LESSON ASSIGNMENT SHEET

LESSON 3	--Molar Solutions.
LESSON ASSIGNMENT	--Paragraphs 3-1 through 3-11.
LESSON OBJECTIVES	--After completing this lesson, you should be able to:
	3-1. Given a solute, solution volume, and molar concentration, compute the weight of the solute needed.
	3-2. Given the weight of a compound, compute the number of moles
	3-3. Given the weight/volume concentration of a solute, compute the mol/L or mmol/L concentration
	3-4. Given the molar concentration and weight of solute, compute the solution volume.
SUGGESTION	--After completing the assignment, complete the exercises of this lesson. These exercises will help you to achieve the lesson objectives.

LESSON 3

MOLAR SOLUTIONS

Section I. MOLE CONCEPT

3-1. DISCUSSION

In a chemical reaction, atoms and molecules are either combined or separated during the reaction. In other words, chemical reactions take place at the level of the atoms and molecules of the reactants.

a. A method that would allow the medical laboratory specialist to know the relative number of reactant particles involved in a chemical reaction would be useful. The concept of the mole and molarity provides such a method.

b. One mole of any substance will contain approximately 6.02×10^{23} particles (Avogadro's number). A mole of a particular substance indicates the number of grams proportional to the atomic or molecular weight of the substance. This weight is often referred to as its gram molecular weight.

c. The importance of the mole concept stems from the fact that a mole of any given element or compound will yield Avogadro's number of particles. If the masses of samples of two elements or compounds have the same ratio as the ratio of their atomic weights, the samples contain identical numbers of atoms or molecules.

3-2. CALCULATING GRAM MOLECULAR WEIGHT (GMW)

The gram molecular weight is the mass in grams of one mole of substance. The first step in solving for GMW is to list each element of the compound as represented by the chemical formula separately. Next, we must take into account the atomic weight of each individual atom along with the total number of each individual atom or element present. (See Appendix C for atomic weights and symbols of elements.) Finally, add all the weights of the atoms making up the formula and express the answer in grams/mole.

a. **Example.** What is the GMW of NaCl?

Solution.

NaCl

Na	23.0
Cl	+ 35.5
	58.5 g/mol

b. **Example.** What is the GMW of H_2SO_4?

Solution. Notice in this problem that the subscripts apply to the hydrogen and oxygen atoms. In this problem we must multiply these elements by their corresponding subscript to obtain the correct GMW for this molecule.

H_2SO_4

H	1.0 X 2 =	2.0
S	32.1 X 1 =	32.1
O	16.0 X 4 =	+ 64.0
		98.1 g/mol

c. **Example.** What is the GMW of $(NH_4)_2CO_3 \cdot 3H_2O$?

Solution. In this problem, the NH_4 radical is enclosed by parentheses and a subscript of 2 is assigned. In this situation, all elements contained within the parentheses are multiplied by 2. Also, the hydrogen atom of the NH_4 radical has a subscript of 4. Therefore, the total number of hydrogens present are 8. The attached water of hydration has a coefficient of 3. This must be considered and each individual atom within the water molecule must be multiplied by a coefficient of 3 in addition to any subscripts.

$(NH_4)_2CO_3 \cdot 3H_2O$

N	14.0 X 2 =	28.0
H	1.0 X 8 =	8.0
C	12.0 X 1 =	12.0
O	16.0 X 3 =	48.0
H	1.0 X 6 =	6.0
O	16.0 X 3 =	+ 48.0
		150.0 g/mol

3-3. MOLES AND GRAM MOLECULAR WEIGHT

Remember from the discussion on moles that a mole of any substance is the number of grams proportional to the atomic or molecular weight of the substance. If this is true, then one mole of NaCl weighs 58.5 grams. One mole of any substance has a mass equal to one gram molecular weight of that substance.

a. **Example.** How many moles are contained in 117.0 grams of NaCl?

Solution. Determine the mass of one gram molecular weight of the substance.

Na	23.0
Cl	+ 35.5
	58.5 g/mol

Now use ratio and proportion to determine the unknown quantity.

$$\frac{58.5\ g}{1\ mol} = \frac{117.0\ g}{x\ mol}$$

(58.5 g)(x mol) = (117.0 g)(1 mol)

$$x\ mol = \frac{(117.0\ g)(1\ mol)}{58.5\ g}$$

x Mol = 2.00 mol There are 2.00 moles contained in 117.0 g of NaCl.

Equivalently:

$$moles = \frac{\text{the number of grams given}}{\text{GMW}}$$

b. **Example.** How many moles are contained in 71.0 grams of Na_2SO_4?

Solution. Calculate the GMW of the compound.

Na	23.0 X 2 =	46.0
S	32.1 X 1 =	32.1
O	16.0 X 4 =	+ 64.0
		142.1 g/mol

Use ratio and proportion to determine the unknown quantity.

$$\frac{142.1\ g}{1\ mol} = \frac{71.0\ g}{x\ mol}$$

(142.1 g)(X mol) = (71.0 g)(1 mol)

$$x\ mol = \frac{(71.0\ g)(1\ mol)}{142.1\ g}$$

x mol = 0.500 mol. There are 0.500 moles contained in 71.0 grams of Na_2SO_4

NOTE: Keep in mind that moles is not an expression of concentration. The unit mole is an expression of mass indicating the number of gram molecular weights. Take caution not to confuse mole with molarity (mol/L). When reporting moles, write the word moles, DO NOT abbreviate by using an M!!

