this activity. The lamp and bulb may become very hot. Do not leave lamps unattended. Wear heat-resistant gloves. Sand grains can scratch eyes. Wear safety glasses. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines

NAME ______________________ DATE ____________ CLASS ____________

Procedure

1. Using the materials provided, design an experiment to test temperature change over time as the four provided samples are heated. Use the space provided to record your detailed procedure as well as any materials to be used.

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2. Record all data in the provided table.

Data Table — Temperature Change				
Time (seconds)	**Water Temperature in °C**	**Soil Temperature in °C**	**Black Sand Temperature in °C**	**White Sand Temperature in °C**
0 (Initial)				

NAME ______________________ DATE ____________ CLASS ____________

3. Use the space, or graphing software to graph your results.

Analyze and Interpret Data

1. **SEP Calculate** Determine the change in temperature of each sample by subtracting the initial temperature from the final temperature.

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2. **SEP Interpret Data** Which material used in this investigation had the largest change in temperature? Explain.

3. **SEP Evaluate and Communicate** Using the results from this lab, explain how the continual reduction of glacial ice on land could impact Earth's climate.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

How Melting Ice Affects Sea Level

Why is sea level rising? Sea level has been rising on average 0.32 cm per year. There are a number of factors contributing to this. The first factor is thermal expansion. When water heats up, it expands and takes up more space. The second factor is the increased melting of sea ice as well as glaciers and ice sheets located on land. In this activity, you will investigate how the location of the melting ice affects sea level.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 6 Constructing Explanations and Designing Solutions
SEP 8 Obtaining, Evaluating, and Communicating Information

Materials Per Group

- Water
- Clay, 2 sticks
- Heat lamp
- Ice
- Marker
- Plastic containers, 2

NAME ______________________ DATE __________ CLASS __________

Procedure

1. Using the materials provided, design an experiment to determine which has a larger impact on sea level: the ice located in the sea melting or the ice located on land melting? Record your detailed procedure as well as any materials used.

2. Make a prediction about what will happen to the water level in each container as the ice melts. Explain.

Analyze and Interpret Data

1. **SEP Make Observations** What happened to the water levels in each plastic container as the ice melted?

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2. **SEP Construct an Explanation** How does the impact of melting sea ice differ from the impact of melting glaciers/ice sheets?

3. **SEP Evaluate and Communicate** What are some potential consequences of rising sea levels?

NAME ______________________ DATE ________ CLASS ________

INQUIRY LAB – OPEN

Observe Air Pollution

How polluted is the air we breathe? Chances are the air in your area is polluted to some extent. Dry air is composed of nitrogen, oxygen, argon, carbon dioxide, and trace amounts of other substances. Human activity has added additional quantities of these and other substances into the atmosphere, creating an imbalance and causing the quality of air to degrade. This activity will introduce effects of common types of air pollution.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 7 Engaging in Argument from Evidence
SEP 8 Obtaining, Evaluating, and Communicating Information

Materials Per Group

- Adhesive label
- Magnifying glass
- Ruler
- Beral-type pipet
- Bromothymol blue indicator solution, 10 drops
- Distilled or deionized water, 20 mL
- Matches, 1 book
- Syringe
- Microscope slide
- Pencil
- Marble chip
- "Simulated acid rain solution," 20 drops
- "Unpolluted rainwater," 20 drops
- Sampling container
- Acid rain test strip
- Tubing, 5 cm

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Hydrochloric acid is corrosive to skin and eyes and toxic by inhalation or skin absorption. Avoid contact with eyes and skin and clean up all spills immediately. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE ____________ CLASS ____________

Procedure

Part I.

1. Place a label, sticky side up, on your microscope slide. This may be done by curling two of the outside edges of the label down so the label will stick to the slide.
2. Choose a location, inside or outside, to place your slide. Be sure to choose a different location than other classmates (i.e., inside a classroom by a window, in a tree, near the corner of the school building, etc.). Choose an area that is exposed to the air, elevated off the ground and, if possible, sheltered from rain. Be sure to describe where the slide was placed. Record placement in the data table.
3. Leave the slide in the same location for seven days.
4. At the end of the seven days, collect each sample. Use a magnifying glass to look at the label. Record your observations in the data table. Measure and draw two 1 cm squares on your label. Count or estimate how many particles are in each of the squares (look for white as well as dark specks) and record these values in the data table. Calculate the average of the two counts for overall particles per square centimeter. Record this value in the data table. Total particle counts between 100 to 500 per square centimeter indicate slight particle pollution. Values over 500 particles per square centimeter relate to high particle air pollution.

Data Table—Particulates in the Air	
Location of slide	
Observations after 1 week	
Count 1 (1 cm^2)	
Count 2 (1 cm^2)	
Average value of count 1 and 2	

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Part II.

5. Fill the sampling container to the 10 mL line with distilled water. Use a Beral-type pipet to add 5 drops of bromothymol blue indicator solution.

6. Swirl the solution in the sampling container. Record the color of the solution and pH in the data table. (Note: At a pH of 6.0 bromothymol blue is yellow, at a pH of 7.0 it is green, and at a pH of 7.6 it is blue.)

7. Light a match and place it in the solution in the sampling container and immediately close the lid. Try to capture all of the smoke from the match in the sampling container

8. Swirl solution in the sampling container so it can interact with the fumes. Record your observations and the pH of the resulting solution.

9. Rinse the sampling container with distilled water for use in the following experiment.

10. Fill the sampling container to the 10 mL line with distilled water. Using a Beral-type pipet, add 5 drops of bromothymol blue indicator solution.

11. Swirl the sampling container and record the color of the solution in the data table.

12. Attach a 5 cm piece of tubing to the end of a syringe. Fill the syringe with outside air.

13. Force the air out of the syringe through the tubing and into the bromothymol blue/water solution by depressing the plunger.

14. Repeat Step 13 ten times and record all observations in the data table. (Note: If the bromothymol blue/water solution does not change color, the air in your area has a fairly low amount of acidic gases. If the solution changes to a yellow color, your local air supply contains a high concentration of acidic gases.)

15. Rinse the syringe, tubing, and sampling container with distilled water. The sampling container will be used in the next step.

NAME ______________________ DATE ____________ CLASS ____________

Data Table—Smoke and Acidic Gases in the Air	
Initial contents, color, and pH of solution	
Observations after match was placed in plastic jar	
Initial contents, color, and pH of solution.	
Observations after outside air is blown through the solution	

Part III.

16. Place a small marble chip in the sampling container.

17. Fill a Beral-type pipet with “unpolluted rain water” Add 20 drops of this water on the marble chip. Record your observations.

18. Fill a Beral-type pipet with “simulated acid rain solution”. Add 20 drops of this water the same marble chip. Record your observations.

19. Gather a small sample of rainwater in the sampling container or another jar.

20. Dip an acid rain test strip into the water.

21. Compare the color of the test strip to the color chart. Record the color of the test strip and the acidity of the rainwater in your area in the data table.

NAME ______________________ DATE __________ CLASS __________

Data Table—Simulated Acid Rain	
Marble chip with "unpolluted water"	
Marble chip with "simulated acid rain solution"	
Color of acid rain test strip after sampling	
pH of rainwater	

Analyze and Interpret Data

1. **SEP Analyze Data** Did your test area have low or high particle pollution? Give examples of possible sources of particle pollution in your test area. Compare your results with your classmates.

2. **SEP Interpret Data** Which location had the most variable types of particulates?

3. **SEP Evaluate and Communicate** What effect does the pH of smoke have on water in the atmosphere?

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4. **SEP Evaluate and Communicate** What are some possible sources of acidic gases in air?

5. **SEP Make Observations** What effect did the simulated acid rain have on the marble chip?

6. **SEP Use Evidence** Based on the results from the acid rain test strip, are the marble buildings in your area in danger of deterioration?

NAME ____________________ DATE __________ CLASS __________

PERFORMANCE BASED ASSESSMENT

Microhabitat in a Bottle

How challenging would it be to recreate the conditions necessary for life? Our planet supports life due to complex interactions between various cycles and a delicate balance between the various biotic and abiotic factors that inhabit it. In this investigation you will build a microhabitat that supports life by managing the various conditions within it.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 6 Construct an Explanation
SEP 8 Obtaining, Evaluating, and Communicating Information

Materials Per Group

- Bottle, 1 liter
- Cap
- Soil 150 g
- Screen
- Light source
- Wood skewer
- Grass seed, 20 g
- Funnel
- Aquarium gravel, 200 g

Procedure

1. Begin by creating a drainage layer by filling the bottom of the bottle with 200 grams of aquarium gravel.
2. To prevent soil from mixing with the gravel, place the screen in the bottle covering the aquarium gravel. Use the wooden skewer to help position and flatten the screen.
3. Break up any large pieces of soil and use the funnel to add 150 grams of soil on top of the screen.
4. Create a microhabitat in the bottle using the grass seed provided and any other additional materials approved by your teacher.
5. Document any modifications your group makes and any notable changes that you observe over the course of this investigation.

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Data Table—Microhabitat Progress	
Day	**Observations or Modifications**

Analyze and Interpret Data

1. **SEP Make Observations** The basis of Earth's global climate systems is the electromagnetic radiation emitted from the sun which is absorbed, reflected, redistributed, and stored. How was this also observed in your microhabitat?

2. **SEP Obtain Information** What types of feedback can be observed in the biological, geological, or chemical cycles in your microhabitat?

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3. **SEP Evaluate and Communicate** Compare your microhabitat to those of other groups. Explain which microhabitat you think has the best air quality and why?

4. **SEP Identify Limitations of a Model** In what ways is the microhabitat you created similar to Earth, and in what ways is it different?

Investigation 11

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INQUIRY LAB – OPEN

Carbon Dioxide and Its Role in Climate

This investigation will illustrate the role that greenhouse gases play in climate change. Using the materials provided, you will design an experiment that allows you to test if the addition of carbon dioxide will cause the air inside a liter bottle to heat up faster and/or reach a higher temperature than a bottle with ordinary air. A variable is then chosen to manipulate in order to test the closed system again and look for patterns.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Antacid effervescent tablets, 8
- Clear plastic bottles, 1 L, 2
- Chunk of modeling clay, 2
- Graduated cylinder, 100 mL
- Light/heat source, 100 W
- Light/heat source, variation
- Plastic wrap, 30 cm. x 30 cm. sheets, 4
- Rubber band, 2
- Ruler
- Stirring rod, glass
- Tap water
- Thermometer, 2

Safety 

Carbon dioxide in the bottle may be under pressure. Wear safety goggles. Wear plastic gloves. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Label one of the 1 liter bottles *control* and the other 1 liter bottle CO_2.

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2. Write a step-by-step procedure that allows you, using the materials provided, to test if the addition of carbon dioxide will cause the air inside a liter bottle to heat up faster or reach a higher temperature than a bottle with ordinary air. Sketch or take a picture of your setup.

3. Take an initial temperature reading for each bottle. Turn on the light.

4. Take a temperature reading for both bottles every three minutes for 15 minutes. Record your observations and readings in the data table

5. Rinse out each of the bottles with cool water.

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6. Repeat the procedure for steps 1–15, changing one of the following variables: wattage of light bulb, quantity of the antacid effervescent tablets, or amount of water in the bottom of the bottles.

7. Record your observations and readings on the data table. "Variation" refers to the variable you chose to manipulate. (For example, if you utilized lightbulb wattage as the independent variable, you might denote this as: "Variation: 150 W.")

Antacid Effervescent Tablet Catabolism						
	Control bottle		**CO_2 bottle**		**Variation:**	
Time (min)	**Observations**	**Temp. (°C)**	**Observations**	**Temp. (°C)**	**Observations**	**Temp. (°C)**
0						
3						
6						
9						
12						
15						
Total Temp. Difference						

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Analyze and Interpret Data

1. **SEP Develop Models** The antacid effervescent tablet contains three active ingredients: aspirin (acetylsalicylic acid), sodium bicarbonate, and anhydrous citric acid. When sodium bicarbonate and citric acid react, the products are sodium citrate, carbon dioxide gas, and water. Complete this chemical equation for the reaction occurring in the CO_2 bottle.

   $3NaHCO_3(aq) + C_6H_8O_7(aq) \rightarrow$

   Sodium bicarbonate + citric acid $\rightarrow$

2. **SEP Apply Scientific Reasoning** How might the temperature of the closed system be impacted if a plant is added? Explain your reasoning.

3. **SEP Identify Patterns** What is the correlation, if any, between lightbulb wattage and the temperature in the bottle?

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INQUIRY LAB – OPEN

How Nature Records Changes in Climate

What can a tree tell us about climate? One way to determine how the climate of an area has changed over the years is to look at the size of the annual growth rings produced by the trees growing in that area. Wider annual growth rings indicate that growing conditions were favorable that year, while narrower annual growth rings indicate less favorable growing conditions. The field of dendrochronology studies historical patterns in plant growth and climate. This activity will introduce dendrochronology as you investigate recent climate data captured in tree rounds.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 6 Constructing Explanations and Designing Solutions
SEP 8 Obtaining, Evaluating, and Communicating Information

Materials Per Group

- Magnifier
- Marking pins
- Ruler, metric, 1
- Tree round sample, 1

Procedure

1. Obtain a tree round sample.
2. Using the provided materials, gather data on your sample's annual growth.

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Data Table — Tree Growth	

3. Graph your data.

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Analyze and Interpret Data

1. **SEP Make Observations** Based on the size of the annual rings in your sample, did the climate vary during the lifetime of the tree? How?

2. **SEP Construct an Explanation** How would the size of the annual growth rings be affected if the tree was growing in an area that had experienced a long, sustained period of drought?

3. **SEP Evaluate and Communicate** Explain one advantage and one disadvantage of using annual growth rings to derive the historical climate information of an area.

4. **SEP Construct an Explanation** Several organizations are starting large global tree planting initiatives focused on adding billions of trees worldwide. Describe how the addition of several billion trees would affect current climate trends. Would the feedback be stabilizing or destabilizing?

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INQUIRY LAB – OPEN

Human Activity and Carbon Emissions

In this experiment, you will investigate the chemistry associated with the three primary sources of anthropogenic carbon emissions: combustion, land use changes and deforestation, and cement production. You will complete Part A of the experiment and Parts B and C as time permits.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 7 Engaging in Argument from Evidence

Materials Per Group

Part A

- Phenolphthalein indicator solution, 1%, 2 drops
- Sodium hydroxide solution, 0.1*M*, 2 drops
- Safety lighter
- Water, distilled or deionized
- Beaker, borosilicate, 50-mL
- Candle, votive
- Jar with lid
- Magnetic stir plate
- Magnetic stir bar
- Pipets, disposable, 2
- Wood splint

Part B

- Bromothymol blue indicator solution, 0.04% aqueous
- *Elodea* (*Anacharis*) sprig
- Sodium hydroxide solution, 0.1*M*, 2 drops
- Glass wide-mouth bottles, with tight-fitting lids, 2
- Medicine dropper or pipet
- Water, aged tap or spring

Part C

- Bromothymol blue indicator solution, 0.04% aqueous
- Copper(II) carbonate, $Cu_2CO_3(OH)_2$, 5 g
- Pipet
- Erlenmeyer flask, borosilicate glass, 250-mL
- Hot plate
- Rubber stopper, size #6, 1-hole
- airlock

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Safety

Sodium hydroxide solution is a skin and eye irritant and is slightly toxic by ingestion. Phenolphthalein solution is a flammable liquid and is toxic by ingestion and inhalation. Copper(II) carbonate is slightly toxic by ingestion and inhalation. Turn off the hot plate immediately after demonstration to avoid burns or hot plate damage. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

Part A—Combustion

1. A candle placed in a jar along with a solution of basic water will, when combusted with a fixed amount of oxygen, produce enough CO_2 to lower the pH of the basic water. With this in mind, develop a procedure to demonstrate directly that CO_2 is a product of combustion.

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Part B—Land Use Changes/Deforestation

1. Obtain two bottles. Fill the bottles about ⅘ full with spring water.
2. Add enough of the BTB indicator solution to the bottle to obtain a green color (about 2–3 mL). If necessary, add a few drops of acid or base to adjust the pH of the BTB so that the solution appears green.
3. Add a sprig of *Elodea* to one of the bottles and nothing to the other bottle.
4. Place the bottles near a light source.
5. Allow the bottles to remain undisturbed until your next class or lab period.
6. During your next class or lab period, observe any color changes that occurred in the bottles.

Part C—Cement Production

1. Add 5 g of copper(II) carbonate, $Cu_2CO_3(OH)_2$, to a 250-mL Erlenmeyer flask.
2. Add 10 mL of bromthymol blue indicator solution to the airlock.
3. Attach the airlock rubber stopper to the flask.
4. Set the flask on the hot plate and begin heating the apparatus. Note: Put the heating level initially to a medium setting, then set higher or lower to adjust the rate of reaction. As the flask is heated, bubbles will be forced through the solution into the airlock.
5. Observe any color changes to the solution in the airlock.
6. Break the seal between the flask and the rubber stopper before removing the Erlenmeyer flask from the hot plate.

Data Table

Part	Observations
A	
B	
C	

NAME ________________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Develop and Use Models** List sources of CO_2 emissions that you can think of. Which do you think are the biggest contributors to global CO_2 emissions?

2. **SEP Develop and Use Models** Based on your observations and results, and those of your classmates, describe how carbon is cycled through the hydrosphere, atmosphere, geosphere, and biosphere.

3. **SEP Develop and Use Models** Discuss how your results and observations, as well as those of your classmates, support the idea that mass is conserved in chemical reactions.

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INQUIRY LAB – OPEN

Model Climate Change with Melting Ice

How does melting ice affect the global climate? Water vapor is the most abundant greenhouse gas and warms the planet. Water absorbs energy in the form of heat to transition from the solid to the liquid to the gaseous phase creating a warmer environment. Climate change is occuring, but the ice is providing a buffer against sea level rise on a global level. The reduction in ice and sea level rise are disproportionate because one kilogram of ice has a larger volume than one kilogram of water. In this lab we will investigate to what level water temperatures are affected by ice melt.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Ice cubes
- Water, tap
- Balance (0.01 g precision)
- Beaker, 400 mL
- Cardboard square, 11.5 cm x 14 cm
- Graduated cylinder, 100 mL
- Heat-resistant gloves
- Hot plate
- Expanded polystyrene cups, 2
- Thermometer
- Weighing dish

Safety

Wear safety glasses when performing this lab. Boiling water can cause severe burns; always handle with heat-resistant gloves. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ____________________ DATE __________ CLASS __________

Procedure

Part 1. Ice and Water

1. Fill a 400 mL beaker with tap water. Heat the water to around 90°C on a hot plate. Keep this water heating to use in both parts 1 and 2. Add more water as needed.
2. As the water is heating, obtain two expanded polystyrene cups and place one inside the other. This will be your calorimeter.
3. Using a pair of scissors, poke a hole in the center of your cardboard square that is just large enough for a thermometer to fit through without any extra space.
4. Obtain about 50 grams of ice and place it inside your calorimeter.
5. Record the temperature of the hot water on your data sheet. The starting temperature of ice has been recorded for you. What is the expected midpoint temperature between the hot water and the ice? Record on your data sheet.
6. Using a heat-resistant glove, carefully measure out 50 mL of the hot water and add it to the calorimeter. Immediately place the lid on top. Make sure the thermometer is just hovering above the bottom of the cup. *Note:* Hold the lid in place on the calorimeter to prevent any heat from escaping and the setup from tipping over.
7. Note the solution temperature every 30 seconds for 10 minutes on your data table.
8. Discard the solution down the sink, and rinse and dry the cup.
9. Rotate the cups so that the one you used earlier is now on the bottom.
10. Pour 50 mL of room temperature tap water into your calorimeter. Take the temperature of the water and record it in your data table. Record the expected temperature midpoint on your data sheet.
11. Repeat steps 6–8.

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Part 2. Latent Heat of Melting Ice

12. **SEP Design A Solution** Using steps 5–8 from part 1 as a guide, gather evidence that the heat required to melt ice is constant. Test different ratios of ice to boiling water. Your ice to water ratio must always add up to 100 grams. If you have 50 g of water you will use 50 mL of water. Record your chosen ratios in the space.

Part 1 – Starting Temperature Values	
	Temperature (°C)
Ice	0
Hot water	
Expected midpoint temperature ice/water	
Hot water	
Room temperature water	
Expected midpoint temperature water/water	

NAME ____________________ DATE __________ CLASS __________

Part 1 – Ice and Water		
Time (sec)	**Temperature (°C)**	
	50 g ice/50 mL hot water	**50 mL water/50 mL hot water**
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		

Part 2 – Starting Temperature Values	
	Temperature (°C)
Ice	0
Hot water	
Expected midpoint temperature ice/water	

NAME ______________________ DATE __________ CLASS __________

Part 2 – Latent Heat of Melting Ice				
Time (sec)	**Temperature (°C)**			
	Ratio 1	**Ratio 2**	**Ratio 3**	**Ratio 4**
30				
60				
90				
120				
150				
180				
210				
240				
270				
300				

Analyze and Interpret Data

1. **SEP Interpret Data** What effect on temperature did you observe as the ice melted in Part 1?

NAME ________________________ DATE ____________ CLASS ____________

2. **SEP Interpret Data** What effect on temperature did you observe as the room temperature water mixed with the hot water in Part 1?

3. **SEP Identify Patterns** What was the final temperature of the water for each experiment in Part 1? Is this the result you expected? Why or why not?

4. **SEP Construct an Explanation** How did the different ratios of ice to water support that the heat energy required to melt the ice was constant? Why was there still ice present in some of the cups?

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Climate Change and Keeping Cool

How do people try to keep cool on hot days? Sweating is our body's automatic response, but we might take additional steps such as moving into the shade and fanning ourselves as well. In this experiment you will examine how effective these cooling methods are, while also considering how changes in our climate might affect them.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Dry jar with lid
- Humid jar with lid
- Fan
- Cloth or paper towel
- Rubber band
- Thermometer clamps, 2
- Clay
- Water
- Thermometers, 2
- Beaker, 50 mL
- Support stand

Safety

Wear safety goggles when performing this lab. Although calcium sulfate is generally regarded as nonhazardous, care should still be taken to avoid breathing in the dust. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part 1. Effect of humidity

1. Obtain a dry jar and a humid jar from your teacher.

2. Remove the lid from the dry jar.

NAME ______________________ DATE __________ CLASS __________

3. Remove the small plug of clay from the lid.

4. Carefully insert the thermometer through the hole in the lid so that it will sit about halfway down the length of the jar.

5. Use the clay to secure the thermometer in place and seal the hole.

6. After 5–10 minutes have elapsed, record the temperature on the thermometer in the data table. (The exact amount of wait time is not critical, but should be the same for each trial.)

7. Repeat steps 2–6, with the humid jar instead of the dry jar.

8. Use a rubber band to secure the piece of cloth to the bulb of the thermometer.

9. Add approximately 20 mL of water to a 50 mL beaker.

10. Submerge the thermometer bulb in the water for 30 seconds.

11. Remove the thermometer from the water and repeat steps 2–7, this time using the wet thermometer. You should re-submerge the thermometer in the water before each trial.

Data Table—Humidity

Sample	**Dry bulb in dry jar**	**Wet bulb in dry jar**	**Dry bulb in humid jar**	**Wet bulb in humid jar**
Temperature (°C)				

NAME ________________ DATE __________ CLASS __________

Part 2. Air flow

12. **SEP Plan an Investigation** Write a procedure to examine the effect of airflow on temperature. Record your detailed procedure, as well as any materials to be used. Show your plan to your teacher before you do your investigation.

