Periodic Properties of the Alkaline Earths and Halogens

Introduction

Your team of research scientists have been hired as consultants by the “Big Bubbly Bath Corporation” or “BBBC”. Their problem is that a rival corporation, “Old Tubby Salts” has developed a new bath oil that is cornering the market and BBBC would like to know what the formula of the new oil is so they can develop a rival product.

One of the ingredients in this new bath oil is listed on the package as a “special new rejuvenating alkali-halide salt.” Other members of your consulting firm have isolated this salt using chromatography and have passed a pure sample of the aqueous bath salt solution to your team for final analysis.

In order to determine the formula of the unknown bath salt your team is going to have to do some research into the chemistry of the Alkaline Earth and Halogen families of the periodic table.

Background

Elements found in a particular column of the periodic table tend to have similar properties and chemical reactivity owing to their similar outer (or valence) electron configurations. Because of this, the columns in the periodic table are often referred to as “groups” or even “families” of elements. The physical and chemical properties of elements in a group tend to change gradually as one goes down the column. In this experiment we will study the properties of the elements in the Alkaline Earth and Halogen groups in order to collect enough data to identify the unknown bath salt.

The alkaline earths:

The alkaline earth elements are all moderately reactive metals and include barium, beryllium, calcium, magnesium, radium, and strontium. Because beryllium compounds are quite rare and often very poisonous and radium compounds are highly radioactive we can safely eliminate these as possibilities for the unknown bath salt and will omit them from our analysis. All alkaline earths exist in their compounds and in solution as M\(^{2+}\) cations (e.g. Mg\(^{2+}\), Ca\(^{2+}\), etc.). If solutions of these cations are mixed with solutions containing X\(^{2-}\) anions (e.g. CO\(_3^{2-}\), SO\(_4^{2-}\), etc.), salts of the alkaline earth elements will precipitate if the compound MX is insoluble:

\[
M^{2+} (aq) + X^{2-} (aq) \rightarrow MX (s) \quad if \, MX \, is \, insoluble
\]

\[
M^{2+} = Ba^{2+}, Ca^{2+}, Mg^{2+}, \, or \, Sr^{2+}; \quad X^{2-} = SO_4^{2-}, CO_3^{2-}, C_2O_4^{2-}, \, or \, CrO_4^{2-}
\]

We would expect the solubilities of these salts to show smooth trends consistent with the order of the cations in the Periodic Table. That is, as we go from one end of the alkaline
earth family to the other, the solubilities of, say, the sulfate salts either gradually increase or decrease. Similar trends should exist for the carbonate, oxalate, chromate, and other salts of these metals. In order to determine which alkaline earth metal is present in the unknown you will first need to investigate these trends by combining the alkaline earth cations with various anions.

The halogens:

The elemental halogens are also relatively reactive. The halogens include astatine, bromine, chlorine, fluorine, and iodine. These are all diatomic elements in their standard states at room temperature and have the symbols At₂(g), Br₂(l), Cl₂(g), F₂(g), and I₂(s), respectively. We can safely eliminate astatine and fluorine from our study since the former is radioactive and the later is too reactive to be safe. Unlike the alkaline earth elements, the halogens tend to gain electrons in reactions forming singly-charged X⁻ halide anions (Cl⁻, Br⁻, etc.). Because of this property, the halogens are strong oxidizing agents; species that tend to oxidize (remove electrons from) other species.

When a solution containing a halogen is mixed with a solution containing a halide ion, a reaction of the sort described by the chemical equation

\[ \text{X}_2 \text{(aq)} + 2 \text{Y}^- \text{(aq)} \rightarrow 2 \text{X}^- \text{(aq)} + \text{Y}_2 \text{(aq)} \]

may occur, where X₂ and Y₂ are halogens (Cl₂, Br₂, or I₂) and X⁻ and Y⁻ are their respective halide ions (Cl⁻, Br⁻, or I⁻).

You should recognize this as a single replacement reaction. The reaction will only occur if X₂ is a stronger oxidizing agent than Y₂, because X₂ can only produce Y₂ by removing electrons from the Y⁻ ions. If Y₂ is a stronger oxidizing agent than X₂, then no reaction will occur. Your team will combine solutions of various halogens and halide ions to determine the relative oxidizing strengths of the halogens. These oxidizing strengths should show a smooth variation down the Periodic Table.

The halogens tend to be more soluble in organic solvents than in water and exhibit characteristic colors when dissolved in various organic solvents. In contrast, the halide ions are colorless in aqueous solution and tend to be insoluble in many organic solvents. In this experiment you will be provided with the organic solvent hexane. The halogens are all soluble in hexane and the distinctive color of each halogen in hexane will allow you to identify it. Hexane is immiscible with water and less dense than water and therefore will form a layer above an aqueous solution. In order to promote a reaction between the halogen in the hexane layer and the halide ion in the aqueous layer you will need to cork and shake these solutions vigorously. After shaking a color change in the hexane layer signals if a reaction has occurred.

For example, suppose you mix a solution of bromine in water, Br₂(aq), with a little hexane. Bromine is much more soluble in hexane than in water, and so moves into the hexane layer, giving it a reddish-brown or orangey color. Now to this mixture we add a
solution containing an aqueous halide ion, for example chloride, and shake well (shaken, not stirred). There are two possible results:

a. If bromine is a stronger oxidizing agent than chlorine (Br₂ > Cl₂), then bromine will remove electrons from the aqueous chloride Cl⁻(aq) ions according to:

\[
\text{Br}_2(aq) + 2 \text{Cl}^-(aq) \rightarrow 2 \text{Br}^-(aq) + \text{Cl}_2(aq) \quad (\text{Br}_2 > \text{Cl}_2)
\]

and the color of the hexane layer will change from reddish-brown or orangey to that of a solution of chlorine in hexane.

b. On the other hand if no reaction occurs,

\[
\text{Br}_2(aq) + 2 \text{Cl}^-(aq) \rightarrow \text{No Reaction} \quad (\text{Cl}_2 > \text{Br}_2)
\]

then there will be no color change implying that chlorine is a stronger oxidizing agent than bromine.

