1. Solubilities Within a Family

Introduction

The periodic table is arranged in such a way that the electron configurations of the elements display a periodic variation (Ebbing/Gammon, Section 8.6). The same kind of outer configuration occurs within a group (vertical column) period after period (horizontal row). For example, the outer electron configuration of an alkaline earth metal (Group IIA) is always ns^2, no matter what period the element occupies.

The periodicity in the outer electron configurations is responsible for the periodic law: When the elements are arranged by atomic number, their physical and chemical properties vary periodically. Because of this periodicity, elements within the same group form compounds that have the same general formula. Thus all the alkaline earth metals form oxides with the same general formula.

The periodic law, however, does not imply that all the properties of the elements within a group will be identical. Trends in properties are usually found instead. Thus atomic size increases smoothly going down a column of main-group elements, whereas ionization energy decreases (Ebbing/Gammon, Section 8.6).

Purpose

This experiment will give you the opportunity to look for trends in the relative solubilities of some compounds of the alkaline earth metals. You will also compare the solubilities of these compounds with those of some similar compounds of lead, a metal in Group IVA.

Concept of the experiment

The solubility of a compound in a liquid is the maximum amount of that compound that will dissolve at a fixed temperature. In this experiment you will be interested in the qualitative aspects of solubility. You will see that the qualitative terms *soluble* and *insoluble* can be used to describe a compound's solubility.

There are two ways to determine the solubility of a compound qualitatively. First, we can take the compound directly from a bottle, place the compound in the desired liquid, and observe the solubility. Second, we can synthesize (make) the compound by a chemical reaction in the liquid. If the compound appears as a precipitate, we know that it cannot be very soluble in the liquid. If it does not appear, it must be soluble. You will employ the second method in this experiment.

The alkaline earth metals and lead form nitrates, hydroxides, chlorides, bromides, and iodides with general formulas of $R(NO_3)_2$, $R(OH)_2$, RCl_2, RBr_2, and RI_2, respectively. You will use the reaction

$$R(NO_3)_2 + 2NaX \rightarrow RX_2 + 2NaNO_3$$

to determine the qualitative solubilities of the hydroxides, chlorides, bromides, and iodides in water. Each of these is represented by X in the general reaction. We know that $NaNO_3$ (sodium nitrate) must be very soluble because all nitrates are very soluble. Thus if a precipitate appears, it can only be RX_2, and this must mean that this compound is not very soluble in water.

The alkaline earth metals and lead also form sulfates, carbonates, oxalates, and chromates with general formulas of RSO_4, RCO_3, RC_2O_4, and $RCrO_4$, respectively. These compounds will be prepared by the reaction

$$R(NO_3)_2 + Na_2Y \rightarrow RY + 2NaNO_3$$

where Y represents sulfate, carbonate, oxalate, and chromate. The solubilities of the RY compounds will be determined in exactly the same way as those of the RX compounds.

Because you will be examining only the qualitative aspects of the solubilities of these compounds, you will not observe trends directly. Instead, you will need to infer their presence. The following example should make this process easier.

Consider the solubilities of the chromates shown in Table 1.1. Let us pretend for the moment that we do not know these solubilities. What would you find if you were to use a chemical reaction to produce 1.0×10^{-4} mol of each substance in 1000 mL of water? Note that only the solubility of $BaCrO_4$ has been exceeded. As a result, all of the $MgCrO_4$, $CaCrO_4$, and $SrCrO_4$ would remain in solution, and a precipitate of $BaCrO_4$ would appear. This experiment would force us to admit the possibility that if a trend exists, the solubilities may decrease as the atomic number of the Group IIA metal increases. As Table 1.1 shows, this is correct.

Table 1.1 Solubilities of Some Chromates (mol/1000 mL H_2O)

$MgCrO_4$	$CaCrO_4$	$SrCrO_4$	$BaCrO_4$
9.9	1.2	5.9×10^{-3}	1.1×10^{-5}

This example is not intended to portray a general trend. In some instances, solubilities will increase as the atomic number of the Group IIA metal increases.

Procedure

Getting started

1. Obtain 5 small test tubes.

2. Use a 5-mL or a 10-mL graduated cylinder to place 1 mL of distilled water in each of these test tubes. Mark the height of the water in each test tube with a small piece of tape or a marking pencil. Add an additional 1 mL to each test tube and mark the new height of the water in each. Pour the water into a sink.
3. Obtain directions for discarding the solutions that you will use in this experiment.
4. Observe the following safety precauation during the remainder of this experiment.

CAUTION: Wash your hands thoroughly after using solutions containing lead, barium, or oxalate because they are poisonous.

Determining the qualitative solubilities

1. Mark the test tubes with identification numbers (1 through 5).
2. Using the lower marks on the test tubes as guides, add 1 mL of 0.1 *M* $Mg(NO_3)_2$ to the first test tube, 1 mL of 0.1 *M* $Ca(NO_3)_2$ to the second, 1 mL of 0.1 *M* $Sr(NO_3)_2$ to the third, 1 mL of 0.1 *M* $Ba(NO_3)_2$ to the fourth, and 1 mL of 0.1 *M* $Pb(NO_3)_2$ to the fifth.
3. Using the upper marks as guides, add 1 mL of 1 *M* NaOH to each test tube. Shake each tube gently and wait about 30 s. Note the colors of all precipitates. If any of the precipitates are virtually colorless, they may be difficult to see. Be observant! Note the relative amounts of the precipitates. If the solubility of a compound is barely exceeded, only a trace of a precipitate will appear. Record your observations.

CAUTION: Do not use your finger as a stopper.

4. Wash the test tubes carefully and rinse them with distilled water.
5. Repeat Steps 1 through 4 in turn with 1 *M* NaCl, 0.1 *M* NaBr, 0.1 *M* NaI, 0.1 *M* Na_2SO_4, 0.1 *M* Na_2CO_3, and 0.1 *M* $Na_2C_2O_4$ instead of the solution of NaOH.

Solubilities Within a Family

Date:	....	Student name:	....
Course:	....	Team members:	....
Section:	....		....
Instructor:	....		....

Prelaboratory assignment

1. Give the names and symbols of the alkaline earth metals that you will encounter in this experiment.

2. a. What is the general electron configuration of the alkaline earth metals?

   b. What is the electron configuration of lead?

   c. Compare the formulas of the oxides formed by the alkaline earth metals with those of lead.

3. Give general formulas for the following compounds with alkaline earth metals or lead:

a. A sulfate

b. A chloride

c. A carbonate

d. An iodide

e. A bromide

f. An oxalate

g. A hydroxide

h. A nitrate

i. A chromate

4. What general method will be used to examine qualitative solubilities in this experiment?

5. What safety precautions must be observed in this experiment?

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Results

	$Mg(NO_3)_2$	**$Ca(NO_3)_2$**	**$Sr(NO_3)_2$**	**$Ba(NO_3)_2$**	**$Pb(NO_3)_2$**
NaOH					
NaCl					
NaBr					
NaI					
Na_2SO_4					
Na_2CO_3					
$Na_2C_2O_4$					

Questions

1. What trends in the solubilities of the compounds of the alkaline earth metals can be inferred?

2. a. Compare the solubilities of the lead compounds with those of the alkaline earth metals. How are the solubilities similar, and how do they differ?

   b. As you have seen, lead can form the same kinds of compounds as the alkaline earth metals. Nevertheless, the solubilities may differ markedly. Give a convincing reason.