Solubility Rules and the Mystery Solutions – Grade 11

Ohio Standards Connection:

Scientific Ways of Knowing

Benchmark A
Explain how scientific evidence is used to develop and revise scientific predictions, ideas or theories.

Indicator 1
Analyze a set of data to derive a hypothesis and apply that hypothesis to a similar phenomenon (e.g., biome data).

Lesson Summary:
Students will use solubility rules, based on data, to predict the results of mixing various solutions. They will then use the data obtained from mixing the solutions to solve a problem involving hazardous waste cleanup.

Estimated Duration: Four hours

Commentary:
This lesson is designed to give students experience with making scientific predictions, deriving hypotheses and applying hypotheses based on sets of data. First, students will use an established solubility table, compiled from data, to predict the solubility of several compounds. Second, students will collect a set of data based on experimentation and use the data to design experiments that will identify unknowns.

Before attempting this lesson, students need to know how to predict products in double-displacement reactions and write formulas for compounds. They also need to understand the concepts of solubility and precipitation.

This lesson was field tested and reviewed by educators across the state of Ohio. Some of their comments were:
- "This is a challenging post-assessment – age appropriate and excellent."
- "What could have been a 'what will I ever do with this?' question is tied in beautifully with the real world using the post-assessment."

Pre-Assessment:
- Give students a list of solubility rules and a list of four solution reactions. (See Attachment A, *Pre-Assessment).*
- Ask students to predict the products and circle any precipitate that is formed.

Scoring Guidelines:
See Attachment B, *Answers and Scoring Guidelines for the Pre-Assessment*.

Post-Assessment:
- Give the students a scenario that requires the cleanup of an abandoned lab. The task involves identifying unlabeled chemicals. (See Attachment C, *Post-Assessment* for the task).
- Provide the seven chemicals in bottles labeled with the numbers one through seven.
- Tell students ahead of time that they will not have access to labeled chemicals during the post-assessment; therefore, their data tables need to be as accurate and thorough as possible.

Instructional Tip:
If time is short, the post-assessment may be limited to having students identify only three or four solutions instead of seven.

Scoring Guideline:
See Attachment D, *Post-Assessment Rubric*.

Instructional Procedures:
1. Ahead of time, prepare 0.1 M (approximately) aqueous solutions of the following compounds:

Salts

The amounts in parentheses indicate the mass to dissolve per liter of solution to make 0.1 M.

sodium carbonate	(10.6g Na_2CO_3)	barium chloride	(39.1g $BaCl_2$)
calcium chloride	(11.1g $CaCl_2$)	sodium hydroxide	(4.0g NaOH)
potassium hydroxide	(5.7g KOH)	copper (II) nitrate	(18.8g $Cu(NO_3)_2$)
potassium carbonate	(12.6g K_2CO_3)	copper (II) sulfate	(15.9g $CuSO_4$)
cobalt(II) nitrate	(18.3g $Co(NO_3)_2$)	silver nitrate	(17.0g $AgNO_3$)
cobalt(II) chloride	(13.0g $CoCl_2$)	barium nitrate	(26.1g $Ba(NO_3)_2$)
sodium phosphate	(16.4 g Na_3PO_4)	iron (III) nitrate	(24.2 g $Fe(NO_3)_3$)

Acids/Bases

ammonium hydroxide	Add 6.8 mL of concentrated NH_3 (NH_4OH) solution to 993.2 mL water.
sulfuric acid	Add 5.5 mL of concentrated H_2SO_4 to 994.5 mL water. (Safety note: Please add the concentrated sulfuric acid to the water carefully while stirring. This is an exothermic dissolution.)
hydrochloric acid	Add 8.3 mL of concentrated HCl to 991.7 mL of water. (Safety note: Please do this in the fume hood because concentrated HCl releases HCl gas when the cap is removed.)

Solubility Rules and the Mystery Solutions – Grade 11

Instructional Tip:
If the number of unknowns in the post-assessment is decreased, also decrease the number of solutions in this activity.

2. Distribute the lab sheet to the students. (See Attachment H, *Predicting Precipitates*). Have students work in pairs to prepare data tables to test all of the possible binary combinations of the following 12 aqueous solutions:

ammonium hydroxide	sodium sulfate	silver nitrate
potassium hydroxide	copper (II) nitrate	barium nitrate
potassium carbonate	hydrochloric acid	sodium phosphate
cobalt (II) nitrate	calcium chloride	iron (III) nitrate

Instructional Tip:
See Attachment E, *Table of Possible Reactions,* for a pre-constructed data table if time is not available for students to create their own. Or, perhaps, help students set up a table for a few solutions and then have them complete the data table.

