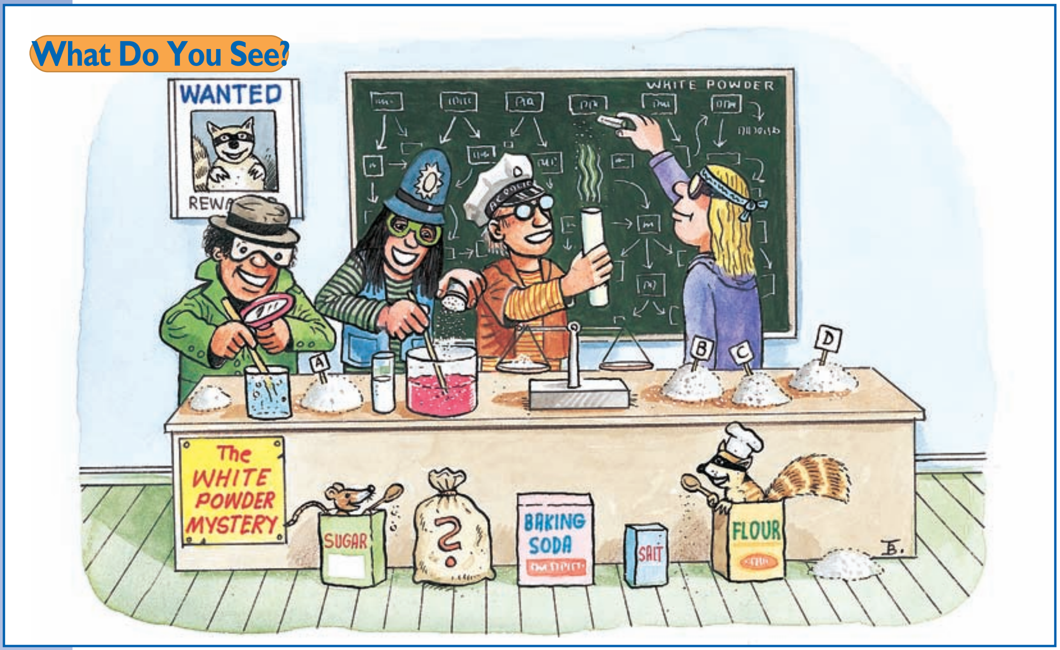
Activity 4 Identification of White Powders

What Do You See?



GOALS

In this activity you will:

- Create and use a flowchart to identify an unknown entity.
- Identify an unknown ionic compound based on an understanding of its chemical and physical properties.
- Identify limitations to white powder tests.

What Do You Think?

Forensic scientists and detectives often find traces of white powders at a crime scene.

- **What information would you need to tell different white powders apart?**
- **Can you think of any methods you could use to identify what they are?**

Record your ideas about these questions in your *Active Chemistry* log. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: Identifying Household White Powders

In this part of the activity, you will test each of six white powders with a set of reagents (water, phenolphthalein, silver nitrate solution, and acetic acid), looking for signs of a physical or chemical change. For safety reasons, you will use common white powders found around the house.

1. How would you design an experiment to carry out these tests? You can share your design with your teacher and you may be given permission to proceed. Alternatively, your teacher may suggest you use the procedure outlined here because the materials have all been prepared and safety considerations taken into account.

Safety goggles and a lab apron must be worn *at all times* in a chemistry lab.

White powder	Solubility in water	Phenolphthalein (PHTH)	Silver nitrate solution ($AgNO_3(aq)$)	Acetic acid ($HC_2H_3O_2$)
calcium carbonate $CaCO_3$				
calcium sulfate $CaSO_4$				
sodium bicarbonate $NaHCO_3$				
sodium carbonate Na_2CO_3				
sodium chloride NaCl				
sodium hydroxide NaOH				

2. Obtain a set of six labeled white powders. Check to make sure the set contains calcium carbonate, calcium sulfate, sodium hydrogen carbonate, sodium carbonate, sodium chloride, and sodium hydroxide.

   a) In your *Active Chemistry* log, prepare a data table similar to the one shown.

