INTERNATIONAL SPY MUSEUM

LESSON PLAN
DEVELOPED SEPTEMBER 2023

CHEMICAL CONUNDRUM

GRADES | 4th - 6th
TIME | 60 minutes
SCIENCE BRANCH | Chemistry
KEY CONCEPTS
Chemical Reactions, Cause and Effect, Solubility, pH, Conductivity

Lesson Overview

In this culminating lesson, students will apply what they have learned about chemical reactions, acids and bases, solubility, and conductivity to determine which mystery powder has the same chemical properties as the unknown substance that was found on the letter. Students will conduct a series of experiments on each of the ten mystery powders and then analyze the data collected to solve the mystery.

Learning Goals / Objectives

Students Will Be Able To:

- Make observations and use cause and effect relationships to explain changes.
- Determine which combinations of materials produce chemical reactions.

NGSS Performance Expectations

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Planning and Carrying Out Investigations Conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.	**PS1.B: Chemical Reactions** When two or more difference substances are mixed, a new substance with different properties may be formed.	**Cause and Effect** Cause and effect relationships are routinely identified and used to explain change.

Background Information for Teachers

Prerequisite Skills

Students should be familiar with identifying chemical changes (color change, odor, temperature change, formation of bubbles/gas, precipitate, etc.), solubility, conductivity, and the pH scale.

Safety Precautions

The substances used in this lesson were chosen because they demonstrate a variety of physical and chemical changes, and they all should be easy to acquire from a supermarket. Nothing adverse should happen when these substances are mixed; however, because the red cabbage indicator can stain clothing and some of the substances may cause a slight irritation if they come in contact with eyes, we recommend having aprons and safety glasses available for students to wear. You may also consider providing latex/non-latex gloves for students to wear during the experiment to align with standard safety protocols for working with unknown substances. All powders, liquids, and waste from this experiment are safe to dispose of in the garbage.

Materials

For Preparation:

- O Baking Powder (1 cup)
- O Baking Soda (2 cups)
- O Corn Starch (1 cup)
- O Epsom Salt (1 cup)
- O All Purpose Flour (1 cup)
- O Powdered Sugar (1 cup)
- O Salt (1 cup)
- O Granulated Sugar (1 cup)
- O Washing Soda (Sodium Carbonate) (1 cup)
- O 10 trays/bins (to transport materials from group to group)
- O 10 clear plastic 8 oz. cups
- O 10 1/4 tsp. measuring spoons (iodine test)
- O 10 1 Tbsp. measuring spoons (water test)
- O 10 1 tsp. measuring spoon (vinegar test)
- O Strand of incandescent (not LED) holiday lights
- O Scissors/wire strippers

Each Group (2-3 students) Needs:

- O 10 clear plastic 8 oz. cups
- O 12 craft sticks/tongue depressors
- O 2 pieces of aluminum foil (4" x 3")
- O A 9-volt battery
- O Masking tape
- O Trash bag
- O 10 zip-top sandwich bags
- O 20 disposable graduated medicine cups
- O 1/2 cup measuring cup
- O 5 cups distilled water, labeled
- O 5 oz. vinegar, labeled
- O 1/2 oz. iodine with dropper (or pipette)
- O 5 tsp. red cabbage indicator* with dropper (or pipette)
- O 1/2 cup measuring cup
- O 10 sheets of paper towel

Each Student Needs:

- O *Chemical Conundrum* Scenario
- O *Chemical Conundrum* Step-by-Step Instructions
- O *Chemical Conundrum* Observation Worksheet
- O *Vocabulary and Overview* Sheet
- O *Build Conductivity Meter* Worksheet

* Red cabbage indicator can be found at any science supply store; however, it is easy (and cheap) to make your own! Instructions for making red cabbage indicator are in the Preparation section below.

Preparation

MYSTERY POWDER TRAYS

- Label 1/4 tsp. measuring spoons "**Iodine Test**"
- Label 1 Tbsp. measuring spoons "**Water Test**"
- Label 1 tsp. measuring spoons "**Vinegar Test**"
- Label each of the plastic cups (10 cups total) with a letter (A – J) and then add 1 cup of each powder to the cup with the corresponding letter:

A Epsom Salt	E All-Purpose Flour	I Baking Soda
B Baking Soda	F Powdered Sugar	J Washing Soda
C Cornstarch	G Salt	
D Baking Powder	H Granulated Sugar	

- Assemble the mystery powder trays. Each tray (or bin) should have:
  - Iodine test spoon
  - Water test spoon
  - Vinegar test spoon
  - One labeled cup of a mystery powder

CONDUCTIVITY METER

Each pair/triad of students will need one light from the strand of holiday lights. Locate the two wires extending from the base of a light. Cut each wire so there are about 2" of wire extending from the base of the small bulb. Then, using scissors or a wire stripper, remove the bottom half inch of wire coating from each wire so the interior wire is exposed. Repeat these steps until you have enough lights for each pair/triad of students in your class.

