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Skill Sheet 23-A

Making Solutions



Chemists are required to make many of the solutions that they use in experiments. They may be provided with a material in solid form and need to dissolve it in a suitable solvent, or they may be provided with a solution and need to dilute it to make a new solution of a certain concentration. Chemists use basic techniques to calculate the necessary amounts of the solute and solvent. You will practice these calculation techniques in the following exercises.

1. What is molarity?

Making solutions is something you already know how to do! For example, when you add some hot cocoa mix to a cup of hot water, you are making a solution. In a science lab, the ingredients for solutions often include water and a chemical compound. These solutions are described according to their *molarity*. *Molarity* is a scientific measure of concentration. The formula for molarity is:

$$\text{molarity} = M = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Remember that a *mole* is equivalent to the mass of Avogadro's number of atoms or molecules. If I had a mole of carbon atoms, I would have 6.022×10^{23} atoms. A carbon atom has a mass of 12.01 atomic mass units (amu). A mole of carbon has a mass of 12.01 grams. Remember you can derive the mass of one mole of an element by finding the atomic mass on a periodic table.

Likewise, if I had a mole of sodium chloride, I would have 6.022×10^{23} molecules of NaCl. What would be the mass of a mole of NaCl molecules?

2. Making solutions from a solid solute

A scientist needs to prepare one liter of a solution of potassium chloride (KCl) for an experiment. The concentration of the required solution is 3.2 M. How will the scientist prepare this solution from the solid KCl she has in a jar on her lab shelf?

To answer this question, let's first break it down.

The scientist needs 1 liter of a solution. She wants the final concentration to be 3.2 M.

After reading part 1, you know how to figure out how much KCl you would need to make a 1 M solution. The mass of a potassium atom is 39 amu and the mass of a chlorine atom is 35 amu. This means that KCl has a mass of 74 amu and one mole of KCl is 74 grams.

To make a 1 M solution of KCl you would dissolve 74.0 grams in one liter of water.

For 1 liter of a 3.20 M solution, we need 3.20 moles of solute. To find out how many grams of KCl we need to make this solution, use the following calculation.

$$3.20 \text{ moles} \times 74.0 \text{ g/mole} = 237 \text{ g KCl}$$

The scientist would make the solution by dissolving 237 grams of KCl in 1 liter of water.

3. Practice preparing solutions

Practice your skills in making solutions by solving the following problems. The first one is done for you.

1. Two liters of a 0.8 M solution of KNO_3 was prepared from solid KNO_3 and water. How many grams of KNO_3 were used in the preparation of this solution?

You need 2 liters of a solution. The final concentration of the solution is 0.8 M.

K = 39 amu; N = 14 amu; O = 16 amu (x 3)

$\text{KNO}_3 = 39 \text{ amu} + 14 \text{ amu} + 48 \text{ amu} = 101 \text{ amu}$

$\text{KNO}_3 = 101 \text{ grams}$

1 mole of $\text{KNO}_3 = 101 \text{ grams}$

$$2.00 \text{ L} \times 0.80 \text{ moles/L} \times 101 \text{ g/mole} = 162 \text{ g } \text{KNO}_3$$

To make two liters of a 0.8 M solution of KNO_3 , you need 162 grams of KNO_3 .

2. A chemist needs 500 ml of a 2.1 M NaOH solution. How many grams of NaOH are required to make this solution?

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3. A scientist uses 68 grams of CaCO_3 to prepare 1.5 liters of solution. What is the molarity of this solution?

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4. An experiment requires 3 liters of a 0.75 M $\text{Mg}(\text{OH})_2$ solution. How many grams of $\text{Mg}(\text{OH})_2$ are required to prepare this reagent?

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5. The density of two solutions—NaCl and MgCl_2 — was measured. If the concentrations and volumes of the solutions were identical, which solution do you think would be more dense? Explain your answer.
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4. Preparing solutions from existing solutions—dilution

Stock solutions of substances are prepared solutions of a given concentration. Stock solutions can be diluted to make a solution of a different concentration. The formula below will help you do this easily.

$$V_i C_i = V_f C_f$$

where V_i and C_i represent the volume and concentration of the stock solution (the initial solution) and V_f and C_f represent the volume and concentration of the final solution. Using this formula, scientists can create any lower concentration solution from a more concentrated stock solution. The concentration of a solution can be represented as molarity or as a percentage.

