Solubility Patterns in the Periodic Table

Periodic Table Demonstrations and Activities

FLINN SCIENTIFIC CHEM FAX!

Introduction

The alkaline earth metals are so-named because their oxides are highly basic (alkaline) and because they occur abundantly on Earth. Alkaline earth metal compounds—carbonates, sulfates, silicates—are abundant in minerals such as *dolomite* (calcium and magnesium carbonate), *epsomite* (magnesium sulfate), and *baryte* (barium sulfate). The solubilities of these compounds vary widely, depending on the metal cation. Are there any patterns or periodic trends in the solubility behavior of alkaline earth metal compounds?

Concepts

- Alkaline earth metals
- Double replacement reactions
- Periodic trends
- Solubility rules

Materials

Alkaline earth metal chlorides

Barium chloride solution, 0.1 *M*, $BaCl_2$, 6 mL

Calcium chloride solution, 0.1 *M*, $CaCl_2$, 6 mL

Magnesium chloride solution, 0.1 *M*, $MgCl_2$, 6 mL

Strontium chloride solution, 0.1 *M*, $SrCl_2$, 6 mL

Reaction plate, 24-well

Testing Solutions

Ammonium oxalate solution, 0.25 *M*, $(NH_4)_2C_2O_4$, 4 mL

Potassium iodate solution, 0.2 *M*, KIO_3, 4 mL

Sodium carbonate solution, 1 *M*, Na_2CO_3, 4 mL

Sodium sulfate solution, 1 *M*, Na_2SO_4, 4 mL

Safety Precautions

Potassium iodate is moderately toxic and is irritating to skin, eyes, and the respiratory tract. Strontium and barium compounds are toxic by ingestion. Oxalates are toxic by ingestion and are irritating to body tissues. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles and chemical-resistant gloves and apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Place a 24-well reaction plate onto the stage of the overhead projector and turn on the projector. Note that each well is identified by a unique combination of a letter and a number, where the letters A–D refer to horizontal rows and the numbers 1–6 refer to vertical columns.
2. Pass out the Solubility Patterns Worksheet. Instruct students to fill out the top part of the Demonstration Worksheet with observations of what is occuring in the reaction wells during the demonstration. Have them use the abbreviation PPT and NR to note the formation of a precipitate or no reaction, respectively.
3. Identify each horizontal row with the correct alkaline earth metal chloride and each vertical column with the correct testing solution.

4. Add 1 mL (about 25 drops or fill the well about ¼ inch or 0.5 cm deep) of an alkaline earth metal chloride solution to each well in a horizontal row, as follows (see Figure 1):
   - magnesium chloride to wells A1–A5
   - calcium chloride to wells B1–B5
   - strontium chloride to wells C1–C5
   - barium chloride to wells D1–D5
5. Add 1 mL (about 25 drops) of testing solution to each well in a vertical column, as follows (see Figure 1):
   - potassium iodate to wells A1–D1
   - sodium sulfate to wells A2–D2
   - ammonium oxalate to wells A3–D3
   - sodium carbonate to wells A4–D4

   Note: The fifth column serves as a control to identify the absence of a precipitate.

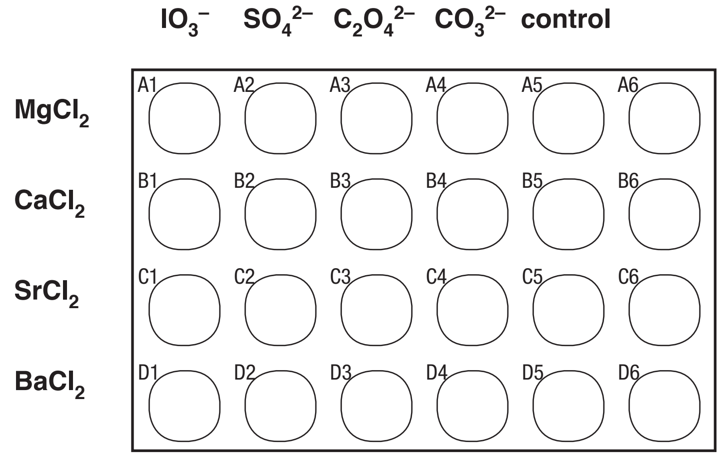

Figure 1. Demonstration Setup

6. Students may now fill out the rest of the Solubility Patterns Worksheet and the Net Ionic Equation Worksheet.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Barium compounds may be disposed of according to Flinn Suggested Disposal Method #27h. All other solutions can be flushed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- A chemical demonstration kit, Solubility Patterns, (Catalog No. AP6353), is available from Flinn Scientific and contains enough materials to perform the demonstration, as written, seven times. The student worksheet may be copied for students to fill out during the demonstration.
- This demonstration provides an excellent exercise for writing and balancing chemical equations and net ionic equations. A second handout (Net Ionic Equation Worksheet) is included for this activity.
- The demonstration can be extended to include the identification of an unknown. Carry an unknown solution containing one or two different alkaline earth metal cations through the sequence of precipitation reactions. Use the resulting solubility pattern to identify the unknown cation(s).
- The strontium chloride forms a precipitate with carbonate but there is not as much precipitate as other precipitate reactions.
- Discuss the relationship between the solubility pattern of alkaline earth metal compounds and hard water. Hard water contains relatively high concentrations of magnesium and calcium ions. The problems caused by hard water range from a nuisance (soaps leave soap scum, calcium stearate; detergents are not effective) to costly industrial "boiler scale" water treatment programs (to eliminate the formation of calcium carbonate).