RED CABBAGE INDICATOR

You will need: 1 red cabbage, boiling distilled water, heat safe bowl, strainer, and a container to store liquid.

1. Roughly chop the head of red cabbage into 1" pieces.
2. Place chopped cabbage in heat safe bowl and add boiling water until cabbage pieces are covered.
3. Steep cabbage for one hour to allow the color to leach out of the cabbage.
4. Use strainer to remove cabbage pieces. The remaining liquid is red cabbage indicator, which can be stored in the refrigerator for up to a week.

Guided Instruction

1 Have students get into their small groups (2-3 students in each) and pass out the following documents, but don't have them look at them yet. (*Pro Tip*: To add to the drama, put the documents in a folder stamped with "Top Secret".)

- *Chemical Conundrum* Scenario
- *Chemical Conundrum* Step-by-Step Instructions
- *Chemical Conundrum* Observation Worksheet
- *Vocabulary and Overview* Sheet
- *Build a Conductivity Meter* Worksheet

2 Introduce the scenario to students (read *Chemical Conundrum* scenario) and review vocabulary terms which students should already be familiar with.

3 In their small groups, students build their conductivity meter based on the Conductivity Meter worksheet instructions.

4 Demonstrate the following steps to engage students and focus their attention on the procedures when testing each mystery powder:

TEST 1

- Hold up the tray for **Mystery Powder A** (Epsom salt). Point to the cup with the mystery powder. Point to the label (A) and then point to the row on the student worksheet for Mystery powder A to show that the results of the tests you are about to run will be recorded on that row.
- Grab a new/unused cup. Measure 1/2 cup of distilled water and pour it into the cup.
- Pick up the measuring spoon labeled "water test" (1 Tbsp.) from the Mystery Powder tray and measure 1 Tbsp. of Mystery Powder A and add it to the cup of water. Stare at the water/powder mixture. Shake your head and say that you do not observe a reaction to the water. Direct the students' attention to the worksheet where they can record "None" in the "Reaction to Water" box for Mystery Powder A.
- Grab a craft stick and stir the powder and water together for 10-15 seconds. Stare at the solution. Ask students what they observe (they should say that the powder dissolved, and that the mystery powder IS soluble! Direct students to mark "Yes" in the solubility box for Mystery Powder A.
- Model throwing away the stir stick in their trash bag. (*Pro-tip*: tape the trash bags to each group's desk so they do not need to get up from their table to discard used materials, and so the trash bag doesn't accidentally tip over and spill out.)
- Demonstrate how to lay the conductivity meter across the rim of the cup with the leads dangling into the solution. Point to the light bulb and ask students if the bulb is lit (it should be!). Direct students to mark

"Yes" in the conductivity box for Mystery Powder A. Model removing the conductivity meter, wiping the ends off with paper towel, and gently placing it back on the table.

- Hold up the bottle of red cabbage indicator and the dropper. Then, hold up 2 fingers to show how many drops of indicator to add to the water solution. Add 2 drops of indicator to the solution.
- Hold up the pH color scale and point to the color on the chart that matches the color of the solution. Direct students to add the results to their worksheet. Neutral or slightly alkaline are acceptable answers.

You are now finished with all the "TEST 1" observations. *Demonstrate how to carefully dispose of the cup of solution into the trash bag.*

TEST 2

- Hold up a disposable medicine cup and the measuring spoon (1/4 tsp.) labeled "Iodine Test." Demonstrate measuring one spoonful of **Mystery Powder A** and adding it to the disposable medicine cup.
- Hold up the iodine bottle and dropper. Then, hold up 1 finger to indicate how many drops of iodine to add to the medicine cup. Demonstrate adding 1 drop of iodine and looking for a color change. Ask students what they observe: *No, there was no reaction or color change*. Direct students to record the results on their worksheet for Mystery Powder A (under Sample 2).