Example 1:

A scientist needs to prepare 2.5 liters of 0.3 M NaCl solution. Her stock solution is 4.5 M. How will the woman prepare the final solution?

First, we need to use the formula to calculate the volume of stock solution necessary to prepare the final solution. We know that the molarity of the stock solution (C_i) is 4.5 M, the desired molarity of the final solution is 0.3 M, and the final volume required is 2.5 liters. Inserting this information into the formula:

$$V_i C_i = V_f C_f$$

$$(V_i) \times 4.5 \text{ M NaCl} = 2.5 \text{ liters NaCl} \times 0.3 \text{ M NaCl}$$

$$V_i = 0.17 \text{ liters, or } 170 \text{ ml of } 4.5 \text{ M NaCl}$$

To prepare the final solution, the scientist would add 170 milliliters of her stock solution and add sufficient solvent to get a final volume of 2.5 liters.

Example 2:

In science laboratories, it is often important to work in a sterile environment. As you might know, alcohol kills bacteria. The least concentrated alcohol solution you need to kill bacteria is 70%. How would you make 500 milliliters of a 70% alcohol solution if you had a 95% alcohol stock solution?

$$V_i C_i = V_f C_f$$

$$(V_i) \times 95\% \text{ ethanol} = 0.5 \text{ L} \times 70\% \text{ ethanol}$$

$$V_i = 0.37 \text{ liters or } 370 \text{ mL of } 95\% \text{ ethanol}$$

To prepare the final solution, you would mix 370 milliliters of stock solution with 130 milliliters of water to get a final volume of 0.5 liters.

5. Practice dilution calculations

1. A chemist purchases a 2.0 M stock solution of KNO_3 . He would like to prepare 100 milliliters of 0.5 M KNO_3 . Describe how he would prepare this solution. Show your work.

2. How many liters of 3.5 M HCl are required to make 0.75 liters of 1.5 M HCl?

3. A scientist uses 1.3 liters of 0.65 M $\text{Ca}(\text{NO}_3)_2$ solution in an experiment. The stock solution from which she prepared this solution was 2.0 M. What volume of the stock solution did she use in the preparation of the solution for the experiment? What volume of solvent was used?

4. 135 ml of a 6.0 M NaHCO_3 solution was used in the preparation of 1.5 liters of diluted NaHCO_3 . What is the molarity of the diluted solution?

5. How many grams of NaHCO_3 went into the preparation of one liter of the 6.0 M stock solution in the previous problem?

6. You have a 80% solution of household vinegar. This means that there are 80 milliliters of vinegar in every 100 milliliters of solution. How could you use this stock solution to make up 1 liter of a 20% vinegar solution?

7. If you take 40 milliliters of a 60% solution and add it to 100 milliliters of water. What is the concentration and volume of the final solution?

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Skill Sheet 23-B

Solubility



In this skill sheet you will practice solving problems about solubility. You will use solubility values to identify solutions that are saturated, unsaturated, or supersaturated. Finally, you will practice your skills in interpreting temperature-solubility graphs.

1. What is solubility?

A solution is made by dissolving a substance in another substance. The substance in the smaller amount is called the *solute* and the substance in the larger amount is called the *solvent*. The degree to which a solute dissolved is described by its *solubility value*. This value is the mass in grams of the solute that can dissolve in a given volume of solvent under certain conditions.

For example, the solubility of table salt (NaCl) is 1 gram per 2.7 milliliters of water at 25°C. Another way to state this solubility value is to say that 0.38 grams of salt will dissolve in one milliliter of water at 25°C. Do you see that these values mean the same thing?

$$\frac{1 \text{ gram NaCl}}{2.7 \text{ mL H}_2\text{O} \cdot 25^\circ\text{C}} = \frac{0.38 \text{ grams NaCl}}{1 \text{ mL H}_2\text{O} \cdot 25^\circ\text{C}}$$

Information about the solubility of table salt and other substances is presented in the table below. Use these values to complete the questions in part 2.