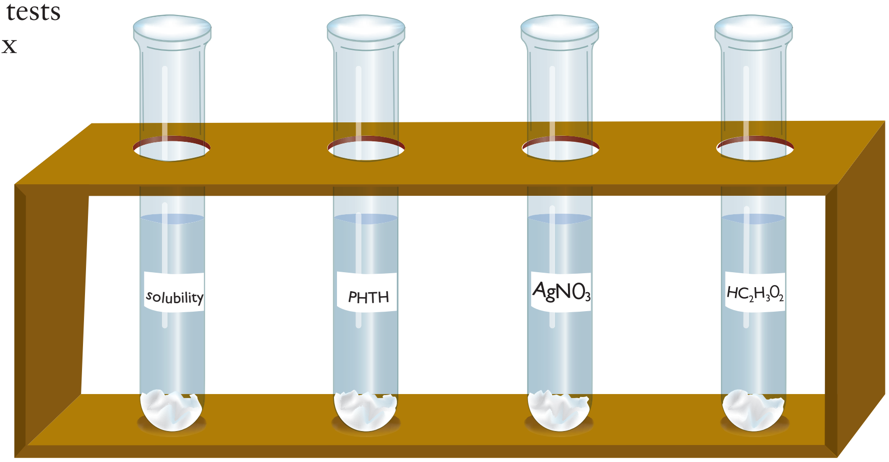
3. Obtain four clean test tubes. Label the first test tube "solubility," the second test tube "PHTH," the third test tube "$AgNO_3$," and the fourth tube "$HC_2H_3O_2$." These labels correspond to the four tests you will use on each of the six white powders.

4. Place the four tubes in a test-tube rack and add 10 mL of distilled water to each test tube.

5. Add a small scoop of calcium carbonate ($CaCO_3$) to each of the test tubes. Stir each test tube using a clean stirring rod. Be very gentle when stirring. It is quite easy to break the bottom of the test tube with the glass rod. Observe the first test tube.

   a) Record your observations on your data table.

Do not mix powders or other chemicals unless instructed to do so by your teacher. Report spills to your teacher immediately.



6. Add 1-2 drops of phenolphthalein solution (PHTH) to the second test tube. Gently swirl the contents of the test tube.
   a) Record your observations in your data table.
7. Add a couple of drops of silver nitrate solution, $AgNO_3(aq)$, to the third test tube. Gently swirl the contents and observe.
   a) Record your observations in your data table. Note the symbol (aq) following the chemical symbol. Recall that this stands for aqueous and means the compound is in a solution with water. Other symbols can be used to represent the states of matter for compounds including (s) for solids, (l) for liquids, and (g) for gases.
8. To the fourth test tube, add a small pipette full of acetic acid solution, $HC_2H_3O_2$. Gently swirl the contents.
   a) Record your observations in your data table.

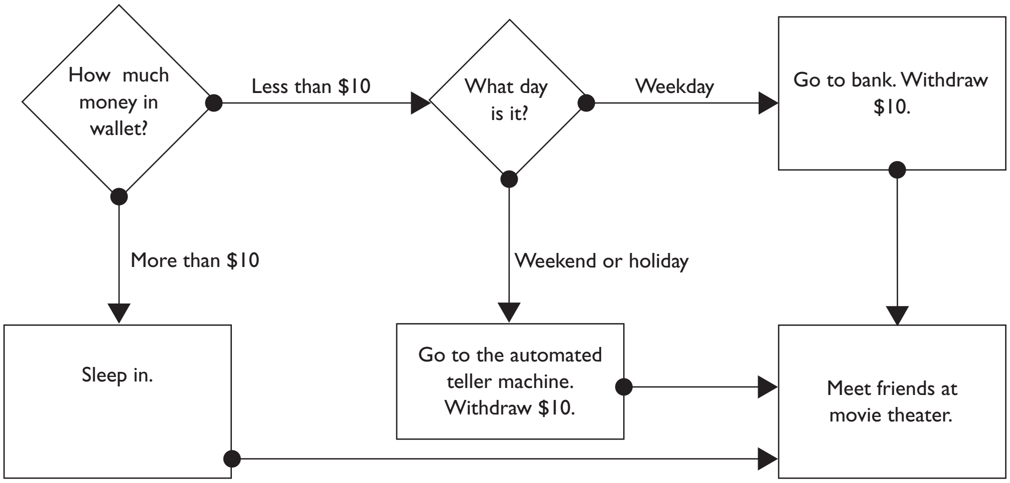
Wash your hands and arms thoroughly after the activity.