NAME ______________________________ DATE ____________ CLASS ____________

Part 3. Shade

13. **SEP Plan an Investigation** Write a procedure to examine the effect of shade on temperature. Record your detailed procedure, as well as any materials to be used. Show your plan to your teacher before you do your investigation.

Analyze and Interpret Data

1. **SEP Calculate** Use your data to determine the difference in the recorded temperature for the dry and wet bulbs in the dry jar by subtracting their temperatures.

NAME ________________ DATE ________ CLASS ________

2. **SEP Calculate** Use your data to determine the difference in the recorded temperature for the dry and wet bulbs in the humid jar by subtracting their temperatures.

3. **SEP Use Data** From your results, will a person sweating in a humid or dry environment feel cooler?

4. **SEP Calculate** Use your data to determine the difference in the recorded temperature for the dry and wet bulbs in still air by subtracting their temperatures.

5. **SEP Calculate** Use your data to determine the difference in the recorded temperature for the dry and wet bulbs in moving air by subtracting their temperatures.

6. **SEP Use Data** From your results, will a person sweating feel cooler with or without a breeze?

7. **SEP Calculate** Use your data to determine the difference in the recorded temperature for the dry and wet bulbs in the shade by subtracting their temperatures.

8. **SEP Calculate** Use your data to determine the difference in the recorded temperature for the dry and wet bulbs in direct sunlight by subtracting their temperatures.

NAME ________________ DATE ________ CLASS ________

9. **SEP Use Data** From your results, will a person sweating feel cooler in the shade or in direct sunlight?

10. **SEP Use Data** Based on your results, what would be the consequence of an increase in global average humidity coupled with an increase in global average temperature?

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Solar Cell Technology

Are scientists able to mimic photosynthesis more closely (biomimicry) to advance photovoltaic cells? Conventional solar cells contain a silicon diode (anode and cathode) as the semiconductor. In 1991, the dye-sensitized solar cell (DSSC) was developed, which does not use silicon. In this lab, you will build a dye-sensitized solar cell using fruits from one of two groups. Using four different light sources, you will test your cell. After examining the results, you will modify your test procedure to attempt higher energy readings.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Iodine/Potassium iodide electrolyte solution, 2–3 drops
- TiO_2 nanocrystalline paste
- Transparent indium tin oxide (ITO) coated glass slide, 2
- Beral pipet
- Binder clips, 2
- Ceramic pad
- Culture (petri) dish, 1
- Forceps/tweezers, metal
- Fruit from group A or B
- Hot plate
- Light source, 100 W
- Microscope slide, plastic
- Multimeter
- Paper towel
- Pencil
- Petri dish
- Spatula
- Tape

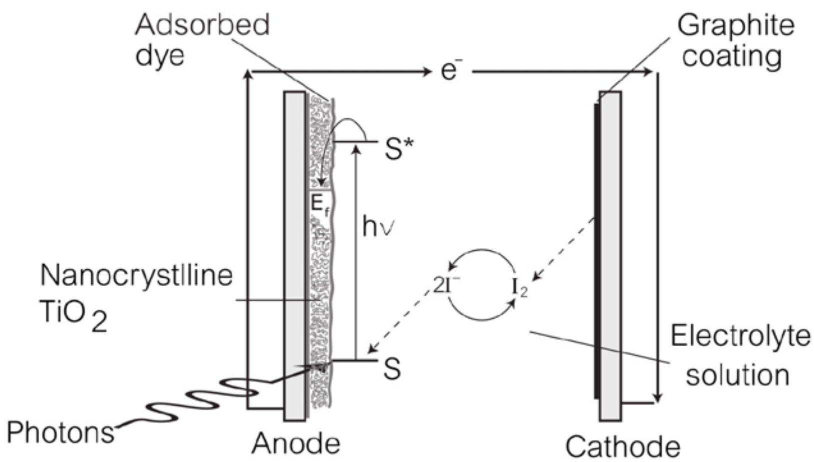
NAME ______________________________ DATE ____________ CLASS ____________

Safety

Propylene glycol is toxic by ingestion. Iodine in this solution is irritating to skin, eyes, and the respiratory tract. Nanocrystalline titanium oxide is a fine dust and may be harmful if inhaled. Avoid breathing the fine-particle dust and avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a lab coat or chemical-resistant apron.

Procedure

Figure 1 Dye-Sensitized Solar Cell



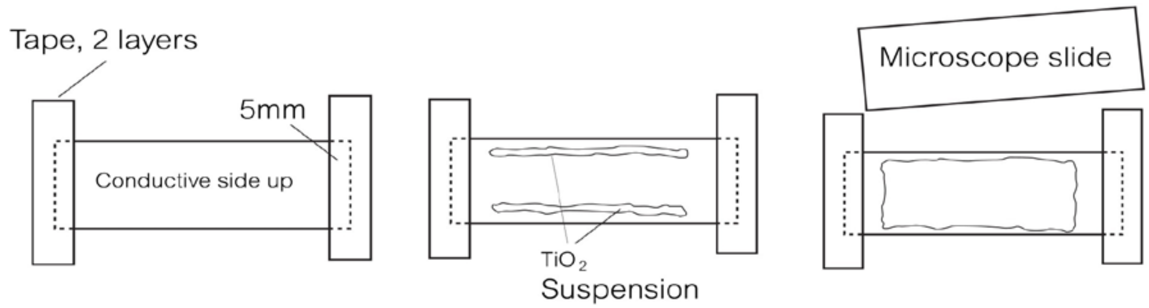
Part A. Titanium Oxide Anode

1. Obtain an ITO-coated glass slide and determine which side the ITO coating is on by using a multimeter set to ohms. Place the multimeter probes on the surface of the glass. The conductive side will register a reading of 10-30 ohms.

2. Tape the glass slide, conductive side up, to a clean surface with two layers of tape, as shown in Figure 2. The tape should mask about 5 mm of glass on each short side of the slide. (The tape will control the thickness of the titanium oxide coating).

3. Using a Beral-type pipet, add a thin line of TiO_2 suspension all the way across both the top and bottom of the glass slide (Figure 2).

Figure 2



4. Use a clean microscope slide as a “squeegee” by using the long, thin edge of the slide to draw the suspension across the glass to coat the entire exposed surface (Figure 2). Do not lift the slide off the glass. If any uncoated areas remain, push the microscope slide back up to the top of the taped-down slide. (This process must be done quickly to avoid drying out the suspension before the surface is covered.)

5. Allow the TiO_2 to dry for about 2–3 minutes before slowly removing tape, in order to avoid damaging the conductive glass.

6.  Place the glass plate, coated side up, on the surface of a hot plate. Turn the hot plate to a low setting (such as 1 or 2) and heat.

7.   After about 5 minutes, the titanium oxide coating will turn light brown at the edges. Continue heating the plate until the off-white color of the titanium oxide coating is restored. This will take less than 15 minutes. (Observe the plate during the heating process to avoid overheating the plate and cracking the glass.)

8. While the plate is heating, a group member should prepare the graphic cathode from Part B.

9.  Turn off the hot plate and allow the glass plate to cool for 5 minutes before attempting to remove it from the surface.

10. Using metal tweezers or forceps, carefully remove the glass plate from the hot plate and place the glass plate on a ceramic pad to cool (about 10 minutes).

11. Dying the anode: Place the fruit you obtained from group A or B in a petri dish. Use a spatula to crush the fruit to extract the juices and remove solid pulp.

12. Place the glass slide with the TiO_2 face down into the petri dish. Allow to sit for 3–5 minutes.

13. Remove the TiO_2 slide from the fruit juice. Use a paper towel to gently blot the excess juice off the slide. Dry the slide as much as possible, but do not remove any of the TiO_2 coating. Do not wipe the slide, as this may remove some of the TiO_2 coating.

Part B. Graphite Cathode

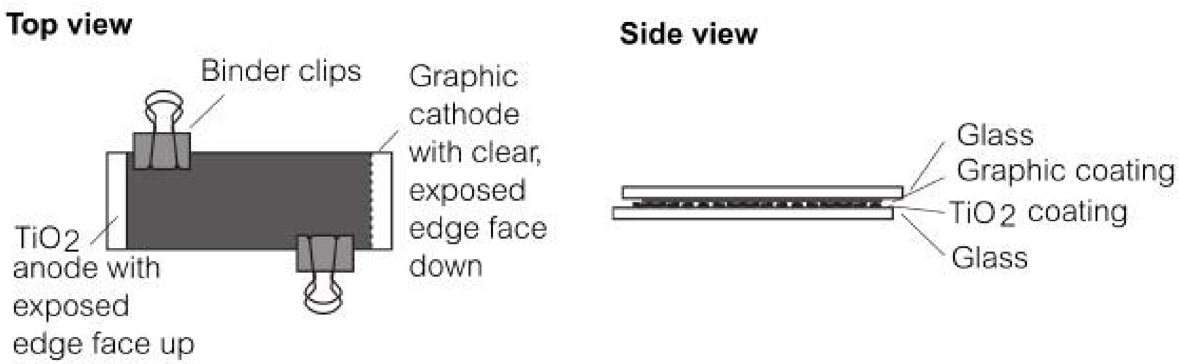
14. Obtain another ITO coated glass slide. Determine which side the coating is on by using a multimeter with its setting placed on resistance (Ω). The indium tin oxide coating is on the side of the slide that gives a non-zero reading on the multimeter.

15. Using the tip of a graphite pencil, lay down the carbon catalyst by shading the indium tin oxide coated side of the slide. The graphite may not leave a visible mark.

Part C. Assembly

16. Lay the dyed titanium oxide electrode face up on a clean surface and place the graphite electrode face down on top of the titanium oxide electrode. Stagger the two plates so that part of the anode and part of the cathode will be exposed. Each plate should extend out about 5 mm on either side of the glass "sandwich" and there should be a clean, exposed surface on each plate. (The exposed surfaces serve as contact points for alligator clip leads to a multimeter.) See Figure 3.

Figure 3



17. Use the two small binder clips to hold the slides together. Label your solar cell with the fruit used for the dye.

18. Carefully add 2–3 drops of iodine/potassium iodide electrolyte solution to one side of the solar cell "sandwich" in the area where the exposed glass meets the opposite electrode. The liquid will seep between the layers by capillary action.

19. Tilt the cell sandwich slightly and gently unclip and clip the binder clips to draw liquid throughout the cell. It may help to place paper towel along the bottom edge of the cell.

20. Set the multimeter to measure the cell potential in volts (1–10 V). Connect the titanium oxide electrode to the negative lead and the graphite electrode to the positive lead. (The titanium oxide is the anode and the graphite is the cathode. Do not reverse the leads, because a reverse bias may damage the cell.)

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Part D. Testing

21. Design a test to compare four different light sources: no light, classroom light, 100 W and one of your choosing. Record your detailed procedure, as well as any materials used.

22. Record your results in table 1.

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23. Modify your test procedure to attempt higher energy readings. Record your detailed procedure, as well as any materials used.

24. Record your results in table 2.

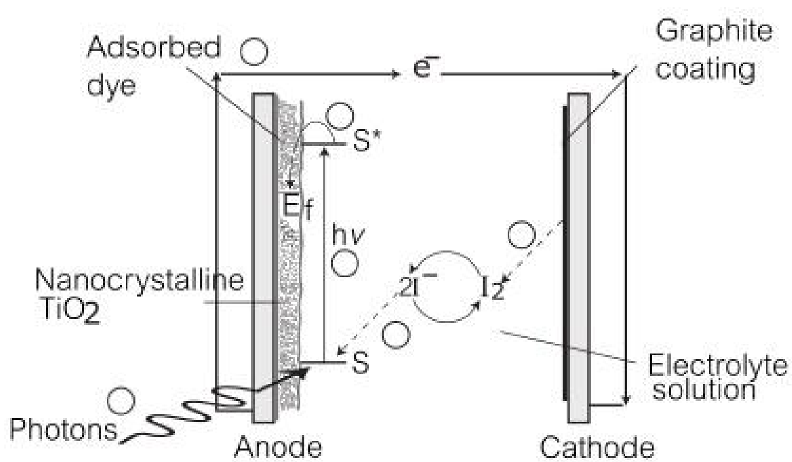
Data Table 1. Solar Cell Electrical Output Test 1				
Dyed Solar Cell **Fruit Group: ___** **Fruit Type: ___________**				
Light Source	**None**	**Classroom Light**	**Light Source, 100 W**	**Other** ___________
Voltage				
Current				

NAME ______________________________ DATE __________ CLASS __________

Data Table 2. Solar Cell Electrical Output Test 2				
Dyed Solar Cell Fruit Group: ___ Fruit Type:____________				
Light Source	**None**	**Classroom Light**	**Light Source, 100 W**	**Other** ________
Voltage				
Current				

Analyze and Interpret Data

1. **SEP Use Models** Label the figure by filling in the circles with the number that correlates with each step of the dye-sensitized solar cell process.



1. Dye molecule absorbs photons – the fundamental particles of visible light.
2. An electron in the dye (S) is promoted to a “photoexcited state” (S*).
3. S* transfers an electron into the conduction band (Ef) of TiO_2.

4. The oxidized dye accepts an electron from the redox catalyst (I^-).
5. Electrons migrate through the external circuit to the cathode.
6. Iodine is reduced to iodide at the cathode, thus regenerating the redox catalyst.

2. SEP Use a Model to Evaluate What is the function of each of the following components in a dye-sensitized solar cell?

a. Titanium oxide

b. Conductive glass

c. Natural dye

d. Iodine/iodide electrolyte solution

3. SEP Construct an Explanation Describe how a dye-sensitized solar cell mimics the process that occurs in photosynthesis.

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4. **SEP Analyze Data** Which fruit provided a more effective solar cell? How do you know?

5. **SEP Interpret Data** Compare your results to those of the other groups in your class. Look for patterns when comparing the solar cell efficiency between fruit groups A and B. From this information, hypothesize what may be causing the differences between group A and B solar cells.

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PERFORMANCE BASED ASSESSMENT

Climate Change and the Carbon Cycle

Carbon dioxide is contributing to global warming through expansion of the greenhouse effect. The rising concentrations of atmospheric CO_2 are creating an imbalance in the carbon cycle, because vegetation and bodies of water have a limited capacity to absorb and chemically transform this gas. Thus, the excess emissions of CO_2 linger in the atmosphere for years to centuries before they are incorporated into soils and deep oceans, and up to millennia before transforming into sediments. In this experiment you will develop a procedure to investigate the role of dissolution of gaseous CO_2 in water, and the role of plant photosynthesis in the removal of carbon dioxide from the atmosphere. Furthermore, you will discuss how these processes relate to seasonal variations in atmospheric CO_2 levels, and their impact on global warming.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Bromothymol blue (BTB) indicator solution, 0.04% aqueous
- *Elodea* sprigs, 4
- Water, tap
- Beaker, 400 mL
- Beral-type pipet, 2
- Hot plate
- Heat-resistant gloves or mittens
- Lamp, white light
- pH meter
- pH paper (optional)
- Spatula or scoop
- Straws, 5
- Test tubes, 16 mm × 125 mm, 5
- Test tube cork caps, 5
- Test tube rack
- Wax pencil or marker

Safety

Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron when handling these chemicals. Avoid exposure to eyes and skin, and clean up all spills promptly. Wash hands thoroughly with soap and water before leaving the laboratory. Do not inhale through the straw at any time.

NAME ______________________ DATE __________ CLASS __________

Procedure

As the amount of CO_2 dissolved in water changes due to the presence of species (e.g., *Elodea* sprigs) capable of engaging in respiration and photosynthesis, the pH of the water changes. These pH changes can be monitored by using an acid–base indicator such as bromothymol blue (BTB), which is yellow in acidic solutions and blue in basic solutions. In addition, a pH meter (or pH paper) can be used to determine changes in pH.

1. Given this information, develop an experiment using the materials provided to determine that (1) carbon dioxide dissolves in water, and (2) the presence of *Elodea* promotes the conversion of the aqueous carbon dioxide through photosynthesis. Use the space to write your procedure, and take into consideration the following suggestions:
   - Preferably use boiled tap water.
   - Control the amount of water and BTB used for each sample.
   - Compare the activity of *Elodea* exposed to light and in the dark.
   - Compare changes to the water/BTB samples with and without *Elodea*.
   - You may add CO_2 to the water by exhaling into it through a straw. ⚠ *Do not suck the water with your mouth*. Use a different straw for each sample.

NAME ______________________ DATE __________ CLASS __________

2. Use the data table to record the composition, pH, color, and relevant changes of the samples in each test tube.

Data Table—The Experiment					

Analyze and Interpret Data

1. SEP Interpret Data Do the results of your experiment indicate that carbon dioxide has dissolved in the water and that photosynthesis has removed it? Explain.

NAME ______________________ DATE ____________ CLASS ____________

2. **SEP Construct an Explanation** Go online or look up in a textbook a graph that shows how the concentration of CO_2 in the atmosphere changes in the course of one year. Construct an explanation to account for these annual changes in atmospheric CO_2 concentration, and how it may relate to the presence or absence of vegetation on Earth. In addition, explain whether your results illustrate a relationship between CO_2 concentration, the presence/absence of vegetation, and light in Earth's atmosphere.

3. **SEP Construct an Explanation** The collection of processes involved in the conversion of carbon (C) from one form to another in Earth's atmosphere is often called the carbon cycle. The two processes discussed in this lab, dissolution of carbon dioxide in water, and photosynthetic conversion of carbon dioxide by plants, are both natural processes. Construct an explanation to account for the fact that the amount of CO_2 consumed by trees and plants on Earth collectively exceeds the amount they produce. Likewise, explain why the amount of carbon dioxide dissolved in ocean waters is also larger than the amount released back to the atmosphere.

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4. **SEP Engage in Argument** Based on your answers to previous questions, explain why the ability of plants and ocean waters to collectively absorb and transform more CO_2 than they release to the atmosphere is relevant to global warming. Will these systems be able to keep up with the rising emissions of CO_2 to the atmosphere?

Investigation 12

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INQUIRY LAB – OPEN

Reaction Rates: Iodine Clock

Kinetics is the study of the rate (or speed) of a reaction and the factors that affect the rate. Chemical reactions occur as a result of collision between molecules. In this lab, you will be studying how the rate of the reaction changes when you change the concentration of one of the reactants.

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Potassium iodate solution, 0.2 *M*, 250 mL
- Sodium metabisulfite/starch solution, 320 mL
- Water, distilled or deionized
- Beakers, 400 mL, 4
- Graduated cylinders, 100 mL and 250 mL, 4
- Plastic cups, small, 10 oz, 4
- Stirring rod
- Stop watch
- Wax pencil

Safety

Potassium iodate solution is moderately toxic by ingestion and a body tissue irritant. Sodium metabisulfite is also irritating to skin, eyes, and other body tissues. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Before lab, review current Safety Data Sheets for additional safety, handling, and disposal information. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE __________ CLASS __________

Procedure

Trial 1 - 0.025 *M* Potassium Iodate

1. Prepare 200 mL of 0.025 M potassium iodate solution in a 400 mL beaker from 0.2 *M* potassium iodate solution.

2. Obtain 80 mL of sodium metabisulfite/starch solution and place in a plastic cup.
3. Pour the contents of the cup into the beaker and immediately start timing.
4. Record the reaction time in the table.
5. Dispose of the final iodine clock mixtures as directed by the instructor.

Trial 2 - 0.05 *M* Potassium Iodate

6. Prepare 200 mL of 0.05 *M* potassium iodate solution in a 400 mL beaker from 0.2 *M* potassium iodate solution.

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7. Obtain 80 mL of sodium metabisulfite/starch solution and place in a plastic cup.

8. Pour the contents of the cup into the beaker and immediately start timing.

9. Record the reaction time in the table.

10. Dispose of the final iodine clock mixtures as directed by the instructor.

Trial 3 - 0.1 *M* Potassium Iodate

11. Prepare 200 mL of 0.1 *M* potassium iodate solution in a 400 mL beaker from 0.2 *M* potassium iodate solution.

12. Obtain 80 mL of sodium metabisulfite/starch solution and place in a plastic cup.

13. Pour the contents of the cup into the beaker and immediately start timing.

14. Record the reaction time in the table.

15. Dispose of the final iodine clock mixtures as directed by the instructor.

NAME ____________________ DATE __________ CLASS __________

Design a Lab/Prediction

16. Predict what the time will be for 0.075 *M* potassium iodate solution.

17. SEP Plan and Carry Out an Investigation Using a 0.20 *M* sodium metabisulfite solution, design an experiment to test 0.075 *M* potassium iodate. Before testing your experiment, get your procedure approved by your instructor. Record your detailed procedure, as well as any materials to be used.

NAME ______________________ DATE __________ CLASS __________

Data Table — Varying KIO_3 Concentration				
Trial	**1**	**2**	**3**	**4**
KIO_3 Concentration (before mixing)	0.025 *M*	0.05 *M*	0.1 *M*	0.075 *M*
KIO_3 Concentration (after mixing with sodium metabisulfite/starch solution)	0.02 *M*	0.04 *M*	0.07 *M*	0.05 *M*
Reaction Time (in seconds)				

Analyze and Interpret Data

1. **SEP Identify Variables** What variable(s) are held constant in this experiment?

2. **SEP Identify Variables** What variable(s) are changed in this experiment?

3. **SEP Analyze Data** As the concentration of potassium iodate (KIO_3) increased, what happened to the reaction time?

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INQUIRY LAB – OPEN

Collision Theory

What leads to a successful collision between particles in a chemical reaction? In this activity, “particles” will be “collided” to determine the effects of concentration on the rate of collisions.

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Magnetic marbles
- Pencils
- Plastic bin with lid
- Pompoms
- String
- Expanded polystyrene spheres, multiple sizes
- Various craft supplies
- Hook and loop fastener dots
- Timers

Safety

Wear safety goggles when performing this lab. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Observe the teacher demonstration.

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2. As a group, design a different experiment to model what would happen to the number of molecules formed if the concentration of the reactants is increased. You may use any of the materials provided by your teacher.

3. Before conducting your investigation, have your procedure approved by your instructor.

4. Conduct the experiment three times and record your data in the table.

Data Table — Teacher Demonstration	
Observations	

Data Table — Molecule Formation				
Trial	**1**	**2**	**3**	**Average**
Number of Molecules Formed				

NAME ______________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Analyze Data** What factors increased the success of a molecule forming?

2. **SEP Analyze Data** What did your group keep constant during the three trials and what did your group change?

3. **SEP Analyze Data** If you made changes, did any of your adjustments increase the product formation? If yes, which ones and why?

4. **SEP Use Models** In the teacher demonstration, what do the marbles represent?

5. **SEP Develop a Model** How could you improve upon the current model? Think of other materials you could use to represent the atoms. If time allows, test your model.

6. **SEP Use Math** Calculate the average of the first three trials. Show your work. Complete the table.

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INQUIRY LAB – OPEN

Explore Chemical Equilibrium

Imagine you have two dishes of berries in front of you and a friend. As fast as you can move five berries from one dish to another, your friend is doing the same thing. While berries are moving back and forth, the actual amount of berries in each dish doesn't change. The same situation can occur in chemical reactions, resulting in a mixture of products and reactants.