Substance	Solubility Value (grams/100 mL water 25°C)
Table salt (NaCl)	38
Sugar (C ₁₂ H ₂₂ O ₁₁)	200
Baking soda (NaHCO ₃)	10
Chalk (CaCO ₃)	insoluble
Talc (Mg silicates)	insoluble

2. Questions and problem solving

1. Chalk and talc are listed as “insoluble” in the table. What do you think this term means? In your response, come up with a reason to explain why chalk and talc cannot dissolve in water.

2. Come up with a reason to explain why table salt, sugar, and baking soda dissolve in different amount for the same set of conditions (same volume and temperature).

3. How much table salt would dissolve in 540 mL of water if the water was 25°C.

4. What volume of water would you need to dissolve 72 grams of salt at 25°C.

5. What volume of water at 25°C would you need to dissolve 50 grams of sugar?

6. How much baking soda will dissolve in 10 milliliters of water at 25°C.

3. Saturated, unsaturated, and supersaturated solutions

The solubility value for a substance indicates how much solute is present in a *saturated* solution. When the amount of solute is less than the solubility value for a certain volume of water, we say the solution is *unsaturated*. When the amount of solute is more than the solubility value for a certain volume of water, we say the solution is *supersaturated*.

Use the table in part 2, to help you fill in the table below. In each situation, is the solution saturated, unsaturated, or supersaturated?

Substance	Amount of substance in 200 mL of water at 25°C	Saturated, unsaturated, or supersaturated?
Table salt (NaCl)	38 grams	
Sugar (C ₁₂ H ₂₂ O ₁₁)	500 grams	
Baking soda (NaHCO ₃)	20 grams	
Table salt (NaCl)	100 grams	
Sugar (C ₁₂ H ₂₂ O ₁₁)	210 grams	
Baking soda (NaHCO ₃)	25 grams	

4. How temperature influences the solubility of solids and gases

Below is a table of some imaginary substances dissolved in water at different temperatures. Study the table and then answer the questions.

Substance dissolved in 100 mL of water	Solubility values (grams per 100 mL of water) at different temperatures				
	10°C	30°C	50°C	70°C	90°C
gas A	0.2	0.2	0.1	0.08	0.05
gas B	0.1	0.05	0.02	0.01	0.005
solid A	30	32	40	55	74
solid B	40	43	39	41	45

1. Use graph paper to make two graphs of the data in the table. On one graph, plot the data for gases A and B. On the other graph, plot the data for solids A and B. Use two different colors to plot the data for A and for B. Label the x -axis, "Temperature (°C)." Label the y -axis, "Solubility value (grams/100 mL H₂O)."
2. How does the solubility of gases A and B differ from the solubility of solids A and B in water? Explain your response.

3. For which substance does temperature seem to have the highest influence on the substance?

4. For which substance does temperature seem to have the lowest influence?

5. If you had 500 mL of water at 70°C and you made a saturated solution by adding 205 grams of a substance, which of the substances above would you be adding?

6. Organisms that live in ponds and lakes, depend on dissolved oxygen to survive. Explain how the amount of dissolved oxygen in a pond or lake might vary with the seasons (winter, spring, summer, and fall). Justify your ideas.

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The pH of a solution is a measure of the concentration of hydrogen ions (H^+) in the solution. The pH scale, which ranges from 0 to 14, provides a tool to assess the degree to which a solution is acidic or basic. As you may remember, solution's with low pH values are very acidic and contain high concentrations of hydrogen ions. Why does a **low** pH value mean a **high** concentration of H^+ ? The answer has to do with what pH means mathematically. In this skill sheet, we will examine the mathematical method that explains how pH values are calculated,

1. What is the formula for pH?

The pH value for any solution is equal to the negative logarithm of the hydrogen ion (H^+) concentration in that solution. The formula is written this way:

$$pH = -\log[H^+]$$

Concentration of hydrogen ions is implied by placing brackets (“[]”) around H^+ .