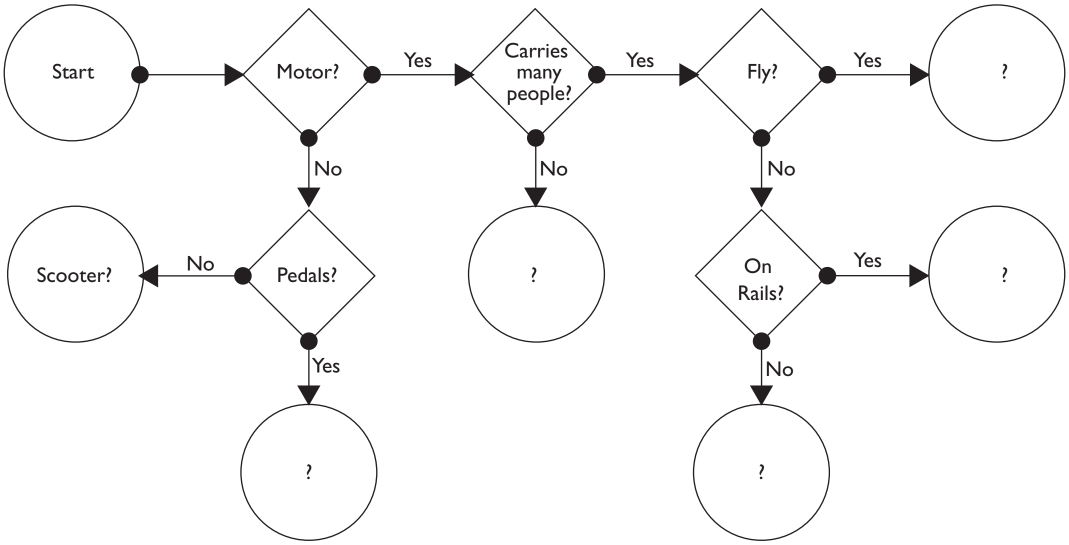
9. Dispose of the contents of the test tubes as indicated by your teacher. Clean the test tubes using a test-tube brush. Rinse them twice with a small amount of distilled water.
10. Now that you are familiar with lab techniques for each material, repeat *Steps 4* to *9* for the remaining five powders, substituting the next white powder in your data table where the directions call for calcium carbonate, $CaCO_3$. Your teacher may have your sodium hydroxide samples already measured for you. In the event that your teacher wants you to do the preparation, you must be extremely careful with solid sodium hydroxide, as it will burn. (Chemically speaking, it will saponify your skin, i.e., make soap). Use gloves in measuring out your solid sodium hydroxide for the different test tubes.
11. You are given a white powder.
   a) What test results would you expect if the white powder were NaCl?
   b) What test results would you expect if the white powder were $NaHCO_3$?
   c) Does each material have a unique set of properties?

Part B: Reading and Creating Flowcharts

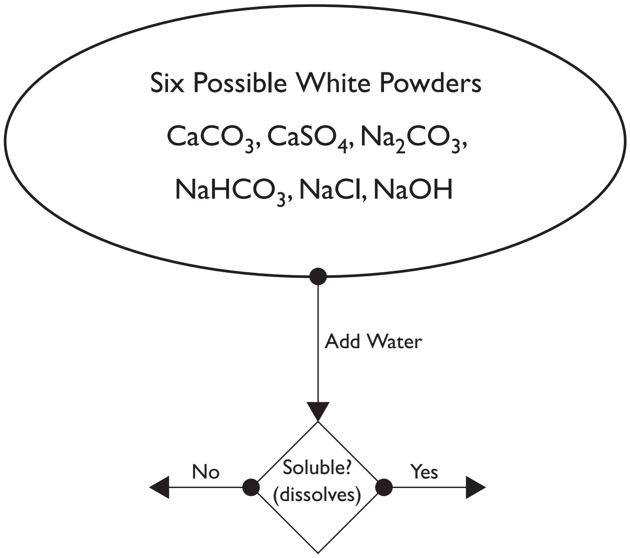
Now that you can identify each compound based on its solubility in water and reaction with the other three reagents, you need a way to represent this simply. In this part of the activity, you will learn how to use a type of map called a flowchart. Flowcharts can be used to illustrate a deductive reasoning process, so they are useful to a forensic scientist.