These reactions are called reversible reactions, as the reaction can proceed in either direction. Once the rate of the forward reaction is equal to the rate of the reverse reaction, the reaction reaches a state called chemical equilibrium. It's important to understand that equilibrium is a dynamic state, as opposed to a static state, because the reaction never comes to a stop. Instead, the forward and reverse reactions continue to occur over time, and there is no net change in the concentrations of either the reactants or the products. Adjusting lab conditions can adjust the equilibrium. Le Chatelier's Principle states that applying stress to a system at equilibrium will cause a shift to compensate for the change and allow the system to return to equilibrium. When more products are added, an equilibrium reaction will "shift left" toward reactants. When more reactants are added, the equilibrium will "shift right" toward the products. In this lab, you will be observing the changes in equilibrium when the amount of reactants and temperature are changed in the following reaction.

Equation 1: $Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$

Yellow — Colorless — Red

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

NAME ______________________________ DATE __________ CLASS __________

Materials Per Group

- Iron(III) nitrate solution, $Fe(NO_3)_3$, 0.1 *M*, 4 mL
- Potassium thiocyanate solution, KSCN, 0.1 *M*, 4 mL
- Beaker, 50 mL
- Beakers, 250 mL, 2
- Beral-type pipets, 3
- Distilled water
- Hot plate
- Ice
- Stirring rod
- Test tubes, small, 5
- Thermometer
- Wax marking pencil

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Iron(III) nitrate solution is a possible skin and body tissue irritant; it will also stain clothes and skin. Potassium thiocyanate is toxic by ingestion. Avoid contact of all chemicals with eyes and skin. Clean up all chemical spills immediately. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and warm water before leaving the laboratory.

Procedure

1. Prepare a reference solution of $FeSCN^{2+}$: To a clean 50 mL beaker, add 40 mL of distilled water followed by 1 mL of 0.1 *M* $Fe(NO_3)_3$ solution and 1 mL of 0.1 *M* KSCN solution. Mix thoroughly with a glass stirring rod.
2. Label five clean test tubes 1–5.
3. Add 1 mL of $FeSCN^{2+}$ reference solution to each test tube 1–5.
4. Add 10 drops of distilled water to test tube 1 and record the color of the solution on the data table.
5. To test tube 2, add 10 drops of 0.1 *M* $Fe(NO_3)_3$. Compare the color of the resulting solution to the solution in test tube 1 and record the color comparison on the data table.
6. To test tube 3, add 10 drops of 0.1 *M* KSCN. Compare the color of the resulting solution in test tube 1 and record the color comparison on the data table.

7. Consult your instructor for appropriate disposal procedures.

8. Design an experiment to test what happens to the solution when it is heated or cooled. Get your procedure approved by your instructor before proceeding.

9. Consult your instructor for appropriate disposal procedures.

NAME ______________________ DATE ____________ CLASS ____________

Data Table—Equilibrium		
Test Tube	**Solution**	**Color**
1	**Reference Solution**	
2	**After Fe^{3+} is Added**	
3	**After SCN^- is Added**	
4	**Cooled**	
5	**Heated**	

Analyze and Interpret Data

1. **SEP Identify Knowns** What variables were kept constant in this experiment?

2. **SEP Analyze Data** How were relative amounts of reactants and products of the solution affected when the solution was cooled and when it was heated?

3. **SEP Analyze Data** Based on the effects of temperature, is the forward reaction endothermic or exothermic? Explain your answer.

NAME ______________________ DATE __________ CLASS ___________

4. **SEP Interpret Data** Write the chemical reaction with heat as a reactant or product based on your answer to question 3.

5. **SEP Interpret Data** Using Le Chatelier's Principle, explain the color changes observed when excess Fe^{3+} was added to the solution.

6. **SEP Interpret Data** Using Le Chatelier's Principle, explain the color changes observed when excess SCN^{-} was added to the solution.

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Supersaturation and Thermodynamics

In this lab you will be studying free energy, enthalpy, and entropy with regards to a supersaturated solution of sodium acetate trihydrate ($NaC_2H_3O_2{\bullet}3H_2O$) and ice melting.

The change in free energy for a process is dependent on the enthalpy and entropy of a system and can indicate if a process is thermodynamically favored or not.

Equation 1: $\Delta G = \Delta H - T\Delta S$

ΔG = change in free energy
ΔH = change in enthalpy
T = temperature in kelvins
ΔS = change in entropy

The enthalpy of a system indicates if the reaction is endothermic or exothermic. If ΔH is positive, the reaction is endothermic and energy is absorbed. If ΔH is negative, the reaction is exothermic and energy is released. To determine the energy released or absorbed by the supersaturated solution into water, the following equation will be used in lab:

Equation 2: $q = mc\Delta T$

q = heat energy
m = mass of the water
c = specific heat of the water (4.184 J/g°C)
ΔT = change in water temperature, $T_{\text{final}} - T_{\text{initial}}$

The entropy of a system is the amount of chaos or disorder in the system. For example, when a single compound decomposes into two or more products, the entropy of the system increases. Another example is water evaporating into water vapor. The particles move more and faster and become less ordered, hence an increased entropy. When the entropy of the system increases, ΔS is positive. The greater the entropy, the more negative ΔG can become. A negative ΔG value indicates a thermodynamically favorable process.

If you look at all the variables involved in $\Delta G = \Delta H - T\Delta S$, it can be determined if a process is thermodynamically favored or not.

NAME ______________________ DATE __________ CLASS __________

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Sodium acetate trihydrate, $NaC_2H_3O_2 \cdot 3H_2O$, 30 grams
- Water, distilled or deionized
- Balance (0.01-g precision)
- Beaker, 600 mL
- Graduated cylinder, 10 mL
- Graduated cylinder, 100 mL
- Hot plate
- Laboratory film, 5 cm × 5 cm
- Polystyrene cup
- Stirring rod, glass
- Tap water
- Test tubes, borosilicate glass, 2
- Thermometer, digital
- Wash bottle
- Wax pencil
- Weighing dish

NAME ______________________ DATE __________ CLASS __________

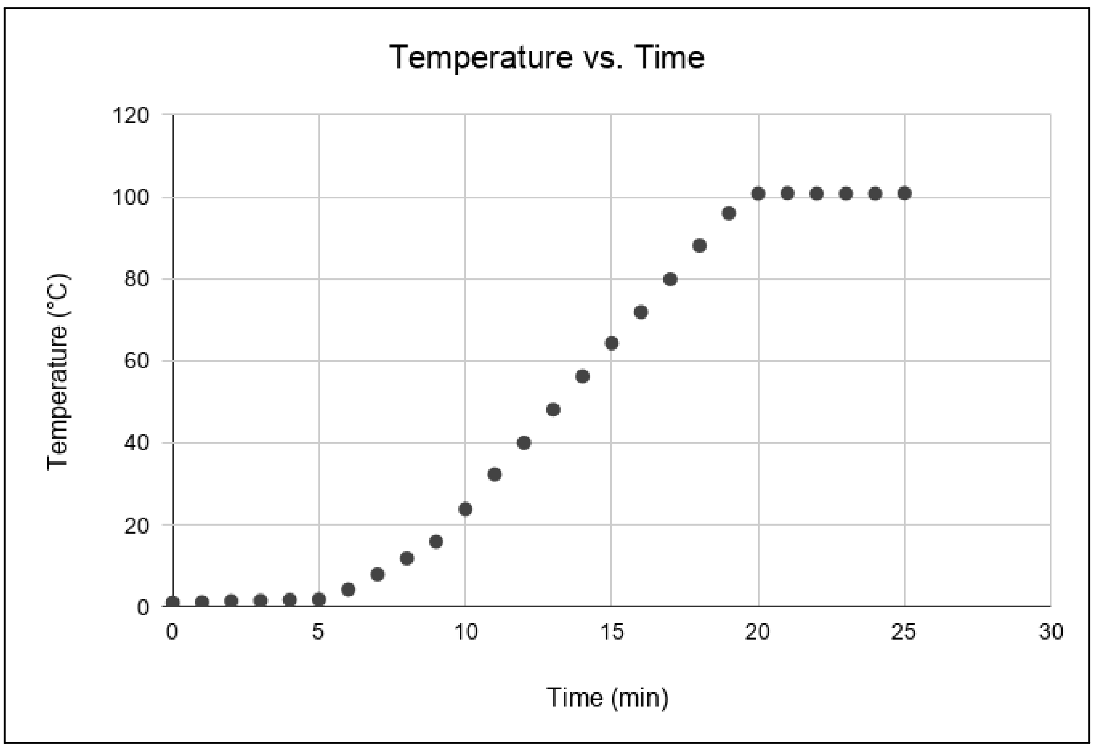
Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Sodium acetate is slightly toxic by ingestion, inhalation, and skin absorption. Wear chemical-resistant gloves, and a chemical-resistant apron. Wear heat-resistant gloves or use tongs when handling the hot glassware. Please review current Safety Data Sheets for additional safety, handling, and disposal information. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part I. Analysis of Ice Melting

A student monitored ice as it melted and plotted the data on the following graph:



1. **SEP Interpret Data** Did the ice absorb heat or release heat and why?

NAME ______________________ DATE __________ CLASS __________

2. **SEP Use Models** Ice melting can be described by the following chemical equation:

$$H_2O(s) \rightarrow H_2O(l)$$

Rewrite the equation and place heat as a reactant or product, based on your answer in step 2.

Part II. Analysis of Supersaturated Sodium Acetate

3.  Fill a 600 mL beaker half full of water and heat on a hot plate. This will be used as a warm water bath. *Note: The water should not be boiling.*

4. With a wax pencil, mark the test tubes 1 and 2.

5. Measure 15 grams of sodium acetate trihydrate into a weighing dish and place it into one of the test tubes. Record the mass in the data table.

6. Add 4.5 mL of distilled or deionized water to the test tube.

7. Repeat steps 6 and 7 for test tube 2.

8. Place the test tubes in the warm water bath and allow the sodium acetate trihydrate to dissolve.

9. After heating for a few minutes, stir the solution with a glass stirring rod. If any sodium acetate trihydrate gets stuck on the side of the test tube, squirt a very small amount of distilled or deionized water to wash it into the solution.

10. When all of the sodium acetate trihydrate is dissolved, turn off the water bath.

11. Cover the test tubes with laboratory film and allow the solution to cool to room temperature overnight. Take care not to disturb the solution as even slight movement may cause crystallization.

12. **SEP Use Models** Write the chemical equation for the crystallization of sodium acetate trihydrate from its supersaturated solution.

NAME ______________________ DATE __________ CLASS __________

13. SEP Plan Your Investigation Develop a procedure and data table to determine the energy released or absorbed of your sodium acetate trihydrate sample when it crystallizes. Review the available materials. Record your detailed procedure as well as any materials to be used.

14. SEP Carry Out Your Investigation Before conducting your investigation, show your plan to your teacher for approval.

Analyze and Interpret Data

For Part I:

1. **SEP Construct an Explanation** Is the process of melting ice endothermic or exothermic? How do you know?

2. **CCC Systems and System Models** Consider how the arrangement of particles in the system changes as the ice melts. Do the particles become more ordered or less ordered during this process?

3. **SEP Use Math** For one mole of ice to melt at room temperature, 298.15 K, ΔG was found to be –0.550 kJ and ΔH was 6.01 kJ. Given that $\Delta G = \Delta H - T\Delta S$, what would ΔS be, in joules? Show your work.

4. **SEP Analyze Data** Does the value you calculated in Question 3 support your answer to Question 2? Explain.

For Part II:

5. **SEP Interpret Data** Is the crystallization of sodium acetate endothermic or exothermic? How do you know?

6. **SEP Use Math** The molar mass of sodium acetate trihydrate is 136.08 g/mol. Calculate the enthalpy (in joules per mole) of sodium acetate trihydrate from the data in your experiment.

7. **CCC Systems and System Models** Consider how the arrangement of particles in the system changes as sodium acetate trihydrate crystallizes. Do the particles become more ordered or less ordered during this process?

8. **SEP Use Math** For one mole of anhydrous sodium acetate at room temperature, 298.15K, ΔG was found to be –607.2 kJ and ΔH was –708.8 kJ. Given that $\Delta G = \Delta H - T\Delta S$, what would ΔS be, in joules? Show your work.

9. **SEP Analyze Data** Does the value you calculated in Question 8 support your answer to Question 7? Explain.

For Comparison of Parts I and II:

10. **SEP Explain Phenomena** Are the two processes you studied in this lab thermodynamically favored at room temperature? Use your observations and the ΔG values given in Questions 3 and 8 to support your claim.

11. **Predict** Processes that are exothermic and undergo an increase in disorder are thermodynamically favorable at all temperatures. A process that meets one of these two criteria are only thermodynamically favorable at certain temperature ranges. Compare the data for the two processes you studied in this lab. Use the information to predict the thermodynamically favorability of each process at other temperatures.

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PERFORMANCE BASED ASSESSMENT

Rates of Reaction and Dissolution

Concepts

- Reaction rates
- Equilibrium
- Collision theory

In this lab, your group will design procedures to analyze the effects of reactant concentration and temperature.

The first phenomenon will be the decomposition of hydrogen peroxide.

Equation 1: $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

The second phenomenon observed will be the solubility of sodium acetate.

Equation 2: $NaC_2H_3O_2(s) \rightleftharpoons Na^+(aq) + C_2H_3O_2^-(aq)$

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Hydrogen peroxide, H_2O_2, 10% solution, 50 mL
- Sodium acetate solution sample in test tube
- Sodium iodide solution, NaI, 2 *M*, 6 mL
- Distilled water
- Tap water
- Alconox cleaner, 3 g
- Beaker, 50 mL
- Beakers, 250 mL, 2
- Ice
- Graduated cylinders, 10 mL, 3
- Graduated cylinders, 50 mL, 3
- Graduated cylinders, 100 mL, 3
- Hot plate
- Plastic demo tray or tub
- Thermometer
- Timer
- Wax pencils

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Safety

Hydrogen peroxide solution, 30%, is severely corrosive to the skin, eyes, and respiratory tract: very strong oxidant. Dangerous fire and explosion risk. Do not heat this substance. Sodium iodide is slightly toxic by ingestion. Although the Alconox detergent is considered nonhazardous, do not ingest the material. Do not stand over the reaction; steam and oxygen are produced quickly. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Watch the teacher demonstration and record your notes.

Teacher Demonstration of Decomposition of Hydrogen Peroxide	
Chemicals and Amounts Used in Demonstration	
Observations	

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Part A: Decomposition of Hydrogen Peroxide

2. With your group, design a procedure to study the effect of hydrogen peroxide concentration on the reaction rate from Equation 1. At least three trials must be performed. Each group will be receiving only 50 mL of 10% hydrogen peroxide solution, 3 grams of Alconox, and 6 mL of 2 *M* sodium iodide, so plan accordingly. Record your detailed procedure as well as any materials to be used. Have your procedure approved by your instructor before proceeding.

Part B: Solubility Equilibrium of Sodium Acetate

3. Obtain a sample of the sodium acetate solution from your instructor.

4. Record your observations of the appearance of the sodium acetate solution in the data table.

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5. Design another procedure to study the effect of temperature on the dissolution of sodium acetate (temperature ranges can be from 0 to 80°C). Have your procedure approved by your instructor before proceeding.

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Data Table—Effects of Concentration		
Trial	**Concentration of Hydrogen Peroxide**	**Observations**
1		
2		
3		
4		
5		

Data Table—Effects of Temperature		
Trial	**Temperature of Solution**	**Observations**
1	Room Temperature	
2		
3		

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Analyze and Interpret Data

1. **SEP Identify Knowns** Identify what variables you held constant for Part A. Why was it important to keep these variables constant?

2. **SEP Make Observations** What trends did you observe in your experiment in Part A?

3. **SEP Identify Knowns** Identify what variables you held constant for Part B. Why was it important to keep these variables constant?

4. **CCC Patterns** In Part B, as the temperature of the solution was increased, what trends did you observe?

5. **SEP Analyze Data** For Part B, explain your results in terms of Le Châtelier's Principle.

Investigation 13

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INQUIRY LAB – OPEN

Measure pH with Indicators

What kind of information does a pH scale provide? The pH scale provides a convenient method for representing the acidity of a solution. In this lab you will examine four different indicators. You will use your results to identify the pH of three unknown solutions.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Bromothymol blue solution, 0.04%, 6–12 drops
- Methyl orange solution, 0.1%, 6–12 drops
- pH 2, 4, 6, 8, 10, and 12 solutions, 4–8 drops each
- Phenolphthalein solution, 6–12 drops
- Universal indicator solution, 6–12 drops
- Unknowns A–C, 6–12 drops each
- Pipets
- Reaction plate, 15 wells
- White paper

Safety

All of the acids and bases used in this lab are corrosive to eyes, skin, and other body tissues. They are toxic by ingestion. Buffers in low pH range are strongly acidic; those in high pH range are strongly alkaline. Avoid contact of all chemicals with eyes and skin. Avoid inhaling vapors. Notify your teacher and clean up all spills immediately. Use sodium carbonate or sodium bicarbonate to neutralize acid solutions. Use citric acid to neutralize base spills. Phenolphthalein and universal indicator are alcohol-based solutions and are flammable. Keep away from flames and other ignition sources. Methyl orange, phenolphthalein, and universal indicator solutions are toxic by ingestion. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

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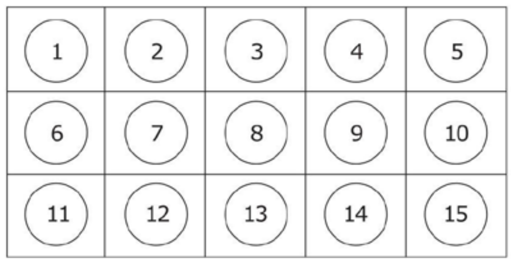
Procedure

Part I. Develop an Indicator Chart

1. Place your 15-well reaction plate on a piece of white paper as shown in Figure 1.

Figure 1



2. Add 1–2 drops of universal indicator into wells 1–6.
3. Add 1–2 drops of pH 2 in well 1, 1–2 drops of pH 4 in well 2, and 1–2 drops of pH 6 in well 3.
4. Add 1–2 drops of pH 8 in well 4, 1–2 drops of pH 10 in well 5, and 1–2 drops of pH 12 in well 6.
5. Record the color change for the corresponding pH in the data table.
6. When finished with the observations, rinse the contents of the reaction plate down the drain with plenty of excess water.
7. Place the well reaction plate back on the white paper as shown in Figure 1.
8. Repeat steps 2–7 using bromothymol blue.
9. Repeat steps 2–7 using phenolphthalein.
10. Repeat steps 2–7 using methyl orange.
11. Look at the data for bromothymol blue, phenolphthalein, and methyl orange. For each, identify the transition (where two colors exist) and record it.

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Part I. Data Table — pH Indicators						
pH	**2**	**4**	**6**	**8**	**10**	**12**
Universal Indicator						
Bromothymol Blue						
Phenolphthalein						
Methyl Orange						

Part II. Unknown Identification

12. Obtain three unknowns from the instructor.

13. Write the three unknowns in Data Table E.

14. **SEP Plan An Investigation** Design an experiment using bromothymol blue, phenolphthalein, and methyl orange to approximate the pH of the unknowns. Include a final step that uses the universal indicator to check the estimates. Show your procedure to your instructor before you begin.

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15. When finished with the observations, rinse the contents of the reaction plate down the drain with plenty of excess water.

Part II. Data Table — Unknowns			

Analyze and Interpret Data

1. **SEP Interpret Data** What is the primary advantage of each indicator you examined?

2. **SEP Interpret Data** Which indicator has the most acidic transition? Would this indicator be useful for identifying when an acidic solution becomes neutral (pH = 7) with the addition of a base? Explain.

3. **SEP Evaluate Data** How close were your pH estimates for the unknowns compared to the results you obtained by mixing the unknowns with universal indicator?

4. **SEP Apply Scientific Reasoning** Suppose a solution including the indicator phenolphthalein is currently colorless. Several drops of a second colorless

solution are added to the first and the color changes to pink. Does the second solution contain an acid or a base? Explain your reasoning.

5. **SEP Develop Models** Aqueous solutions contain water molecules, hydronium ions (H_3O^+), hydroxide ions (OH^-), and solute particles. Solutions with lower pH values have more hydronium ions, which are ions that cause a solution to be acidic. Solutions with higher pH values have more hydroxide ions, which are ions that cause a solution to be basic. Draw a model that shows the difference between an acidic and basic solution. The charges do not need to be balanced.

6. **SEP Use Models** Which solution in your model in Question 5 best describes each of the unknown solutions?

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INQUIRY LAB – OPEN

Measure Acid Strength

Acids vary greatly in their strength—their ability to ionize or produce hydrogen ions when dissolved in water. How do the pH values of acids of equal concentration indicate the relative equilibrium positions of the acids? And how can the equilibrium that represents the dissociation of a weak acid be shifted to the left or the right?

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Potassium dihydrogen phosphate (potassium phosphate, monobasic), KH_2PO_4, 0.8 g
- Potassium hydrogen sulfate (potassium bisulfate), $KHSO_4$, 0.8 g
- Potassium hydrogen phthalate, $KHC_8H_4O_4$, 1.2 g
- Potassium hydrogen tartrate (potassium bitartrate), $KHC_4H_4O_6$, 1.2 g
- Beaker
- pH meter
- Stirring rod
- Wash bottle and distilled or deionized water
- Volumetric flask with cap, 50 mL
- Weighing dishes, 2
- Balance, centigram (0.01 g precision)

Safety

Acids and bases are skin and eye irritants. Avoid contact of all chemicals with eyes and skin. Inform the teacher and clean up all acid and base spills immediately. Phenolphthalein is an alcohol-based solution and is flammable. Keep the solution away from flames. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.

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Procedure

1. **SEP Plan and Carry Out an Investigation** Develop a procedure to determine which of the four acids that form part of the salts in the table is the weakest. Record your detailed procedure as well as any materials to be used. Prepare a data table to record your results. Share your plan with your teacher before proceeding.

Acid	**Formula**
Potassium dihydrogen phosphate	KH_2PO_4
Potassium hydrogen sulfate	$KHSO_4$
Potassium hydrogen phthalate	$KHC_8H_4O_4$
Potassium hydrogen tartrate	$KHC_4H_4O_6$

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Analyze and Interpret Data

1. **SEP Construct Explanations** How do the pH values of weak acids having the same concentration indicate the relative equilibrium positions of the acids? Which of the four weak acids' equilibrium positions lies farthest to the right?

2. **SEP Use Mathematics and Computational Thinking** Rank the conjugate bases of the four weak acids from weakest base to strongest base. Explain the reasoning behind your ranking.

3. **SEP Develop and Use Models** How can the equilibrium that describes the dissociation of a weak acid be shifted to the left?

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4. **SEP Plan and Carry Out Investigations** If you were given two weak bases, how would you go about determining which of the two was the stronger base?

5. **SEP Develop and Use Models** Draw examples of two acid solutions. The solution on the left should represent a 0.1 *M* weak acid and the solution on the right should represent a 0.1 *M* strong acid solution.

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INQUIRY LAB – OPEN

Titrations—The Study of Acid–Base Chemistry

How can we determine the concentration of an acid if the label is damaged or missing? This is a common question chemists have to answer and is usually addressed with a titration experiment. Acid–base titrations can be used to measure the concentration of an acid or base in solution, to calculate the formula (molar) mass of an unknown acid or base, and to determine the equilibrium constant of a weak acid (K_a) or a weak base (K_b).

