**Solubility**

**HIGH SCHOOL**

**Green Chemistry & Sustainable Science**

**Teacher Background Information:**

Solubility appears in many state standards and is a key concept for students to understand. Many labs similar to the one located here use soluble ionic solids, such as nitrate salts. The disposal of these compounds has a negative impact on an aquatic environment. Introduction of a nitrate into an ecosystem causes a spike in algal growth and a ripple effect is felt up the food chain, or in worst case scenario eutrophication can occur.

Solubility can also be used to discuss the hazards of certain forms of chemical substances and can also help students understand solubility rules. The example of barium is a useful one and this lab can be used to discuss how different forms of an element (i.e., barium) can be toxic, while other forms can be non-toxic to humans. Soluble barium compounds are toxic to humans (chloride, nitrate and carbonate salts), while insoluble barium compounds can be very useful for medical applications. Barium sulfate is ingested by patients before they undergo x-ray imagine for diagnostic procedures. The barium can be used to observe the GI tract, for example, in these procedures because barium absorbs x-rays more strongly than other compounds.

**Safety Information:** Students should wear eye-protection and know the safety rules of using a hotplate.

**Educational Goals:** Students will…

* Recognize the relationship between temperature and solubility of solids and gases
* Produce a graphical representation of the relationship between a change in temperature and concentration of a solid.
* Understand solubility rules
* Understand how solubility can be used to predict toxicity of some chemicals

**Student Objectives:** Students will …

* qualitatively and quantitatively describe the relationship between temperature and solubility for gases and solids.

**Materials:**

**Part 1** (teacher demo)

* 2 x 400 ml beakers
* 3 x 100 ml graduated cylinders (one with poked hole in it so that students can see that it is not just a liquid leaking out of the carbonated beverage)
* 2 x alcohol thermometers
* 1 x hot plate
* 4 x Parafilm pieces (2 in. x 2 in. pieces)
* Scissors
* Clear Carbonated Beverage
* Ice

**Part 2** (student lab)

* Magnesium Chloride Hexahydrate (MgCl2•6H2O, MW = 203.31 g/mol)
* Magnesium Sulfate Heptahydrate (Epsom salt) (MgSO4•7H2O, MW = 246.47 g/mol)
* Alcohol Thermometers
* Hot plate
* Stirring rod
* Balance
* Scoopula
* 8 aluminum weigh pans
* 2 x 150 ml beakers
* 100 ml graduated cylinder
* Water

**Time Required:** 2 x 45-60-minute class periods

**NGSS Standards Met:**

* **HS-PS1-5.** Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
* **HS-PS1-10.** Use evidence to support claims regarding the formation, properties and behaviors of solutions at bulk scales.

**Key Terms**: solubility of solids and gases; toxicity of a chemical related to its solubility

**Teacher Prep:**

**Procedure (Part 1):**

* Explain to students that you will show them through a demo the relationship between solubility and gas mixtures.
* Ask students to record their observations on **Part** 1 of the observation sheet

**Demo:**

1. Prepare ice bath by placing ice into one 400 ml beaker until it reaches the 150-ml line. Add water to the 150-ml line in the same beaker. Record the temperature of the ice bath after allowing the temperature to equilibrate for 5 minutes.
2. Add water to the other 400 ml beaker until it reaches the 150-ml line. Heat this beaker on a hot plate until it reaches 80°c. Record temperature of the hot water bath after 5 minutes of heating.
3. Pour the clear carbonate beverage into each of the 100 ml graduated cylinders until it reaches the top brim (more than 100 ml added to each one).
4. Tightly seal each graduated cylinder using 2 pieces of Parafilm per cylinder.
5. Slowly invert each cylinder and check for leaks. If leaking occurs, re-wrap the Parafilm until a tight, leak-free seal is obtained.
6. Using the tip of one scissor blade, poke a hole into the top of the cylinder’s Parafilm seal. Repeat for the other cylinder, making sure that the holes for each cylinder are equal in size.
7. Simultaneously invert cylinder #1 in the 400-ml beaker ice bath and cylinder #2 in a 400-ml beaker hot water bath. Allow the cylinders to sit inverted in the beakers for 5 minutes.
8. Ask students to note the starting volume and ending volume of liquid in 400 ml beakers. Students should make observations and answer questions on the student data sheet.
9. Group students into lab groups of 2-3 for Part 2 of the experiment
10. Hand out the students’ sheet and ask students to follow the directions and complete the lab.

