Experiment 10: Using Periodic Properties to Identify the Group 2A Cations and Group 7A Anions

(This experiment was adapted from Santa Monica College, last updated June 5, 2019.)

Purpose

To observe the solubility properties of various ionic compounds containing alkaline earth metal cations (Group 2A).

To observe the relative abilities of the halogens to be reduced to halides, or act as oxidizing agents (Group 7A).

To use the above observations to identify an unknown salt consisting of an alkaline earth metal cation and a halide anion.

As an additional side experiment, the emission lines of elements will be observed. Emission lines can also be used to identify cations and anions.

Background

Elements within a given column of the periodic table tend to have similar properties due to their similar valence electron configurations. Because of this, columns of elements are often referred to as “groups” or “families” of elements. These families include the alkali metals, alkaline earth metals, halogens, and noble gases. The physical and chemical properties of the elements within a given family tend to change gradually as one goes from one element in the column to the next. In this experiment the properties of elements in the alkaline earth metal and halogen families will be studied and this data used to identify an unknown salt consisting of an alkaline earth metal cation and a halide anion.

Group 2A: The Alkaline Earth Metals

The alkaline earth metals— beryllium, magnesium, calcium, strontium, barium, and radium—are all moderately reactive. Beryllium compounds are quite rare and often very poisonous and radium compounds are highly radioactive; thus, neither of these will be studied. Alkaline earth metals lose two electrons to make ions with a +2 charge and can thus be represented generically as M^{2+}. When solutions containing these cations are mixed with solutions containing anions such as CO_2^{3-} or SO_4^{2-}, ionic compounds of the general form MX will precipitate if the compound MX is insoluble under the reaction conditions used, as shown in the net ionic equation below.

$$M^{2+}{}_{(aq)} + X^{2-}{}_{(aq)} \longrightarrow MX_{(s)} \quad \text{if MX is insoluble}$$

In this experiment M^{2+} = Mg^{2+}, Ca^{2+}, Sr^{2+}, or Ba^{2+}

and X^{2-} = SO_4^{2-}, CO_3^{2-}, or $C_2O_4^{2-}$

No precipitate will be observed if the compound MX is soluble.

When the solubilities of compounds containing various cations combined with a given anion are compared, a solubility trend that follows the order in the periodic table is expected. For example, for the solubilities of the sulfate salts, the solubility is expected either to increase or decrease as we go down the alkaline earth family. These solubility properties will be used to identify an unknown compound containing a Group 2A cation.

Group 7A: The Halogens

The elementary halogens are also relatively reactive. They include fluorine, chlorine, bromine, iodine, and astatine. We will not study astatine or fluorine since astatine is radioactive and fluorine is too reactive to be safe. Unlike the alkaline earth metals, the halogens tend to gain electrons to form anions, such as Cl^{1-} and Br^{1-}. Since they are reduced when this occurs, the halogens are oxidizing agents, species that tend to oxidize (remove electrons from) other species. Thus, it is possible for some halogens (Cl_2, Br_2, I_2) to react with halide ions (Cl^{1-}, Br^{1-}, I^{1-}) in a single replacement reaction. An example would be as follows:

$$Cl_2 + 2\ I^{1-} \longrightarrow 2\ Cl^{1-} + I_2$$

The reaction will occur because Cl_2 is a better oxidizing agent than I_2, since Cl_2 has to remove electrons from the I^{1-} ions. If I_2 were a better oxidizing agent than Cl_2 then no reaction would occur. When comparing two or more halogens, the one that is a better oxidizing agent is considered to be "more active." Solutions of halogens and halide ions will be combined to determine the relative oxidizing abilities of the halogens. These should show a trend as one goes from one halogen to the next in the Periodic Table. Since the halogens have characteristic colors in non-polar organic solvents, such as hexane, while the halide ions are colorless, we can use the color changes that occur (or don't occur) to determine whether or not one halogen has displaced another in the above reaction. The relative oxidizing strengths of the halogens will be determined from the reactivity patterns. This data will then be used to determine the identity of the halide anion in an unknown compound.

It is important to keep in mind the difference between the halogen elements and the halide ions:

> The **halogens** are molecular substances, oxidizing agents, have odors, and are distinct colors. They are only slightly soluble in water and much more soluble in hexane. Do not breath the vapors!!!!
>
> The **halide ions** are soluble only in water, have no color or odor, and are <u>not</u> oxidizing agents. They do not dissolve in hexane.

Identification of an Ionic Compound Containing an Alkaline Earth Cation and a Halide

Given the observed solubility properties of the alkaline earth cations and the oxidizing ability of the halogens, it is possible to determine the identities of the alkaline earth cation and halide present in an unknown ionic compound. You will obtain an unknown substance containing an alkaline earth cation and a halide. Analyze this unknown with the chemical tests you use for the known samples.