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Phenolphthalein indicator solution, 1.0%, 1 mL
- Sodium hydroxide solution, NaOH, 0.1 *M*, 60 mL
- Sodium hydroxide solution, NaOH, 1.0 *M*, 60 mL
- Vinegar sample of unknown concentration, 45 mL
- Water, distilled or deionized
- Balance, 0.001 or 0.0001 g precision
- Beaker 250 mL
- Buret, 50 mL
- Buret clamp
- Erlenmeyer flasks, 250 mL, 2
- Funnel
- Graduated cylinder, 25 mL
- Reaction plate, 24-well
- Pipets, Beral-type, microtip, 3
- Support stand
- White paper

Safety

All the acids and bases used in this lab are irritating to eyes, skin, and other body tissues. Phenolphthalein is an alcohol-based solution and is flammable. It is moderately toxic by ingestion and a possible carcinogen. Keep away from flames and other ignition sources. Avoid contact of all chemicals with eyes and skin, and wash hands thoroughly with soap and water before leaving the laboratory. Wear chemical splash goggles and chemical-resistant gloves and apron.

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Procedure

Part A. Sodium Hydroxide Concentration Determination

1. Position a 24-well reaction plate on top of a white piece of paper. Obtain three micro-stem Beral-type pipets. Use one pipet for the vinegar, one for the phenolphthalein, and one for sodium hydroxide.

2. Obtain 5.0 mL of vinegar with an unknown concentration. Record the unknown letter in your data table.

3. Place 10 drops of your unknown vinegar sample into wells A1–A3. It is important to always hold the pipet at the same angle to obtain drops of equal size.

4. Use a clean pipet to add 1 drop of phenolphthalein indicator to the vinegar.

5. Titrate the sample of vinegar with a 0.1 *M* solution of sodium hydroxide to reach the endpoint. The endpoint (neutralization) is reached when the solution remains a light pink color. The lighter the pink color, the closer it is to the true endpoint.

6. Record the number of drops of sodium hydroxide used in your data table.

7. Repeat the process two more times, and record your results for each trial. Calculate the average number of drops of NaOH used for the three trials. Record your result in the data table.

8. Repeat steps 2–6 for the 1.0 *M* sample of NaOH.

Part B. Determining Molarity of a Vinegar Sample with Unknown Concentration

9. Based on your results from Part A, determine which concentration of NaOH to use to titrate your vinegar sample. Use the following space to explain your choice.

10. Measure 40.0 mL of your unknown vinegar solution.

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11. Measure 20.0 mL of the vinegar into a clean Erlenmeyer flask. Record the exact volume in your data table.

12. Add 20.0 mL of distilled water to the flask. Add 3 drops of phenolphthalein to the flask.

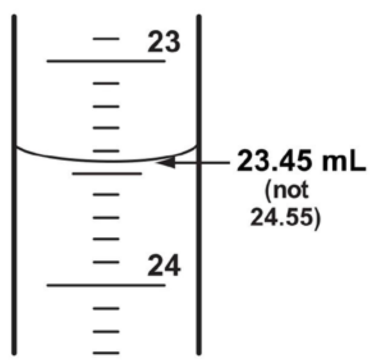
13. Clean a 50 mL buret, then rinse it with three small portions (about 5 mL each) of the NaOH solution.

14. Fill the buret to above the zero mark with your chosen NaOH solution.

13. Open the buret stopcock to allow any air bubbles to escape from the tip. Close the stopcock when the liquid level is between the 0 and 10 mL marks.

14. Measure the precise volume of the solution in the buret, and record this value in your data table as the “initial volume.” *Note*: Volumes are read from the top down in a buret. Always read from the bottom of the meniscus, remembering to include the appropriate number of significant figures (see Figure 1).

Figure 1



15. Place a white piece of paper under the Erlenmeyer flask to help see the color change.

16. Begin the titration by adding 1.0 mL of the NaOH solution to the Erlenmeyer flask, then closing the buret stopcock and swirling the flask.

17. Reduce the incremental volumes of NaOH solution to 0.5 mL until the pink color starts to persist. Reduce the rate you add the NaOH solution to drop by drop until the pink color persists for 15 seconds. Remember to constantly swirl the flask and rinse the walls of the flask with distilled water before the endpoint is reached.

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18. Measure the volume of NaOH remaining in the buret, estimating to the nearest 0.05 mL. Record this value as the "final volume" in your data table.

Unknown vinegar letter:	

Sodium Hydroxide Concentration Determination		
Trials	**Drops of 0.1 *M* NaOH used**	**Drops of 1.0 *M* NaOH used**
1		
2		
3		
Average		

Unknown Concentration of Vinegar		
	Trial 1	**Trial 2**
Volume of acid, mL		
Initial volume of NaOH in the buret, mL		
Final volume of NaOH in the buret, mL		
Volume of NaOH added, mL		

Analyze and Interpret Data

1. **SEP Use Math** Use your data from Part A to calculate the molarity of your unknown vinegar sample for each concentration of sodium hydroxide.

$$(M_a)(Drops_a) = (M_b)(Drops_b)$$

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2. **SEP Construct an Explanation** Did the concentrations you calculated for the two vinegar samples match the two given concentrations of the sodium hydroxide? If not, what experimental factors could have contributed to the discrepancy?

3. **SEP Use Math** Use your data from Part B to calculate the concentration of your acetic acid sample for each trial. What is the average concentration? Use the equation $M_aV_a = M_bV_b$, where M_a is the molarity of the acid, V_a is the volume of the acid, M_b is the molarity of the base, and V_b is the volume of the base.

4. **SEP Interpret Data** Obtain the actual concentration of your unknown from your teacher. Was your calculated concentration accurate? If not, provide experimental factors that could improve your results.

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5. SEP Construct an Explanation What was the purpose of rinsing the buret with NaOH before beginning the experiment? How could not doing this affect the calculated unknown concentration?

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INQUIRY LAB – OPEN

Analysis of Buffer Solutions and Ranges

How can our blood maintain a consistent unchangeable pH of 7.4? Blood is a complex and naturally buffered solution. One of the most important applications of acids and bases in chemistry and biology is that of buffers. A buffer protects against rapid changes in pH when acids or bases are added to it. Every living cell is buffered to maintain constant pH and proper cell function. Consumer products are often buffered to safeguard their activity. The purpose of this lab activity is to investigate how buffers are made and the pH range in which they are effective.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Acetic acid solution, CH_3COOH, 0.1 M, 24 mL
- Bromocresol green indicator solution, 0.04%, 5 mL
- Buffer solution A, 12 mL
- Buffer solution B, 12 mL
- Buffer solution C, 12 mL
- Congo red indicator, 0.1%, 5 mL
- Hydrochloric acid, HCl, 0.1 M, 10 mL
- Sodium acetate solution, $NaCH_3COO$, 0.1 M, 24 mL
- Sodium hydroxide solution, NaOH, 0.1 M, 10 mL
- Water, distilled
- Graduated cylinders, 10 mL, 2
- Microscale reaction plate, 24-well, 2
- pH paper, narrow range, 3.0–5.5
- Pipets, Beral-type, graduated, 8
- Test tubes (medium), 16 mm x 150 mm, 8
- Test tube (small), 13 mm x 100 mm, 2
- Test tube rack
- Toothpicks

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Safety

Dilute (0.1 M) solutions of acetic acid, hydrochloric acid, and sodium hydroxide are body tissue irritants. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron when handling these chemicals. Avoid exposure to eyes and skin and clean up all spills promptly. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Pre-lab Preparation

1. Set up six medium-size test tubes in a rack. Label them 1–6.
2. Add 12 mL of 0.1 M acetic acid solution to test tube 1.
3. Measure 12 mL of each buffer solution prepared by your teacher. Add buffer A to test tube 2, buffer B to test tube 3, and buffer C to test tube 4. The contents for each buffer are listed in the following table for your reference.

Buffer Solutions			
Solution	**Buffer solution A**	**Buffer solution B**	**Buffer solution C**
Acetic acid, 0.1 M (mL)	9	6	3
Sodium acetate, 0.1 M (mL)	3	6	9

4. Measure 12 mL of 0.1 M sodium acetate solution to test tube 5.
5. Add 12 mL of distilled water to test tube 6 for your control.
6. Measure 10 mL of 0.1 M hydrochloric acid and place in a labeled, medium-size test tube.
7. Place 5 mL of bromocresol green in a small labeled test tube.
8. Place a clean microscale 24-well reaction plate on a piece of white paper.
9. Label six graduated Beral-type pipets 1–6.

10. Measure the pH of each solution 1–4 using a piece of narrow range pH paper (3.0–5.5). The pH values for solutions 5 and 6 are outside of this range and have already been entered in the data table.

11. Record the estimated pH for each solution 1–4 in the data table.

12. **SEP Plan and Carry Out an Investigation** Using the materials provided, develop a procedure to test the pH ranges of each buffer solution using HCl and NaOH. Describe your plate setup and procedure in the following space. As you develop your procedure, keep the following in mind:

a. You must have controls and references in place for comparing your results. Distilled water is a necessary control. Only 1 drop of either HCl or NaOH should be added to the water.

b. It is important to keep the HCl and NaOH tests separate. Determine which indicator goes with which test. Only use 1 drop of indicator per well. Be sure to note the initial colors of each solution before proceeding.

c. Add different drop amounts of the HCl and NaOH to the solutions to effectively gauge the amount needed for the indicator to change color. Do not exceed 20 drops of either.

d. Before starting, show your procedure to your teacher.

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Initial pH and Indicator Colors						
Solution	**1**	**2**	**3**	**4**	**5**	**6**
	Acid reference	**Buffer solution A**	**Buffer solution B**	**Buffer solution C**	**Base reference**	**Control**
Measured pH (pH paper)					7.5	6–7
Bromocresol green indicator color						
Congo red indicator color						

Effect of HCl Addition							
	Solution	**1**	**2**	**3**	**4**	**5**	**6**
Row	**Indicator color**	**Acid reference**	**Buffer solution A**	**Buffer solution B**	**Buffer solution C**	**Base reference**	**Control**

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Effect of NaOH Addition							
	Solution	**1**	**2**	**3**	**4**	**5**	**6**
Row	**Indicator color**	**Acid reference**	**Buffer solution A**	**Buffer solution B**	**Buffer solution C**	**Base reference**	**Control**

Analyze and Interpret Data

1. **SEP Use Math** Use the buffer equation to calculate the expected $[H_3O^+]$ and pH values for buffer solutions A, B, and C. Compare the calculated values against the experimental data for Buffers A, B, and C (*Hint:* The concentrations of the acetic acid and sodium acetate solutions are the same, and the total volume of the buffer solutions is constant; therefore, the volume of each component used to prepare the buffer can be substituted directly into the concentration ratio expression in the equation. $K_a = 1.8 \times 10^{-5}$.

$$[H_3O^+] = K_a \times \frac{[HA]}{[A^-]} \qquad \text{pH} = -\log[H_3O^+]$$

2. **SEP Interpret Data** Did all of the buffer solutions exhibit buffering activity with respect to added HCl? Explain. Which buffer solution was most effective with respect to added acid? Explain.

3. **SEP Interpret Data** Did all of the buffer solutions exhibit buffering activity with respect to added NaOH? Explain. Which buffer solution was most effective with respect to added base? Explain.

4. SEP Construct an Explanation The behavior of solution 5 in demonstrates that a buffer can be made by partial neutralization of the basic component A^{-} with HCl.

(a) Write an equation for the neutralization reaction of sodium acetate in solution 5 upon addition of HCl.

(b) Describe and explain the significance of the color changes observed for solution 5.

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5. SEP Construct an Explanation The behavior of solution 1 demonstrates that a buffer can be made by partial neutralization of the acidic component HA with NaOH.

(a) Write an equation for the neutralization reaction of acetic acid in solution 1 upon addition of NaOH.

(b) Describe and explain the significance of the color changes observed for solution 1.

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PERFORMANCE BASED ASSESSMENT

Quantitative Analysis of Acid Rain

When nonmetal oxides dissolve in water they can react to form acidic products. These can be either strong or weak acids. For example, sulfur dioxide forms sulfuric acid, and nitrogen dioxide reacts to form nitric acid, which are both strong acids. Conversely, carbon dioxide reacts to form carbonic acid, which is a weak acid.

Another consideration is how many acidic protons each acid has. Nitric acid is monoprotic, whereas sulfuric and carbonic acid are both diprotic. Because of these differences the corrosive power of acid rain cannot be assessed purely by a pH measurement.

In this lab you will examine three acid samples, and compare and contrast their observed pH with the amount of base needed to reach the end point in a titration.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Phenolphthalein indicator solution
- Sodium hydroxide solution, NaOH, 0.005 *M*, 100 mL
- Unknown acid solutions, 45 mL each
- Water, distilled or deionized
- Buret, 50 mL
- Beakers, 50 mL, 3
- Graduated cylinder, 50 mL
- Erlenmeyer flasks, 250 mL, 3
- pH probe

Safety

All the acids and bases used in this lab are irritating to eyes, skin, and other body tissues. Phenolphthalein is an alcohol-based solution and is flammable. It is moderately toxic by ingestion, and a possible carcinogen. Keep away from flames and other ignition sources. Avoid contact of all chemicals with eyes and skin, and wash hands thoroughly with soap and water before leaving the laboratory. Wear chemical splash goggles and chemical-resistant gloves and apron.

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Procedure

1. Classify each of the following as either weak or strong acids: hydrochloric acid, citric acid, acetic acid, nitric acid, and hydrofluoric acid.

2. **SEP Plan an Investigation** Write a detailed procedure to examine the three acids. Show it to your teacher for review. This procedure must include rough pH measurements with a pH probe followed by more precise titrations. Remember to keep key variables constant.

3. **SEP Carry Out an Investigation** Once your procedure has been approved, conduct your experiment. A blank data table has been provided to record your results.

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4. Clean up and dispose of solutions as instructed by teacher.

Analyze and Interpret Data

1. **SEP Analyze Data** Assume that all of the unknowns were strong monoprotic acids. Based on the results of the pH probe, what is the concentration of each unknown acid?

2. **SEP Use Math** Use the results of your titrations to calculate the concentration of acid protons in each unknown.

3. **SEP Analyze Data** Based on your results from questions 1 and 2, which acids (if any) would you classify as strong acids? Explain your reasoning.

4. **SEP Analyze Data** Based on your results from questions 1 and 2, which acids (if any) would you classify as weak acids? Explain your reasoning.

5. **SEP Analyze Data** Based on your results from questions 1 and 2, which acids (if any) would you classify as monoprotic? Explain your reasoning.

6. **SEP Analyze Data** Based on your results from questions 1 and 2, which acids (if any) would you classify as diprotic? Explain your reasoning.

7. **SEP Analyze Data** The three most common forms of acid rain are carbonic acid, nitric acid, and sulfuric acid. From your results, identify which form of acid rain each of the unknowns best aligns with.

Investigation 14

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INQUIRY LAB – OPEN

The pH of Seawater

The surface of the ocean has an average pH of 8.1, which is approximately 0.1 units lower than before the Industrial Revolution started. The decrease in the pH of seawater is directly related to the increase in carbon dioxide emissions to the atmosphere, mostly from human activities involving the burning of fossil fuels. In this laboratory, you will investigate the equilibrium of water, carbon dioxide, bicarbonate, and carbonate species, and its role in determining the pH levels of ocean water.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Acetic acid solution, CH_3COOH, 2*M*, 40 mL
- Sodium bicarbonate, $NaHCO_3$, 3.5 g
- Sodium carbonate, Na_2CO_3, 0.5 g
- Sodium chloride, NaCl, 15 g
- Phenolphthalein indicator, 1% solution, 0.5 mL
- Universal indicator solution, 0.5 mL
- Water, distilled or deionized
- Beakers, 400 mL and 250 mL
- Clamp
- Beral-type pipet, 2
- Heat-resistant gloves
- Hot plate
- Erlenmeyer flask for filtering, 250 mL
- Graduated cylinder, 50 mL and 100 mL
- pH meter
- pH test strips (optional)
- Plastic tubing, 2–3 feet long
- Ring stand
- Rubber stopper (for use with Erlenmeyer flask)
- Spatula
- Temperature sensor or thermometer
- Weighing dishes, 3

NAME ______________________ DATE __________ CLASS __________

Safety

Sodium bicarbonate is slightly toxic by ingestion. Sodium carbonate is toxic by ingestion, and can cause skin and eye irritation. Acetic acid solution is toxic by ingestion and inhalation, and is corrosive to skin and eyes. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron when handling these chemicals. Avoid exposure to eyes and skin, and clean up all spills promptly. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part 1. The Solubility of CO_2 in Water

1. Prepare 400 mL of a 0.5*M* sodium chloride solution that will resemble seawater by dissolving the appropriate amount of NaCl in deionized/distilled water. Record your detailed calculations.

2. Transfer a known volume of the seawater solution prepared in Step 1 to a beaker. Measure the pH of the solution and record it in the data table.

3. Boil the solution in the beaker. Once it boils for a few minutes, allow the solution to cool down to room temperature. Use heat-resistant gloves to grab the hot beaker. Use a thermometer/temperature sensor to make sure the water is back to room temperature.

4. Measure the pH of the seawater solution at room temperature. Record this pH value.

5. Add a few drops of universal indicator to the seawater solution. Record your observations in the data table.

6. Choose a volume of 2*M* acetic acid solution and a mass of sodium bicarbonate to mix in the Erlenmeyer flask to generate carbon dioxide gas. Measure the amounts of each reagent to be used, and record the values in the space below.

7. Attach the plastic tubing to the short glass tube on the Erlenmeyer flask. At first, it may be helpful to heat up one end of the plastic tubing by placing it in hot water to stretch it out a little. This should facilitate sliding it onto the glass tube on the Erlenmeyer flask.

8. Bubble carbon dioxide into the seawater solution in the beaker.

9. Monitor the pH and color of the seawater solution. Continue to measure the pH of the seawater solution until it becomes stable. Record this pH value as the final pH of the solution. Record any other observations in the data table.

10. Rinse the pH meter with distilled/deionized water, and store it as indicated by your instructor.

11. Dispose of solutions and any other chemical waste as indicated by your instructor. Rinse it with distilled/deionized water.

NAME ______________________ DATE __________ CLASS __________

Part 2. The Effect of CO_2 on the pH of Seawater Solution

12. Real seawater has a pH around 8.1. Using the materials and reagents available, develop a procedure in which you investigate the effect of dissolving carbon dioxide in seawater, using a sample of seawater that has a pH close to 8.1. Record the measured pH values and your observations in the data table. Write your procedure.

NAME ______________________ DATE __________ CLASS __________

Data Table—Part 1		
Parameter		**Observations (color, appearance, etc.)**
pH before boiling		
pH after boiling		
$[H^+]$ after boiling (moles/liter)		
pH after treatment with CO_2		

NAME ______________________ DATE __________ CLASS __________

Data Table—Part 2		
Parameter		Observations (color, appearance, etc.)
pH before treatment with CO_2		
$[H^+]$ before treatment with CO_2 (moles/liter)		

Analyze and Interpret Data

Part 1. The Effect of CO_2 on the pH of Water

1. **SEP Analyze Data** Compare the pH of the seawater solution before and after boiling the solution. How can you explain the differences in the pH before and after boiling the solution?

2. **SEP Use Models** Write a balanced chemical equation to represent the reaction(s) that takes place in the Erlenmeyer flask.

3. **SEP Use Models** The dissolution of carbon dioxide in water produces carbonic acid (H_2CO_3) at first, which then dissociates into bicarbonate (HCO_3^-) and hydrogen ions (H^+). Write a balanced equation for this reaction (as an equilibrium).

4. **SEP Use Math** Using the equation that defines pH, calculate the concentration of hydrogen ions ([H^+], in moles/liter) before and after treating the seawater solution with carbon dioxide.

5. **SEP Use Math** Based on the results of your calculations in question 4, determine the percent change in acidity (that is, the percent change in [H^+]) for the seawater solution upon treatment with carbon dioxide.

NAME ______________________________ DATE __________ CLASS __________

6. **SEP Construct an Explanation** Explain what happens to the seawater solution when the gas generated in the Erlenmeyer flask bubbles into it. How do the pH and the color of the solution change, and why?

Part 2. The Effect of CO_2 on the pH of Seawater Solution

7. **SEP Construct an Explanation** Based on your results for Part 2, are the changes in pH and color of the seawater solution in agreement with the explanation you constructed for question 6? Explain.

8. **SEP Use Math** Using the equation that defines pH, calculate the concentration of hydrogen ions ($[H^+]$ in moles/liter) before and after treating the seawater solution with carbon dioxide.

NAME ______________________ DATE __________ CLASS __________

9. SEP Use Math Based on the results of your calculations in question 8, determine the percent change in acidity (that is the percent change in $[H^+]$) for the seawater solution upon treatment with carbon dioxide.

10. SEP Engage in Argument Compare your results from Parts 1 and 2, and develop an argument about the possible relationship between initial pH, content of carbonate/bicarbonate ions, and the capacity of the seawater solutions to absorb carbon dioxide.

11. SEP Engage in Argument Surface ocean water has a pH of approximately 8.1, and it contains dissolved carbon dioxide in equilibrium with water, bicarbonate ions (HCO_3^-), and, to a lesser extent, carbonate ions (CO_3^{2-}). Based on your results from this investigation, how would an increase in atmospheric carbon dioxide influence the pH and acidity of seawater and why?

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Carbon Dioxide Levels in Water

How does temperature affect dissolved carbon dioxide (CO_2) in salt water samples? When atmospheric carbon dioxide levels rise, carbon dioxide dissolves in the ocean. You get to be the scientist in this open inquiry lab! Explore the fizzing action of dissolved carbon dioxide in salt water samples at four different temperatures of your choice. Then, plot the level of carbon dioxide absorption vs. temperature to observe the graphical trend.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Beaker, 200 mL, 4
- Antacid tablet, 2
- Sodium chloride, 6 g
- Water, distilled or DI, 400 mL
- Heat-resistant gloves, 1 pair
- Hot plate
- Marker
- Thermometer
- Scoopula

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Wear heat-resistant gloves when handling the hot water sample. Allow hot water sample to cool before discarding it. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. **SEP Carry Out Your Investigation** Review the materials your teacher provided. Develop a procedure to look at how temperature affects the dissolution of carbon dioxide in salt water. Select four different temperatures to explore.

NAME ______________________ DATE __________ CLASS ____________

2. **SEP Plan Your Investigation** Select the dependent and independent variables in the experiment.

3. Create your own data table to record your observations and findings for this experiment.

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Use Models** What does the sodium chloride and water mixture represent in this experiment?

2. **SEP Use Models** What does the antacid tablet represent? In other words, what is it a source for in this experiment?

3. **SEP Use a Model to Evaluate** Describe the carbon dioxide cycle in oceans. Look up this information digitally or in your textbook.

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4. **SEP Make Observations** Compare and contrast your observations between samples 1, 2, 3, and 4.

5. **SEP Interpret Data** Did temperature affect the carbon dioxide dissolution in the samples of salt water? How does the ocean releasing carbon affect temperatures?

6. **SEP Use Graphs** Plot a trend line to compare the fizzing rate of carbon dioxide in all four samples vs. temperature.

7. **SEP Identify Patterns** Describe the plot trend from Step 6 in this section.

