Guide to Chapter 3. Formulas, Equations and Moles

We will spend three lecture days on this chapter and one review day. In this chapter we will learn to balance chemical equations and do the arithmetic of chemistry: mole calculations. These two concepts form an important part of the foundation of most of chemistry. This chapter is so important that Exam 2 will cover only this chapter!

This is a chapter study guide, given section-by-section. Work problems on separate sheets of paper and keep them with this guide. *When working problems, use plenty of space and when appropriate, show all work.*

Read the introductory paragraph to Chapter 3. Formulas, Equations and Moles

Read Section 3.1 Balancing Chemical Equations.

2. Balancing chemical equations.

Learning Objective 1: Given a formula of an ionic or molecular compound, correctly count the number of atoms in a molecular formula or ions present in a formula unit (hydrates too)

Learning Objective 2: Be able to balance simple chemical reactions by inspection.

Learning Objective 3: Be able to balance more difficult chemical reactions by using "link lines" (a Mattson trick — not in book).

Learning Objective 4: Given a balanced chemical equation, correctly count the number of atoms or ions on each side of the arrow.

Learning Objective 5: Be able to write and balance chemical equations given *only the names* of the substances (not formulas).

Do Problems 1 – 3 at the end of the section.

Do the following end-of-chapter problems: 38, 40,

Problem Club Question A. Balance the following equations:

a. $UO_2 + HF \longrightarrow UF_4 + H_2O$

b. $PH_3 + O_2 \longrightarrow P_4O_{10} + H_2O$

c. $C_2H_3Cl + O_2 \longrightarrow CO_2 + H_2O + HCl$

Answer:

a. $UO_2 + 4\ HF \longrightarrow UF_4 + 2\ H_2O$

b. $4\ PH_3 + 8\ O_2 \longrightarrow P_4O_{10} + 6\ H_2O$

c. $2\ C_2H_3Cl + 5\ O_2 \longrightarrow 4\ CO_2 + 2\ H_2O + 2\ HCl$

Problem Club Question B. Write a balanced equation for

a. the decomposition of ammonium nitrate to dinitrogen monoxide and steam, $H_2O(g)$.

Answer: $NH_4NO_3 \longrightarrow N_2O + 2\ H_2O$

b. the combustion (combustion can be defined as "combination with oxygen") of ammonia to produce nitrogen and steam.

Answer: $4\ NH_3 + 3\ O_2 \longrightarrow 2\ N_2 + 6\ H_2O$

Problem Club Question C. Answer: *C*

Problem Club Question Answer: *D*

Problem Club Question E. Answer: *C*

Read Section 3.2 Chemical Symbols on Different Levels

Learning Objective 6: Know how a chemical equation can describe a reaction on a microscopic or macroscopic level.

Do the following end-of-chapter problems: 34

Read Sections 3.3. Avogadro's Number and the Mole

Learning Objective 7: Define and describe the relationship between the following terms: mole, molecular mass, formula mass, molar mass, and Avogadro's number.

Learning Objective 8: Be able to convert the number of moles of an element into the number of atoms of the element.

Learning Objective 9: Be able to convert the number of moles of an ionic compound into the number of formula units of the compound.

Learning Objective 10: Be able to convert the number of moles of a molecular compound into the number of molecules.

Learning Objective 11: Given the formula of a compound (or its name) along with the number of moles, be able to convert this to the number of moles of each element present. Use Avogradro's number to determine the number of atoms, ions, molecules, or formula units present.

Do Problems 4 – 6 at the end of the section.

Do the following end-of-chapter problems: 42, 44, 46, 48, 50, 52, 54, 56

Problem Club Question F. Tungsten is used as the wire filament in incandescent light bulbs.

a. Calculate the mass in grams of a single tungsten atom.

Answer: 3.05 X 10^{-22} g

b. Calculate how many atoms are present in a filament with a mass of 10 mg.
Answer: 3.3 x 10^{19} atoms W

 Problem Club Question G. Consider a glass of water that contains 250 mL water (d = 1 g/mL)
a. How many moles of H_2O are there in the glass of water?
b. How many molecules of water are present?
c. How many hydrogen atoms are there in this sample of water?
d. How many moles of atoms are there in total in this sample of water?

Answer: (a) 13.8 mol of H_2O; (b) Answer: 8.36 x 10^{24} molecules of H_2O; (c) 1.67 x 10^{25} hydrogen atoms; (d) 41.7 moles of atoms in sample

 Problem Club Question H. What is the mass in grams of a single water molecule?
Answer: 3.0 x10^{-23} g

 Problem Club Question I. How many protons are there in a single xenon atom?
Answer: 54 protons

 Problem Club Question J. How many protons are there in 100 g of xenon atoms?
Answer: 2.48 x 10^{25}

 Problem Club Question K. Calculate the mass, in grams, of 7.7 moles of ammonia, NH_3.
Answer: 131 g NH_3