Section II. MOLARITY AND MOLAR SOLUTIONS

3-4. DEFINITION

Molarity (mol/L) is defined as the number of moles of a substance per liter of solution

3-5. SOLVING MOLARITY PROBLEMS

a. **Method.** Based on the definition given above, it follows that:

(1) Molarity = # moles/liter of solution.

(2) GMW = g/mol

(3) Liter = total volume of solution

(4) Therefore: grams of solute = (mol/L)(g/mol)(L)

or equivalently: g = (mol/L)(GMW)(L)

b. **Example.** How much Na_2SO_4 is needed to make 300 mL of a 2.00 mol/L Na_2SO_4 solution?

Solution. Notice in this problem that the wording suggests that a solution is to be prepared. If you examine the problem, you should find that the type of solution to be prepared is a *molar solution.* Read the problem carefully, and select the formula that generates the desired quantity.

g = (mol/L)(g/mol)(L)

Calculate the GMW of the compound.

Na_2SO_4

Na	23.0 X 2 =	46.0	
S	32.1 X 1 =	32.1	
O	16.0 X 4 =	+ 64.0	
		142.1	g/mol

Substitute the given values.

g = (2.00 mol/L)(142.1 g/mol)(300 mL)

Make appropriate conversions.

g = (2.00 mol/L)(142.1 g/mol)(0.300 L)

Solve for the unknown quantity.

$$\underline{85.3\ g} = (2.00\ mol/L)(142.1\ g/mol)(0.300\ L)$$

Using **dimensional** analysis: Carefully read the problem and determine the unknown quantity.

Grams of Na_2SO_4

Express the desired volume in liters

$$300\ mL \times \frac{1\ L}{1000\ mL} = 0.300\ L$$

Multiply the volume expressed in liters times the molar concentration times the gram molecular weight to determine the amount of salt, in grams, needed to prepare the solution.

$$0.300\ L \times \frac{2.00\ mol}{L} \times \frac{142.1\ g}{mol} = 85.3\ g$$

c. **Example.** What volume of $CaCO_3$ solution can be prepared from 25.0 g of $CaCO_3$ if a 0.50 mol/L $CaCO_3$ is desired?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$g = (mol/L)(g/mol)(L)$$

Calculate the GMW of the compound.

$CaCO_3$

Ca	40.1	X	1	=		40.1
C	12.0	X	1	=		12.0
O	16.0	X	3	=	+	48.0
						100.1 g/mol

Substitute the given values.

$$25.0\ g = (0.50\ mol/L)(100.1\ g/mol)(L)$$

Solve for the unknown quantity.

$$L = \frac{25.0\ g}{(0.50\ mol/L)(100.1\ g/mol)} = \underline{0.50\ L}$$

Using **dimensional analysis:** Carefully read the problem and determine the unknown quantity.

Volume of $CaCO_3$ solution

Determine the number of moles contained in 25.0 grams of solute.

$$25.0 \text{ g} \times \frac{1 \text{ mol}}{100.1 \text{ g}} = 0.250 \text{ mol}$$

Use **ratio** and **proportion** to determine the amount of solution that can be prepared.

$$\frac{0.50 \text{ mol}}{1 \text{ L}} = \frac{0.250 \text{ mol}}{x \text{ L}}$$

$$(0.50 \text{ mol})(x \text{ L}) = (0.250 \text{ mol})(1 \text{ L})$$

$$x \text{ L} = \frac{(0.250 \text{ mol})(1 \text{ L})}{0.50 \text{ mol}} = 0.50 \text{ L}$$

Section III. MILLIMOLES PER LITER

3-6. INTRODUCTION

Another expression with which one should be familiar is millimoles per liter (mmol/L). It is a variation of the mole/liter concentration unit.

3-7. DISCUSSION

a. A millimole = 0.001 mole and 1 mole = 1000 millimoles.

b. A millimole has the same numerical value as one molecular weight, expressed in mg/mmol.

c. To convert mol/L to mmol/L, multiply the mol/L concentration by 1000 mmol/1 mol.

Example.

(0.25 mol/L)(1000 mmol/1 mol) = <u>250 mmol/L</u>

d. To convert mmol/L to mol/L, multiply mmol/L by (1 mol/1000 mmol).

Example.

(2000 mmol/L)(1 mol/1000 mmol) = <u>2.000 mol/L</u>

e. Use the following formula to solve millimole/liter problems:

(1) <u>Formula</u>. mg = (mmol/L)(mg/mmol)(L)

(2) Example. How much NaCl is needed to make 250 mL of a 300 mmol/L solution?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

mg = (mmol/L)(mg/mmol)(L)

Determine the millimolar weight of the compound.

NaCl

Na	23.0
Cl	+ 35.5
	58.5 mg/mmol

Substitute the given information.

mg = (300 mmol/L)(58.5 mg/mmol)(250 mL)

Make any necessary conversions.

mg = (300 mmol/L)(58.5 mg/mmol)(0.250 L)

Evaluate the expression to determine the unknown quantity.

mg = 4387.5 mg

3-8. SOLVING MILLIMOLE PER LITER PROBLEMS

Calculations involving millimole per liter solution are very similar to the calculations involving simple mole per liter solutions.