Chemicals

0.1 M $Mg(NO_3)_2$	**0.1 M** $Ca(NO_3)_2$	**0.1 M** $Sr(NO_3)_2$	**0.1 M** $Ba(NO_3)_2$
1 M H_2SO_4	**1 M** Na_2CO_3	**0.25 M** $Na_2C_2O_4$	**1 M** Chlorine water
~~***1 M** Bromine water*~~	**1 M** Iodine water	**0.1 M** NaCl	~~***0.1 M** NaBr*~~
0.1 M NaI	Cyclohexane	----------------	----------------

Equipment: 6 small test tubes, test tube rack, stirring rod, and Parafilm

Safety

a) Hexane is flammable. Do not use it anywhere near an open flame.
b) Barium solutions are toxic.
c) All waste must be poured into the waste container.
d) Avoid breathing the halogen vapors.
e) Don't use your finger to stopper the tubes.
f) Notify your instructor if you spill any bromine solution.

Part A: Relative Solubilities of Some Salts of the Alkaline Earth Metals

1. Each of the following reactions is performed in a small test tube, using about 1 mL (12-15 drops from the reagent bottle dropper) of each solution. The reaction mixtures must be mixed well by using a stirring rod. The stirring rod should be rinsed in a beaker of deionized water and wiped dry between uses. The test tubes must be rinsed with distilled water before you reuse them for another reaction.

2. The results are to be recorded in your notebook. Observe whether a precipitate forms, and any characteristics, such as color, size of particles, and settling tendencies. These observations will help you distinguish one element from another.

3. These are the reactions. Record your observations in the following order:

$Na_2CO_3 + Mg(NO_3)_2$	$Na_2C_2O_4 + Mg(NO_3)_2$	$H_2SO_4 + Mg(NO_3)_2$
$Na_2CO_3 + Ca(NO_3)_2$	$Na_2C_2O_4 + Ca(NO_3)_2$	$H_2SO_4 + Ca(NO_3)_2$
$Na_2CO_3 + Sr(NO_3)_2$	$Na_2C_2O_4 + Sr(NO_3)_2$	$H_2SO_4 + Sr(NO_3)_2$
$Na_2CO_3 + Ba(NO_3)_2$	$Na_2C_2O_4 + Ba(NO_3)_2$	$H_2SO_4 + Ba(NO_3)_2$
Na_2CO_3 + Unknown	$Na_2C_2O_4$ + Unknown	H_2SO_4 + Unknown

Part B: Relative Oxidizing Abilities of the Halogens

1. The color of a halogen in cyclohexane is determined by placing 1 mL of halogen-saturated water in a small test tube, adding 1 mL of cyclohexane, and mixing the contents well until the color is mostly in the cyclohexane layer. The color of the cyclohexane layer should be noted at this point. Although the colors of the two layers may be different it is the color in the cyclohexane layer that will be used throughout this experiment. *(Note: Bromine observations will be from the PowerPoint slides.)*

	Chlorine water	Bromine water	Iodine water
Cyclohexane layer	*record the color*	*record the color from PowerPoint*	*record the color*

2. Each of the following reactions is to be performed in a small test tube by combining 1 mL of cyclohexane with 1 mL of each of the other two reagents listed. The contents should be mixed well and the color of the (upper) cyclohexane layer noted. The test tubes must be washed and then rinsed with distilled water before you reuse them for another reaction. *(Get NaBr observations from the PowerPoint slides.)*

Cyclohexane + Cl_2 + NaCl	Cyclohexane + Br_2 + NaCl	Cyclohexane + I_2 + NaCl
Cyclohexane + Cl_2 + NaBr	Cyclohexane + Br_2 + NaBr	Cyclohexane + I_2 + NaBr
Cyclohexane + Cl_2 + NaI	Cyclohexane + Br_2 + NaI	Cyclohexane + I_2 + NaI
Cyclohexane + Cl_2 + unknown	Cyclohexane + Br_2 + unknown	Cyclohexane + I_2 + unknown

Part C: The Unknown

Determine the chemical formula of the unknown that contains one alkaline earth metal cation and one halide ion. Perform the tests on the unknown as you are working with the known samples.

Part D: Emission Lines of Elements

Each element has its own unique pattern of emission lines, like a fingerprint. These emission lines are used to identify elements in samples.

1. You will observe the emission lines of hydrogen. Record the wavelength, in nm, for three lines in the visible region of light: red, greenish-blue, blueish-purple (the violet line is often too faint to observe). Then use the Rydberg equation to calculate each emission line wavelength (in nm units). Do the calculated wavelengths agree or not agree with observed wavelengths? Show your calculations in your notebook worksheet.

Rydberg Equation

$R = 1.0974 \times 10^7 \ \frac{1}{m}$

$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$n_2 \to n_1$	$5 \to 2$	$4 \to 2$	$3 \to 2$

2. Observe the emission lines of the unknown element. Use the emission line images of various elements provided to you to identify the unknown element.