1. What does the first flowchart on the next page represent?
   a) Write down your thoughts in your *Active Chemistry* log and be prepared to share them with the class.
2. The next flowchart can be used to identify the six modes of transportation shown. Choose a mode of transportation and see if the flowchart identifies it correctly. Choose a second one and try it again.
   a) Copy the flowchart into your *Active Chemistry* log and fill in all the blanks. Is each blank unique? If so, the flowchart works.





Notice that a flowchart does not need to be based on yes-or-no questions to work. For example, one of the questions could have been, “How many wheels does it have?” Answers to this could have been, “two,” “four,” and “more than four.”



3. Now that you've had some practice creating flowcharts, use your test results from *Part A* to create a flowchart for identifying the household white powders. Hint: you might want to start with whether the solid dissolves in water as your first decision. (See the example flowchart shown.)

4. Once you have created your chart, try it out using at least two of the white powders to test its validity. (See if it works!). If your flowchart does not correctly identify all six of the powders, revise it and test it again.

    a) Once you have a flowchart that works, copy it into your *Active Chemistry* log.

Chem Talk

IDENTIFYING UNKNOWNS IN CHEMISTRY

Qualitative Analysis

Forensic chemists are often faced with the challenging task of identifying unknown compounds. There are millions of possible compounds and mixtures of compounds to choose from. Forensic chemists must develop tests that identify each one! The use of tests to determine the identity of an unknown compound is called **qualitative analysis**. In this type of analysis, it is the identity of the unknown—the *qualities* that make it unique—that is important and not the quantity, or amount, of the substance. In this experiment, you used the results from a series of tests performed on six different compounds to develop a flowchart. This flowchart will allow you to identify one or more unknown white powders found at the *Chapter Challenge* crime scene, if the powder or powders are the ones you have tested in this activity.

The key to identifying a white powder is testing properties that allow one powder to be differentiated from another. For example, both sugar and salt dissolve easily in water. Therefore, testing a powder that may be either sugar or salt by dissolving the powder in water would not help

Chem Words

qualitative analysis: the determination of which substances are present in the sample with little or no regard to the exact amount of each.

tell them apart. But sugar melts at a relatively low temperature, while salt melts at a much higher temperature, so if the white powder melts in a pan on the stove, you know that it cannot be salt. The tests used in a qualitative analysis depend on the properties of the possible unknown substances. If the number of possible substances is large or some of the possible substances have many physical and chemical properties in common, a scientist might have to conduct several different tests before accurately identifying the unknown substance.

Ionic Compounds

The white powders you used in this activity are all **ionic compounds**. Ionic compounds are made of a combination of positive and negative **ions**. Sodium chloride is an ionic compound, so its chemical formula, NaCl, means there is one positive sodium ion (Na^+) for every one negative chloride ion (Cl^-).

Ionic compounds form on the basis that opposite charges attract. The positive sodium ion is attracted to the negative chloride ion. This attraction between the positive ion (also called a **cation**) and the negative ion (also called an **anion**) is called an **ionic bond**, and the substance formed by the bond is the ionic compound. The sodium ion and chloride ion join to form the ionic compound sodium chloride, NaCl, as shown.

$$Na^+ + Cl^- \rightarrow NaCl$$

In calcium chloride, $CaCl_2$, there is one positive calcium ion (Ca^{2+}) for every two negative chloride ions (again, Cl^-).

$$Ca^{2+} + 2Cl^- \rightarrow CaCl_2$$

Notice since there are two chloride ions for every one calcium ion there is a 2 in front of the chloride ion. You must always have the same number of ions or atoms of each element on both sides of a chemical equation. This is due to the **Law of Conservation of Matter**. It states that matter cannot be created or destroyed. Chloride ions must be equal in the reactants and products, so there must be two on each side.