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INQUIRY LAB – OPEN

Ocean Currents

What happens when fresh water and saltwater mix? In this experiment you will investigate possible currents that could form due to mixing water with different salinities or at different temperatures.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Blue saltwater solution, 20 mL
- Red warm water solution, 20 mL
- Water, tap, 40 mL
- Beral-type pipet, 4
- Shell vial, 30 mL, 2

Procedure

Part 1. Salinity

1. Add 10 mL of the blue salt water solution water to the first shell vial.
2. Using a Beral-type pipet, carefully add 10 mL of tap water to the top of the blue salt water solution.
3. Record your observations in the data table.
4. Add 10 mL of tap water solution to the second shell vial.
5. Using a Beral-type pipet, carefully add 10 mL of blue salt water to the top of the tap water.
6. Record your observations in the data table.
7. Wash and dry your shell vials.

NAME ________________________ DATE ____________ CLASS ____________

Data Table—Salinity		
Sample	**Saltwater on bottom**	**Tap water on bottom**
Observations		

Part 2. Temperature

8. **SEP Plan an Investigation** Devise a method for investigating the effect of temperature on ocean currents. Record your detailed procedure, as well as any materials to be used. Show your procedure to your teacher before beginning any experimental work.

NAME ______________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Identify Patterns** What happened when the tap water was placed on top of the saltwater?

2. **SEP Identify Patterns** What happened when the saltwater was placed on top of the tap water?

3. **SEP Form a Hypothesis** Propose an explanation that accounts for your answers to questions 1 and 2.

4. **SEP Identify Patterns** What happened when the cool tap water was placed on top of the warm water?

5. **SEP Identify Patterns** What happened when the warm water was placed on top of the cool tap water?

NAME ______________________ DATE __________ CLASS __________

6. **SEP Form a Hypothesis** Propose an explanation that accounts for your answers to questions 4 and 5.

7. **SEP Develop Models** Based on your results, describe what types of currents might exist in a location where fresh water glaciers are melting into the sea.

8. **SEP Develop Models** Based on your results, describe what types of currents might exist in a location where a hot fresh water spring emerges under the sea.

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INQUIRY LAB – OPEN

The Fate of Carbonate in Acidifying Oceans

In addition to affecting the global climate, the increase in concentration of carbon dioxide (CO_2) emissions to the atmosphere is causing the acidification of ocean waters. The dissolution of CO_2 in the ocean consumes carbonate ions (CO_3^{2-}) and produces bicarbonate (HCO_3^-), which increases the acidity of the water. Given that oceans absorb about a quarter of the CO_2 released into the atmosphere every year, the rising emissions of this greenhouse gas are causing a slow and detrimental decrease in the pH of seawater. The acidification of ocean waters threatens the availability of carbonate ions, which are required in the formation of calcium carbonate ($CaCO_3$) structures by numerous marine organisms. In this investigation, you will explore the equilibrium between HCO_3^-, CO_3^{2-}, and H^+ ions, and its relationship to $CaCO_3$ formation in ocean waters.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Calcium chloride, $CaCl_2$, 1 g
- Hydrochloric acid solution, HCl, 3.0*M*, 3 mL
- Sodium bicarbonate, $NaHCO_3$, 1 g
- Sodium carbonate, Na_2CO_3, 2 g
- Sodium chloride, NaCl, 6 g
- Water, distilled or deionized
- Beaker, 400 mL
- Beral-type pipet, 9
- Centrifuge (optional)
- Graduated cylinder, 10 mL
- Graduated cylinder, 100 mL
- pH paper, 1.0–14.0
- Stirring rod, glass
- Scoop or spatula
- Test tubes (medium), 16 mm x 150 mm, 9
- Test tube rack
- Wax marking pencil or marker
- Weighing dishes or paper

NAME ______________________ DATE __________ CLASS __________

Safety

Calcium chloride is slightly toxic. Sodium bicarbonate is slightly toxic by ingestion. Sodium carbonate is toxic by ingestion, and can cause skin and eye irritation. Hydrochloric acid solution is toxic by ingestion and inhalation, and is corrosive to skin and eyes. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron when handling these chemicals. Avoid exposure to eyes and skin, and clean up all spills promptly. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Prepare 200 mL of a 0.5*M* sodium chloride (molar mass = 58.44 g/mol) solution that will model seawater, by dissolving the appropriate amount of NaCl in deionized or distilled water.

2. Prepare and label test tubes containing 10 mL of the following control solutions:

- Seawater solution from Step 1
- 0.1*M* $CaCl_2$ (molar mass = 110.98 g/mol)
- 0.1*M* Na_2CO_3 (molar mass = 105.99 g/mol)
- 0.1*M* $NaHCO_3$ (molar mass = 84.00 g/mol)

3. Measure the pH of these control solutions. Record these pH values, and any observations, in the data table.

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4. **SEP Plan and Carry Out an Investigation** Design an experimental procedure to investigate the formation of calcium carbonate ($CaCO_3$). Perform at least two separate trials in which you mix $CaCl_2$ and Na_2CO_3, or $CaCl_2$ and $NaHCO_3$, to observe the formation of $CaCO_3$. Measure the pH value of the reaction mixtures, and write your observations in a data table. Record your detailed procedure, as well as any materials to be used. Show your procedure to your teacher before conducting the investigation.

NAME ______________________ DATE __________ CLASS __________

5. **SEP Plan and Carry Out an Investigation** Design a procedure to investigate the effect of adding HCl solution to acidify seawater solutions in which a calcium carbonate precipitate has formed. Perform two trials using the $CaCl_2$ and Na_2CO_3 solutions prepared (or $NaHCO_3$) in Part 1, to prepare mixtures in which $CaCO_3$ precipitates. Vary the number of drops of 3.0*M* HCl added to each test tube. Measure the pH value of the solution in each test tube before and after adding the HCl solution, and include any observations in the Data Table. Record your detailed procedure as well as any materials to be used. Show your procedure to your teacher before conducting the investigation.

NAME ______________________ DATE ____________ CLASS ____________

Data Table—The Experiment			

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Analyze Data** Compare your observations and the pH values you measured for control solutions prepared in **Step 2**. How do these solutions compare to those prepared in **Step 4**?

2. **SEP Analyze Data** In **Step 4**, what happened when $CaCl_2$ and Na_2CO_3 were mixed? Use chemical formulas and balanced equations to represent this process.

3. **SEP Analyze Data** In **Step 4**, what happened when $CaCl_2$ and $NaHCO_3$ were mixed? Use chemical formulas and balanced equations to represent this process.

NAME ____________ DATE ____________ CLASS ____________

4. **SEP Construct an Explanation** Compare the pH and other observations you made for reactions performed in **Step 4.** Describe the pH of the resulting solutions (supernatants) as “acidic,” “basic,” or “neutral.” What explains the pH of the resulting solutions?

5. **SEP Construct an Explanation** Develop an explanation for the results of experiments done in **Step 4**, correlating your observations and the reactivity of the chemicals combined in each test tube.

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6. **SEP Obtain Information** The dissolution of CO_2 in aqueous media may generate carbonic acid (H_2CO_3), which dissociates into hydrogen ions (H^+, or H_3O^+) and bicarbonate anions (HCO_3^-). In addition, an equilibrium is established between carbonate anions (CO_3^{2-}) and bicarbonate anions in solution. Research these chemical reactions and write balanced equations to represent them.

7. **SEP Use Models** Based on your research for question 6, describe what would happen to the pH of seawater as increasing amounts of CO_2 dissolve in it. Include in your explanation what would happen to the concentration of HCO_3^-, CO_3^{2-}, and H_3O^+ as more CO_2 dissolves in seawater.

8. SEP Use a Model to Evaluate Based on your responses to the previous questions, explain what could happen to $CaCO_3$ in marine organisms as increasing amounts of CO_2 dissolve in seawater. Does your prediction agree with the results of the experiments performed in Step 4?

9. SEP Analyze Data In **Step 5**, what type of reaction(s) took place as you acidified the reaction solutions? Write a balanced chemical equation to represent the reaction(s).

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10. SEP Construct an Explanation Compare and explain what happens to the contents of the different test tubes prepared in **Step 5** when acidified. How does this relate, if at all, to the acidification of oceans and the impact of this phenomenon on marine organisms that depend on calcification to form $CaCO_3$ structures?

11. SEP Design A Solution Considering your results from this experiment, think of a possible solution to prevent the dissolution of calcium carbonate structures in the oceans due to sea water acidification. Briefly describe your solution, and explain what criteria would this solution need to satisfy to be successful.

NAME ______________________ DATE __________ CLASS __________

12. SEP Design A Solution Identify and describe at least one limitation or constraint associated with the solution you proposed in question 11. Explain whether these obstacles may be overcome and how.

NAME ______________________ DATE __________ CLASS __________

PERFORMANCE BASED ASSESSMENT

Calcium Carbonate and Shell Production

How does carbon dioxide absorption impact the health of the ocean? The ocean has a natural buffering system that absorbs the carbon dioxide. As more and more carbon dioxide is produced, the ocean will reach its limit and the buffering capability will decline, leading to a more acidic environment. Rising carbon dioxide levels in the atmosphere are directly harming the ocean ecosystems through ocean acidification, which is interfering with the ability of many organisms to form shells. When atmospheric carbon dioxide dissolves in the ocean, it produces carbonic acid. This lab will focus on different concentrations of acid and how that plays a role in shell formation.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

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

NAME ______________________ DATE __________ CLASS __________

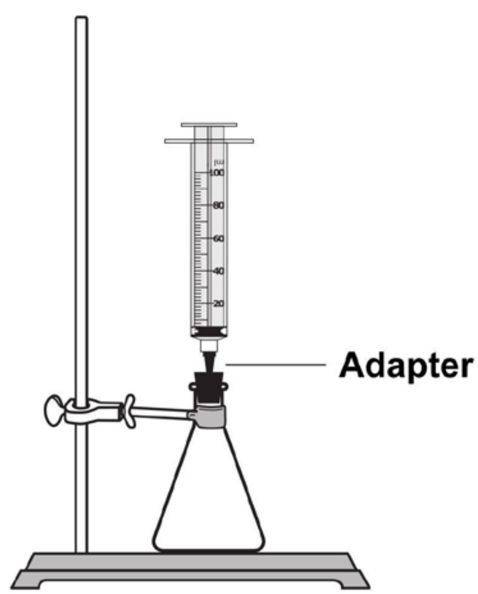
Safety

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

Procedure

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

Figure 1



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2. **SEP Plan an Investigation** Using the materials provided, develop a method to test the effects of different concentrations of hydrochloric acid on calcium carbonate. Describe your testing method and procedure in the space. Show your method to your teacher before conducting the investigation.

   - Each test will require 0.3 g of calcium carbonate and 5 mL of hydrochloric acid.
   - The stopper and syringe assembly must be immediately placed back on the flask to prevent any loss of gas.
   - Data collection should occur for 10 minutes.

3. Record all data in the blank table provided and graph your results.

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Calcium Carbonate and HCl			
Time	*y*-axis measurement:_________________________		
	Concentration of HCl		
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

NAME ______________________ DATE ____________ CLASS ____________

Analyze and Interpret Data

1. **SEP Identify Patterns** How did the change in concentration of hydrochloric acid affect the amount of gas produced by the calcium carbonate?

2. **SEP Interpret Data** What gas is being produced in the reaction? How does the addition of this gas to the ocean buffering system affect its equilibrium?

3. **SEP Construct an Explanation** How does an increase in the acidity of the ocean affect calcifying organisms and their efforts to produce shells?

NAME ______________________ DATE ____________ CLASS ____________

4. **SEP Apply Scientific Reasoning** How could the amount of available calcium carbonate affect the ocean food web? How could that, in turn, affect humans?

Investigation 15

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INQUIRY LAB – OPEN

Explore Iron Corrosion

Can we prevent or reduce the corrosion of iron? The corrosion of iron, better known as rusting, is a process that transfers electrons and destroys iron objects left out in moist air. This is the balanced chemical equation for the chemical reaction of iron, oxygen, and water:

$$2Fe(s) + O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4OH^-(aq)$$

Fe^{2+} and OH^- ions may combine to form solid iron(II) hydroxide, $Fe(OH)_2$. This is almost never observed, however, because iron(II) hydroxide reacts further with oxygen and water to form hydrated iron(III) oxide, $Fe_2O_3 \cdot nH_2O$, the flaky, reddish-brown solid commonly known as rust.

$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$$

$$4Fe(OH)_2(s) + O_2(g) + xH_2O(l) \rightarrow \underset{\text{Rust}}{2Fe_2O_3 \cdot (x+4)H_2O(s)}$$

What kinds of metals can be wrapped around the iron nail to protect it from corrosion?

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 6 Construct Explanations

Materials Per Group

- Agar mixture, 20 mL
- Labels and/or marker pen
- Petri dishes with covers, disposable plastic, 2
- Iron nails, 3
- Sandpaper or steel wool
- Copper wire, 10 cm
- Zinc strip, Zn, 12 cm
- Spatula
- Scissors
- Beaker, 400-mL
- Stirring rod
- Hot plate or Bunsen burner
- Weighing dish

NAME ______________________________ DATE __________ CLASS ___________

Safety

Potassium ferricyanide solution is a skin and eye irritant. Contact with concentrated acids may generate a toxic gas; avoid contact with strong acids. Phenolphthalein is an alcohol-based solution—it is a flammable liquid and moderately toxic by ingestion. Keep away from flames and other sources of ignition. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

1. Clean all of the nails with the steel wool before starting.
2. Prepare the Petri dishes for your experiment and pour the agar suspension into both Petri dishes. Fill the dishes so that the nails will be completely submerged into each.
3. **SEP Plan and Carry Out an Investigation** With your partner, write a procedure on how to prevent or minimize iron corrosion from the available materials provided by your instructor. Before conducting your investigation, show your plan to your teacher for approval.

NAME ______________________ DATE __________ CLASS __________

4. Cover both Petri dishes and set them aside for viewing later.

5. Observe the Petri dishes at the end of the class period. Record your observations indicating where any color changes may be observed.

6. Observe the Petri dishes the next day. Record your observations indicating where any color changes may be observed.

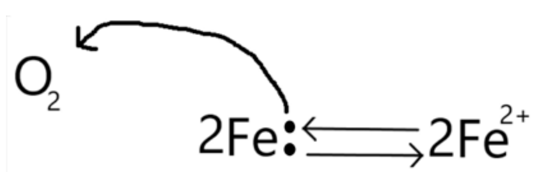
Analyze and Interpret Data

1. **SEP Use Models** Recall the reaction discussed in the introduction to this lab:

$$2Fe(s) + O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4OH^-(aq)$$

A key part of this reaction is illustrated in Figure 1. What process does it show?

Figure 1



NAME ______________________ DATE ____________ CLASS ____________

2. **SEP Use Models** Assign charges to each species in the overall reaction of iron, oxygen, and water.

$$2Fe(s) + O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4OH^-(aq)$$

3. **SEP Use Models** How many electrons did elemental iron lose in the overall reaction?

$$2Fe(s) + O_2(g) + 2H_2O(l) \rightarrow 2Fe^{2+}(aq) + 4OH^-(aq)$$

4. **SEP Construct an Explanation** The Fe^{2+} ions in the control nail can react with the potassium ferricyanide in the agar mixture to produce ferrous ferricyanide (blue solid). Explain why this test is indicative that corrosion happened.

5. **SEP Construct an Explanation** In the presence of OH^- ions, phenolphthalein turns pink, phenolphthalein is present in the agar mixture. Explain why this test is indicative that corrosion happened in the control iron nail.

6. **SEP Support Your Explanation with Evidence** Does copper protect the iron nail from corrosion? Does zinc? What evidence supports this?

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INQUIRY LAB – OPEN

Metal Activity

How are the activity series of metals explored? Take ownership and write your very own procedure to explore the activity series of metals in this lab. You and your partner will carry out a series of possible single replacement reactions of metals with solutions of metal cations in order to determine the activity series of the metals. Which metal is most active? Which metal is least active? Let's find out!

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Copper, Cu, 1 cm^2 strips, 5
- Forceps or tweezers
- Copper(II) sulfate solution, $CuSO_4$, 0.2*M*, 4 mL
- Iron, Fe, 1-cm^2 strips, 5
- Marking pen
- Iron(II) sulfate solution, $FeSO_4$, 0.2*M*, 4 mL
- Paper towels
- Magnesium ribbon, Mg, 1 cm, 5
- Pipets, Beral-type, 5
- Magnesium nitrate solution, $Mg(NO_3)_2$, 0.2*M*, 4 mL
- Reaction plate, 24-well
- Silver nitrate solution, $AgNO_3$, 0.2*M*, 4 mL
- Ruler
- Paper, blank, 1
- Zinc foil, Zn, 1 cm^2 squares, 5
- Sandpaper (optional)
- Zinc sulfate solution, $ZnSO_4$, 0.2*M*, 4 mL
- Distilled water and wash bottle
- Toothpicks (optional)
- Cotton swabs

NAME ______________________ DATE __________ CLASS __________

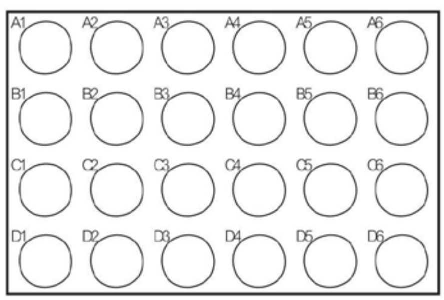
Safety

Silver nitrate is slightly toxic by ingestion and will stain skin and clothing. Copper(II) sulfate and iron(II) sulfate are toxic by ingestion. Metal pieces may have sharp edges—handle with care. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

1. Place a 24-well reaction plate on top of a sheet of white paper as shown below. Each well is identified by a unique combination of a letter and a number, where the letter refers to a horizontal row and the number to a vertical column.

Figure 1



2. Obtain five 1 cm^2 pieces of each metal to be tested—copper, iron, magnesium, and zinc—and lay out the metals in labeled rows on a paper towel. Follow your instructor's directions for polishing the metals, if necessary.

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3. From the available metal ion solutions and the given metal samples, work with your partner to determine the activity series of these metals. In other words, which metal is most active and which metal is least active? Fill in observations in the data table.

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Redox Reactions Data Table					
Metal	**Copper sulfate**	**Iron sulfate**	**Magnesium nitrate**	**Silver nitrate**	**Zinc sulfate**
Copper					
Iron					
Magnesium					
Zinc					

Analyze and Interpret Data

1. **SEP Use Math** Write the balanced net ionic equation for each reaction performed in this activity.

2. **SEP Use Math** In a redox reaction, you can use balanced half-reactions that show just the oxidation or just the reduction that takes place in the reaction. Write the balanced half-cell reactions for three of the reactions performed in this activity such as this oxidation half-reaction:

$$Mg(s) \rightarrow Mg^{2+}(aq) + 2e^{-}$$

3. SEP Make Observations Which metals reacted with (a) the most metal ion solutions and (b) the fewest metal ion solutions?

4. CCC Patterns Compare the general trend in the reactivity of Cu, Fe, Mg, and Zn, and rank the metals from most active (first) to least active (last).

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INQUIRY LAB – OPEN

Build a Micro Battery

Can a small LED (light emitting diode) emit light without a power source? Watch your instructor's large scale voltaic cell demonstration and as a class discuss the different parts of the voltaic cell (battery). A voltaic cell is a device that uses chemical potential energy and converts it to electrical energy. Then, head into lab and build your very own micro battery with an LED and a few other materials. You will not be provided with a detailed procedure.

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Copper(II) sulfate filter paper, 1
- Sodium sulfate filter paper, 1
- LED, 1
- Copper metal tape, 2 cm
- Magnesium metal, 2 cm
- Water, distilled, 2 drops
- Pipet, 1
- Sandpaper, small square, 1
- Scissors
- Tweezers
- Ruler

Safety

The copper(II) sulfate solution is harmful if swallowed and causes serious skin and eye irritation. The sodium sulfate solution may be harmful if in contact with skin. Magnesium ribbon is a flammable solid. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

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Procedure

1. Gently polish both negative (short) and positive (long) terminals on the LED with the sandpaper.
2. Make sure the copper conductive adhesive tape piece and magnesium metal piece are 2 cm in length. Cut the pieces with scissors if necessary.
3. Cover the positive terminal of the LED with the 2-cm piece of the conductive adhesive tape. The sticky side should come in contact with the positive terminal.
4. Place all of the materials on the lab bench top. Materials include: prepped LED, magnesium metal piece, 1 each of copper(II) sulfate and sodium sulfate filter paper squares, and DI water.
5. Assemble this battery so a thermodynamically favored redox reaction occurs and the LED illuminates.

Analyze and Interpret Data

1. **SEP Identify Knowns** Identify and write the equation of the half-reaction that occurs at the positive terminal you constructed.

2. **SEP Identify Knowns** Identify and write the equation of the half-reaction that occurs at the negative terminal you constructed.

3. **SEP Make Observations** How does the micro battery you constructed compare to the battery in the demonstration?

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4. **SEP Use a Model to Evaluate** Describe why the micro battery is a voltaic cell and not an electrolytic cell.

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PERFORMANCE BASED ASSESSMENT

Battery Challenge

How many volts can a battery produce when built from a few simple lab materials? Your chemistry teacher needs help finding the best materials to build a battery with the highest voltage output. In this lab, chemical energy is converted to electrical energy in the form of a battery (a thermodynamically favored cell). You will design, build, and refine your battery and then compare your voltages with the class in a data table. The zinc half-cell is chosen as the reference standard, and all potentials are measured with respect to the zinc electrode. A value of 0.00 volts is assigned to the electrode made from zinc metal in a 1.0*M* solution of zinc ions. A data table of voltage of each half-cell versus the zinc electrode is provided.

Focus on Science Practices

SEP 1 Asking Questions and Defining Problems
SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Metal ion aqueous solutions, 3 mL, 4
- Metal samples, 4
- Beaker, 50-mL
- Sandpaper or steel wool
- Filter paper
- Voltmeter
- Pipets, Beral-type, graduated, 10
- Wires and alligator clips
- Reaction plate, 24-well

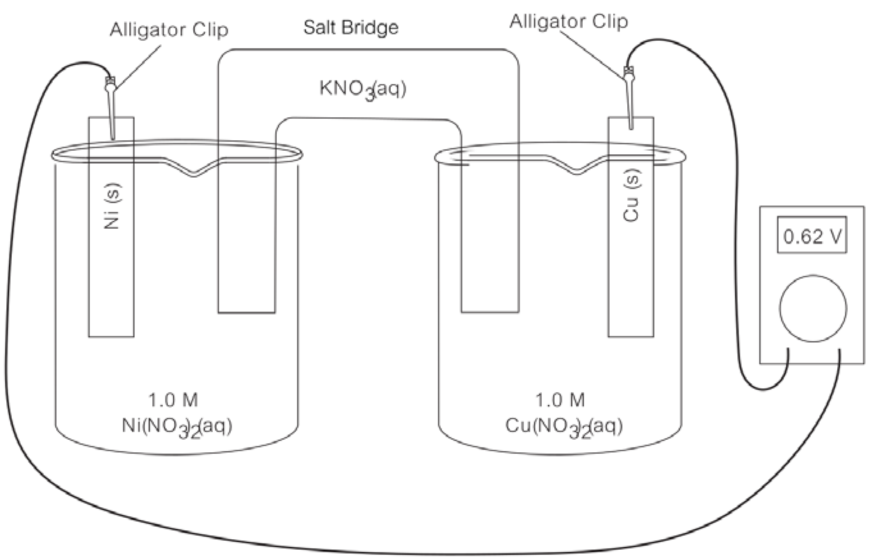
Safety

Silver nitrate solution is toxic by ingestion and irritating to body tissue. It also stains skin and clothing. Lead nitrate solution is a possible carcinogen. It is also moderately toxic by ingestion and inhalation; irritating to eyes, skin, and mucous membranes. Zinc nitrate solution is slightly toxic by ingestion; it is corrosive to body tissue/severe tissue irritant. Copper(II) nitrate solution is slightly toxic by ingestion and irritating to skin, eyes, and mucous membranes. Iron(III) nitrate solution is corrosive to body tissue. Magnesium nitrate solution is a body tissue irritant. Wear chemical splash goggles and *chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.*

Procedure

1. **SEP Identify Knowns** Write a paragraph that describes the parts of the battery shown in Figure 1.