A term used by scientists to describe the concentration of a substance in a solution is *molarity*. Molarity (M) means how many moles of a substance are present in a given volume of solution.

For hydrogen ions in solutions, the concentration generally ranges from 10^{-14} to 10^{-1} M. The larger the molarity, the greater the concentration of H^+ in the solution. If a solution had a H^+ concentration of 10^{-3} M, the corresponding pH value would be:

$$pH = -\log[10^{-3}]$$

$$10^{pH} = -[10^{-3}]$$

$$pH = -[-3]$$

$$pH = 3$$

For a solution with an H^+ concentration of 10^{-5} M, the corresponding pH value would be:

$$pH = -\log[10^{-5}]$$

$$10^{pH} = -[10^{-5}]$$

$$pH = -[-5]$$

$$pH = 5$$

The first solution has a higher H^+ concentration than the second solution (10^{-3} M versus 10^{-5} M); however, its pH value is a smaller number. Strong acids have small pH values. Larger pH values (like 14) have lower concentrations of H^+ , and the solutions represent weaker acids.

2. Practice problems

- Practice working with numbers that have exponents. In the blank provided, write greater than, less than, or equal to.
 - 10^{-2} _____ 10^{-3}
 - 10^{-14} _____ 10^1
 - 10^{-7} _____ 0.0000001
 - 10^0 _____ 10^1
- Solutions that range in pH from 0 to 7 are acidic. Solutions that range in pH from 7 to 14 are basic. Solutions that have pH of 7 are neutral. The hydrogen ion concentrations for some solutions are given below. Use the pH formula to determine which is an acid, which is a base, and which is neutral.
 - Solution A: The hydrogen ion concentration is equal to 10^1 .
 - Solution B: The hydrogen ion concentration is equal to 0.0000001
 - Solution C: The hydrogen ion concentration is equal to 10^{-13} .
- Orange juice has a hydrogen ion concentration of approximately 10^{-4} M. What is the pH of orange juice?

- Black coffee has a hydrogen ion concentration of roughly 10^{-5} M. Is black coffee a stronger or weaker acid than orange juice? Justify your answer and provide all relevant calculations for supporting evidence.

- Pure water has a hydrogen ion concentration of 10^{-7} M. What is the pH of water? Would you say water is an acid or a base? Explain your answer.

- A solution has a pH of 11. What is the H^+ concentration of the solution? Is this solution an acid or a base?

- A solution has a pH of 8.4. What is the H^+ concentration of this solution?

- Acids are very good at removing hard water deposits from bathtubs, sinks, and glassware. Your father goes to the store to buy a cleaner to remove such deposits from your bathtub. He has a choice between a product containing lemon juice ($H^+ = 10^{-2.5}$ M) and one containing vinegar ($H^+ = 10^{-3.3}$ M). Which product would you recommend he purchase? Explain your answer.

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Skill Sheet 24

Salinity and Concentration Problems



Bodies of water like a pond or ocean are solutions of dissolved substances. Often these substances are in small quantities. Three commonly referred to small quantities are parts per thousand (ppt), parts per million (ppm), and parts per billion (ppb). This skill sheet will provide you with practice in using these quantities and in doing calculations with them.

1. Unit conversions

Table 1 includes unit conversions that will be helpful to you as you complete this skill sheet.

Table 1: Unit Conversions

Milligrams	=	Grams	=	Kilograms	=	Liters of water
1		0.001		0.000 001		0.000 001
10		0.01		0.000 01		0.000 01
1,000		1		0.001		0.001
1,000,000		1,000		1		1
1,000,000,000		1,000,000		1,000		1,000

2. Small concentrations

The practice problems use the following concentrations—parts per thousand, parts per million, and parts per billion.