In an ionic compound the cations take the name of the element. The anions take the name of the element but the ending is changed to *–ide*. Notice that metals form positive ions and nonmetals form negative ions.

Chem Words

ionic compound: a compound that is composed of positive ions (cations) and negative ions (anions).

ion: an electrically charged atom or group of atoms that has acquired a net charge, either negative or positive.

cation: an ion that has a positive charge.

anion: an ion that has a negative charge.

ionic bond: the attraction between oppositely charged ions.

Law of Conservation of Matter: the amount of matter present before and after a chemical change remains the same.

Chem Words

polyatomic ion: an ion that consists of two or more atoms that are covalently bonded and have either a positive or negative charge.

solubility: the amount of a substance that can dissolve in a given quantity of solvent at a given temperature.

soluble: a substance that dissolves in a liquid.

solution: a homogeneous mixture of two or more substances.

insoluble: a substance that will not dissolve in a liquid.

Some Common Ions

Formula	Name	Formula	Name
Na^+	sodium ion	Cl^-	chloride ion
K^+	potassium ion	F^-	fluoride ion
Ag^+	silver ion	O^{2-}	oxide ion
Ca^{2+}	calcium ion	S^{2-}	sulfide ion

Groups of atoms may act as a single ion in an ionic compound, like in calcium carbonate, $CaCO_3$. There is one calcium cation (Ca^{2+}) for every one carbonate anion (CO_3^{2-}). Ions like carbonate, (CO_3^{2-}), are called **polyatomic ions**. Sulfate (SO_4^{2-}), hydroxide (OH^-), nitrate (NO_3^-), acetate ($C_2H_3O_2^-$) and bicarbonate (HCO_3^-) are other polyatomic anions found in the white powders and reagents used in this activity.

Solubility

In *Part A*, you placed a sample of each white powder in water to see if it would dissolve. This property of matter is called **solubility**. The powders that dissolved in water are **soluble**. When a solid dissolves in water the mixture of the dissolved solid and the water is called a **solution**. The powders that did not dissolve are **insoluble**. Whether or not a particular powder dissolves in water is a complex matter that depends on many factors. Fortunately, the solubility of many substances in water has been investigated. The results of some of the investigations are summarized in the table.

You can use the thousands of hours of work of chemists that resulted in this table to help you make identifications. Chemists don't memorize these tables, though some remember parts of the table. For example, some chemists through their repeated experiences with chlorides may remember which ones are not soluble.

Solubility Rules

Nitrates (NO_3^-)	All are *soluble*.
Chlorides (Cl^-)	All are *soluble* **except** those containing ions of silver, mercury (I), and lead (II).
Sulfates (SO_4^{2-})	All are *soluble* **except** those containing ions of barium, calcium, strontium, silver, lead (II), and mercury (I).
Carbonates (CO_3^{2-})	All are *insoluble* **except** those containing ions of the Group I metals or the ammonium ion.
Hydroxides (OH^-)	All are *insoluble* **except** those containing ions of the Group I metals or the ammonium ion.

This table can be used to predict if a given solid will dissolve in water. To determine if a solid is soluble, look at the chemical formula for the solid, and identify which of the five negatively charged ions listed in the table the solid contains. Then read the rule for solids containing that ion and the exceptions to the rule. For example, sodium carbonate, Na_2CO_3, contains the ion carbonate, CO_3^{2-}. According to the table, all carbonates are insoluble except for the ones containing Group I metals. Sodium is a Group I metal, so sodium carbonate is an exception to the general rule that carbonates are insoluble. Therefore, sodium carbonate is soluble and dissolves in water. Other examples are given below.

- KCl is soluble because all chlorides are soluble except those containing ions of silver, mercury (I), and lead (II). KCl does not contain any of the exceptions.
- $Mg(OH)_2$ is insoluble because hydroxides are insoluble except for those containing Group I metals, and magnesium is not a Group I metal.

Determining whether a given solid is soluble is another example of deductive reasoning using both the table of solubility rules and the periodic table.