3. On a separate piece of paper, have students write the chemical equation for each double-displacement reaction.
4. Ask the students to examine the two possible products from each reaction and, using solubility rules, predict which, if either, of the two products is an insoluble compound. If the compound is insoluble, tell them to circle it.
5. On the data table, have students write "ppt," the abbreviation for precipitate, in the boxes of the combinations that produce insoluble compounds.
6. For the microscale investigation, copy the page with the large X's on it. See Attachment G, *Template for the Spot Sheet.* Make enough copies to have one per lab group. Either laminate the copies or place them in page protectors. Tell the students to place one or two drops of the combinations of chemicals to be tested on the X's and record their observations in the data table. If the students have never observed the formation of precipitates, demonstrate one and point out that cloudiness or clumping in the solution is the formation of the insoluble compound, the precipitate.
7. Have the students answer the follow-up questions in the lab and lead a discussion about the following points:
   - What were their successes and failures in predicting the precipitates?
   - Do they understand that when an acid and a carbonate react, the bubbling they observe is a gas (CO_2) being formed?
   - Did they conclude that it is the metal cations that produce the color in the copper, iron and cobalt solutions? These colors can help make predictions about other solutions' identities.
8. Tell the students that they are now ready for the challenge (the post-assessment), the *Hazardous Waste Report*.

Differentiated Instructional Support:
Instruction is differentiated according to learner needs, to help all learners either meet the intent of the specified indicator(s) or, if the indicator is already met, to advance beyond the specified indicator(s).
- Based on students' skills, knowledge and experiences either give them the pre-constructed data table or ask them to construct their own data tables for testing the 12 solutions.
- Give students who are having difficulty with the post-assessment various hints on how to proceed.
- Challenge students to attempt a greater number of unknowns.

Extension:
Prepare additional chemicals for those students who desire a greater challenge than the seven unknown solutions in the post-assessment.

Homework Options and Home Connections:
- Have students examine storage areas at home for unlabeled substances.
- Have students contact local agencies to determine acceptable ways for disposing of unidentified substances.

Materials and Resources:
The inclusion of a specific resource in any lesson formulated by the Ohio Department of Education should not be interpreted as an endorsement of that particular resource, or any of its contents, by the Ohio Department of Education. The Ohio Department of Education does not endorse any particular resource. The Web addresses listed are for a given site's main page, therefore, it may be necessary to search within that site to find the specific information required for a given lesson. Please note that information published on the Internet changes over time, therefore the links provided may no longer contain the specific information related to a given lesson. Teachers are advised to preview all sites before using them with students.

For the teacher: Spot sheets (laminated or in page protectors), dropper bottles, sodium carbonate, barium chloride, calcium chloride, sodium hydroxide, potassium hydroxide, copper (II) nitrate, potassium carbonate, copper (II) sulfate, cobalt(II) nitrate, silver nitrate, cobalt(II) chloride, barium nitrate, sodium phosphate, iron (III) nitrate, ammonium hydroxide, sulfuric acid, hydrochloric acid.

For the students: Spot sheets (laminated or in page protectors), dropper bottles, sodium carbonate, barium chloride, calcium chloride, sodium hydroxide, potassium hydroxide, copper (II) nitrate, potassium carbonate, copper (II) sulfate, cobalt(II) nitrate, silver nitrate, cobalt(II) chloride, barium nitrate, sodium phosphate, iron (III) nitrate, ammonium hydroxide, sulfuric acid, hydrochloric acid.

Solubility Rules and the Mystery Solutions – Grade 11

Vocabulary:
- precipitate
- solubility
- insoluble
- cation
- anion
- aqueous
- solution
- binary
- hazardous waste

Technology Connections:
Search the Internet to find acceptable methods for disposing of hazardous or unknown substances.

Research Connections:
Johnson, D.W., and R.T. Johnson. *Learning together and alone: Cooperative, competitive, and individualistic learning.* Boston: Allyn &Bacon, 1999.

Cooperative groups can enhance learning and help motivate students to progress faster.

Kumar, D.D. "A Meta-Analysis of the Relationship Between Science Instruction and Student Engagement." *Education Review* 43:1 (1991): 49-66.
This exercise provides repetition, which research has shown increases recall.

Gardner, H. *Frames of Mind: The Theory of Multiple Intelligences.* New York: Basic Books, Inc., 1983.
Students not only participate in writing and predicting reactions on paper, but they also perform the reactions in the laboratory to cement their learning.

General Tips:
- In the post-assessment, if the students are concerned, assure them that these chemicals are not really "hazardous wastes," but they should treat them with the same respect as any chemicals in the laboratory.
- Make the solutions approximately 0.1 M, but they don't have to be exact.
- Be sure to remind students that they must wear safety goggles during this activity and that they should wash their hands afterwards.