Use dimensional analysis:

a. **Example.** What is the mmol/L concentration of a 0.25 mol/L NaOH solution?

Solution. Read the problem carefully and determine the desired unit of concentration.

mmol/L.

Multiply the given mol/L concentration times the appropriate conversion factor.

$$\frac{0.25\ \text{mol}}{\text{L}} \times \frac{1000\ \text{mmol}}{\text{mol}} = 250\ \text{mmol/L}$$

b. **Example.** What is the mol/L concentration of a 2000 mmol/L KCl solution?

Solution. Read the problem carefully and determine the desired unit of concentration.

mol/L

Multiply the given mmol/L concentration times the appropriate conversion factor.

$$\frac{2000\ \text{mmol}}{\text{L}} \times \frac{1\ \text{mol}}{1000\ \text{mmol}} = 2.000\ \text{mol/L}$$

c. **Example.** How much NaCl is needed to make 250 mL of a 300 mmol/L solution?

Solution. Read the problem carefully and determine the desired quantity.

Milligrams of NaCl.

Determine the millimolar weight of the compound.

NaCl

Na	23.0
Cl	+ 35.5
	58.5 mg/mmol

Express the desired volume of solution in liters

$$250\ \text{mL} \times \frac{1\ \text{L}}{1000\ \text{mL}} = 0.250\ \text{L}$$

Multiply the desired volume in liters times the millimolar concentration times the millimolar weight to determine the amount of salt needed to prepare the solution.

$$0.250 \times \frac{300\ \text{mmol}}{\text{L}} \times \frac{58.5\ \text{mg}}{\text{mmol}} = 4387.5\ \text{g}$$

Section IV. VARIATIONS OF MOLARITY PROBLEMS

3-9. PROBLEMS INVOLVING HYDRATES

Since molarity is based on the number of moles (Avogadro's number) per liter of solution, then one mole per liter of $CuSO_4$ will contain the same number particles as one mole per liter of $CuSO_4 \cdot 5HOH$. When calculating molarity problems involving hydrates, use the gram molecular weight of the substance being used (weighed) in the preparation of the solution.

a. **Example.** How much $CuSO_4 \cdot 5HOH$ is required to prepare 250 mL of a 2.00 mol/L $CuSO_4$ solution?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$g = (mol/L)(g/mol)(L)$$

Determine the GMW of the available compound.

$CuSO_4 \cdot 5HOH$

Cu	63.5	X	1	=	63.5
S	32.1	X	1	=	32.1
O	16.0	X	4	=	64.0
H	1.0	X	10	=	+ 10.0
O	16.0	X	5	=	+ 80.0
					249.6 g/mol

Substitute the given information.

$$g = (2.00 \text{ mol/L})(249.6 \text{ g/mol})(250 \text{ mL})$$

Make any necessary conversions.

$$g = (2.00 \text{ mol/L})(249.6 \text{ g/mol})(0.250 \text{ L})$$

Solve for the unknown quantity.

$$g = \underline{125 \text{ g}}$$

Use dimensional analysis: Read the problem carefully and determine the desired quantity.

Grams of $CuSO_4.5H_2O$

Express the desired volume in liters.

$$250 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.250 \text{ L}$$

Multiply the volume expressed in liters times the molar concentration times the gram molecular weight to determine the amount of hydrate salt, in grams, needed to prepare the solution.

$$0.250\ L \times \frac{2.00\ mol}{L} = \frac{249.6\ g}{mol} = 125\ g$$

3-10. PROBLEMS INVOLVING ONLY PART OF THE MOLECULE

When preparing solutions using compounds formed by ionic bonding, realize that these molecules will ionize when placed into solution. For example, 1 mole of Na_2SO_4 will ionize to 2 moles of sodium and 1 mole of sulfate radical. If we were to prepare a 1 mol/L sodium solution using Na_2SO_4, then only 0.5 moles of sodium sulfate would be needed for every liter of solution since 2 moles of sodium are contained in 1 mole of sodium sulfate.

When solving this type of problem, simply divide the GMW by the number of moles of the desired element contained within one mole of the compound or use an appropriate factor to account for the moles of desired substance per mole of compound.

Example. How much Na_2SO_4 is needed to prepare 2.00 liters of 1.50 mol/L sodium solution?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

g = (mol/L)(g/mol)(L)

Calculate the GMW of the compound.