Phenolphthalein: An Acid-Base Indicator

In the second test, you added phenolphthalein (PHTH) to your sample. PHTH is one of a class of compounds known as acid-base indicators. **Acids** are compounds that form H^+ ions in solution and strong acids are 100% dissociated in water. Acids taste sour (citric and maleic acids are used in sour candies), react with metals (corrosive), neutralize bases, and react with indicators to produce a color change. **Acid-base indicators** are substances that change color when exposed to an acid or a base. Some common acids and their uses are listed in the table. Unlike HCl, weak bases are only slightly dissociated in water.

Common Acids and their Uses

Name	Formula	Use	Strength
acetic acid	$HC_2H_3O_2$	vinegar	weak
carbonic acid	H_2CO_3	carbonated sodas	weak
hydrochloric acid	HCl	stomach acid	strong

Bases are compounds that form hydroxide ions (OH^-) in solution. Bases taste bitter, are corrosive, feel slippery, saponify fats (turns fats into soaps), neutralize acids, and cause indicators to change color.

Chem Words

acid: a solution that has a pH value less than 7.

acid-base indicator: a substance that changes color when exposed to either an acid or a base.

base: a solution that has a pH value greater than 7.

Chem Words

double-replacement reaction: a reaction in which two elements or groups of elements in two different compounds exchange places to form new compounds.

precipitate: an insoluble salt that is formed when two solutions are mixed together.

Bases cause phenolphthalein to turn bright pink. Some common bases and their uses are listed in the table.

Common Bases and their Uses

Name	Formula	Use	Strength
sodium hydroxide (lye)	NaOH	drain cleaners	strong
ammonia	NH_3	window cleaners	weak
magnesium hydroxide	$Mg(OH)_2$	antacids	strong
sodium carbonate	Na_2CO_3	glass manufacture	strong

Reactions of Ionic Compounds: Double-Replacement Reactions

Ionic compounds can form insoluble solids in chemical reactions. For example, when silver nitrate solution is added to sodium chloride solution, a milky white solid is formed. The chemical equation for this reaction is shown below.

silver nitrate + sodium chloride → sodium nitrate + silver chloride

$$AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow NaNO_{3(aq)} + AgCl_{(s)}$$

By examining the reaction, you can see that the metals, sodium (Na) and silver (Ag), exchange places to form two new compounds. This reaction is called a **double-replacement reaction**. You can determine the identity of the milky white solid, called a **precipitate**, by looking at the two products and using the solubility rules. The first product, sodium nitrate, dissolves in water because all nitrates are soluble. The second product, silver chloride, is insoluble because all chlorides are soluble with the exception of mercury (II), lead (II), and silver. Because of silver chloride's insolubility, instead of dissolving and being invisible like the sodium nitrate, the silver chloride that is formed is visible as a milky white precipitate.

Here are more examples of double-replacement reactions.

potassium chloride + silver nitrate → potassium nitrate + silver chloride

soluble *precipitate*

calcium chloride + sodium carbonate → calcium carbonate + sodium chloride

precipitate *soluble*

Another example of a double-replacement reaction from this activity is the reaction of acetic acid solution with sodium carbonate solution.

$$2HC_2H_3O_{2(aq)} + Na_2CO_{3(aq)} \rightarrow 2NaC_2H_3O_{2(aq)} + H_2CO_{3(aq)}$$

The hydrogen ion in acetic acid trades places with the sodium ion in the sodium carbonate. The carbonic acid product, H_2CO_3, immediately decomposes to produce carbon dioxide gas (the bubbles in *Part A*) and water.

$$H_2CO_{3(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)}$$

Whenever carbonic acid is a product in a chemical equation, it is replaced with water and carbon dioxide.

$$2HC_2H_3O_{2(aq)} + Na_2CO_{3(aq)} \rightarrow 2NaC_2H_3O_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$$

Generally, acetic acid and other acids react with carbonates and hydrogen carbonates to form carbon dioxide gas. The gas is in the bubbles that form in the solution. A carbonate is a compound that contains the CO_3^{2-} ion. Some common carbonates include sodium carbonate (Na_2CO_3) and calcium carbonate ($CaCO_3$). Hydrogen carbonates are compounds that contain the bicarbonate ion HCO_3^-. The most common bicarbonate is sodium bicarbonate, $NaHCO_3$, commonly known as baking soda. Bicarbonates react with acids in a manner similar to carbonates.