Discussion

Periodic trends are observed in the solubility of alkaline earth metal compounds. Although their chlorides and nitrates are all water-soluble, alkaline earth metal compounds with other anions do not always dissolve in water. The solubility of alkaline earth metal compounds with different anions is tested by carrying out *double replacement reactions*. Reaction of calcium chloride with sodium carbonate, for example, leads to an exchange of anions between the two metals to give calcium carbonate, which is relatively insoluble in water and precipitates out as a solid when the two solutions are mixed. The chemical equation for this reaction is given in Equation 1, where the abbreviations (aq) and (s) refer to aqueous solutions and solid precipitates, respectively.

$$\underset{\text{calcium chloride}}{CaCl_2(aq)} + \underset{\text{sodium carbonate}}{Na_2CO_3(aq)} \rightarrow \underset{\text{calcium carbonate}}{CaCO_3(s)} + \underset{\text{sodium chloride}}{2NaCl(aq)} \qquad \textit{Equation 1}$$

The solubility pattern observed for alkaline earth metal compounds is shown below. The solubility of alkaline earth metal compounds decreases as you go down the column in the periodic table, i.e., solubility decreases as the atomic mass of the alkaline earth metal increases.

	IO_3^-	SO_4^{2-}	$C_2O_4^{2-}$	CO_3^{2-}	control	
$MgCl_2$	A1 NR	A2 NR	A3 NR	A4 PPT	A5 NR	A6 X
$CaCl_2$	B1 NR	B2 NR	B3 PPT	B4 PPT	B5 NR	B6 X
$SrCl_2$	C1 NR	C2 PPT	C3 PPT	C4 PPT	C5 NR	C6 X
$BaCl_2$	D1 PPT	D2 PPT	D3 PPT	D4 PPT	D5 NR	D6 X

Figure 1. Demonstration Setup

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

Answers to Solubility Patterns Worksheet

	IO_3^-	SO_4^{2-}	$C_2O_4^{2-}$	CO_3^{2-}	control	
$MgCl_2$	A1 NR	A2 NR	A3 NR	A4 PPT	A5 NR	A6 X
$CaCl_2$	B1 NR	B2 NR	B3 PPT	B4 PPT	B5 NR	B6 X
$SrCl_2$	C1 NR	C2 PPT	C3 PPT	C4 PPT	C5 NR	C6 X
$BaCl_2$	D1 PPT	D2 PPT	D3 PPT	D4 PPT	D5 NR	D6 X

Figure 1. Demonstration Setup

1. Observe the reactions that develop in the reaction plate and have students record the results in the table of circles. Use the abbreviations PPT and NR to note the formation of a precipitate or no reaction, respectively.
2. What patterns or trends are obvious in the solubility behavior of the alkaline earth metal compounds?

   Which alkaline earth metal ion formed the most precipitates? *Barium*
   The fewest? *Magnesium*
   Which testing solution gave the most precipitates? *Carbonate*
   The fewest? *Iodate*
3. Ask students to identify any periodic trend in the solubility behavior of alkaline earth metal compounds. Is there any relationship between the solubility of alkaline earth metal compounds and the position of the metal in the periodic table?

   Solubility decreases as you proceed down a family in the periodic table.
4. Propose an explanation for the observed solubility pattern.

   The size or radius of an atom increases as one goes down a row (family) in the periodic table. For cations, the charge density (charge per unit volume) will therefore decrease going down a row. The solubility of metal cations in water is strongly influenced by the hydration of the positive ions by the polar water molecules. The hydration energy of an ion represents the change in energy that occurs when water molecules attach to the cation. Water molecules are more attracted to a cation with a high charge density (i.e., a smaller atom) than one that is larger with a lower charge density. Therefore, as one moves down a family of elements in the periodic table, the charge density will decrease as will the solubility.
5. Use the observed solubility pattern to predict a chemical method for the separation of a mixture of calcium and barium ions in solution. (Imagine a solution that is 0.1 M in both $CaCl_2$ and $BaCl_2$. What reagents can be added to this mixture and in what order to separate the two compounds?)

   First, add potassium iodate solution to precipitate barium iodate. Filter the solution to isolate barium iodate. Then, add sodium carbonate solution to precipitate calcium carbonate. Filter the solution to isolate calcium carbonate.

Answers to Net Ionic Equation Worksheet

Write out the net ionic equation for each reaction. If no reaction occurs, write NR.