Figure 1



2. **SEP Identify Knowns** What is the purpose of the salt bridge in the battery shown in Figure 1?

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3. **SEP Reason Quantitatively** The nickel metal/nickel(II) nitrate solution is the reference standard in Figure 1. Based on this information, what is the potential, in volts, for the half-reaction $Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$?

4. **SEP Plan Your Investigation** As a collaborative class activity, your instructor will provide your team with four metals and four aqueous solutions. You and your partner will select appropriate materials to build two batteries; refine them; and measure the potential of each battery in volts. At the end of class, you will compare the performance of your refined batteries to those built by other teams and determine which battery produced the highest voltage. As you plan your investigation, keep the following in mind:

   A. A data table indicating voltage of each half-cell versus the zinc electrode is provided to predict the cell potential of each constructed battery.
   B. Make sure to polish each metal with sandpaper or steel wool.
   C. Use the well plates in this experiment as a small-scale comparison to Figure 1.

Voltage of Each Half-cell versus the Zinc Electrode			
	Voltage	**Anode**	**Cathode**
Zn versus Ag	1.41 V	Zn	Ag
Zn versus Cu	0.98 V	Zn	Cu
Zn versus Fe	0.54 V	Zn	Fe
Zn versus Mg	0.62 V	Mg	Zn
Zn versus Pb	0.47 V	Zn	Pb

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5. **SEP Plan and Carry Out Your Investigation** Write out your procedure, making sure to include the materials that will be used. Show your procedure to your teacher before you begin.

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Predicted and Measured Cell Potentials — Class Data				
Anode	**Cathode**	**Chemical Equation**	**Predicted Potential**	**Measured Potential**
Mg	Cu			
Fe	Cu			
Fe	Ag			
Mg	Pb			
Pb	Cu			
Cu	Ag			
Mg	Ag			

Analyze and Interpret Data

1. **SEP Evaluate Your Solution** Of the two batteries that your team built, refined, and tested, which one resulted in a higher voltage?

2. **SEP Compare Solutions** Share your team's measured potential data with the class and collect the measured potentials for the entire class in the data table. Which battery produced the highest voltage according to the class data?

NAME ________________________ DATE ____________ CLASS ____________

3. **SEP Use Models** Write balanced chemical equations for the two cell reactions observed by your team and record in the data table. (Balanced equations for the remaining anode-cathode combinations will be obtained as the class shares and discusses the data.)

4. **SEP Use Math** Refer back to step 4 of the Procedure, which listed the voltage of each half-cell versus the zinc electrode. Use this information to calculate the predicted potentials of the two cell reactions observed by your team, and record in the data table. Show your work; an example is shown below. (Predicted cell potentials for the remaining anode-cathode combinations will be obtained as the class shares and discusses the data.)

Anode	**Cathode**	**Chemical Equation**	**Predicted Potential**	**Measured Potential**
Mg	Cu	$Cu^{2+}(aq) + Mg(s) \rightarrow Cu(s) + Mg^{2+}(aq)$	0.98 + 0.62 = 1.60 V	1.51 V

5. **SEP Evaluate** What factors can cause a difference between the predicted potential and the measured potential values?

Investigation 16

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INQUIRY LAB – OPEN

Investigate Different Hydrocarbons

Hydrocarbons are organic compounds containing only carbon and hydrogen. This apparent simplicity in the structure of hydrocarbons is belied by great variation in the size or length of hydrocarbon molecules, the extent of branching in carbon-carbon chains, the number of possible ring sizes, and the presence of alkene, alkyne, and aromatic functional groups. In this activity you will investigate the properties of some simple hydrocarbons before synthesizing your own sample of polystyrene.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Acetone wash bottle
- Alumina, Al_2O_3, 1 g
- Bromine water, Br_2, 2 mL
- Copper wire
- Cyclohexane, C_6H_{12}, 4 mL
- Cyclohexene, C_6H_{10}, 4 mL
- Dibenzoyl peroxide, $(C_6H_5CO_2)_2$, 0.1 g
- Food dye, red
- Oil dye, blue
- Potassium permanganate solution, 1%, $KMnO_4$, 2 mL
- Toluene, $C_6H_5CH_3$, 4 mL
- Styrene, $C_6H_5CH{=}CH_2$, 1 mL
- Water
- Beaker, 250 mL
- Black (UV) light
- Boiling stones
- Cork stoppers to fit test tubes, 3
- Cotton ball
- Hot plate
- Litmus paper, blue
- Micro spatula
- Paper towels
- Pasteur pipet, glass
- Plastic pipets, disposable, or medicine droppers, 10
- Test tube rack
- Test tubes, borosilicate glass, 13 mm × 100 mm, 7
- Tweezers
- Watch glass, borosilicate glass

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Safety

Carry out all procedures in an operating fume hood. Cyclohexane, cyclohexene, and toluene are flammable liquids and vapors. Keep away from heat, sparks, and open flames. Hydrocarbons may cause drowsiness or dizziness if inhaled. Avoid breathing vapors or mist. Styrene and toluene are suspected reproductive hazards and may damage an unborn child. Work with these compounds in an operating fume hood only and do not use them if you are pregnant. Dibenzoyl peroxide is a self-reactive substance; heating may cause a fire or explosion. Keep away from heat, sparks, and open flames. Avoid breathing dust or fumes. Bromine water is a dilute solution of bromine; it is toxic by inhalation and will irritate skin and eyes. Avoid breathing the vapor, and work with bromine water in an operating fume hood only. Wear chemical splash goggles, chemical-resistant gloves, and a lab coat or chemical-resistant apron. Please follow all normal laboratory safety guidelines and wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part I. Polymerization of Styrene

1. Set up a boiling water bath: Fill a 250 mL beaker about half-full with water and add a boiling stone. Heat on a hot plate at a medium-high setting.
2. Styrene contains an inhibitor to prevent unwanted polymerization. Remove the inhibitor by passing the styrene through a short column of alumina (aluminum oxide). Using Figure 1 as a reference: Place a small plug of cotton into a glass Pasteur pipet, and push the cotton down into the neck of the pipet using copper wire. Fill the pipet with about 1 cm of alumina.
3. Obtain 1 mL of styrene in a clean disposable pipet, and slowly drip the liquid through the alumina column in the Pasteur pipet. Collect the purified styrene in a clean and dry borosilicate glass test tube.

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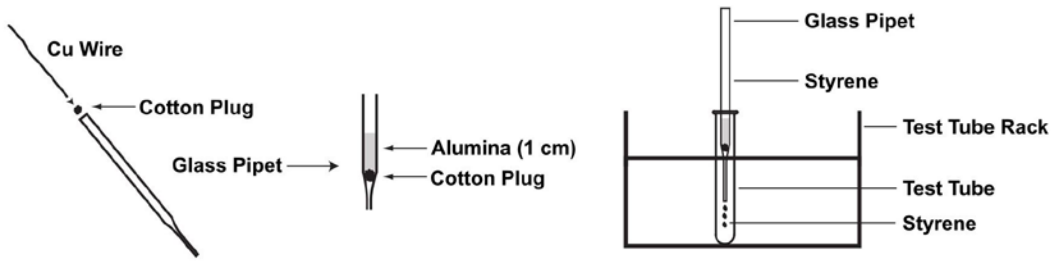
Figure 1



4. ⚠ Using a micro spatula, add 2 grains of dibenzoyl peroxide to the styrene and place the test tube in the boiling water bath for about 10 minutes.

5. After 10 minutes, remove the test tube from the boiling water bath using a test tube clamp and carefully pour the contents of the test tube onto a large borosilicate glass watch glass. Allow the product to harden and cool and record observations.

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Part II. Properties of Hydrocarbons

6. **SEP Plan An Investigation** Plan an experiment to examine the properties of the provided hydrocarbons. *Warning: Bromine water must only be used in a fume hood.* Record your detailed procedure as well as any materials to be used. Show your procedure to your instructor before beginning any experimental work. The first three steps are already included for you.

   1. Obtain 1 mL each of the following liquids in clean, dry test tubes (1−6).

Test Tube	1	2	3	4	5	6
Compound	Cyclohexane	Cyclohexene	Toluene	Cyclohexane	Cyclohexene	Toluene

   2. Add 2–3 drops of red food coloring to each test tube 1–3 and observe the color and appearance of each mixture.
   3. Add 2–3 drops of blue oil dye to each test tube 4–6. Observe the color and appearance of each mixture.

7. Record the results of your tests in the data table.

8. Dispose of all waste liquids and solids as directed by your instructor.

NAME ______________________ DATE __________ CLASS __________

Data Table—Hydrocarbon Observations/Properties			

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Obtain Information** Look up and draw the structures of cyclohexane, cyclohexene, and toluene.

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2. **SEP Identify Patterns** Based on your observations, classify each of the dyes as either polar or nonpolar. Explain your reasoning.

3. **SEP Form a Hypothesis** Why do you think the bromine water and permanganate solution reacted differently with different hydrocarbons?

4. **SEP Apply Scientific Reasoning** Predict what will happen if bromine water is mixed with cyclooctyne (C_8H_{12}).

5. **SEP Obtain Scientific Information** One of the most common uses for polystyrene is in packaging. Compare the sample of polystyrene you produced with the type used in packaging, then research and describe how it is that manufacturers are able to generate these different forms of polystyrene.

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INQUIRY LAB – OPEN

Ester Synthesis

What do you "taste" when you bite into an apple or a banana? The unique flavor of any food is due to a combined sense of both taste and smell. Indeed, the first taste perception of a food comes from the aroma or fragrance of volatile organic compounds. In the case of fruits, the primary flavor and fragrance ingredients are organic compounds called esters. What are esters and how can they be prepared in the lab?

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 6 Construct Explanations and Design Solutions

Materials Per Group

- Acetic acid, CH_3COOH, 4 mL
- Benzoic acid, C_6H_5COOH, 2 g
- Ethanol, CH_3CH_2OH, 4 mL
- Methanol, CH_3OH, 4 mL
- 3-Methyl-1-butanol, $(CH_3)_2CHCH_2CH_2OH$, 4 mL
- 1-Octanol, $CH_3(CH_2)_7OH$, 4 mL
- Propanoic acid, CH_3CH_2COOH, 4 mL
- 1-Propanol, $CH_3(CH_2)_2OH$, 4 mL
- Salicylic acid, $HOC_6H_4CO_2H$, 2 g
- Sodium bicarbonate solution, $NaHCO_3$ saturated, 8 mL
- Sulfuric acid, H_2SO_4, concentrated, 2 mL
- Water, tap
- Beaker, 400 mL
- Boiling stone
- Beral-type pipets, 4
- Cotton balls
- Graduated cylinder, 10 mL, 2
- Hot plate
- Pasteur pipet, glass
- Test tube clamp
- Test tube rack
- Test tubes, medium, 8
- Thermometer
- Watch glasses, 4
- Wax pencil

Safety

Perform this experiment in a hood or well-ventilated lab. Concentrated sulfuric acid causes severe skin burns and eye damage. Wear protective gloves and clothing. Wash your hands thoroughly after handling. Notify the instructor and clean up all spills, even a few drops, immediately! Acetic acid is corrosive to skin and body tissue. It is a moderate

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fire risk and toxic by ingestion and inhalation. Methanol (methyl alcohol) is extremely flammable, a dangerous fire risk, and toxic by ingestion. Keep away from heat, sparks, and open flames. Ethanol (ethyl alcohol) is a flammable solvent and toxic by ingestion. Propanoic acid is a flammable liquid and causes severe skin burns and eye damage. It may be harmful if swallowed and has a rancid odor. Salicylic acid is moderately toxic by ingestion. 1-Propanol (propyl alcohol) is irritating to skin and eyes and is slightly toxic by ingestion. Benzoic acid is slightly toxic by ingestion and causes serious eye irritation. Avoid contact of all chemicals with skin and eyes. Do not use any flames in the laboratory when working with alcohols and other flammable liquids. Keep away from all sources of ignition.

Volatile organic liquids, such as the low–molecular weight alcohols and carboxylic acids used in this experiment, may cause drowsiness or dizziness and may be harmful if inhaled. Do not breathe vapors, mist, or spray. To smell a product, carefully waft the vapors to your nose—do NOT "sniff!" Never taste anything in a laboratory setting. Wear chemical splash goggles, chemical-resistant gloves, and a lab coat or chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Fill a 400 mL beaker two-thirds full with hot tap water and add a boiling stone. Heat the water to about 80 °C on a hot plate.

2. Choose two alcohols and two carboxylic acids from the list of materials. Write the names of the alcohols and acids selected for testing in the data table. Note: In order to test all possible combinations, the instructor may select the alcohols and carboxylic acids that will be tested by each group.

3. Obtain four medium test tubes. Make sure each test tube is clean and dry. Label the test tubes with the name or an abbreviation for each reagent selected (e.g., MeOH for methanol, BA for benzoic acid, etc.).

4. Obtain about 4 mL of each alcohol and acid to be tested in the corresponding test tube. Note: In the case of solids, obtain about 2 grams of the compound.

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5. **SEP Plan An Investigation** Plan out how you intend to synthesize your four different esters. Remember esters are formed by the reaction of an alcohol with a carboxylic acid. Record your detailed procedure as well as any materials to be used. Show your procedure to your instructor before beginning any experimental work.

6. Once your reaction is complete, add 2 mL of saturated sodium bicarbonate solution to each test tube. Record observations in the data table.

7. ⚠ Using a glass Pasteur pipet, remove 1–2 drops of liquid from the upper layer in test tube 1. Add the drops to a cotton ball on a clean watch glass. Carefully waft the vapors from the watch glass to your nose to smell the product. To detect the odor, first hold your breath briefly and then fan your fingers across the cotton ball. Inhale slightly. See Figure 1.

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Figure 1

8. In the data table, describe the odor of the ester product. Some odors will be easy to identify. Adjectives that fragrance chemists use to describe odors include floral, fruity, earthy, pungent, musky, sweet, herbal, green, etc.

9. Wait a few minutes, then use a similar technique to detect the odors of the ester products in test tubes 2–4.

10. Dispose of the contents of the test tubes according to your instructor's directions.

Data Table—Ester Formation			
Test Tube	**Alcohol**	**Carboxylic Acid**	**Observations**
1			
2			
3			
4			

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Analyze and Interpret Data

1. **SEP Construct an Explanation** Why was sulfuric acid added to the test tube? (Hint: the exact quantity was not important)

2. **SEP Obtain Information** Look up and draw the structures of the alcohols and carboxylic acids you selected, and the esters you produced. Write your answer as a chemical reaction.

3. **SEP Identify Patterns** Look at the names of the ester you synthesized and the chemicals you synthesized them from. Which two chemicals should be reacted together to form ethyl butanoate?

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INQUIRY LAB – OPEN

Protein and Amino Acid Tests

How can we detect proteins and the amino acids they contain? Proteins are large organic molecules that perform essential functions within organisms. In this lab you will conduct tests to detect the presence of proteins, and some of their amino acids.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 8 Obtaining, Evaluating, and Communicating Information

Materials Per Group

- Albumin, 2%, 4 mL
- Arginine, 1%, 4 mL
- Biuret test solution, 10 mL
- Casein, 2%, 4 m
- Cysteine, 1%, 4 mL
- Gelatin, 2%, 4 mL
- α-Naphthol, 0.1% in ethyl alcohol, 2–3 mL
- Nitric acid, HNO_3, 3 M, 7 mL
- Sodium hydroxide, NaOH, 3 M, 10 mL
- Sodium hypochlorite (bleach), NaOCl, 5%, 30 mL
- Sodium nitroferricyanide, $Na_2Fe(CN)_5NO \cdot H_2O$, 2%, 5 mL
- Tyrosine, 1%, 4 mL
- Unknown A, 4 mL
- Unknown B, 4 mL
- Beakers, 400 mL and 600 mL
- Boiling stone
- Hot plate
- Pipets, Beral-type, graduated, 8
- Test tubes, small, 13 mm × 100 mm, 7
- Test tube clamp
- Test tube rack
- Wash bottle
- Water, distilled or deionized
- Wax pencil

Safety

Biuret test solution contains copper sulfate, which is moderately toxic by ingestion, and sodium hydroxide, which is corrosive to eye and body tissue. α-Naphthol is slightly toxic by ingestion, inhalation, and skin absorption and is a body tissue irritant. α-Naphthol *solution contains ethyl alcohol and is a flammable liquid—avoid contact with flames or other sources of ignition.*

Hydrochloric acid, nitric acid, sodium hydroxide, and sodium hypochlorite solutions are corrosive liquids and can cause skin burns. Sodium nitroferricyanide is highly toxic by ingestion and inhalation. Do not allow this solution to come in contact with acids. Do not heat the solution. Dispense and use sodium nitroferricyanide in the hood or in a well-ventilated lab only. Avoid exposure of all chemicals to eyes and skin. Follow instructor guidelines for disposing of test solutions. A solution of sodium hypochlorite may be used for oxidizing sodium nitroferricyanide solutions. Sodium hypochlorite and sodium nitroferricyanide will generate toxic gases upon reaction with concentrated strong acids. Wear chemical splash goggles, chemical-resistant gloves, and a lab coat or chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

Prepare a boiling water bath for use in the xanthoproteic test and protein denaturation. Fill a 400 mL beaker half-full with water, add a boiling stone, and heat to boiling on a hot plate at a medium setting.

Part I. Biuret Test

1. Label a set of seven test tubes 1–7.
2. Use a graduated Beral-type pipet to add 1 mL of each solution to be tested to the appropriate test tube, as follows:

Test Tube	1	2	3	4	5	6	7
Solution	Water	Albumin	Casein	Gelatin	Arginine	Cysteine	Tyrosine

3. Add 1 mL of biuret test solution to each test tube.
4. Observe and record the color and appearance of each mixture.
5. Pour 25 mL of 5% sodium hypochlorite solution into a 600 mL beaker. Place this "waste beaker" in an operating fume hood for use in steps 6, 12, 17, 21, and 24.

6. Rinse the contents of the test tubes with a large amount of water into the waste beaker. Wash the test tubes and rinse well with distilled water. Relabel them 1–7, if necessary, for use in the next test.

Part II. Xanthoproteic Test

7. Repeat step 2 to prepare a set of protein and amino acid samples to be tested.

8. Add 1 mL of 3 M nitric acid to each test tube.

9. Place the test tubes in the boiling water bath for 3–5 minutes.

10. Use a test tube clamp to remove the test tubes from the boiling water bath. Allow the solutions to cool and record observations.

11. Turn off the hot plate.

12. Rinse the contents of the test tubes with a large amount of water into the waste beaker containing sodium hypochlorite and excess sodium hydroxide from steps 5 and 6.

13. Wash the test tubes and rinse well with distilled water. Relabel them 1–7, if necessary, for use in the next test.

Part III. Sakaguchi Test

14. Repeat step 2 to prepare a set of protein and amino acid samples to be tested.

15. Add 3 drops of 3 M sodium hydroxide, followed by 5 drops of α-naphthol solution to each test tube.

16. Add 10 drops of sodium hypochlorite to each test tube and record the color and appearance of each solution.

17. Rinse the contents of the test tubes with a large amount of water into the waste beaker. Wash the test tubes and rinse well with distilled water. Relabel them 1–7, if necessary, for use in the next test.

Part IV. Nitroprusside Test

18. Repeat step 2 to prepare a set of protein and amino acid samples to be tested.

19. Add 20 drops of 3 M sodium hydroxide, followed by 10 drops of sodium nitroferricyanide solution to each test tube.

20. Record the color and appearance of each solution.

21. Rinse the contents of the test tubes with a large amount of water into the waste beaker. Wash and rinse the test tubes.

Parts I–IV. Data Table—Test Results

Test Tube	1	2	3	4	5	6	7
Biuret							
Xanthoproteic							
Sakaguchi							
Nitroprusside							

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Part V. Unknown identification

22. Obtain two knowns from your instructor.

23. **SEP Plan An Investigation** Plan out how you intend to identify these unknowns. You should aim to have them identified in the fewest number of steps. Record your detailed procedure as well as any materials to be used. Show your procedure to your instructor before beginning any experimental work.

24. Rinse the contents of the test tubes with a large amount of water into the waste beaker. Wash and rinse the test tubes.
25. Consult your instructor regarding proper disposal of the contents of the waste beaker.

Part V. Data Table—Unknown Identification		
Test Tube	**Unknown A**	**Unknown B**

NAME ______________________ DATE __________ CLASS __________

Analyze and Interpret Data

1. **SEP Interpret Data** What does a negative biuret test look like?

2. **SEP Interpret Data** Which samples tested positive for protein?

3. **SEP Interpret Data** What does a negative xanthoproteic test look like?

4. **SEP Interpret Data** Which amino acid is detected by the xanthoproteic test?

5. **SEP Interpret Data** What does a negative Sakaguchi test look like?

6. **SEP Interpret Data** Which amino acid is detected by the Sakaguchi test?

NAME ______________________ DATE __________ CLASS __________

7. **SEP Interpret Data** What does a negative nitroprusside test look like?

8. **SEP Interpret Data** Which amino acid is detected by the nitroprusside test?

9. **SEP Obtain Information** Look up each of the species that you tested. Were there any false negatives/positives?

10. **SEP Interpret Data** What are the identities of your two unknowns?

11. **SEP Apply Scientific Reasoning** Why did some of the samples test positive for both protein and specific amino acids?

NAME ______________________ DATE __________ CLASS __________

PERFORMANCE BASED ASSESSMENT

Prepare and Characterize Biodiesel

Biodiesel is an alternative processed fuel obtained from biological sources, usually vegetable oils, for use in cars and trucks. There is currently a great deal of interest in alternative fuels such as biodiesel or bioethanol because of concerns about climate change and the depletion of nonrenewable energy sources such as petroleum. The purpose of this activity is to prepare biodiesel and investigate the amount of energy it releases when burned.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking

Materials Per Group

- Canola or corn oil, 25 mL
- Methanol, CH_3OH, with 2.5% KOH, 10 mL
- Alcohol burner with wick and cap, empty
- Aluminum soda can, with opening tab, 355 mL
- Balance, 0.01 g precision
- Beaker, 50 mL
- Graduated cylinders, 25 and 50 mL
- Erlenmeyer flask and rubber stopper, 125 mL
- Lighter
- Hot plate or hot water bath
- Magnetic stirrer and stir bar
- Ring clamp and support stand
- Separatory funnel, 125 mL
- Stirring rod
- Thermometer, digital

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Safety

Methanol (methyl alcohol) is a flammable liquid and a dangerous fire risk—keep away from heat, sparks, and open flames. It is toxic by ingestion and inhalation and is rapidly absorbed by the skin, eyes, and mucous membranes. Potassium hydroxide solution in methanol is a corrosive liquid and will cause severe skin burns and eye damage. The biodiesel fuel is a flammable liquid. Carefully inspect the workplace area before doing the calorimetry experiment.