By noting which halogens react with which halides you can rank the relative oxidizing strengths of the halogens. You can then use these data to experimentally determine the identity of the halide anion in the unknown bath salt.

<table>
<thead>
<tr>
<th>Elemental Halogens</th>
<th>Aqueous Halide Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bromine, Br₂</td>
<td>Bromide ion, Br⁻(aq)</td>
</tr>
<tr>
<td>Chlorine, Cl₂</td>
<td>Chloride ion, Cl⁻(aq)</td>
</tr>
<tr>
<td>Iodine, I₂</td>
<td>Iodide ion, I⁻(aq)</td>
</tr>
</tbody>
</table>

The **halogens** are molecular substances, are strong oxidizing agents, and all have characteristic odors. They are only slightly soluble in water and much more soluble in hexane, where they produce distinct colors.

The **halide ions** exist in aqueous solution, have no color or odor, and are not strong oxidizing agents. They remain in aqueous solution and are not soluble in hexane.

Keep in mind when performing your experiments that your unknown bath salt contains an aqueous alkaline earth cation and halide anion. For example, if the formula of your unknown is BeCl₂, then your unknown solution will contain Be²⁺(aq) cations and Cl⁻(aq) anions.
Experimental Guidelines

Wear your safety goggles while performing this experiment.
All waste MUST be poured into the waste container in the fume hood.

Before beginning record your unknown number in your notebook. Your instructor may also require you to turn in the label from this sample.

Determining the aqueous Alkaline Earth cation:

You will have available 0.1 M aqueous solutions containing nitrate salts of barium, calcium, magnesium, and strontium as sources of known alkaline earth cations:

<table>
<thead>
<tr>
<th>Known solutions containing alkaline earth cations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 M Ba(NO₃)₂</td>
</tr>
<tr>
<td>0.1 M Ca(NO₃)₂</td>
</tr>
<tr>
<td>0.1 M Mg(NO₃)₂</td>
</tr>
<tr>
<td>0.1 M Sr(NO₃)₂</td>
</tr>
</tbody>
</table>

You will also have available the following solutions that you can use as precipitating agents to help you in your determination:

<table>
<thead>
<tr>
<th>Precipitating agents for alkaline earth cations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M H₂SO₄</td>
</tr>
<tr>
<td>1 M Na₂CO₃</td>
</tr>
<tr>
<td>0.25 M (NH₄)₂C₂O₄</td>
</tr>
<tr>
<td>1 M K₂CrO₄ with 1 M CH₃COOH (acetic acid)</td>
</tr>
</tbody>
</table>

Combining about 1 mL of any of these in a small test tube with an equal quantity of a nitrate salt solution containing a known cation will allow you to observe any precipitation reactions that occur.

Your team should use these chemicals to determine the alkaline earth cation in your unknown aqueous bath salt solution.
Determining the aqueous halide anion:

In a small test tube place about 2 mL of bromine-saturated water and add about 1 mL of hexane. Stopper the test tube and shake well (see cautions below) until the bromine color is mostly in the hexane layer. This will allow you to observe the color of bromine in hexane.

**CAUTIONS:** Avoid breathing the halogen vapors. Don’t use your finger to stopper the tubes because halogen solutions can give you a bad chemical burn. You may want to wear gloves during this step.

Now add about 1 mL of 0.1 M aqueous sodium chloride solution, \( \text{NaCl}(aq) \), to this test tube. Stopper and shake well. If you observe a color change in the hexane layer, then a reaction has occurred. (If you observe a only slight change or are unsure of your results, try adding more of the halide solution, up to about 3 mL total.) Record your results in your notebook. Rinse the chemicals from this test tube into the waste container.

Proceeding in a similar manner your team should be able to determine the relative oxidizing strength of each of the halogens and then use these data to experimentally determine the identity of the unknown halide ion (not halogen) in your bath salt solution.

In addition to hexane, the following solutions are available for this experiment:

<table>
<thead>
<tr>
<th>Known halide solutions</th>
<th>Halogen test solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 M ( \text{NaBr}(aq) )</td>
<td>( \text{Br}_2 ) saturated water</td>
</tr>
<tr>
<td>0.1 M ( \text{NaCl}(aq) )</td>
<td>( \text{Cl}_2 ) saturated water</td>
</tr>
<tr>
<td>0.1 M ( \text{NaI}(aq) )</td>
<td>( \text{I}_2 ) saturated water</td>
</tr>
</tbody>
</table>
Report

There is no specific format for the write-up for this experiment. Your report should include the names of your team members and your unknown number. Your instructor may also require you to affix the label from your unknown bath salt to the report. The report should contain the following:

1. The unknown number and the formula that you experimentally determined for your bath salt, for example: “Unknown Salt 42A = BeCl$_2$(aq)”

2. The data that allowed you to determine the identity of the cation and anion in your salt. These should include the relative solubility of various precipitates and the relative oxidation strengths you determined for the halogens as well as any other data or observations made. (These data are generally best presented in tables).

3. A brief summary of the procedure you devised to experimentally determine the identity of the cation and the anion in your bath salt. Include a few sentences stating your confidence in your results and detail any other experiments or additional tests that could be done in the event of any uncertainty.

4. A brief examination of the data you collected to see if the properties you observed for the alkaline earths and halogens are consistent with the order of these elements in the Periodic Table.

5. Citations to any reference materials you consulted.