Checking Up

1. In your own words, explain the difference between a quantitative and a qualitative analysis.
2. What is a polyatomic ion?
3. Is sodium chloride (NaCl) soluble? Explain how you arrived at your answer.

What Do You Think Now?

At the beginning of this activity you were asked:

- **What information would you need to tell different white powders apart?**
- **Can you think of any methods you could use to identify what they are?**

Review your ideas about these questions. Now that you have completed this activity, you should have more informed answers to the two questions. Re-answer the two questions in your *Active Chemistry* log using terms and specific concepts from this activity.

Chem Essential Questions

What does it mean?

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

MACRO	NANO	SYMBOLIC
What are some of the macroscopic properties that you observed with the white powders in this activity?	*Explain what is happening at the nano level during a double-replacement reaction. You can use potassium chloride and silver nitrate as examples.*	*Chemists use formulas as symbols to represent elements and compounds. Explain the meaning of the formula NaOH. How do chemists name this ionic compound?*

How do you know?

What was the evidence in the laboratory of physical and chemical changes? Explain.

Why do you believe?

Explain a situation where you have seen a chemical and physical change in your experiences outside of the classroom.

Why should you care?

List at least two concepts from this activity that you think would be useful in analyzing a crime scene. Explain why you chose each concept.

Reflecting on the Activity and the Challenge

You have learned how to identify white powders based on their chemical and physical properties. If your crime scene includes a white powder, you will need to analyze it to determine its identity. You will also need to assign different powders to different suspects so that the identity of the powder will help to identify the suspect.

Chem to Go

1. Use the list of ions below to answer the questions.

   Cl^-, Na^+, Al^{3+}, SO_4^{2-}, MnO_4^-, NH_4^+, O^{2-}, Fe^{2+}

   a) Which ions are cations?

   b) Which ions are anions?

   c) Which ions are polyatomic ions?

2. Which of the following compounds are insoluble in water?

   K_2CO_3, Na_2SO_4, $MgCO_3$, $Ba(OH)_2$, $FeCl_3$, $Cu(NO_3)_2$, $PbCl_2$

3. Which of the following are double-replacement reactions?
   a) $AgNO_3 + NaBr \rightarrow NaNO_3 + AgBr$ b) $CaCO_3 \rightarrow CaO + CO_2$
   c) $FeCl_3 + 3KOH \rightarrow 3KCl + Fe(OH)_3$ d) $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$
4. Complete the word equations for the following double-replacement reactions.
   a) potassium chloride + lead (II) nitrate →
   b) iron (III) chloride + potassium hydroxide →
   c) sodium hydroxide + calcium nitrate →
5. Identify the precipitates formed in each of the reactions in *Question 4*.
6. Name one other physical property and one other chemical property you could use to identify any powdered chemical found at a crime scene.
7. How could a defense attorney prove that a white powder was NOT the chemical that the prosecutors claimed it to be?
8. In the reaction described in the *Chem Talk* section,

   $2HC_2H_3O_2 + Na_2CO_3 \rightarrow 2NaC_2H_3O_2 + H_2O + CO_2$

   a) Show that the number of H, C, O and Na atoms are identical on both sides of the equation.
   b) Why must the number of these elements be identical on both sides of the equation?
9. List a few properties of one of the white powders so another team can use their flowchart to identify the powder.
10. What is the minimum number of tests you must conduct to determine if the white powder is NaCl, if the only possibilities are the powders you used in the activity?
11. ***Preparing for the Chapter Challenge***

    Each of the chemicals in this lab was called a "household" chemical. Create a table with three columns: white powder, possible uses of the white powder, and crime scenes where you might find this chemical. Use the Internet and references suggested to you by your instructor to determine each chemical's possible use or uses.

Inquiring Further

Instrumental techniques

On many of the crime dramas, you will notice researchers using machines to identify samples from the crime scene, or more commonly, they send it off to the lab and get back a printed report. Research instrumental methods forensic chemists use to identify white powders found at a crime scene. Identify the name of one of these instruments and explain how it functions on the physical or chemical properties of the white powder.