**Procedure and Notes (Part 2):**

* Discuss solubility rules of ionic solids.
* Discuss how different forms of certain elements have different solubility.
* Hand out Student Worksheet **Part 2**
* Allow students to perform the procedure outlined in Part 2 and record their results on the student worksheet tables
* After students perform the procedure, allow the pans to dry in either a drying oven (set at 80-100°C) for one hour, or allow them to sit overnight in a safe location to evaporate the water. Note: If you are allowing them to dry on their own, the magnesium chloride samples might not dry since magnesium chloride is so water soluble. If you do not have a drying oven, then you can alternatively gently heat the samples on a hot plate to dry off the water. Be careful when doing this – do not heat too high or too fast (keep the hotplate around 80C).
* Students should determine that the chloride salt of magnesium is more soluble than the sulfate salt. Once they come to this conclusion, you may use the supplemental information sheet about barium compounds. Ask them to read the information and relate their findings to the case of barium.

**Disposal Information:**  Magnesium Chloride Hexahydrate (MgCl2•6H2O) and Magnesium Sulfate Heptahydrate (Epsom salt) (MgSO4•7H2O) can be safely poured down the drain. **Student Sheet Part 1:**

**Solubility of a Gas Observations**

Fill out the data below, and answer the questions based on your observations.

Cylinder #1 – in ice water bath

Temperature of ice water bath °C

Initial volume of gas ml

Final volume of gas ml

Initial volume in beaker ml

Final volume in beaker ml

Cylinder #2 – in hot water bath

Temperature of hot water bath °C

Initial volume of gas ml

Final volume of gas ml

Initial volume in beaker ml

Final volume in beaker ml

Observations:

1. Which cylinder had its liquid volume decrease faster?
2. As the liquid in the cylinders decrease, does the volume of the gas increase or decrease?
3. After 30 seconds, which cylinder has the most bubbling?
4. After 2 minutes, is there any bubbling of gas in cylinder #1 (ice water bath)?
5. After 2 minutes, is there any bubbling of gas in cylinder #2 (hot water bath)?

**Student Sheet Part 2: Solubility of solids**

**Materials**:

* Magnesium Chloride
* Magnesium Sulfate
* Alcohol Thermometers
* Hot plate
* Stirring rod
* Balance
* Scoopula
* Weigh boats
* Aluminum weigh pans (8)
* 2 x 150 ml beakers
* 10 ml graduated cylinder
* Pipette (auto-pipette or graduated pipette) and pipette tips
* Water

**Procedure:**

1. Weigh out 25 grams of magnesium chloride and put it in one of the 150 mL beakers. Label the beaker MgCl2.
2. Measure 12.5 mLs of water in to the beaker and stir until all of the MgCl2 dissolves.
3. Weigh out 25 grams of magnesium sulfate and put it in the second 150 mL beakers. Label the beaker MgSO4.
4. Measure 25 mLs of water in to the beaker and stir until all of the MgSO4 dissolves.
5. Measure the temperature of both solutions. Record your results.
6. Prepare aluminum weigh pans numbered 1 through 8.
7. Weigh the aluminum pans and record the weight of the empty pans in the table.
8. Place both beakers on the hot plate. Heat the solutions to raise the temperature to 30°C. Gently stir the solution occasionally as the temperature goes up (allow any solids to settle before taking the 1 mL sample as explained in step #9).
9. At 30°C, remove 1 mL of solution from the MgCl2 solution and place it in the beaker labeled #1. Record the mass of the aluminum pan with the 1 mL of solution.
10. Repeat step #9 for the MgSO4 solution, but place the 1 mL solution in pan #5. Weigh the pan with the solution in it, record the weight in the table.
11. Heat both solutions to 40°C and again remove 1 mL of solution and place the solution in pans #2 (MgCl2) and pans #6 (MgSO4). Record the weights of the pans and solutions in the table. Remember to gently stir the solutions as the temperature increases and allow any solid to settle before removing a sample of the liquid.
12. Repeat step #11, bringing the solution temperatures to 50°C.
13. Place all 8 pans in drying oven, or in a location to allow to dry overnight.
14. The next day (or next lab session), record the weight of the pans after they are dry.