1. $MgCl_2$ and KIO_3 — *NR*
2. $MgCl_2$ and Na_2SO_4 — *NR*
3. $MgCl_2$ and $(NH_4)_2C_2O_4$ — *NR*
4. $MgCl_2$ and Na_2CO_3 — $Mg^{2+}(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s)$
5. $CaCl_2$ and KIO_3 — *NR*
6. $CaCl_2$ and Na_2SO_4 — *NR*
7. $CaCl_2$ and $(NH_4)_2C_2O_4$ — $Ca^{2+}(aq) + C_2O_4^{2-}(aq) \rightarrow CaC_2O_4(s)$
8. $CaCl_2$ and Na_2CO_3 — $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$
9. $SrCl_2$ and KIO_3 — *NR*
10. $SrCl_2$ and Na_2SO_4 — $Sr^{2+}(aq) + SO_4^{2-}(aq) \rightarrow SrSO_4(s)$
11. $SrCl_2$ and $(NH_4)_2C_2O_4$ — $Sr^{2+}(aq) + C_2O_4^{2-}(aq) \rightarrow SrC_2O_4(s)$
12. $SrCl_2$ and Na_2CO_3 — $Sr^{2+}(aq) + CO_3^{2-}(aq) \rightarrow SrCO_3(s)$
13. $BaCl_2$ and KIO_3 — $Ba^{2+}(aq) + 2IO_3^{-}(aq) \rightarrow Ba(IO_3)_2(s)$

14. $BaCl_2$ and Na_2SO_4 — $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

15. $BaCl_2$ and $(NH_4)_2C_2O_4$ — $Ba^{2+}(aq) + C_2O_4^{2-}(aq) \rightarrow BaC_2O_4(s)$

16. $BaCl_2$ and Na_2CO_3 — $Ba^{2+}(aq) + CO_3^{2-}(aq) \rightarrow BaCO_3(s)$

Reference

This activity is from *Flinn ChemTopic™ Labs*, Volume 4, The Periodic Table; Cesa, I., Ed., Flinn Scientific: Batavia, IL, 2002.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Solubility Patterns in the Periodic Table* activity, presented by Peg Convery, is available in *Periodic Table Demonstrations and Activities*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Solubility Patterns in the Periodic Table* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Solubility Patterns—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6353	Solubility Patterns—Chemical Demonstration Kit
AP6254	Flinn ChemTopic™ Labs, Volume 4, The Periodic Table
AP1447	Reaction plate, 24-well
A0198	Ammonium Oxalate Solution, 0.25 M, 500 mL
B0144	Barium Chloride Solution, 0.1 M, 500 mL
C0234	Calcium Chloride Solution, 0.1 M, 500 mL
M0121	Magnesium Chloride Solution, 0.1 M, 500 mL
P0168	Potassium iodate Solution, 0.2 M, 500 mL
S0234	Sodium Carbonate Solution, 1 M, 500 mL
S0352	Sodium Sulfate Solution, 1 M, 500 mL
S0255	Strontium Chloride Solution, 0.1 M, 500 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Solubility Patterns Worksheet

	IO_3^-	SO_4^{2-}	$C_2O_4^{2-}$	CO_3^{2-}	control	
$MgCl_2$	A1	A2	A3	A4	A5	A6 X
$CaCl_2$	B1	B2	B3	B4	B5	B6 X
$SrCl_2$	C1	C2	C3	C4	C5	C6 X
$BaCl_2$	D1	D2	D3	D4	D5	D6 X

Figure 1. Demonstration Setup

1. Observe the reactions that develop in the reaction plate and record the results in the table of circles. Use the abbreviations PPT and NR to note the formation of a precipitate or no reaction, respectively.
2. What patterns or trends are obvious in the solubility behavior of the alkaline earth metal compounds?

   a. Which alkaline earth metal ion formed the most precipitates?

   b. The fewest?

   c. Which testing solution gave the most precipitates?

   d. The fewest?
3. Identify any periodic trend in the solubility behavior of alkaline earth metal compounds. Is there any relationship between the solubility of alkaline earth metal compounds and the position of the metal in the periodic table?
4. Propose an explanation for the observed solubility pattern.
5. Use the observed solubility pattern to predict a chemical method for the separation of a mixture of calcium and barium ions in solution. (Imagine a solution that is 0.1 M in both $CaCl_2$ and $BaCl_2$. What reagents can be added to this mixture and in what order to separate the two compounds?)

Net Ionic Equation Worksheet

Write out the net ionic equation for each reaction. If no reaction occurs, write NR.

1. $MgCl_2$ and KIO_3

2. $MgCl_2$ and Na_2SO_4

3. $MgCl_2$ and $(NH_4)_2C_2O_4$

4. $MgCl_2$ and Na_2CO_3

5. $CaCl_2$ and KIO_3

6. $CaCl_2$ and Na_2SO_4

7. $CaCl_2$ and $(NH_4)_2C_2O_4$

8. $CaCl_2$ and Na_2CO_3

9. $SrCl_2$ and KIO_3

10. $SrCl_2$ and Na_2SO_4

11. $SrCl_2$ and $(NH_4)_2C_2O_4$

12. $SrCl_2$ and Na_2CO_3

13. $BaCl_2$ and KIO_3

14. $BaCl_2$ and Na_2SO_4

15. $BaCl_2$ and $(NH_4)_2C_2O_4$

16. $BaCl_2$ and Na_2CO_3