Na_2SO_4

Na	23.0	X 2 =	46.0	
S	32.1	X 1 =	32.1	
O	16.0	X 4 =	+ 64.0	
			142.1	g/mol

Divide the GMW by the moles of Na per mole of compound.

$$142.1\ g/mol\ Na_2SO_4 \times \frac{1\ mol\ Na_2SO_4}{2\ mol\ Na} = 71.00\ g\ Na_2SO_4/mol\ Na$$

Substitute the revised GMW and given data, and solve for the unknown quantity.

g = (1.50 mol/L Na)(71.00 g Na_2SO_4/mol Na)(2.00 L)

g = <u>213 g Na_2SO_4</u>

Use dimensional analysis: Multiply the volume expressed in liters times the molar concentration times the gram molecular weight times the ratio of ionized sodium per mole of compound to determine the amount of salt, in grams, needed to prepare the solution.

$$2.00\ L \times \frac{1.50\ mol\ Na}{L} \times \frac{142.1\ g}{mol} \times \frac{1\ mol\ Na_2SO_4}{2\ mol\ Na} = 213\ g\ Na_2SO_4$$

3-11. ADVANTAGES AND DISADVANTAGES OF MOLAR SOLUTIONS

a. Advantage: Number of particles in solution known.

b. Disadvantage: Reactive strength of solution unknown.

EXERCISES, LESSON 3

REQUIREMENT. The following exercises are to be answered by writing the answer in the space provided at the end of the question.

After you have completed all the exercises, turn to "Solutions to Exercises," at the end of the lesson and check your answers with the review solutions.

1. How much $CaCl_2$ is needed to make 200 mL of a 6.00 mol/L $CaCl_2$ solution?

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2. What weight of NaOH would be required to prepare 3000 mL of a 1.50 mol/L NaOH solution?

____

3. In a solution containing 3000 mg of NaCl in 250 mL, what is the mol/L concentration?

____

4. How many moles of $CaCl_2$ are contained in 333.0 g of $CaCl_2$?

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5. What is the mmol/L concentration of a KOH solution prepared by adding 14.0 g of KOH to a 500-mL volumetric flask and adjusting to the mark with deionized water?

____

6. How much 250 mmol/L solution can be prepared from 149 mg of KCl?

____

7. A solution of NaCl contains 300 grams per liter. What is the mol/L concentration of the solution?

____

8. What amount of $Na_2SO_4 \cdot 4H_2O$ is needed to make 750 mL of a 1.25 mol/L solution of Na_2SO_4?

____

9. How much $CuSO_4 \cdot 5HOH$ is needed to prepare 250 mL of a 2.00 mol/L $CuSO_4$ solution?

____

10. How much $NaNO_3$ is needed to make 200 mL of a 30.0 mmol/L $NaNO_3$ solution?

____

SOLUTIONS TO EXERCISES, LESSON 3

1. 133 g (para 3-5)
2. 180 g (para 3-5)
3. 0.205 mol/L (para 3-5)
4. 2.997 moles (para 3-3)
5. 499 mmol/L (para 3-8)
6. 7.99 mL (para 3-7)
7. 5.13 mol/L (para 3-5)

8. 201 g (para 3-8)

9. 125 g (para 3-9)

10. 510 mg (para 3-7)

LESSON ASSIGNMENT SHEET

LESSON 4 --Equivalent Solutions.

LESSON ASSIGNMENT --Paragraphs 4-1 through 4-12.

LESSON OBJECTIVES --After completing this lesson, you should be able to:

Perform computations related to gram equivalent weight, normality of solutions, milliequivalent per liter problems, and variations involving hydrates or only part of a molecule.

SUGGESTION --After completing the assignment, complete the exercises of this lesson. These exercises will help you to achieve the lesson objectives.

LESSON 4

EQUIVALENT SOLUTIONS

Section I. EQUIVALENT WEIGHT

4-1. INTRODUCTION

a. A gram equivalent weight by definition is the mass of substance that will combine with or displace one mole of hydrogen.

b. In solutions of ionic compounds, the compound dissociates into positive or negative ions to react with other ions. An example is KOH, which separates into one K^+ ion and one OH^- ion. One mole of K^+ will replace one mole of H^+ in a chemical reaction; hence, one equivalent weight of KOH is equal to one mole of KOH. Consider now the combining ability of the SO_4^{-2} ion in sulfuric acid, H_2SO_4. One mole of the SO_4^{-2} ion will combine with two moles of H^+. Since one gram equivalent weight of a compound or element is the mass that will combine with one mole of H^+, then one gram equivalent weight of H_2SO_4 equals 0.5 moles (1/2 the gram molecular weight) of H_2SO_4 because two H^+ ions will combine with one SO_4^{-2} ion. For our purposes, the gram equivalent weight (GEW) of a compound may be considered to be equal to the gram molecular weight (GMW) divided by the total positive ionic valence (TPIV). TPIV expresses the number of equivalents per mole of substance. Equivalently, GEW = GMW/TPIV.

NOTE: This is true for metathesis reactions only, where ionic valence does not change.

4-2. DETERMINING THE GRAM EQUIVALENT WEIGHT (GEW)

In solving for GEW, the first step is to find the GMW of the compound and then divide by the total positive ionic valence (TPIV). The TPIV is normally determined by finding the valence of the first ion in the chemical compound. (See Appendix C for the valences of common ions.) The valence of that ion is then multiplied by any subscripts pertaining to that ion. If two or more valences are possible for the ion, simply find the valence of the negative ion. Multiply the valence by any subscripts that pertain to that ion giving a total negative ionic valence. Since the sum of the positive valence and negative valence is zero, the TPIV is numerically equal to the total negative valence.

a. **Example.** Find the GEW of KOH.