Make sure there are no open methanol containers. Avoid contact of all chemicals with eyes and skin and perform this experiment in a hood or well-ventilated lab. Wear chemical splash goggles, chemical-resistant gloves, and a lab coat or chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

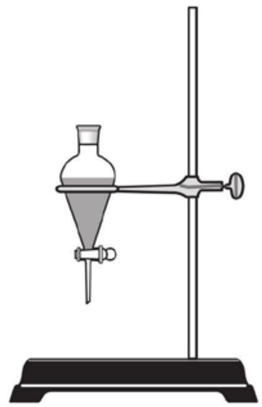
Procedure

Part I. Preparation of Biodiesel

1. Using a clean 25 mL graduated cylinder, add 25 mL of canola or corn oil to a 125 mL Erlenmeyer flask. Gently heat the oil to 45–50°C in a hot water bath or on a hot plate at the lowest setting. Turn off the heat when the oil reaches the desired temperature.
2. Measure 10 mL of methanol/KOH solution in the 25 mL graduated cylinder and transfer it to the flask.
3. Add a stir bar to the flask. Stopper the flask and mix the contents rapidly on a magnetic stirrer for 5 minutes.
4. Stop stirring and check the mixture. The mixture should be an emulsion, which will gradually separate into two layers.
5. Continue stirring the mixture for 20 minutes.
6. Making sure the stopcock at the bottom of the separatory funnel is closed, carefully decant the reaction mixture from the Erlenmeyer flask into the funnel.
7. Place the separatory funnel in a ring and secure the ring to the ring stand (Figure 1).

NAME ______________________________ DATE ____________ CLASS ____________

Figure 1



8. Allow the mixture to sit until two distinct liquid layers are observed.

9. Place a 50 mL beaker under the funnel and slowly open the stopcock. Collect the lower layer in the small beaker. The lower or more dense layer contains glycerol and methyl alcohol.

10. Close the stopcock when the lower layer has been removed. Pour the remaining liquid from the separatory funnel into a flask or graduated cylinder. This is the crude biodiesel.

11. Measure the volume of biodiesel in a 50 mL graduated cylinder. Record the volume of fuel produced and its color and appearance.

12. Clean all glassware and dispose of the bottom layer, which is a mixture of glycerol, methyl alcohol, and potassium hydroxide, as directed by the instructor.

NAME ______________________ DATE __________ CLASS __________

Part II. Biodiesel Heat of Combustion

13. **SEP Plan An Investigation** Plan an investigation to measure the heat of combustion for your biodiesel. Record your detailed procedure as well as any materials to be used. Show your procedure to your instructor before beginning any experimental work. A blank data table has been provided for you to record your results.

14. Dispose of the biodiesel fuel as directed by the instructor.

NAME ________________________ DATE ____________ CLASS ____________

Part II. Data Table—Biodiesel Heat of Combustion		

Analyze and Interpret Data

1. **SEP Calculate** What was the average heat of combustion (kJ/g) for your biodiesel?

2. **SEP Interpret Data** The heat of combustion for commercial diesel is 44.80 kJ/g. How does your sample of biodiesel compare?

3. **SEP Evaluate Your Plan** Identify at least two reasons why your experimental heat of combustion is different from the expected value.

NAME ______________________ DATE __________ CLASS __________

4. **SEP Refine Your Plan** What changes to your experimental setup could be made to improve your result?

5. **SEP Develop Models** Construct a model describing how energy flows from the biodiesel into the water. Your model should account for where the energy comes from and where it ends up.

6. **SEP Apply Scientific Reasoning** There are several oils, such as canola, olive, and peanut) that are commonly used in cooking. Would you expect all oils to have the same heat of combustion?

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INQUIRY LAB – OPEN

Radioactive Decay

Radon–222 is a naturally occurring radioactive gas that is generated as part of the uranium decay series. Unlike the other products in this decay chain, radon is a gas. It can seep from the ground (through rock) into homes. It is the second highest cause of lung cancer in the United States of America and has an approximate half-life of 3.8 days, which means it can be inhaled and decay before being exhaled. When radon decays it produces polonium and eventually lead. These are heavy metal solids that can attach to lung tissue causing metal toxicity, which generally leads to cancer. They also continue to put off radiation as they decay. In this activity you will use radiation decay cards to identify the elements formed by the radioactive decay of radon–222.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions
SEP 8 Obtaining, Evaluating, and Communicating Information

Materials Per Group

- Radioactive decay cards
- Six-sided dice, 20

Procedure

1. **SEP Use Models** Arrange the radioactive decay cards in order of the natural radioactive decay with either an alpha or beta particle between each element.

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2. After putting the cards in order, make a graph of mass number (y-axis) vs. atomic number (x-axis) for each element in the series. Write the element's symbol at its point on the graph and connect the appropriate points in order of decay with an arrow.

3. Give one example each for an alpha decay equation and a beta decay equation from the graph.

NAME ______________________________ DATE ____________ CLASS ____________

4. **SEP Use Models** The half-lives for each of the elements on the radioactive decay cards are given in the table. Use the provided dice to model the decay of radon–222. You will need to decide which values correspond to a decay for each relevant species, what time period each role represents, and which species is stable enough to represent the end of the modeled decay process. The decay dice values don't need to be 100 percent accurate, however, they should be qualitative.

Half-Life of Uranium–238 Decay Products		
Isotope	**Half-Life**	**Dice result for decay**
Bismuth–210	5.01 days	
Bismuth–214	19.9 minutes	
Lead–206	Stable	
Lead–210	22.3 years	
Lead–214	28.6 minutes	
Polonium–210	138.4 days	
Polonium–214	164.3 μs	
Polonium–218	3.1 minutes	
Protactinium–234	6.75 hours	
Radium–226	1600 years	
Radon–222	3.82 days	
Thorium–230	75,400 years	
Thorium–234	24.1 days	
Uranium–234	246,000 years	
Uranium–238	4.468 billion years	

NAME ______________________ DATE ____________ CLASS ____________

5. Graph the relative amounts of each species present following each dice roll.

Analyze and Interpret Data

1. **SEP Communicate Scientific Information** Radon–222 is a gas. Identify the states of all the daughter species.

2. **SEP Analyze Graphs** Uranium–235 is able to undergo alpha decay. If the product of this decay then undergoes beta decay, which species is produced?

3. **SEP Construct an Explanation** The most stable known isotope of thorium is thorium–232, which produces radon–220 as part of its decay chain. Radon–220 has a half-life of 55.6 seconds. Based on their respective half-lives, would you expect radon–220 or radon–222 to be the greater household hazard? Explain your reasoning.

NAME ____________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Nuclear Energy

From weapons to electrical power generation, the chain reaction of certain radioisotopes has had a profound effect on society and the environment. How do these chain reactions occur and what do they look like? Use the common domino to create a dramatic visual model of this subatomic process.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data

Materials Per Group

- Dominoes, 28
- Ruler
- Stopwatch

Procedure

Part I. Critical Process

1. **SEP Develop Models** Begin laying tiles in a straight row on a stable, flat, and hard surface. Space the tiles approximately 1.5 cm apart.
2. If a turn is needed, make a 180 degree curve of at least six tiles, with the tiles closer on the inside of the turn than on the outside.
3. Knock over the first tile to start the domino chain reaction. Start the stopwatch at the same time as the first domino is knocked over.
4. Stop the stopwatch when all the dominoes have fallen. Record the time in the data table.
5. Repeat steps 1–4 for a second trial.

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Part II. Supercritical Process

6. **SEP Develop Models** Design a domino pattern that represents a supercritical process. Sketch your pattern and show it to your teacher before proceeding.

7. Lay out the tiles according to your pattern.

8. Knock over the first tile to start the domino chain reaction. Start the stopwatch at the same time as the first domino is knocked over.

9. Stop the stopwatch when all the dominoes have fallen. Record the time in the data table.

10. Repeat steps 7–9 for a second trial.

Part III. Nuclear Reactor

11. **SEP Develop Models** Nuclear reactors use control rods to absorb some of the released neutrons to prevent a supercritical process from occurring.

12. Lay out the dominoes in the same pattern as you used for the supercritical process.

13. Choose three dominos to represent control rods and relocate them. A "control rod" domino should be placed in between two other dominos to prevent the chain reaction from occurring.

14. Knock over the first tile to start the domino chain reaction. Start the stopwatch at the same time as the first domino is knocked over.

15. Stop the stopwatch when all the dominoes have fallen. Record the time in the data table.

16. Repeat steps 12–15 for a second trial. Place your control rods in the same position as the first trial.

Data Table—Domino Chain Reaction Times	
Layout	**Time (seconds)**
Critical	
Supercritical	
Reactor	

Analyze and Interpret Data

1. **SEP Calculate** Use your results to calculate the number of dominoes per second that fell down during your critical fission simulation.

2. **SEP Calculate** Use your results to calculate the number of dominoes per second that fell down during your supercritical fission simulation.

3. **SEP Calculate** Use your results to calculate the number of dominoes per second that fell down during your reactor simulation.

NAME ______________________ DATE __________ CLASS ____________

4. **SEP Develop Models** With reference to your data, explain why nuclear power plants use control rods to absorb some of the neutrons released during the fission of uranium-235.

5. **SEP Use a Model to Evaluate** How does the difference between a critical and supercritical reaction explain why we use U-235 instead of U-238?

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INQUIRY LAB – OPEN

Nuclear Radiation and Shielding

Do different sources of radiation require different types of shielding? In this activity we will investigate alpha, beta, and gamma radiation. Their activity, or counts per minute, will be measured using a radiation monitor, which "counts" the number of atoms ionized by nuclear radiation. The relative penetrating power of each radiation will be investigated by measuring how the recorded activity changes as different materials are placed between the sources and the detector. The radiation intensity will then be examined as the distance between the source and radiation monitor is changed.

Focus on Science Practices

SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Alpha source, Po-210, 0.1 μCi
- Beta source, Sr-90, 0.1 μCi
- Gamma source, Co-60, 1.0 μCi
- Metric ruler
- Radiation monitor
- Shielding materials
  - Aluminum sheet, 0.64 mm thick
  - Lead sheet, 1.6 mm thick
  - Paper sheet

Safety

The radiation levels produced by the radioactive sources are extremely low (less than 1.0 μCi) and the sources are contained within sealed disks. Because the ionizing radiation "dose" is very low, no special safety precautions need to be taken. Observe normal laboratory safety guidelines. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands after handling any radioactive materials.

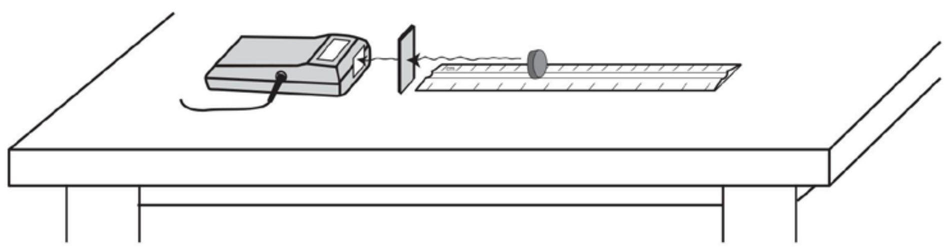
NAME ______________________ DATE __________ CLASS __________

Procedure

Part I. Radiation Shielding

1. Set up the radiation monitor horizontally on the bench and place a metric ruler in front of the detector window (see Figure 1).

Figure 1



2. Set a data collection interval of 60 seconds—this will be the length of time the activity of the radioactive source will be "counted." Set a sampling rate or "count interval" of 10 seconds/sample (0.1 samples/second).

3. Determine the "background" activity when there is no radioactive source placed in front of the radiation detector:

   a. Begin collecting data.

   b. Wait 60 seconds to complete the data collection interval. Record the number of background counts per minute in the data table.

4. Place the alpha source approximately 1 cm from the radiation detector, with the unlabelled side of the disc facing the detector. Begin collecting data, and wait 60 seconds for the program to complete the data collection interval. Record the number of counts per minute in the data table.

5. Place a single sheet of paper between the alpha source and the detector using a plastic mirror support to hold the paper. Measure the activity as before. Try to keep the source in the same position with respect to the radiation detector. Record the number of counts per minute in the data table.

6. Remove the paper and place a sheet of aluminum in the plastic mirror support between the alpha source and the detector. Measure the activity and record the data in the data table.

7. Remove the aluminum and place a piece of lead between the alpha source and the detector. Measure the activity and record the data in the data table.

8. Repeat steps 4–7 for the beta source and then the gamma source.

Part II. Effect of Distance on Radiation Intensity

9. SEP Design A Solution Design an experiment to test how changing the distance between the radiation source and the monitor affects the measured intensity of a radioactive source. Outline your procedure in the space provided. Have your instructor approve your procedure before beginning any lab work.

- Choose a radiation source. Only beta or gamma should be used. Alpha is too weak for reliable results.

NAME ______________________ DATE __________ CLASS __________

Part I. Data Table — Radiation Shielding				
	Number of counts per minute			
Radiation	**No Shielding**	**Shielding**		
		Paper	**Aluminum**	**Lead**
Background		X	X	X
Alpha				
Beta				
Gamma				

Part II. Data Table — Distance and Activity				
Source				
Distance from radiation monitor				
Activity (counts per minute)				

Analyze and Interpret Data

1. **SEP Analyze Data** Compare the background activity versus that of the alpha, beta, and gamma sources. Is it necessary to "correct" (subtract the background radiation from the readings for the sources) the activity of the sources to take into account the level of background radiation? Explain.

2. **SEP Interpret Data** Which shielding material best absorbed each type of radiation?

3. **SEP Construct an Explanation** Which metal, aluminum or lead, is more effective in shielding against beta radiation? What is the reason for the difference in shielding ability of aluminum versus lead?

4. **SEP Identify Patterns** Is it possible to completely stop gamma radiation using a sheet of metal? Would increasing the thickness of the metal stop more gamma radiation? Why or why not?

NAME ______________________________ DATE __________ CLASS __________

5. **SEP Use Graphs** Use graphing software or the space provided to prepare a graph of radiation activity on the y-axis versus distance of the beta or gamma source from the detector on the x-axis.

6. **SEP Design A Solution** How could shielding be used to decide what type of radiation is emitted by an "unknown" radioactive source?

7. **SEP Construct an Explanation** Why do different forms of nuclear radiation travel at different speeds? How is the speed of the radiation related to (a) its ability to "penetrate" matter and (b) its ability to ionize atoms as it travels through matter? Explain.

8. **SEP Apply Scientific Reasoning** X-rays are a form of ionizing radiation. They are high-energy photons (electromagnetic radiation) released when inner shell electrons that have been excited to higher energy levels release their excess energy. What form of nuclear radiation are X-rays similar to? What type of shielding is normally used to protect against X-rays?

NAME ______________________ DATE __________ CLASS __________

PERFORMANCE BASED ASSESSMENT

Natural Radiation

How much radiation does potassium produce? Most people think of nuclear radiation as an artificial or human-made danger. There are, however, numerous natural sources of low-level nuclear radiation in our lives. Natural sources of “background” radiation include cosmic rays from the sun, uranium in soil and rocks, radon in the atmosphere, and carbon-14 as well as potassium-40 in all living things. Potassium, one of the most abundant minerals on Earth, is present in most foods and is an essential element in the human body. It is also a major source of natural radiation. Technology has created additional sources of background radiation. Nuclear medicine encompasses traditional X-rays, as well as radiation therapy and newer forms of diagnosis such as CAT scans. The average radiation dose per person in the United States is 3.6 millisieverts (mSv) per year.

Focus on Science Practices

SEP 2 Developing and Using Models
SEP 3 Planning and Carrying Out Investigations
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Potassium chloride, KCl
- Balance, 0.01 g precision
- Clamp
- Radiation monitor
- Metric ruler
- Spatula
- Support stand
- Watch glass

Safety

Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Wash hands thoroughly with soap and water before leaving the laboratory.

NAME ______________________ DATE ____________ CLASS ____________

Procedure

Part I.

1. Fill in the missing values in the table to estimate your exposure to background radiation. Uranium and other ground elements are based on where you live, and the rest of the answers are based on your exposure over the last year.

Part I. Data Table—Natural Radiation Exposure		
Natural Radiation		**Dose Equivalent (mSv/year)**
Radon		2
Uranium and other ground elements	Coastal regions, 0.16 mSv	
	Continental US, 0.30 mSv	
	Colorado Plateau, 0.63 mSv	
Carbon–14 and potassium–40		0.40
Cosmic radiation (depends on elevation)	0–1000 ft, 0.26 mSv	
	1000–2000 ft, 0.31 mSv	
	2000–3000 ft, 0.35 mSv	
	3000–40000 ft, 0.41 mSv	
Artificial radiation		
X-rays	Dental, 0.01 mSv	
	Arm or leg, 0.01 mSv	
	Chest, 0.06 mSv	
	Head, 0.20 mSv	
Nuclear medicine	CAT Scan, 1.1 mSv	
	Radiographic imaging, 0.14 mSv	
Air travel	0.01 mSv per 2-hour flight	
Total		

NAME ______________________ DATE ____________ CLASS ____________

Part II.

2. **SEP Develop a Model** There are three pathways for the radioactive decay of potassium–40 nuclei—beta emission, positron emission, and electron capture. Write out the nuclear decay equations of each in the space provided.

3. **SEP Plan Your Investigation** Usea radiation detector to design an experiment to measure the radioactivity of potassium chloride. Consider the points that follow and record your procedure in the space provided. Show your procedure to your instructor before beginning.

   - Test two different masses of KCl. Use any mass between 2–10 grams.
   - Determine the best distance for the radiation detector to be from the sample. Conduct various smaller tests to optimize.
   - Be sure to include proper controls, such as background radiation.
   - For reliable data, both the background radiation and KCl samples must be measured for 10 minutes with 10 seconds sampling rate.

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Part II. Data Table—Potassium Chloride Radiation		
Mass of KCl (*g*)	Sample 1	
	Sample 2	
	Counts	**Time Interval (sec)**
Background Radiation		
Sample 1 Radiation		
Sample 2 Radiation		

Analyze and Interpret Data

1. **SEP Use Math** For both the background radiation and the sample radiation, divide the number of "counts" by the time (in seconds) to obtain the rate of decay, R_{back} and R_{KCl}, respectively, in units of disintegrations per second.

2. **SEP Use Math** Use the equation provided to determine the actual rate of decay (R_{actual}) for both potassium chloride samples.

$$R_{actual} = 5 \times (R_{KCl} - R_{background})$$

3. **SEP Use Models** Write a nuclear equation to represent radon-222 decaying to polonium-218. What type of decay does radon-222 undergo and what is its half-life?

NAME ________________________ DATE ____________ CLASS ____________

4. SEP Use a Model to Evaluate Potassium-40 most often undergoes beta decay. Compare this equation with the one for radon-222 in question 3 to explain why radon is considered more hazardous.

5. SEP Apply Scientific Reasoning Artificially produced radioisotopes are used as tracers in nuclear medicine to diagnose disease. Most of these radioactive tracers have fairly short half-lives. What are the advantages and disadvantages of using radioisotopes with short half-lives?

6. SEP Construct an Explanation Why does air travel increase exposure to background radiation?

Investigation 18

NAME ______________________ DATE ____________ CLASS ____________

INQUIRY LAB – OPEN

Toxicity of Road Deicers

Deicers are chemical compounds, or mixtures, that are effective at preventing the formation of ice on roads and sidewalks, thus reducing the likelihood of accidents during the winter months. However, scientists argue that certain substances used as deicers can be hazardous if allowed to leach into the environment. Green chemistry promotes the design of chemical products and processes that reduce or eliminate the use and generation of toxic and hazardous substances. In this investigation, you will compare the ecotoxicity of common ionic salts used as road deicers by measuring their effects on the germination rate of lettuce seeds, and the length of their sprouts, in aqueous solutions containing each one of these salts.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Use Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Sodium chloride solution, 10% NaCl, 10 mL
- Calcium chloride solution, 10% $CaCl_2$, 10 mL
- Magnesium chloride solution, 10% $MgCl_2$, 10 mL
- Sodium acetate solution, 10% CH_3CO_2Na, 10 mL
- Lettuce seeds, 380
- Water, distilled or deionized
- Filter paper, 9
- Forceps or tweezers
- Graduated cylinder, 10 mL
- Graduated plastic pipette
- Ink marker or wax pencil
- Paper towels
- Petri dishes, 9
- Test tubes, 16 mm × 100 mm, 9
- Test tube rack
- Zip lock bag, 2

NAME ______________________ DATE __________ CLASS __________

Safety

Wear safety goggles when performing this or any lab that uses chemicals or glassware. The chemicals used in this laboratory are considered non-hazardous. However, all standard laboratory safety procedures must be followed. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Preparing Lettuce Seeds for Germination

1. **SEP Plan a Procedure** In this investigation, you will design a procedure to determine the effect of deicers on the germination and growth of lettuce seeds. You will have access to stock solutions containing 10% of deicer, which you may use to prepare dilutions that will allow you to explore how the concentration of deicer affects the seeds. Follow these recommendations to design your experimental procedure:

    A. Prepare at least three dilutions of each deicer using the respective stock solution. The dilutions should allow you to explore a wide range of concentration of deicer, from the most concentrated (10%) to a very dilute concentration (e.g. 0.0001%).

    B. Petri dishes may be used to grow the seeds immersed in solutions of varying concentrations of deicer. Place a filter paper at the bottom of each Petri dish, and put the seeds on top. Control for the volume of deicer solution added to each Petri dish, and the number of seeds placed in each dish.

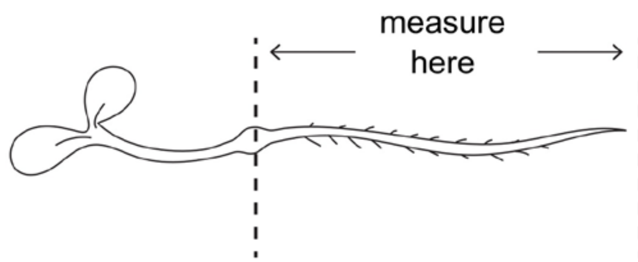
    C. Include a “control” experiment.

    D. Allow the seeds to germinate during five to seven days, in a well-lit location. Record your daily observations during growth in the Data Table–Daily Observations.

    E. Use Figure 1 as a guide to measure the length of the germinated roots.

NAME ______________________ DATE __________ CLASS ___________

Figure 1



2. **SEP Plan a Procedure** Write your procedure.

NAME ______________________ DATE ____________ CLASS ____________

Data Table–Daily Observations	
Day	**Observations**

Data Collection After One Week of Germination

3. Use Data Table–Germination Results to report the results after one week of germination. Note: Calculate the average length (mean) for each plate of seeds. Do not include the seeds that did not germinate or seeds with broken roots when calculating average.