You are now finished with Test 2. *Demonstrate how to carefully dispose of the medicine cup into the trash bag.*

TEST 3

- Hold up a zip-top bag, a new disposable medicine cup, vinegar and the measuring spoon (1 tsp.) labeled "Vinegar Test." Demonstrate adding 1 scoop of **Mystery Powder A** to the bottom corner of the zip-top bag. Carefully place the bag on a flat surface (with zip-top open).
- Measure 1 oz. of vinegar into the disposable medicine cup. Carefully set the medicine cup inside the bag, ensuring the vinegar does not spill out of the cup. Squeeze the air out of the bag and seal it.
- Pick up the bag and begin to shake it so the vinegar and mystery powder combine. Observe any reactions taking place inside the bag. Record the results (none) in the Sample 3 boxes for Mystery Powder A on the student worksheet. Be sure to model feeling the outside of the bag for any possible temperature changes.

You are now finished with Test 3. *Demonstrate how to carefully dispose of the sealed bag into the trash bag.*

5 **You are now finished testing Mystery Powder A**. Demonstrate how to check that all necessary materials are on the tray (container of Mystery Powder A, Water Test spoon, Iodine Test spoon, and Vinegar Test spoon) and ready to be passed to the next table of students.

6 When students are familiar with the lab procedures, pass out 1 tray of mystery powder to each table. Depending on the size and setup of your classroom, tables may have multiple groups of students testing the same Mystery Powder. Once groups have finished testing the Mystery Powder at their table, rotate the trays of Mystery Powders so that each table has a new powder to test. Repeat this until each table has been able to test each of the Mystery Powders. (*NOTE: you may choose to not include Mystery Powder A in the rotation as students observed the results during the demonstration.*)

7 Finish the lesson by having each group go around and state which apartment mailed the letter. Collect each group's worksheet for grading (if applicable).

Adaptations to Increase Accessibility and Extend the Learning:

1 Do all experiments together as a class and discuss the results as you go.

2 Encourage students to write the chemical equations for the powders which react with water, iodine, and/or vinegar.

3 Limit the testing to 5 powders instead of 10 (making sure Baking Soda is one of the 5 powders tested though).

Building Real World Connections

Historical Connections:

In the 1970s, tensions ran high in Northern Ireland. Unionists and loyalists wanted Northern Ireland to remain part of the United Kingdom, whilst Irish nationalists and republicans wanted Northern Ireland to leave the United Kingdom and join the Republic of Ireland. As political tensions intensified, violence broke out across Northern Ireland. Bombs, planted by a terrorist group known as the Irish Republican Army (IRA), rocked Belfast. IRA bombers used an explosive material that left traces on clothing – until the clothes were washed. So British undercover agents created Four Square Laundry, a laundromat in an IRA stronghold in Belfast, offering discount coupons. Clothes poured in. So did clues. The laundromat had a special "sniffer" washing machine capable of testing laundry for explosive materials, gun residue, even blood. It likely used IR (infrared) spectroscopy to identify these substances. Anything suspicious triggered a house search by British undercover agents.

INTERNATIONAL SPY MUSEUM

CHEMICAL CONUNDRUM

ACCOMPANYING WORKSHEETS

Chemical Conundrum

Scenario

Last night, a letter addressed to the director of our security service arrived at Headquarters. During the security scan of the letter (done for all mail sent to Headquarters), a mysterious white powder was detected to be inside. Investigators were called to the mail room to test the substance but could not identify the powder, so it was sent to the lab for processing. In the meantime, investigators determined that the letter was mailed from an apartment building that contained 10 apartment units. Investigators assume that whoever mailed the letter would also have traces of the white powder on their clothes.

Because of this, investigators collected a piece of clothing from each apartment and found white powder on each piece. Investigators are short-staffed and need assistance, which is where you come in! Samples of each substance have been collected. Below is what we know about the powder found in the piece of mail.

> "The substance is a conductive, alkaline substance, is water soluble, and chemically inert, although an endothermic reaction does temporarily occur when mixed with vinegar."

Using the lab materials provided, **your mission** is to **conduct a series of experiments on the ten substances** in question to determine which substance matches the powder in the envelope. Use the chart to uncover who mailed the suspicious powder!

Chemical Conundrum

	TEST 1				TEST 2	TEST 3	
Apartment Unit	Reaction with Water	Solubility with Water	Conductivity	pH	Reaction with Iodine	Reaction with Vinegar	Temperature change with Vinegar
A							
B							
C							
D							
E							
F							
G							
H							
I							
J							

