Five White Powders & Chemical Reactivity

Many substances can be described as a white, powdery solid. Often, their chemical properties can be used to distinguish them.
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Introduction

In previous labs, you’ve seen that many physical properties can be used to distinguish one material from another (think about density and your first week of lab) and even separate materials from one another (think about properties like size, color, magnetism, and other properties used to separate mixtures.) Last week, you performed some of your first chemical reactions. This week, we’ll put together what you’ve learned so far and build on it. You will examine several types of reactions and identify substances based on their chemical reactivity.

Recall from Chapter 4 and the previous experiment that we can use a chemical equation to describe chemical changes. There, the chemical equations there highlighted ionization (oxidation) and electron affinity (reduction). We can use chemical equations for any type of chemical change. We denote the change or conversion with an arrow. Substances on the left are starting materials or reactants. Substances to the right of the arrow are the ending materials or products. We often tag the different substances with one- or two-letter abbreviations that tell us about its state of matter: solid (s), liquid (l), gas (g), or dissolved in water (or “aqueous solution.”) Thus, the chemical equation

$$\text{SrSO}_4\text{(aq)} + \text{K}_2\text{CO}_3\text{(aq)} \rightarrow \text{SrCO}_3\text{(s)} + \text{K}_2\text{SO}_4\text{(aq)}$$

Means that two different salt solutions (the ones with “aq” on the left) are combined, resulting in a solid substance and some leftover dissolved ions. The formation of a solid, often called a precipitate, is only one visual clue that a reaction has occurred.

In fact, each “aqueous” species is actually dissolved ions, as per the chemical equation:

$$\text{SrSO}_4\text{(aq)} \rightarrow \text{Sr}^{2+}\text{(aq)} + \text{SO}_4^{2-}\text{(aq)}$$

We can use chemical equations to describe what we observe in the lab when we mix various solutions. Furthermore, observations of chemical change can sometimes be used to identify a compound.

As you know, chemical reactivity and physical properties are characteristic of a substance and may be used to identify a compound. Although one or more properties of compounds may be similar, it is those properties which are different that may serve to distinguish one substance from another. In the first part of this experiment, you will perform various chemical tests on of five white, powdery inorganic compounds: BaCO₃, BaCl₂, BaSO₄, Na₂CO₃, and NaCl. For each of these, you will test their solubility, solution pH, and chemical reactivity. For chemical reactivity, you will react each powder with nitric acid (HNO₃), the sulfate ion (SO₄²⁻), and the silver ion (Ag⁺).

In part two of the experiment, after completing these qualitative tests, each group will receive an “unknown” containing only two of these white powders. The binary (2-component) mixtures will be subjected to a battery of similar qualitative tests, and your observation data will be used to identify the constituent compounds.
Pre-lab

**Safety:** Goggles must be worn at all times. Care must be exercised when using nitric acid. Barium, silver, and copper compounds in solid or solution form (and the first washing of the precipitates of these ions) must be collected and disposed of as directed by your TA.

**Pre-lab Assignment:** Write out the following in your lab notebook. This assignment must be completed before the beginning of lab. You will not be allowed to start the experiment until this assignment has been completed and accepted by your TA.

1. Name the following compounds: (a) BaCO₃; (b) BaCl₂; (c) BaSO₄; (d) Na₂CO₃; (e) NaCl; (f) CuCl₂; and (g) HNO₃.

2. An alkali metal (A) and a halide (B) form the salt AB. Write the chemical equation for AB dissolving in water.

2. Below is a chemical reaction in which two solutions are combined:

   \[ \text{CdSO}_4 (aq) + \text{K}_2\text{S} (aq) \rightarrow \text{CdS} (s) + \text{K}_2\text{SO}_4 (aq) \]

   a) What does the subscript (s) mean?
   b) For cadmium sulfate, write a chemical equation similar to problem 2 showing that cadmium sulfate dissolves in water. Do the same for potassium sulfide. How many ions are present in this solution?
   c) Some of these ions react with one another to produce cadmium sulfide. Look up the physical properties of cadmium sulfide. What would you expect to see when you mix cadmium sulfate and potassium sulfide?
   d) What is the name for this type of reaction?
   e) Potassium sulfate is shown as a soluble product. What ions are still present in solution after the reaction?