Solubility Rules and the Mystery Solutions – Grade 11

Attachments:
Attachment A, *Pre-Assessment*
Attachment B, *Answers and Scoring Guidelines for the Pre-Assessment*
Attachment C, *Post-Assessment*
Attachment D, *Post-Assessment Rubric*
Attachment E, *Table of Possible Reactions*
Attachment F, *Key to Table of Possible Reactions*
Attachment G, *Template for the Spot Sheet*
Attachment H, *Predicting Precipitates*

Attachment A
Pre-Assessment

Solubility Rules
1. All nitrates and acetates are soluble.
2. All salts of alkali metals and ammonium are soluble.
3. All halides are soluble, except those of silver, mercury (I) (Hg_2^{2+}), and lead (II) (Pb^{2+}).
4. All sulfates are soluble, except those of calcium (slightly), strontium, barium, lead (II) (Pb^{2+}), and mercury (I), (Hg_2^{2+}).
5. All hydroxides, phosphates, carbonates and sulfides are insoluble, except those of the alkali metals and ammonium. Also, hydroxides and sulfides of calcium, strontium and barium are slightly soluble.

As a memory device use "CHOPS NAAA."
Mostly Insoluble: (CHOPS) Carbonates, Hydroxides, Oxides, Phosphates, and Sulfides
Mostly Soluble: (NAAA) Nitrates, Acetates, Alkali Metals, Ammonium

Directions

Using the above solubility rules and a list of common cations and anions, write the chemical formulas for the reactants, predict the possible products of the following double-displacement reactions in solution and identify any precipitates in the products by circling them.

1. silver nitrate + sodium chloride →

2. potassium chromate + lithium bromide →

3. copper (II) sulfate + sodium hydroxide →

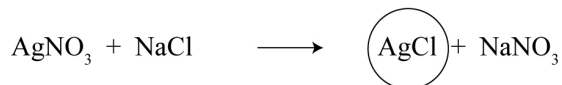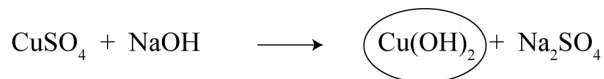4. ammonium carbonate + iron (III) nitrate →

Attachment B
Answers and Scoring Guidelines for the Pre-Assessment

Answers to Pre-Assessment
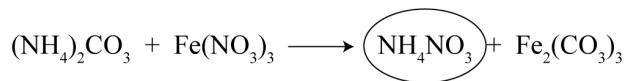
1. silver nitrate + sodium chloride $\longrightarrow$

    $AgNO_3 + NaCl \longrightarrow \boxed{AgCl} + NaNO_3$

2. potassium chromate + lithium bromide $\longrightarrow$

    $K_2CrO_4 + LiBr \longrightarrow KBr + Li_2CrO_4$ no precipitate!

3. copper (II) sulfate + sodium hydroxide $\longrightarrow$

    $CuSO_4 + NaOH \longrightarrow \boxed{Cu(OH)_2} + Na_2SO_4$

4. ammonium carbonate + iron (III) nitrate $\longrightarrow$

    $(NH_4)_2CO_3 + Fe(NO_3)_3 \longrightarrow \boxed{NH_4NO_3} + Fe_2(CO_3)_3$

Scoring Guidelines:

Student Results	Teacher Action
The student can predict the products and write the formulas of the compounds in all four of the solution reactions.	Have the student skip the instructional strategies and proceed directly to the post-assessment.
The student cannot predict the products and write the formulas of the compounds in all four of the solution reactions.	Have the student follow through the instructional strategy before attempting the post-assessment.

Solubility Rules and the Mystery Solutions – Grade 11

Attachment C
Post-Assessment
Hazardous Waste Cleanup

You have been called in to help with the cleanup of an abandoned lab. On one of the lab benches is a box with seven bottles in it. The labels have fallen off the bottles, but they are still in the box with the bottles. The labels are:

sodium carbonate	sulfuric acid	copper (II) sulfate
barium chloride	cobalt (II) chloride	ammonium hydroxide
sodium hydroxide		

Caution: Wear safety goggles in the laboratory!

The owners of the lab want to dispose of these chemicals, but before that can be done, each chemical must be identified. You have been asked to do this on site. No other chemical solutions are available to help you in this test. Use only the seven chemicals to determine the identity of each. Submit your results to the **Hazardous Waste Inspector** in this format:

I.   Procedure for the Identification Determination.

II. Data Table

III. Conclusions:
    1. Bottle #1 is (<u>chemical</u>). I believe this is so because _____.
    2. Bottle #2 is (<u>chemical</u>). I believe this is so because _____.
    3. . . . . and so on.

IV. Method for Analysis

V. Answer the following questions:
    1. Did you run into any unexpected results? If so, how did you resolve the problem of identifying the unknown solution?
    2. Did you need to revise your testing method from your initial plan for identification? If so, please explain your modifications.
    3. Explain how you used data to form hypotheses.