Which apartment mailed the letter? _____

Chemical Conundrum | Answer Key

TEACHER'S EYES ONLY

	TEST 1				TEST 2	TEST 3	
Apartment Unit	Reaction with Water	Solubility with Water	Conductivity	pH	Reaction with Iodine	Reaction with Vinegar	Temperature change with Vinegar
A Epsom Salt	No	Yes	Yes	Neutral	No	No	No
B Baking Soda	No	No	Yes	Alkaline	No	Yes Bubbles	Yes
C Cornstarch	No	No	No	Neutral	Yes Dark Purple	No	No
D Baking Powder	Yes Bubbles	No Although it does have some soluble ingredients	Yes	Neutral	Yes Dark Purple	Yes Bubbles	No
E Flour	No	No	No	Neutral	Yes Dark Purple	No	No
F Powdered Sugar	No	Yes	No	Neutral	Yes Slightly Purple	No	No
G Salt	No	Yes	Yes	Neutral	No	No	No
H Sugar	No	Yes	No	Neutral	No	No	No
I Baking Soda	No	Yes	Yes	Alkaline	No	Yes Bubbles	No
J Washing Soda	No	Yes	Yes	Alkaline	Yes Turns iodine clear	No	No

Which apartment mailed the letter? Apartments B and I

Build A Conductivity Meter

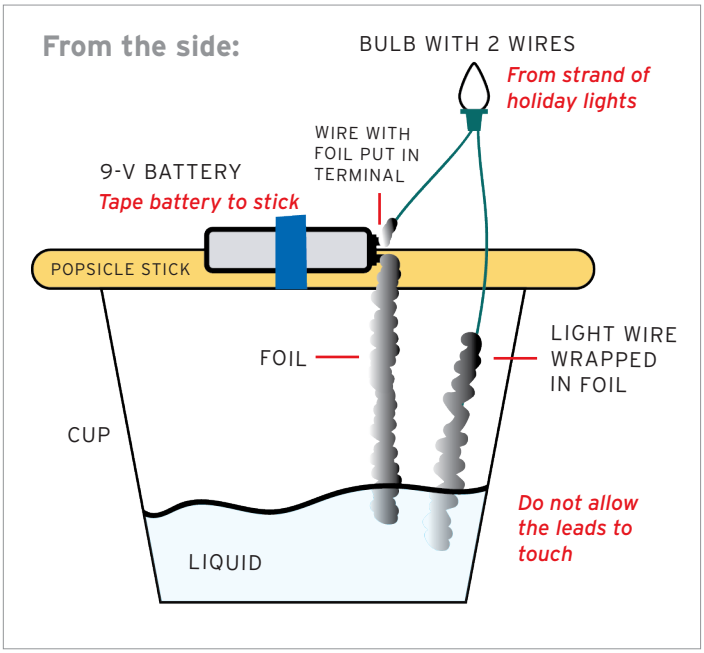
Materials Needed
for each group of students

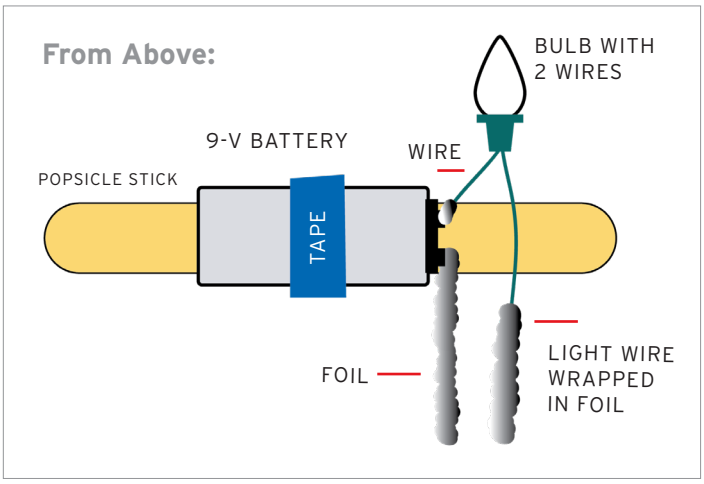
- O 9-volt battery
- O 2 pieces of aluminum foil (each piece – 4" x 3")
- O Pencil
- O 1 – 2 craft sticks/tongue depressors
- O 1 prepared light from strand of lights
- O Masking Tape
- O Scissors

See below for step-by-step instructions for building a conductivity meter:

1. Cut off a 1" strip from one piece of aluminum foil so that the remaining piece is a 3" x 3" square.
2. Wrap the 1" strip of foil around the exposed part of a wire attached to the light bulb.
3. Using the tip of a pencil, gently stuff the foil-wrapped part of the wire into the battery's positive terminal. Use tape to cover and secure the foil-wrapped wire inside the terminal.
4. Roll the 4" x 3" wire into a stick. Gently push one end of the aluminum stick directly into the battery's negative terminal. Secure it with tape. This will be one of your "leads."
5. Roll the 3" x 3" wire into a stick with the bulb's remaining exposed wire securely inside the foil stick. Secure it with tape. This is your other "lead."
6. Lay the battery in the middle of a craft stick. Secure the battery to the craft stick with tape.
7. Test your conductivity meter by touching the aluminum leads together. The bulb should light up. Your conductivity meter is now ready!
8. To test a solution's conductivity: Lay the popsicle stick (battery side up) across the rim of a cup with the solution inside. Allow the aluminum leads to dangle from the battery into the cup. **Do not allow the leads to touch**. If the bulb lights up, the solution is conductive.