3. Below is a chemical reaction in which two solutions are combined:

   \[ 3 (\text{NH}_4)_2\text{S} (aq) + 2 \text{H}_3\text{PO}_4 (aq) \rightarrow 2 (\text{NH}_4)_3\text{PO}_4 (aq) + 3 \text{H}_2\text{S} (g) \]

   a) What does the subscript (g) mean?
   b) Look up the physical properties of hydrogen sulfide. What are two ways you might be able to tell if you generated hydrogen sulfide?
   c) What is the name for this type of reaction?
   d) For any chemical equation that takes place in a liquid solution, if there’s a product with (g) next to it, what do you expect to see in the solution?

In addition to these pre-lab requirements, a short quiz may be given at the beginning of lab based on the material in this lab write-up.
Procedure

Part 1—Identifying Chemical Properties

Reagents: 5 white powders - BaCO₃, BaCl₂, BaSO₄, Na₂CO₃, and NaCl; 3 M HNO₃, 0.1 M Na₂SO₄, 0.1 M AgNO₃, Universal Indicator Solution

This part of the experiment involves the qualitative analysis of five white powders, namely BaCO₃, BaCl₂, BaSO₄, Na₂CO₃, and NaCl. Each of these solids will be tested for solubility in water. The resulting aqueous mixtures will be tested for pH, treated with nitric acid, and then subsequently treated with sodium sulfate and silver nitrate solutions.

Construct a table in your laboratory notebook like the one shown below.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solubility in water</th>
<th>pH</th>
<th>Reaction with HNO₃</th>
<th>Reaction with Na₂SO₄</th>
<th>Reaction with AgNO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaCO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaCl₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaSO₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td></td>
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</tr>
</tbody>
</table>

Record your observations in this table as you perform the five tests on each of the five white solids.

A small amount (pea-sized or less is appropriate) of each of the white solids should be placed in separate small test tubes. Add water to each test tube to dissolve (or attempt to dissolve) the solids. Record your observations. Add Universal Indicator to the "solution" or mixture. Note the approximate pH of each. (A chart indicating the color of the Universal Indicator solution at various pHs will be available in the laboratory.) Record whether the measured pH indicates an acidic, neutral, or basic solution. Add nitric acid to each test tube in a drop-wise manner until the solution becomes acidic. Record your observations. The resulting solutions should be decanted (if necessary) and divided in half. Add sodium sulfate solution to one portion and silver nitrate solution to the other. Record your observations.

Part 2—Identification of Components in a Mixture using Chemical Reactivity

Reagents: 3 M HNO₃, 0.1 M Na₂SO₄, 0.1 M AgNO₃, Universal Indicator Solution, and unknown binary mixtures of BaCO₃, BaCl₂, BaSO₄, Na₂CO₃, and/or NaCl

A binary mixture of two of the white solids will be subjected to the same tests used in Part 2 of this experiment, and the composition of the mixture will be determined.

Your TA will give you a small amount of an unknown mixture containing two of the white solids you have studied. Record the number (#1, #2, #3, #4, or #6) assigned to your unknown. Devise a method of analysis to determine the composition of your binary mixture. Discuss this with your group and with your TA before you begin. You may wish to develop a flow chart for your analysis. Perform your analysis. Be sure to identify the components of your unknown binary mixture in your notebook. In your laboratory report, you must justify how your data support your conclusions.
Lab Clean-up:

Acidic solutions should be neutralized before disposal in the sink. Stock solutions of acids should be put in a separate waste receptacle. If you have questions, ask your TA.

Glassware, including test tubes, should be thoroughly cleaned using deionized water and then returned to your lab drawer.
Post-Lab Questions

Solubility tests, not unlike the ones that you performed in this lab, have been used to formulate a list of rules that allow one to predict the solubility of common inorganic compounds.