A. Parts per thousand (ppt)

Example: 0.009 grams of phosphate in about 1000 grams of oxygenated water makes a solution that has an phosphate concentration of 0.009 ppt.

$$\frac{0.009 \text{ grams}}{1,000 \text{ grams}} = 0.009 \text{ ppt}$$

B. Parts per million (ppm)

Example: A good level of oxygen in a pond is 9 ppm. This means that there are 9 milligrams of oxygen for every one liter (1000 grams) of oxygenated water.

$$\frac{9 \text{ milligrams}}{1 \text{ liter}} = \frac{9 \text{ milligrams}}{1,000 \text{ grams}} = 9 \text{ ppm}$$

C. Parts per billion (ppb)

Example: The concentration of trace elements in seawater is very low. For example, the concentration of iron in seawater is 0.06 ppb. This means that there are 0.06 mg of iron in 1,000 liters of water. One thousand liters is equal to 1,000 times 1,000 grams of seawater.

$$\frac{0.06 \text{ milligrams}}{1,000 \text{ liters}} = \frac{0.06 \text{ milligrams}}{1,000 \times 1,000 \text{ grams}} = \frac{0.06 \text{ milligrams}}{1,000,000,000 \text{ grams}} = 0.06 \text{ ppb}$$

3. Problem Set Examples

1. There are 16 grams of salt in 984 grams of water. What is the salinity of this solution?

$$\text{salinity} = \frac{16 \text{ grams}}{984 \text{ grams water} + 16 \text{ grams salt}} = \frac{16 \text{ grams}}{1000 \text{ grams}} = 16 \text{ ppt}$$

2. A liter of solution has a salinity of 40 ppt. How many grams of salt are in the solution? How many grams of pure water are in the solution?

$$40 \text{ ppt} = \frac{40 \text{ grams}}{x \text{ grams} + 40 \text{ grams}} = \frac{40 \text{ grams}}{1000 \text{ grams}}$$
$$960 \text{ grams of water} + 40 \text{ grams salt} = 1000 \text{ grams total}$$

3. You measure the salinity of a seawater sample to be 34 ‰. How many grams of salt are in this sample if the mass is 2 kilograms?

$$\frac{34 \text{ grams salt}}{1 \text{ kilogram total}} = \frac{x}{2 \text{ kilograms total}}$$
$$x = \frac{34 \text{ grams salt} \times 2 \text{ kilograms total}}{1 \text{ kilogram total}} = 68 \text{ grams salt}$$

4. Problem Set

For each problem, show your work.

1. Fill in Table 2 and show your work on a separate piece of paper.

Table 2: Salinity of Famous Places

Place	Salinity (ppt)	Amount of salt in 1 liter (grams)	Amount of pure water in 1 liter (grams)
Salton Sea California	44		
Great Salt Lake Utah	280		
Mono Lake California	210		
Pacific Ocean	87		

1. How many grams of salt are in 2 liters of seawater that has a salinity of 36 ‰?

2. A one-liter sample of seawater contains 10 grams of salt. What is the salinity of this sample?

3. You want to make a salty solution that has the same salinity as the Dead Sea. The salinity of the Dead Sea is 210 ppt. Write a recipe for how you would make 2 liters of this solution.

4. Five kilograms of seawater contains 30 grams of salt. What is the salinity of the volume of seawater?

5. You measure the salinity of a seawater sample to be 30 ‰. How many grams of salt are in this sample if the mass is 1.5 kilograms?

6. A solution has 2 grams of a substance in 1,000,000 grams of solution. Would you describe the concentration of the substance in solution as 2 parts per million or parts per billion?

7. A solution has 5 grams of a substance in 1,000,000,000 grams of solution. Would you describe the concentration of the substance as 5 ppb or 5 ppm?

8. Menthol is a substance that tastes sweet and minty and causes a cooling effect on your tongue. The taste threshold for menthol is 400 ppb. Could you taste menthol if there were 400 milligrams in 1,000,000 grams of menthol solution? Could you taste menthol if there were 400 milligrams in 1000 liters of menthol solution?

9. Above ground pipelines are used to transport natural gas, an important energy source. Gas leaks are potential problems with the pipelines. German Shepherd dogs can be trained to detect the gas leaks. The dogs sniff along the pipeline and then indicate a leak by perking up their ears or pawing the ground. The most sensitive electronic devices can detect gas leaks as low as 50 ppm. A German Shepherd can detect a gas leak as low as 1 ppb. How many times more sensitive is the dog as compared to the electronic device?