4. Dispose of solid waste in the waste container provided by your instructor.

NAME ______________________ DATE __________ CLASS __________

Data Table–Germination Results					
	Dish No.____ (10% ______)				
Seeds germinated (count)					
Percent of seeds germinated (%)					
Mean root length (cm)					
	Dish No.____ (10% ______)				
Seeds germinated (count)					
Percent of seeds germinated (%)					
Mean root length (cm)					

Analyze and Interpret Data

1. **SEP Analyze Data** Briefly describe the results obtained and what you found out about the effect of the deicer solutions on the germination and growth of lettuce seeds.

NAME ______________________ DATE __________ CLASS ____________

2. **SEP Interpret Data** Based on your results for this experiment, what concentration or concentration range of deicer(s) had effects on the germination and growth of lettuce seeds? Explain.

3. **SEP Evaluate** Do the ionic compounds you tested appear to be green options for use as deicers? Explain your reasoning.

4. **SEP Engage in Argument** Based on the results of this experiment, would you feel comfortable using ecotoxicity data to estimate toxicity for other living organisms? That is, would you feel comfortable saying that deicers that did not prevent germination and growth in a vast majority of lettuce seeds would not be toxic to animals? Explain.

NAME ______________________ DATE __________ CLASS __________

INQUIRY LAB – OPEN

Green Chemistry Analysis of a Reaction

Alkali metal bicarbonates such as sodium bicarbonate ($NaHCO_3$) and potassium bicarbonate ($KHCO_3$) have plenty of uses, including as food additives, and as active ingredients in cleaning products and cosmetics. Bicarbonates can be used as a source for carbon dioxide gas in baking, for example, to cause cakes and pastries to rise. This is because, when decomposed by heat, bicarbonates are transformed into their respective carbonate plus carbon dioxide gas and water vapor. Imagine that you are tasked with analyzing a sample of bicarbonate to be distributed to food manufacturing companies. Unfortunately the bicarbonate may be “contaminated” with carbonate, and you will have to determine the percent composition (by mass) of bicarbonate in the sample. You will need to develop a procedure to test the thermal decomposition of the bicarbonate salts available to you for this laboratory. The results of your measurements will allow you to determine the percent composition of the active ingredient (i.e., the bicarbonate) present in the samples.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Potassium bicarbonate, $KHCO_3$, 2 g
- Potassium carbonate, K_2CO_3, 4 g
- Sodium bicarbonate, $NaHCO_3$, 2 g
- Sodium carbonate, Na_2CO_3, 4 g
- Balance, 0.001 g precision
- Bunsen burner
- Crucible and cover, 2
- Heat-resistant gloves
- Matches or lighter
- Pipe stem triangle
- Ring clamp
- Spatula
- Support stand
- Tongs
- Wire gauze
- Weighing dish or paper, 4

NAME ______________________ DATE ____________ CLASS ____________

Safety

Potassium carbonate, potassium bicarbonate, sodium carbonate, and sodium bicarbonate are slightly toxic by ingestion and are skin irritants. Handle the crucible only with tongs and heat-resistant gloves. Do not touch the crucible with bare fingers or hands. There is a significant burn hazard associated with handling a crucible–remember that a hot crucible looks like a cold one. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron or lab coat. Thoroughly wash hands with soap and water before leaving the laboratory. Follow all laboratory safety guidelines.

Procedure

Read the instructions for proper use of a crucible and a Bunsen burner to carry out thermal decomposition analyses of samples.

Proper Technique for Thermal Decomposition Analysis

1. Set up a Bunsen burner on a support stand beneath a ring clamp holding a pipe stem triangle (see Figure 1). Do not light the Bunsen burner.

2. Adjust the height of the ring clamp so that the bottom of a crucible sitting in the clay triangle is 1–2 cm above the burner. This will ensure that the crucible will be in the hottest part of the flame when the Bunsen burner is lit.

3. Place the crucible with its cover in the clay triangle and heat over a burner flame until the crucible is red hot.

4. Turn off the gas source and remove the burner.

5. Using crucible tongs, remove the crucible cover and place it on wire gauze on the bench top. Using tongs, remove the crucible from the clay triangle and place it on the wire gauze as well (Figure 2).

NAME ______________________ DATE ____________ CLASS ____________

Figure 1

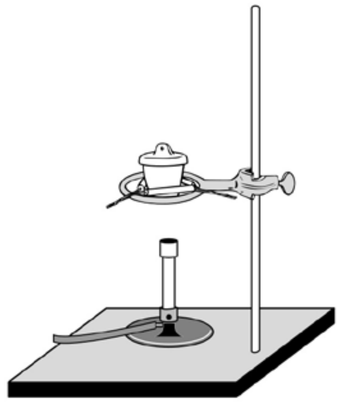
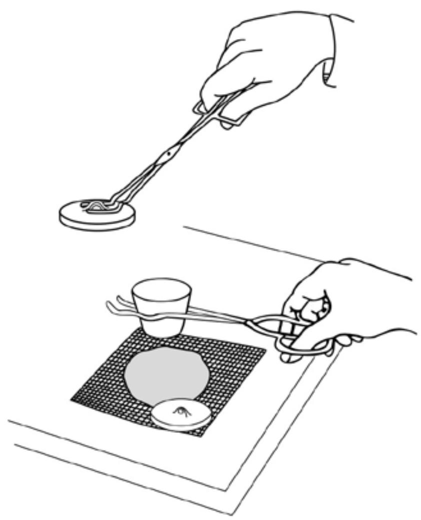


Figure 2



6. Allow the crucible and its cover to cool completely on the wire gauze for at least 10 minutes.

7. Use an analytical balance to find the mass of the crucible and its cover. Handle with tongs and gloves to avoid getting fingerprints on the crucible and cover. Record the mass in the data table.

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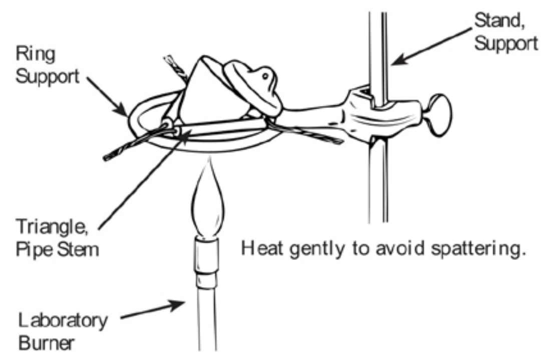
Figure 3



8. Add known mass of solid metal bicarbonate to the crucible. Weigh the crucible, cover, and sample. Record the combined mass in the data table.

9. Set the crucible at an angle in the clay triangle held in the ring on the support stand. Cover the crucible loosely with the crucible cover, and heat very gently. It is important that the escaping vapor does not carry any of the solid along with it, so be sure that the crystals are heated very gently for at least five minutes (Figure 3).

10. Turn off the gas source and remove the burner.

11. Use tongs to remove the crucible cover and place it on wire gauze on the benchtop. With tongs, remove the crucible from the clay triangle and place it on the wire gauze as well.

12. Allow the crucible and its cover to cool completely on the wire gauze for at least 10 minutes.

13. Measure and record the mass of the crucible, its cover, and product in the data table.

14. Repeat the procedure until constant mass is obtained.

15. Record the final mass of the crucible, its cover, and product in the data table.

16. Dispose of the crucible contents according to your instructor's directions. Carefully clean the crucible and crucible cover for use in the next part of the lab.

Develop a Procedure

17. Research the decomposition of sodium bicarbonate and potassium bicarbonate when heated, and write chemical equations to represent these processes.

18. **SEP Plan a Procedure** Write a procedure for this study, and record your results for each compound analyzed in the data table.

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Data Table		
	Crucible 1	**Crucible 2**
Sample name		
Mass of crucible and cover		
Mass of solid sample		
Mass of crucible, cover, and solid sample		
Mass of crucible, cover, and sample after heating		
***Final* mass of crucible, cover, and sample after heating**		
Mass loss		

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Analyze and Interpret Data

1. **SEP Construct an Explanation** Examine the following chemical equations, and use them to explain what the mass loss of each sample is due to.

$2NaHCO_3(s) + heat \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

$2KHCO_3(s) + heat \rightarrow K_2CO_3(s) + CO_2(g) + H_2O(g)$

2. **SEP Use Math** Using the information from question 1, the mass loss measured with each crucible, and the following mathematical relationships (where $MHCO_3$ represents any metal bicarbonate used in this investigation), calculate the moles of sodium or potassium bicarbonate originally present in each mixture. Enter these values in the data table. *Note:* Examine the following mathematical relationships

$$\textit{mass loss} = \textit{mass of } H_2O + \textit{mass of } CO_2$$

From the chemical equations in question 1:

moles of CO_2 = *moles of* H_2O, and *moles of* $MHCO_3$ = 2(*moles of* H_2O)

Because the molar mass of H_2O is 18 g/mol, and the molar mass of CO_2 is 44 g/mol, the mass loss can be expressed as:

$$\textit{mass loss} = (\textit{moles of } H_2O)(18 \text{ g/mol}) + (\textit{moles of } CO_2)(44 \text{ g/mol})$$

Which can be rewritten as:

$$\textit{mass loss} = (\textit{moles of } H_2O)(18 \text{ g/mol} + 44 \text{ g/mol}) = (\textit{moles of } H_2O)(62 \text{ g/mol})$$

Because (*moles of* $MHCO_3$)/2 = *moles of* H_2O

Then, *mass loss*/(62 g/mol) = (*moles of* $MHCO_3$)/2

From this,

$$\textit{moles of } MHCO_3 = 2 \times \textit{mass loss}/(62 \text{ g/mol})$$

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3. **SEP Use Math** Using the information from question 2, calculate the mass of sodium or potassium bicarbonate originally present in each mixture. Enter these values in the data table. *Note:* Use the fact that the mass of one mole of $NaHCO_3$ is 84 g/mol, and that of $KHCO_3$ is 100 g/mol.

4. **SEP Use Math** Using the results from question 3, calculate the percent composition (by mass) of bicarbonate in each sample. Enter these values in the data table. *Note:* To calculate the percent composition (by mass) of bicarbonate in each sample, divide the mass of bicarbonate by the original mass of the sample, and then multiply by 100.

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5. **SEP Use Math** The Atom Economy is a measure of the conversion efficiency of a chemical reaction. The Atom Economy is calculated by dividing the mass of the desired product by the total mass of all the reactants used, and then multiplying by 100. Analyze the chemical equations of the decomposition of sodium bicarbonate and potassium bicarbonate by heating. Calculate the Atom Economy for each reaction. Make sure the chemical equations are balanced before calculating Atom Economy values.

6. **SEP Interpret Data** Are the Atom Economy values for each reaction the same? Are they different? What does this mean for each reaction? Explain.

7. **SEP Construct an Explanation** Based on the Atom Economy values calculated in question 5, is there any difference in the "greenness" of the decomposition of sodium bicarbonate and potassium bicarbonate samples by heating? If you wanted to use any of these reactions to generate carbon dioxide gas, how would you make your decision? Explain.

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8. SEP Construct an Explanation Research the twelve principles of green chemistry online or in a textbook. Besides the Atom Efficiencies, what other aspects of the reactions studied speak to their “greenness”? Is there anything not so “green” about them? Explain.

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INQUIRY LABS – OPEN

How to Recycle Polylactic Acid Plastics

Biobased polymers are derived from renewable biomass resources. This lab features polylactic acid (PLA), a polymer derived from corn. Two of the twelve principles of green chemistry are featured in this lab: the use of renewable feedstocks as starting material, and pollution prevention by converting a waste cup into a cleaning solution. In this laboratory, you will demonstrate how to chemically transform plastic cups made from PLA into household cleaning agents.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 4 Analyzing and Interpreting Data
SEP 6 Constructing Explanations and Designing Solutions

Materials Per Group

- Hydrochloric acid solution, 6*M* HCl, 20 mL
- Polylactic acid cup
- Sodium hydroxide in 1:1 ethanol/water, 1.4*M* NaOH, 100 mL
- Balance
- Beral-type plastic pipette
- Erlenmeyer flask, 250 mL
- Funnel
- Graduated cylinder, 100 mL
- Heat-resistant gloves
- Ice-water bath
- Litmus or pH testing paper
- Magnetic stir bar
- Paper towels
- Permanent marker
- Scissors
- Stirring hot plate
- Stirring rod
- Squirt bottle, plastic
- Thermometer or temperature sensor
- Watch glass
- Weighing dish or paper

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Safety

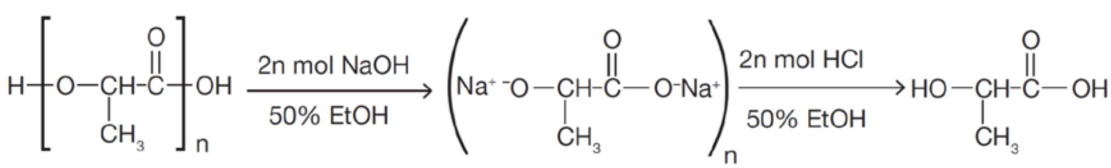
Concentrated hydrochloric acid and aqueous sodium hydroxide solutions are highly toxic by ingestion or inhalation, and both are severely corrosive to skin and eyes. Wear safety goggles when performing this or any lab that uses chemicals, heat, or glassware. Use a glass stirring rod to stir or a magnetic stir bar to stir liquids; never stir with a thermometer. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Make sure you are wearing all the recommended personal protective equipment (PPE) before starting your experiments.

2. Examine the chemical equation in Figure 1, which describes the hydrolysis of PLA in hot sodium hydroxide to sodium lactate, followed by acidification to produce lactic acid. To the left, in brackets, is the chemical structure of the monomer or repeating unit that makes up the polymer. The subscript n represents the number of monomers that constitute the structure of PLA.

Figure 1



3. Design and write a procedure to guide the dissolution of a PLA cup using sodium hydroxide, followed by acidification to generate lactic acid. Your procedure should include the materials listed for this experiment. Take into consideration the following recommendations when you design the procedure.

    - Work with a known amount (i.e., mass) of PLA and sodium hydroxide solution (i.e., volume).

- Keep control of the temperature of the hydrolysis reaction mixture. Begin heating up the solution gently and increase the temperature as needed without allowing the solution to boil vigorously. Use a data table to record temperatures as a function of time.
- Be aware of the pH of the reaction mixture during the acidification process. Record pH values in a data table as a function of acid added.
- Prove that the final lactic acid solution can be used for cleaning purposes.
- Have your teacher check your procedure before implementing it.

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Data Table — PLA Hydrolysis Reaction Progress		
Time	**Temperature**	**Observations**

Data Table — PLA Solution pH		
Amount of ___*M* HCl Added	**Color of Litmus Paper/pH Paper After Addition**	**pH**

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Analyze and Interpret Data

1. **SEP Use Math** Examine the chemical equation in Figure 1. Use this information to calculate the molar mass of the monomer, and the number of moles of NaOH required to completely react with the PLA pieces used in this experiment.

2. **SEP Construct an Explanation** Why is the acidification by HCl required in this process? Explain.

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3. **SEP Make Observations** Describe the appearance of the plastic before it is placed in solution and after it is placed in solution.

4. **SEP Make Observations** Describe the appearance of the solution before the reaction starts and after the reaction is complete.

5. **SEP Make Observations** What is the pH of the solution after the reaction stops, and before any HCl is added?

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6. **SEP Construct an Explanation** Does the plastic degrade under base (or alkaline) hydrolysis conditions? Explain.

7. **SEP Evaluate** How does the lactic acid cleaning solution prepared in this experiment compare to the conventional surface cleaner? Based on its performance and other factors you identify, which cleaning solution would you recommend using?

8. **SEP Construct an Explanation** Discuss whether or not the conversion of polylactic acid cups into a cleaning agent could be considered as an example of green chemistry in action.

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PERFORMANCE BASED ASSESSMENT

Make the Chemistry Lab Greener

Chemistry experiments typically involve working with hazardous substances and may lead to producing large amounts of waste. Minimizing and preventing hazardous working conditions in the lab and reducing the amount of chemical waste is at the core of green chemistry. In this investigation, you will develop greener versions of classical chemistry experiments using innocuous or low-toxicity chemicals, while making efficient use of materials to minimize the generation of waste.

Focus on Science Practices

SEP 3 Planning and Carrying Out Investigations
SEP 6 Constructing Explanations and Designing Solutions
SEP 7 Engaging in Argument from Evidence

Materials Per Group

- Beeswax, 1 g
- Lip balm
- Wax candle
- Wax pencil
- Paper, without any special coating
- Bismuth(III) nitrate solution, $Bi(NO_3)_3 \cdot 5H_2O$, 0.1*M*, 2 mL
- Copper(II) sulfate solution, $CuSO_4 \cdot H_2O$, 0.1*M*, 2–3 mL
- Hydrochloric acid, HCl, 3*M*, 100 mL
- Zinc strip, 5” × 1/2” × 0.01”, 1
- Water, distilled or deionized
- Balance, 0.001 g precision
- Beakers, 50 mL and 200 mL
- Cardboard piece, or clipboard, 1
- Plastic pipettes, Beral-type, 3
- Ruler
- Scissors
- Test tubes, 13 mm × 100 mm, 5
- Test tube rack
- Tweezers (optional)

Safety 

Beeswax, lip balm, and any other wax used in this experiment should be treated as a chemical and is not for consumption as it has been stored with other nonfood-grade chemicals. Bismuth(III) nitrate solution contains nitric acid, and it is irritating and corrosive to skin and eyes. Copper(II) sulfate solutions may be irritating to skin and eyes.

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Hydrochloric acid solutions may cause severe skin and eye irritation and burns; hydrochloric acid is toxic when inhaled or ingested orally. Wear safety goggles, gloves, and an apron when performing this lab. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Before starting, your instructor will assign you the part(s) of the investigation you will be working on.

Part I. Hydrophobic and Hydrophilic Surfaces

1. **SEP Plan Your Investigation** The objective of this experiment is to investigate what makes a surface hydrophilic or hydrophobic. Using a paper strip, wax (you may use different types of wax), a wax pencil, or lip balm, design an experiment in which you compare the hydrophilic or hydrophobic character of paper before and after applying a uniform coating of any of these materials. Consider the following instructions in the design of your experiment.
    - Cut the paper into several strips. Cut the strips so that their length is at least four times their width.
    - Apply a thin, uniform coating of wax/wax pencil/lip balm to a clean strip of paper.
    - Compare the effect of each type of coating on the hydrophobic/hydrophilic character of the treated paper.
    - If time permits, you can compare how fast a drop of water travels on the surface of each paper strip by supporting the latter on a piece of cardboard or a clipboard, and inclining it to an angle between 20–30° with respect to the lab bench.

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2. **SEP Plan and Carry Out Your Investigation** Write your procedure. Show your plan to your teacher before you carry out your investigation.

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3. Write your observations for each paper strip in the data table for Part I.

Part I. Data Table–Hydrophobic and Hydrophilic Surfaces		
Trial	**Coating Material**	**Observations**
1	Paper without coating	
2	Beeswax	

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Part II. Precipitation Reactions

4. Investigate the reaction of silver nitrate ($AgNO_3$) and chloride ions (Cl^-), and the reaction of bismuth nitrate ($Bi(NO_3)_3$), hydrochloric acid (HCl), and water. Write the chemical equations that represent these reactions.

5. SEP Plan and Carry Out Your Investigation Design a procedure to demonstrate the precipitation reaction that involves $Bi(NO_3)_3$, HCl, H_2O, and the solid product. In addition, use your experiment to show how changing the concentration of HCl and H_2O affects the equilibrium of this reaction. Write the steps of your procedure. Note: Begin by mixing small volumes (1–2 mL) of $Bi(NO_3)_3$ solution and HCl solution.

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6. Write your observations for the reaction in the data table for Part II.

Part II. Data Table–Precipitation Reactions		
Step	**Reaction Mixture**	**Observations**
1	$Bi(NO_3)_3$ solution + HCl solution	
2	$Bi(NO_3)_3$ solution + HCl solution + H_2O	

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Part III. Using a Catalyst to Increase the Rate of a Reaction

The oxidation of zinc metal (Zn) to zinc ions and electrons ($Zn^{2+} + 2e^-$) takes place in acidic solutions (e.g. in a hydrochloric acid solution, HCl(*aq*)). This reaction also generates hydrogen gas ($H_2(g)$) as a product. However, the formation of H_2 when Zn is placed in an acid solution can be slow. To speed up the production of H_2, copper in the form of copper(II) ions can be added to the reaction. In this investigation, you will explore how copper(II) ions can increase the rate of H_2 production when Zn is placed in an HCl solution.

7. Equation 1 represents the reaction between metal zinc and HCl in water, which generates hydrogen gas, and zinc and chloride ions. Copper(II) ions are not shown in the equation because they are a catalyst. Balance the equation using the appropriate stoichiometric coefficients.

Equation 1:

$$\_\_\_ Zn(s) + \_\_\_ H^+(aq) + \_\_\_ Cl^-(aq) \rightleftharpoons \_\_\_ Zn^{2+}(aq) + \_\_\_ H_2(g) + \_\_\_ Cl^-(aq)$$

8. SEP Plan and Carry Out Your Investigation Develop a procedure to test the reaction between metal zinc and the HCl solution with and without the catalyst. Also, test what happens if only the catalyst and HCl solution are mixed. Ask your instructor for the catalyst solution. Write your procedure. Show your plan to your teacher before you carry out your investigation.

9. Write your observations for each trial (Zn + HCl solution; Zn + catalyst solution + HCl solution; and catalyst solution + HCl solution) in the data table for Part III.

Part III. Data Table–Using a Catalyst to Increase the Rate of a Reaction		
Trial	**Reaction Mixture**	**Observations**
1	Zn + HCl solution	

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Analyze and Interpret Data

1. **SEP Construct an Explanation** Briefly explain the outcome of your investigation with hydrophobic and hydrophilic surfaces in Part I. What causes the differences in the interactions between paper and water before and after treating the paper with the waxes utilized for this experiment?

2. **SEP Engage in Argument** Another experiment to explore hydrophobic versus hydrophilic properties of surfaces involves chemically treating a copper metal surface with organic molecules to form a coating that repels or attracts water molecules. This experiment commonly utilizes highly pure copper and toxic, pungent organic compounds that have sulfhydryl groups (–SH). Use the 12 Principles of Green Chemistry to argue whether the experimental procedure for Part I “Hydrophobic and Hydrophilic Surfaces” is a greener approach compared to the experiment involving a chemically treated copper surface.

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3. **SEP Construct an Explanation** Write a concise explanation of your results and observations from Part II, in which you explored a precipitation reaction.

4. **SEP Engage in Argument** A classic experiment to study the formation of a solid precipitate is the reaction between silver cations (Ag^+) and chloride anions (Cl^-), which generates silver chloride (AgCl), a solid that is insoluble in water. Use the 12 Principles of Green Chemistry to argue whether the experimental procedure for Part II "Precipitation Reactions" is a greener approach compared to the experiment involving the formation of AgCl.

5. **SEP Construct an Explanation** Explain your results and observations from Part III, in which you investigated the use of a copper(II) catalyst to increase the rate of reaction between zinc metal and hydrochloric acid. How do the rates of production of hydrogen bubbles compare with and without the copper(II) added? Does the copper(II) mixed with HCl produce hydrogen bubbles too?

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6. **SEP Engage in Argument** Use the 12 Principles of Green Chemistry and argue whether the experimental procedure for Part III "Using a Catalyst to Increase the Rate of a Reaction" can be considered a greener approach to the production of hydrogen using zinc metal in pure hydrochloric acid solution.

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