### Solubility Rules for Common Ionic Compounds in Water at 25 °C

<table>
<thead>
<tr>
<th>Soluble Compounds</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Compounds containing alkali metal ions or the ammonium ion (NH₄⁺)</td>
<td>- Halides of Ag⁺, Hg₂²⁺, Pb²⁺</td>
</tr>
<tr>
<td>- Nitrates (NO₃⁻), bicarbonates (HCO₃⁻), chlorates (ClO₃⁻)</td>
<td>- Sulfates of Ag⁺, Ca²⁺, Sr²⁺, Ba²⁺, Hg₂²⁺, Pb²⁺</td>
</tr>
<tr>
<td>- Halides (Cl⁻, Br⁻, and I⁻)</td>
<td></td>
</tr>
<tr>
<td>- Sulfates (SO₄²⁻)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Insoluble Compounds</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Carbonates (CO₃²⁻), phosphates (PO₄³⁻), chromates (CrO₄²⁻), sulfides (S²⁻)</td>
<td>- Compounds containing alkali metal ions or the ammonium ion</td>
</tr>
<tr>
<td>- Hydroxides</td>
<td>- Compounds containing alkali metal ions or the Ba²⁺ ion</td>
</tr>
</tbody>
</table>

In this experiment, we’ve used the idea of solubility extensively, and solubility will be discussed in more detail in class. The table above, however, allows you to answer questions about real chemistry in a simple way. Use these solubility rules to help you answer the following.

1. Acids react with carbonates and bicarbonates to produce a “salt,” H₂O(l), and carbon dioxide gas (CO₂(g)). Did you see evidence of gas formation when you added nitric acid to the two carbonates used in this lab (BaCO₃ and Na₂CO₃)? Explain.

2. When an ionic compound dissolves in solution, the ionic substance dissociates into its component ions. Based on solubility rules, which cation(s) in the five white solids would be expected to react with the sulfate anion (SO₄²⁻) to form an insoluble ionic compound? What is/are the precipitate(s) that should form? Explain how your observations agree or disagree with your predictions.

3. Based on solubility rules, Ag⁺ should form silver carbonate (Ag₂CO₃), an insoluble solid, when it reacts with CO₃²⁻. Indeed, Ag₂CO₃(s) readily forms when aqueous solutions of Na₂CO₃ and AgNO₃ are mixed. Did you see a precipitate form when AgNO₃ was added to an acidified solution of Na₂CO₃? Explain why you would or would not expect a precipitate to form under these conditions (consider solubility rules and the ideas presented in Question 1.)
Glossary

**Acid-base reaction**  
(*neutralization reaction*)  
a reaction in which an acid reacts with a base and the two neutralize each other, producing water

**Chemical Equation**  
a simplified representation of what occurs during a chemical reaction. By convention, starting materials (reactants) are placed on the left of an arrow. The ending materials are placed to the right of the arrow. The arrow itself represents the chemical change or rearrangements of electrons, atoms, etc. A “balanced” chemical equation obeys Conservation of Matter and Conservation of Mass.

**Double displacement reaction**  
(*metathesis reaction*)  
a chemical reaction in parts of the two reactants switch places, thereby forming two new products; often the “parts” of the reactants are their cations and anions and one or both products is insoluble

**Insoluble**  
Unable to dissolve to a significant extent; insoluble materials are often identifiable by the presence of visible pieces of solid material or by a cloudy look to a solution.

**Precipitate**  
a solid, insoluble ionic compound that forms in, and separates from, a solution

**Precipitation reaction**  
a reaction in which a solid, insoluble product (a “precipitate”) forms upon mixing two solutions

**pH**  
the negative logarithm of the concentration of $\text{H}^+$ (or $\text{H}_2\text{O}^+$) in a solution; the pH scale is a compact way to specify the acidity of the solution; the lower the pH, the more acidic the solution is; pH can also be measured crudely using pH paper or dissolved pH indicators.

**Product**  
the material or chemical species resulting from a chemical reaction.

**Reactant**  
the material or chemical species present before a chemical reaction occurs

**Solubility**  
The extent to which a substance dissolves in a liquid, typically water. Solubility can be quantitative, providing the mass or number of moles of the substance that can be dissolved in some volume or mass of liquid (*e.g.*, g / L). Solubility can also be qualitative: “Soluble” indicates the material in a solution is dissolved, with the solution appearing clear or translucent. “Insoluble” indicates that the material in a solution is not dissolved, with the solution appearing cloudy from the formation of small solid particles; large enough solid particles may also sink to the bottom.

**Soluble**  
able to dissolve to a significant extent, usually in water