Attachment D
Post-Assessment Rubric

Factor	Level 4	Level 3	Level 2	Level 1
Accuracy	All seven chemicals have been correctly identified.	At least six chemicals have been correctly identified.	At least four chemicals have been correctly identified.	At least two chemicals have been correctly identified.
Comprehension	Scientific information and ideas are accurate and thoughtfully explained.	Scientific information and ideas are accurate.	Scientific information has occasional inaccuracies or is simplified.	Scientific information has major inaccuracies or is overly simplified.

Solubility Rules and the Mystery Solutions – Grade 11

Attachment E
Table of Possible Reactions

	K_2CO_3	KOH	NH_4OH	HCl	$Cu(NO_3)_2$	Na_2SO_4	$Co(NO_3)_2$	Na_3PO_4	$AgNO_3$	$CaCl_2$	$Ba(NO_3)_2$
$Fe(NO_3)_3$											
$Ba(NO_3)_2$											
$CaCl_2$											
$AgNO_3$											
Na_3PO_4											
$Co(NO_3)_2$											
Na_2SO_4											
$Cu(NO_3)_2$											
HCl											
NH_3OH											
KOH											

Your job is to predict which of the combinations of solutions will produce a precipitate. On a separate sheet of paper, write out the possible double-displacement reaction for each of the combinations. Write "ppt" in each box that represents a reaction you think will form a precipitate, based on the solubility rules. Then, proceed with testing your hypotheses.

Attachment F
Key to Table of Possible Reactions

	K_2CO_3	KOH	NH_4OH	HCl	$Cu(NO_3)_2$	Na_2SO_4	$Co(NO_3)_2$	Na_3PO_4	$AgNO_3$	$CaCl_2$	$Ba(NO_3)_2$
$Fe(NO_3)_3$	*ppt*	*ppt*	*ppt*					*ppt*			
$Ba(NO_3)_2$	ppt					*ppt*		*ppt*			
$CaCl_2$								*ppt*			
$AgNO_3$	*ppt*	*ppt*	*ppt*	*ppt*				*ppt*			
Na_3PO_4					*ppt*		*ppt*				
$Co(NO_3)_2$	*ppt*	*ppt*	*ppt*								
Na_2SO_4											
$Cu(NO_3)_2$	*ppt*	*ppt*	*ppt*								
HCl	*bubbles*										
NH_3OH											
KOH											

> Your job is to predict which of the combinations of solutions will produce a precipitate. On a separate sheet of paper, write out the possible double-displacement reaction for each of the combinations. Write "ppt" in each box that represents a reaction you think will form a precipitate, based on the solubility rules. Then, proceed with testing your hypotheses.

Department of
Education

Attachment G
Template for Spot Sheet

X X X X X X X X X X X

X X X X X X X X X X

X X X X X X X X X

X X X X X X X X

X X X X X X X

X X X X X X

X X X X X

X X X X

X X X

X X

X

Solubility Rules and the Mystery Solutions – Grade 11

Name _____

Attachment H
Predicting Precipitates

Purpose:
Using the solubility rules, you will predict (hypothesize) which reactions of aqueous solutions will produce precipitates.

Procedure:
1. Working in pairs, you will each prepare a data table to test all the possible binary combinations of the following 12 aqueous solutions:

ammonium hydroxide	sodium sulfate	silver nitrate
potassium hydroxide	copper (II) nitrate	barium nitrate
potassium carbonate	hydrochloric acid	sodium phosphate
cobalt (II) nitrate	calcium chloride	iron (III) nitrate

2. On a separate piece of paper, write out the chemical equation for each combination. These are all double-displacement reactions.
3. Now examine the two possible products from each reaction. Using your solubility rules, predict which, if either, of the two products is an insoluble compound. If the compound is insoluble, circle it.
4. On the data table, write "ppt," the abbreviation for "precipitate," in the boxes of the combinations that produce insoluble compounds.
5. Now test your hypotheses! **Caution: Wear your safety goggles in the laboratory!** Using the laminated "X" sheet, drop one or two drops of each chemical to be tested in all the combinations you have in your data table. Be sure to watch for the formation of precipitates in the boxes that you have predicted as precipitates. Record your observations in the data table. If there is no obvious reaction, write "NR" for no reaction.

Disposal:
Please use a paper towel to wipe the laminate clean and dispose of it in the wastebasket. Do not wash the chemicals down the sink. Wash your hands before leaving the lab.

Questions:
1. Discuss the accuracy of your predictions. Were you correct most of the time? Which combinations, if any, gave you difficulty?
2. Some of the combinations should have produced small bubbles. What gas do you think was produced?
3. Some of the solutions were colored. Which part of the compound, the cation or the anion, do you think caused the color? List the colors and the ions responsible.
4. Explain how scientific evidence (data) is used in this activity to derive a hypothesis.