Solution. Determine the GMW of the compound

KOH

K	39.1
O	16.0
H	+ 1.0
	56.1 g/mol

Divide the GMW by the TPIV.

$$\frac{56.1\ g/mol}{1\ Eq/mol} = 56.1\ g/Eq$$

Using dimensional analysis multiply the GMW, expressed in grams per mole, times 1/TPIV, expressed in moles per equivalent, used as an appropriate factor.

$$\frac{56.1\ g}{mol} \times \frac{mol}{1\ Eq} = 56.1\ g/Eq$$

b. **Example.** Find the GEW of $CaCO_3 \cdot 2H_2O$.

Solution. Determine the GMW of the compound.

NOTE: Water, being a relatively neutral species, is not considered when determining the TPIV of a hydrate. However, its weight must be considered when determining the GMW.

$CaCO_3 \cdot 2H_2O$

Ca	40.1	X	1	=	40.1
C	12.0	X	1	=	12.0
O	16.0	X	3	=	48.0
H	1.0	X	4	=	4.0
O	16.0	X	2	=	+ 32.0
					136.1 g/mol

Divide the GMW by the TPIV.

$$\frac{136.1\ g/mol}{2\ Eq/mol} = \underline{68.05\ g/Eq}$$

Using dimensional analysis multiply the GMW, expressed in grams per mole, times the 1/TPIV, expressed in moles per equivalent, used as an appropriate factor.

$$\frac{136.1\ g}{mol} \times \frac{mol}{2\ Eq} = 68.05\ g/Eq$$

c. **Example.** Calculate the GEW of $Fe_2(SO_4)_3$.

Solution. Determine the GMW of the compound.

NOTE: The iron in ferric sulfate is ambivalent. The term ambivalent refers to the iron's ability to have more than one valence. In order to determine the TPIV of this and like compounds it is necessary to examine the charge of the anion (negative ion). The TPIV will be equal to the absolute value (integer value, excluding the sign) of the negative charge of the anion.

$Fe_2(SO_4)_3$

Fe	55.8	X	2	=	111.6
S	32.1	X	3	=	96.3
O	16.0	X	12	=	+ 192.0
					399.9 g/mol

Divide the GMW by the TPIV.

$$\frac{399.9 \text{ g/mol}}{6 \text{ Eq/mol}} = \underline{66.65 \text{ g/Eq}}$$

Using dimensional analysis multiply the GMW, expressed in grams per mole, times the 1/TPIV, expressed in moles per equivalent, used as an appropriate factor.

$$\frac{399.9 \text{ g}}{\text{mol}} \times \frac{\text{mol}}{6 \text{ Eq}} = 66.65 \text{ g/Eq}$$

4-3. EXCEPTIONS IN CALCULATING GEW

The only exact method of calculating the GEW is to examine the complete reaction that the molecule will undergo. For example:

$$H_3PO_4 + NaOH \Longleftrightarrow NaH_2PO_4 + HOH$$

In this reaction, only one of the hydrogen ions on the phosphoric acid molecule reacted with the sodium hydroxide. The TPIV for the acid in this example is 1.

$$H_3PO_4 + 2NaOH \Longleftrightarrow Na_2HPO_4 + 2HOH$$

In this example, two moles of sodium hydroxide were reacted with one mole of phosphoric acid and the TPIV is 2 since two of the hydrogen ions from the acid reacted.

$$H_3PO_4 + 3NaOH \Longleftrightarrow Na_3PO_4 + 3HOH$$

The TPIV in this reaction is 3 since three hydrogen ions from the acid reacted with the three moles of sodium hydroxide. A general rule to follow is to examine the reaction that is to occur. If the products of the reaction cannot be determined by inspecting the given material, then assume complete ionization unless other information is given. In the case of phosphoric acid, if no guidance is given as to the type of reaction that the molecule will undergo, or if the degree of ionization is not given, then assume the TPIV to be 3.

4-4. EQUIVALENTS

An equivalent indicates the number of grams equal to the equivalent weight of the substance. One equivalent has the mass of one gram equivalent weight. The mechanism of solving for the number of equivalents is similar to that of solving for the number of moles except GEW is used instead of GMW.

Section II. NORMAL SOLUTIONS

4-5. NORMALITY

A normal solution is defined as the number of equivalents per liter of solution. Normality is used to account for different degrees of reactivity of chemicals. One gram equivalent weight of a substance will react exactly with one gram equivalent weight of another substance. A one Normal solution contains one GEW of solute in one liter of total solution. The following information can be used in solving normality problems:

4-6. SYMBOLS

Based on the definition given above, it follows that;

a. Normality (Eq/L) = number of equivalents per liter of solution

b. GEW = grams per equivalent

c. Liter = total volume of solution

d. Therefore, grams of solute = (Eq/L)(g/Eq)(L)

or equivalently:

$$g = (Eq/L)(GEW)(L)$$

4-7. EXAMPLES

a. **Example.** How much NaOH is needed to prepare 400 mL of a 10.0 Eq/L NaOH solution?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$g = (Eq/L)(g/Eq)(L)$$

Calculate the GEW of the compound.