**Student Worksheet Part 2: Solubility of Solids**

Record your observations below:

Weight of MgCl2: \_\_\_\_\_\_\_\_\_\_\_\_\_\_ grams Water added to MgCl2:\_\_\_\_\_\_\_\_\_\_\_\_\_\_ mLs

Weight of MgSO4:\_\_\_\_\_\_\_\_\_\_\_\_\_\_ grams Water added to MgSO4:\_\_\_\_\_\_\_\_\_\_\_\_\_ mLs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Pan #** | **Solid** | **Empty pan weight (g):** | **Pan weight with liquid (g):** | **Temperature of sample taken (°C):** | **Pan weight after drying (g):** |
| 1 | MgCl2 |  |  |  |  |
| 2 | MgCl2 |  |  |  |  |
| 3 | MgCl2 |  |  |  |  |
| 4 | MgCl2 |  |  |  |  |
| 5 | MgSO4 |  |  |  |  |
| 6 | MgSO4 |  |  |  |  |
| 7 | MgSO4 |  |  |  |  |
| 8 | MgSO4 |  |  |  |  |

**Use the table below to calculate the concentration of each sample that you took from both solutions.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pan #** | **Solid** | **Weight of solid left after drying:** | **Weight of water in sample (before drying):** | **Concentration of sample (g/mL)\*:** |
| 1 | MgCl2 |  |  |  |
| 2 | MgCl2 |  |  |  |
| 3 | MgCl2 |  |  |  |
| 4 | MgCl2 |  |  |  |
| 5 | MgSO4 |  |  |  |
| 6 | MgSO4 |  |  |  |
| 7 | MgSO4 |  |  |  |
| 8 | MgSO4 |  |  |  |

\*Assume 1 mL of water = 1 gram of water

**Student Sheet Questions: Part 1**

1. Which cylinder collected more gas?
2. What is happening to the gas in cylinder #2 (in hot water bath)? What affect does it have on the liquid’s containment inside the cylinder?
3. Why is there more volume in the hot water beaker than in the ice water beaker at the end of the experiment?
4. Does more gas escape when it is warmer or cooler?
5. When gas escapes from the liquid, is it because it is more or less soluble in the liquid?
6. Is the gas more soluble at higher or lower temperatures?
7. When gas escapes from a carbonated beverage, what affect does it have on the taste of the beverage?
8. Name the gas present in the carbonated beverage that is responsible for its fizz.
9. Which would you rather drink, hot soda or cold soda? Explain your reasoning using the principles from this lab.

**Student Questions: Part 2**

1. Using excel, or graph paper, plot the concentration of MgCl2 versus the temperature. Plot the concentration of MgSO4 versus temperature on the same graph. Be sure to place the independent and dependent variables on the appropriate axes, and include labels, units and a title.
2. Based on the graph, how many grams of MgSO4 will dissolve in 100 mL of water at 70°C?
3. Describe the difference between the solubility of gases versus solids with a change in temperature.
4. Write a sentence to answer the question: What is the relationship between the solubility of magnesium chloride and the temperature of its solution?
5. How do your results help you to predict the solubility of barium chloride and barium sulfate? Which one would you expect to be more soluble?
6. Discuss the importance of understanding solubility and how solubility relates to the toxicity of certain chemicals.

**Solubility: Teacher Answer Key**

Part 1 – Solubility of a Gas (Teacher Demo)

Fill out the data below, and answer the questions based on your observations.

Cylinder #1 – in ice water bath

Temperature of ice water bath 2 °C

Initial volume of gas 0 ml

Final volume of gas ~8 ml

Initial volume in beaker 150 ml

Final volume in beaker ~175 ml

Cylinder #2 – in hot water bath

Temperature of hot water bath 68 °C

Initial volume of gas 0 ml

Final volume of gas 55 ml

Initial volume in beaker 150 ml

Final volume in beaker ~250 ml

Observations

1. Which cylinder had its liquid volume decrease faster?

Cylinder # 2 in the hot water bath.

1. As the liquid in the cylinders decrease, does the volume of the gas increase or decrease?

The volume of the gas increases as the volume of the liquid decreases.

1. After 30 seconds, which cylinder has the most bubbling?

Cylinder #2 in the hot water bath.

1. After 2 minutes, is there any bubbling of gas in cylinder #1 (ice water bath)?

No, or very little

1. After 2 minutes, is there any bubbling of gas in cylinder #2 (hot water bath)?

Yes

Part 2 – Solubility of Solids

***Typical results are listed below:***

Record your observations below:

Weight of MgCl2: \_\_\_\_\_\_25\_\_\_\_ grams Water added to MgCl2:\_\_\_\_\_\_12.5\_\_\_ mLs