Diagrams of Conductivity Meter:





Chemical Conundrum | Mysterious Powder Test

Step-By-Step Instructions

(For Each Mystery Powder)

TEST 1

1. Grab a new/unused cup. Measure 1/2 cup of distilled water and pour it into the cup.
2. Measure 1 Tbsp. of the Mystery Powder and add it to the cup of water. Stare at the water/powder mixture. Does it react to water? Record observation on sheet.
3. Grab a craft stick and stir the powder and water together for 10-15 seconds. Stare at the solution. Is it soluble? Record observation on sheet. Throw away the stir stick.
4. Lay the conductivity meter across the rim of the cup with the leads dangling into the solution. Is it conductive? Record observation on sheet. Wipe ends off with paper towel and put conductivity meter back on table.
5. Grab red cabbage indicator and the dropper. Add 2 drops of indicator to the solution. Grab pH color scale find the color that matches the color of the solution. Is the solution Acidic, Neutral, or Alkaline? Record observation on sheet.
6. Dispose the cup of solution into the trash bag.

TEST 2

1. Grab a new medicine cup. Using the "iodine test" measuring spoon (1/4 tsp.), measure 1/4 tsp. of Mystery Powder and add it to the disposable medicine cup.
2. Grab the iodine bottle and dropper. Add 1 drop of Iodine to the medicine cup. Is there a color change? Record observation on sheet.
3. Dispose of the medicine cup into the trash bag.

TEST 3

1. Grab a zip-top bag, a new disposable medicine cup, vinegar, and the "Vinegar Test" measuring spoon (1 tsp.). Add 1 tsp. of Mystery Powder to the bottom corner of the zip-top bag. Carefully place the bag on a flat surface (with zip-top open).
2. Measure 1 oz. of vinegar into the disposable medicine cup. Carefully set the medicine cup inside the bag, ensuring the vinegar does not spill out of the cup. Squeeze the air out of the bag and seal it.
3. Pick up the bag and begin to shake it so the vinegar and mystery powder combine. Is there a reaction? Record observation on sheet.
4. Dispose of the sealed bag into the trash bag.

Vocabulary and Overview

PHYSICAL REACTIONS AND CHEMICAL REACTIONS

- A **physical reaction** is an observable change to a substance's color, density, hardness, melting/boiling points, etc. without changing the identity of the substance.
- **Chemical reactions** undergo a specific chemical change which changes the composition of the substance. During chemical reactions, chemical bonds between atoms are either formed or broken, creating new substances. It is extremely difficult to "undo" a chemical reaction.

SOLUBILITY

- **Solubility** is the ability of a chemical substance, or **solute**, to dissolve in a **solvent** resulting in a homogenous solution.
    - Example: When a solute like table salt is added to a solvent like water the salt's molecular bonds are broken causing the salt to break apart into dissolved ions in the water. For the solute to dissolve completely, there must be a larger concentration of solvent (water) than solute.

CONDUCTIVITY

- **Electrical conductivity** is based on the ability of electrons to flow through a medium.
    - Example: Distilled water is a poor conductor of electricity since very little electricity flows through water. However, soluble compounds conduct electricity well by providing a plentiful supply of ions. Ions carry the electric charge through the solution thus creating an electric current.

ACIDS, BASES, AND pH LEVELS

- **Acids** and **bases** are opposites. When **acids** come in contact with water, hydronium ions are released. When **bases** and water combine, hydroxide ions are released. **Acids**, like lemon juice and vinegar, typically taste sour. **Bases**, like soaps, taste bitter. When hydronium ions from an acid combine with hydroxide ions from a **base**, they create water. Water is neither an acid nor a **base** – water is **neutral**.
- Cabbage juice is referred to as a **pH indicator** because it can tell us if a substance is an acid or base by changing color. When anthocyanin and the hydronium ions in an acid come in contact with one another, the liquid turns yellow, orange, pink or red depending on how acidic the liquid is. When anthocyanin and the hydroxide ions in a base combine, the liquid turns green or blue depending on how basic – or **alkaline** – the liquid is. A 0-14 scale, called the **pH scale**, measures how acidic or alkaline a substance is.