NaOH

Na	23.0
O	16.0
H	+ 1.0
	40.0 g/mol

$$\frac{40.0 \text{ g/mol}}{1 \text{ Eq/mol}} = 40.0 \text{ g/Eq}$$

Substitute the given values.

$$g = (10.0 \text{ Eq/L})(40.0 \text{ g/Eq})\ (400 \text{ mL})$$

Make any necessary conversions.

$$g = (10.0 \text{ Eq/L})(40.0 \text{ g/Eq})(0.400 \text{ L})$$

Solve the equation for the unknown quantity.

$$g = \underline{160 \text{ g}}$$

Using **dimensional analysis:** Read the problem carefully and determine the desired quantity.

Grams of NaOH

Calculate the gram equivalent weight

$$\frac{40.0 \text{ g}}{\text{mol}} \times \frac{\text{mol}}{1 \text{ Eq}} = 40.0 \text{ g/Eq}$$

Express the desired volume in liters

$$400 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.400 \text{ L}$$

Multiply the normal concentration times the gram equivalent weight times the volume expressed in liters to determine the amount of solute needed to prepare the solution.

$$\frac{10 \text{ Eq}}{\text{L}} \times \frac{40.0 \text{ g}}{\text{Eq}} \times 0.400 \text{ L} = 160 \text{ g}$$

b. **Example.** What is the Eq/L concentration of an $AlPO_4$ solution that was prepared by adding 120.0 grams of $AlPO_4$ to a 250 mL flask and adjusting the volume to the mark?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$g = (Eq/L)(g/Eq)(L)$$

Determine the GEW of the compound.

$AlPO_4$

Al	27.0 X 1 =	27.0	
P	31.0 X 1 =	31.0	
O	16.0 X 4 =	+ 64.0	
		122.0 g/mol	

$$\frac{122.0 \text{ g/mol}}{3 \text{ Eq/mol}} = 40.67 \text{ g/Eq}$$

Substitute the given information into the formula.

$$120.0 \text{ g} = (Eq/L)(40.67 \text{ g/Eq})(250 \text{ mL})$$

Make any needed conversions.

$$120.0 \text{ g} = (Eq/L)(40.67 \text{ g/Eq})(0.250 \text{ L})$$

Determine the unknown quantity.

$$Eq/L = \frac{120.0 \text{ g}}{(40.67 \text{ g/Eq})(0.250 \text{ L})}$$

$$Eq/L = \underline{11.8 \text{ Eq/L}}$$

Using dimensional analysis: Read the problem carefully and determine the desired quantity.

Eq/L concentration.

Determine the GEW of the compound as follows.

$$\frac{122.0 \text{ g}}{\text{mol}} \times \frac{\text{mol}}{3 \text{ Eq}} = 40.67 \text{ g/Eq}$$

Express the grams of solute as equivalents using the appropriate conversion factor.

$$120.0 \text{ g} \times \frac{\text{Eq}}{40.67 \text{ g}} = 2.951 \text{ Eq}$$

Express the desired volume in liters.

$$250 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.250 \text{ L}$$

Concentration is an expression of the relative amounts of solute and solvent present, a ratio. Express the equivalents per liter and simplify the expression.

$$\frac{2.951 \text{ Eq}}{0.250 \text{ L}} = 11.8 \text{ Eq/L}$$

c. **Example.** What is the maximum volume of Na_2CO_3 solution that can be prepared from 106.0 grams of Na_2CO_3 if the desired concentration of solution is 0.500 Eq/L?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$g = (\text{Eq/L})(\text{g/Eq})(\text{L})$$

Determine the GEW of the compound.

Na	23.0 X 2 =	46.0	
C	12.0 X 1 =	12.0	
O	16.0 X 3 =	+ 48.0	
		106.0 g/mol	

$$\frac{106.0 \text{ g/mol}}{2 \text{ Eq/mol}} = 53.00 \text{ g/Eq}$$

Substitute the given information into the formula.

$$106.0 \text{ g} = (0.500 \text{ Eq/L})(53.00 \text{ g/Eq})(\text{L})$$

Determine the unknown quantity.

$$\text{L} = \frac{106.0 \text{ g}}{(0.500 \text{ Eq/L})(53.0 \text{ g/Eq})}$$

$$\text{L} = \underline{4.00 \text{ L}}$$

Using **dimensional analysis:** Read the problem carefully and determine the desired quantity.

Volume in liters

Determine the GEW of the compound.

$$\frac{106.0\ g}{mol} \times \frac{mol}{2\ Eq} = 53.00\ g/Eq$$

Calculate the grams per liter by multiplying the equivalent per liter concentrations times the grams per equivalent.

$$\frac{0.500\ Eq}{L} \times \frac{53.00\ g}{Eq} = 26.5\ g/L$$

The calculated value of 26.5 g/L is now used as a factor to determine the volume of solution that can be prepared. However, the reciprocal of the value must be used as a factor. If there are 26.5 grams per liter then for every liter there are 26.5 grams of solute. This relationship is true of all factors we have used.

$$106.0\ g \times \frac{L}{26.5\ g} = 4.00\ L$$

Section III. MILLIEQUIVALET PER LITER SOLUTIONS (mEq/L)

4-8. INTRODUCTION

Milliequivalent per liter problems are based on the same principle as normality. If we examine the definition of normality we will find that a normal solution contains one gram equivalent weight per liter of solution. Equivalently, we can say that a normal solution is one equivalent per liter of solution (Eq/L). A milliequivalent per liter solution would, therefore, contain one milliequivalent weight per liter of solution.