Weight of MgSO4:\_\_\_\_\_\_25\_\_\_\_ grams Water added to MgSO4:\_\_\_\_\_\_25\_\_\_ mLs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Pan #** | **Solid** | **Empty pan weight (g):** | **Pan weight with liquid (g):** | **Temperature of sample taken (°C):** | **Pan weight after drying (g):** |
| 1 | MgCl2 | 0.97g | 2.26g | 18-20°C | 1.76g |
| 2 | MgCl2 | 0.94g | 2.24g | 30°C | 1.85g |
| 3 | MgCl2 | 0.94g | 2.23g | 40°C | 1.84g |
| 4 | MgCl2 | 0.95g | 2.24g | 50°C | 1.86g |
| 5 | MgSO4 | 1.02g | 2.26g | 18-20°C | 1.39g |
| 6 | MgSO4 | 1.04g | 2.29g | 30°C | 1.48g |
| 7 | MgSO4 | 1.00g | 2.26g | 40°C | 1.47g |
| 8 | MgSO4 | 0.96g | 2.25g | 50°C | 1.48g |

**Use the table below to calculate the concentration of each sample that you took from both solutions.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pan #** | **Solid** | **Weight of solid left after drying:** | **Weight of water in sample (before drying):** | **Concentration of sample (g/mL)\*:** |
| 1 | MgCl2 | 0.79g | 0.49g | 1.61 |
| 2 | MgCl2 | 0.91g | 0.39g | 2.33 |
| 3 | MgCl2 | 0.9g | 0.39g | 2.31 |
| 4 | MgCl2 | 0.91g | 0.38g | 2.39 |
| 5 | MgSO4 | 0.37g | 0.87g | 0.43 |
| 6 | MgSO4 | 0.44g | 0.81g | 0.54 |
| 7 | MgSO4 | 0.47g | 0.79g | 0.59 |
| 8 | MgSO4 | 0.52g | 0.77g | 0.68 |

\*Assume 1 mL of water = 1 gram of water

**Student Lab Question Answer Key: Part 1**

1. Which cylinder collected more gas?

Cylinder #2 in the hot water bath collected more gas. It collected 55 ml gas,

whereas cylinder #1 in the ice water bath collected less than 10 ml gas.

1. What is happening to the gas in cylinder #2 (in hot water bath)? What affect does it have on the liquid’s containment inside the cylinder?

The gas is escaping from the liquid and entering the top space of the inverted cylinder. As its volume increases, it exerts pressure on the liquid inside the cylinder and forces the liquid out into the beaker.

1. Why is there more volume in the hot water beaker than in the ice water beaker at the end of the experiment?

The liquid inside cylinder #2 escapes from the cylinder and into the beaker

because of the increasing gas pressure.

1. Does more gas escape when it is warmer or cooler?

Gas escapes more when it is warmer.

1. When gas escapes from the liquid, is it because it is more or less soluble in the liquid?

Less soluble.

1. Is the gas more soluble at higher or lower temperatures?

Gas is more soluble at lower temperatures.

1. When gas escapes from a carbonated beverage, what affect does it have on the taste of the beverage?

As the gas content of the beverage decreases, it becomes less carbonated and tastes “flat”.

1. Name the gas present in the carbonated beverage that is responsible for its fizz.

Carbon dioxide

1. Which would you rather drink, hot soda or cold soda? Explain your reasoning using the principles from this lab.

Cold soda – it would retain more carbon dioxide and have more fizz.

**Student Lab Question Answer Key: Part 2**

1. Using excel, or graph paper, plot the concentration of MgCl2 versus the temperature. Plot the concentration of MgSO4 versus temperature on the same graph. Be sure to place the independent and dependent variables on the appropriate axes, and include labels, units and a title.
2. Based on the graph, how many grams of MgSO4 will dissolve in 100 mL of water at 60°C?

According to the graph, the concentration should be about 0.75 g/mL. Therefore:

0.75 g/1 mL x 100mL = 75grams of MgSO4 should dissolve in 100 mL of water at 60°C

1. Describe the difference between the solubility of gases versus solids with a change in temperature.

Gases are more soluble at lower temperatures, whereas solids are more soluble at higher temperatures.

1. Write a sentence to answer the question: What is the relationship between the solubility of magnesium chloride and the temperature of its solution?

As the temperature of the solution increases, so does the solubility of the magnesium chloride.

1. How do your results help you to predict the solubility of barium chloride and barium sulfate? Which one would you expect to be more soluble?

The sulfate salt was less soluble; therefore, we would expect that barium sulfate would be less soluble than the chloride salt.

1. Discuss the importance of understanding solubility and how solubility relates to the toxicity of certain chemicals.

More soluble compounds can be absorbed by the body easier, as in the case of barium sulfate, which is insoluble and not absorbed by the body (and can be ingested), but other forms of barium are toxic to humans when ingested because they are so soluble.