4-9. DISCUSSION

a. A milliequivalent = 0.001 equivalent and 1 equivalent = 1000 milliequivalents.

b. A milliequivalent has the numerical value of one equivalent weight expressed in mg/mEq.

c. To convert Eq/L to mEq/L, multiply the Eq/L concentration by 1000 mEq/1 Eq.

d. To convert mEq/L to Eq/L, multiply the mEq/L concentration by 1 Eq/1000 mEq.

e. Formula for solving mEq/L problems:

$$mg = (mEq/L)(mg/mEq)(L)$$

4-10. SOLVING MILLIEQUIVALENT PER LITER PROBLEMS

a. **Example.** How much NaCl is needed to prepare 500 mL of a 25.0 mEq/L NaCl solution?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$mg = (mEq/L)(mg/mEq)(L)$$

Determine the milliequivalent weight of the compound.

NaCl

$$\begin{array}{ll} Na & 23.0 \\ Cl & \underline{+\ 35.5} \\ & 58.5\ mg/mmol \end{array}$$

$$\frac{58.5\ mg/mmol}{1\ mEq/mmol} = 58.5\ mg/mEq$$

Substitute the given information into the formula.

$$mg = (25.0\ mEq/L)(58.5\ mg/mEq)(500\ mL)$$

Make any necessary conversions.

$$mg = (25.0\ mEq/L)(58.5\ mg/mEq)(0.500 L)$$

Solve for the unknown quantity.

$$mg = \underline{731\ mg}$$

Using **dimensional** analysis: Read the problem carefully and determine the desired quantity.

Milligrams NaCl.

Determine the milliequivalent weight of the compound.

$$\frac{58.5\ mg}{mmol} \times \frac{mmol}{1\ mEq} = 58.5\ mg/mEq$$

Express the desired volume in liters.

$$500\ mL \times \frac{1\ L}{1000\ mL} = 0.500\ L$$

Determine the amount of salt needed using the appropriate factors.

$$\frac{25.0\ \text{mEq}}{\text{L}} \times \frac{58.5\ \text{mg}}{\text{mEq}} \times 0.500\ \text{L} = 731\ \text{mg}$$

b. **Example.** How much $MgSO_4$ is needed to make 100 mL of a 50.0 mEq/L $MgSO_4$ solution?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

mg = (mEq/L)(mg/mEq)(L)

Determine the milliequivalent weight of the compound.

$MgSO_4$

Mg	24.3 X 1 =	24.3	
S	32.1 X 1 =	32.1	
O	16.0 X 4 =	+ 64.0	
		120.4 mg/mmol	

$$\frac{120.4\ \text{mg/mmol}}{2\ \text{mEq/mmol}} = 60.20\ \text{mg/mEq}$$

Substitute the given information into the formula.

mg = (50.0 mEq/L)(60.20 mg/mEq)(100 mL)

Make any necessary conversions

mg = (50.0 mEq/L)(60.20 mg/mEq)(0.100 L)

Solve for the unknown quantity.

mg = <u>301 mg</u>

Using dimensional analysis: Read the problem carefully and determine the desired quantity.

Milligrams of $MgSO_4$

Determine the milliequivalent weight of the compound.

$$\frac{120.4\ \text{mg}}{\text{mmol}} \times \frac{\text{mmol}}{2\ \text{mEq}} = 60.20\ \text{mg/mEq}$$

Express the desired volume in liters

$$100\ \text{mL} \times \frac{1\ \text{L}}{1000\ \text{mL}} = 0.100\ \text{L}$$

Determine the amount of salt needed using the appropriate factors.

$$\frac{50.0 \text{ mEq}}{\text{L}} \times \frac{60.20 \text{ mg}}{\text{mEq}} \times 0.100 \text{ L} = 301 \text{ mg}$$

Section IV. VARIATIONS OF NORMALITY PROBLEMS

4-11. PROBLEMS INVOLVING HYDRATES

Like molar solutions, normal solutions contain a known number of particles per liter of solution. An one equivalent per liter (Eq/L) solution of $CuSO_4$ will have the same concentration as a one equivalent per liter $CuSO_4 \cdot 5HOH$ solution. **When solving normal problems involving hydrates, use the gram equivalent weight of the substance being weighed in the preparation of the solution.**

Example. How much $CuSO_4 \cdot 5HOH$ is required to prepare 500 mL of a 1.50 N $CuSO_4$ solution?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$g = (Eq/L)(g/Eq)(L)$$

Determine the GEW of the compound that is available (actually being weighed out).

$CuSO_4 \cdot 5HOH$

Cu	63.5 X 1 =	63.5
S	32.1 X 1 =	32.1
O	16.0 X 4 =	64.0
HOH	18.0 X 5 =	+ 90.0
		249.6 g/mol

NOTE: When determining the TPIV of hydrates, the water (HOH) molecules are not considered. Water has a low degree of reactivity. Also, note that copper is ambivalent, and we must consider the charge of the anion (-) in order to correctly determine the TPIV.

$$\frac{249.6 \text{ g/mol}}{2 \text{ Eq/mol}} = 124.8 \text{ g/Eq}$$

Substitute the given information into the formula.

$$g = (1.50 \text{ Eq/L})(124.8\text{g/Eq})(500 \text{ mL})$$

Make any necessary conversions.

$$g = (1.50 \text{ Eq/L})(124.8 \text{ g/Eq})(0.500 \text{ L})$$

Solve for the unknown quantity.

$$g = \underline{93.6\ g}$$

Using dimensional analysis: Read the problem carefully and determine the desired quantity.

Grams of $CuSO_4.5H_2O$

Determine the GEW of the compound (the hydrate)

$$\frac{249.6\ g}{mol} \times \frac{mol}{2\ Eq} = 124.8\ g/Eq$$

Now determine the grams of hydrate needed using the appropriate factors.

$$\frac{1.50\ Eq}{L} \times \frac{124.8\ g}{Eq} \times 0.500\ L = 93.6\ g$$

4-12. PROBLEMS THAT CONSIDER ONLY PART OF THE MOLECULE

When preparing solutions using compounds where only part of the molecule will be involved in the reaction, a factor must be used to account for the reactivity of the ion of interest per mole of compound or divide the molecular weight of the entire molecule by the equivalents per mole of the particle of interest involved in the reaction (TPIV).

NOTE: TPIV expresses the number of equivalents per mole of substance.

Example. How much Na_2HPO_4 is required to prepare 2.00 liters of a 1.00 Eq/L sodium standard?

Solution. Read the problem carefully and select the formula that generates the desired quantity.

$$g = (Eq/L)(g/Eq)(L)$$

Calculate the GEW of the compound using the TPIV of the ion of interest.

Na_2HPO_4

Na	23.0	X	2	=	46.0
H	1.0	X	1	=	1.0
P	31.0	X	1	=	31.0
O	16.0	X	4	=	+ 64.0
					142.0 g/mol Na_2HPO_4

$$\frac{142.0\ g\ Na_2HPO_4/mol\ Na_2HPO_4}{2\ Eq\ Na/mol\ Na_2HPO_4} = 71.00\ g\ Na_2HPO_4/Eq\ Na$$

Substitute the given values and evaluate the expression to determine the unknown quantity.

$$g = (1.00 \text{ Eq Na/L})(71.00 \text{ g } Na_2HPO_4/\text{Eq Na})(2.00 \text{ L})$$

$$g = \underline{142 \text{ g}} \; Na_2HPO_4$$

Using dimensional analysis: Read the problem carefully and determine the desired quantity.

Grams of Na_2HPO_4

Calculate the GEW of the compound.

$$\frac{142.0 \text{ g } Na_2HPO_4}{\text{mol } Na_2HPO_4} \times \frac{\text{mol } Na_2HPO_4}{2 \text{ Eq Na}} = 71.00 \text{ g } Na_2HPO_4/\text{Eq Na}$$

Determine the amount of salt (hydrate) needed in the usual manner using the appropriate factors.

$$\frac{1.00 \text{ Eq Na}}{\text{L}} \times \frac{71.00 \text{ g } Na_2HPO_4}{\text{Eq Na}} \times 2.00 \text{ L} = 142 \text{ g } Na_2HPO_4$$

EXERCISES, LESSON 4

REQUIREMENT. The following exercises are to be answered by writing the answer in the space provided at the end of the question.

After you have completed all the exercises, turn to "Solutions to Exercises," at the end of the lesson and check your answers with the review solutions.

1. What is the GEW of K_2SO_4?

____

2. What weight of $Ba(OH)_2$ is needed to make 1500 mL of a 0.500 Eq/L $Ba(OH)_2$ solution?

____

3. What amount of $CuSO_4$ solution can be prepared from 80.1 grams of compound, if the desired concentration is 1.50 Eq/L?

____

4. A solution contains 6.00 gram equivalents per liter of solution. What is the normality of the solution?

____

5. What is the Eq/L concentration of a 6 mEq/L solution?

____

6. How many milligrams are required to make 250 mL of a 75.0 mEq/L Na_2CO_3 solution?

____

7. A KCl solution was prepared by adding 745 mg and adjusting the volume to 1.00 liter. What is the mEq/L concentration of the solution?

____

8. What is the Eq/L concentration of 40.0 g of NaOH in 400 mL of solution?

____

9. How many grams of $LiNO_3$ are needed to make 1000 mL of a 300 mEq/L $LiNO_3$ solution?

____

10. What amount of $Fe_3(PO_4)_2 \cdot 4HOH$ is required to make 500 mL of a 2.50 Eq/L $Fe_3(PO_4)_2$ solution?

____

SOLUTIONS TO EXERCISES, LESSON 4

1. **87.15 g (para 4-2)**
2. **64.2 g (para 4-5)**
3. **0.669 L (para 4-5)**
4. **6 Eq/L = 6 Normal (para 4-5)**
5. **0.006 Eq/L (para 4-7)**

6. 994 mg (para 4-7)

7. 9.99 mEq/L (para 4-7)

8. 2.50 Eq/L (para 4-5)

9. 20.7 g (para 4-7)

10. 89.5 g (para 4-10)