 Problem Club Question L. By US law, tuna can contain no more than 17 parts per million (ppm) of mercury (that is 17 g Hg for every 10^6 g tuna).
a. How many moles of mercury are there in a 6 ounce tin of tuna containing 17 ppm Hg?
Answer: 1.44 x 10^{-5} mol Hg
b. How many atoms of mercury are there in this same tin?
Answer: 8.67 x 10^{18} atoms Hg

 Problem Club Question M. One of the most common minerals on earth is feldspar, $CaAl_2Si_2O_8$. How much aluminum (in kg) can be obtained by mining 4.0 metric tons (1 metric ton = 10^3 kg) of feldspar?
Answer: 7.74 x 10^5 g Al or 7.74 x 10^2 kg

 Read Section 3.4 Stoichiometry: Chemical Arithmetic
  Learning Objective 12: Given the name or formula of a compound, use the periodic table to calculate its molar mass.

  Learning Objective 13: Given the mass of a compound or element, determine the number of moles and likewise perform conversions of moles to mass of a compound or element.

  Learning Objective 14: Determine how many atoms are present for each element present in a given mass or number of moles of a compound.

  Learning Objective 15: Use Avogadro's number to convert between the number of moles (or mass) and number of molecules (or atoms).

 Do Problems 7 - 8 at the end of the section

 Do the following end-of-chapter problems: 31, 58, 60, 62, 64, 66

 Problem Club Question N. Consider the following equation which occurs between ammonia and the air pollutant NO:

$$4\ NH_3(g) + 6\ NO(g) \longrightarrow 5\ N_2(g) + 6\ H_2O(l)$$

a. How many moles of NO would be required to react with 29 moles of NH_3?

Answer: 43.5 mol NO

b. How many moles of NH_3 would be required to react with 55 g of NO?

Answer: 1.22 mol NH_3

 Problem Club Question O. Iron ore consists mostly of ferric oxide. When ferric oxide is heated with an excess of coke (carbon), iron metal and carbon monoxide are produced.

a. Write the balanced equation for the reaction.

Answer: $Fe_2O_3 + 3\ C \longrightarrow 2\ Fe + 3\ CO$

b. How many moles of ferric oxide are required to form 15.2 moles of iron?

Answer: 7.6 mol Fe_2O_3

c. What mass of CO is formed from 9.7 g coke?

Answer: 22.6 g CO

Advice from a former student:

I had a very good chemistry teacher in high school, so that has helped me a lot here. However, I have found it challenging here and that I work more independently. I've found it helps to read the chapters and take notes so I can grasp the concepts easier. Staying caught up in assignments and actually doing the homework has allowed me to understand the lectures better than if I wasn't prepared for that day.

 Problem Club Question P. (ACS-style) Answer: A

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 Problem Club Question Q Answer: C

Problem Club Question R Answer: A

Problem Club Question S Answer: A

Problem Club Question T Answer: C

Read Section 3.5 Yields of Chemical Reactions

Learning Objective 16: Given a balanced chemical equation, calculate the number moles or the mass of a product obtained from a given amount of reactant (called theoretical yield)

Learning Objective 17: Given a balanced chemical equation, calculate the number of moles or the mass of a reactant required to generate a desired amount of product.

Learning Objective 18: Calculate a reaction's percent yield from the actual experimental amount of product obtained and the theoretical yield

Learning Objective 19: Be able to express conceptual understanding of percent yields, theoretical yields and reaction stoichiometry.

Do Problems 9 and 10 at the end of the section

Problem Club Question U. Consider the following equation which occurs between ammonia and the air pollutant NO:

$$4\ NH_3(g) + 6\ NO(g) \longrightarrow 5\ N_2(g) + 6\ H_2O(l)$$

a. How many moles of NO would be required to react with 29 moles of NH_3?

Answer: 43.5 mol

Read Section 3.6 Reactions with Limiting Amounts of Reagents

Learning Objective 20: Given the masses of two reactants involved in a balanced chemical equation, determine the limiting reactant.

Learning Objective 21: Use the limiting reagent to calculate the mass in grams of the product(s) formed, and the amount of excess reactant that remains.

Do Problems 11 — 13 at the end of the section.

Do the following end-of-chapter problem: 36, 68, 70, 72, 74, 76

Problem Club Question V. Consider the following equation which occurs between ammonia and the air pollutant NO:

$$4\ NH_3(g) + 6\ NO(g) \longrightarrow 5\ N_2(g) + 6\ H_2O(l)$$

If 240 g ammonia and excess nitrogen monoxide were allowed to react,

a. what is the theoretical yield of nitrogen?

Answer: 17.6 mol or 493 g

b. What is the theoretical yield of water?

Answer: 21.2 mol or 382 g

c. If the actual yield turned out to be 135 g of N_2 during one experiment, calculate the percent yield.

Answer: 27%

 Problem Club Question W. Nitrogen trichloride gas reacts with water to form ammonia and hypochlorous acid, HOCl(aq), the main component in household bleach.

a. Write a balanced equation for this reaction.

Answer: $NCl_3 + 3\ H_2O \longrightarrow NH_3 + 3\ HOCl$

b. How many moles of NH_3 are produced from 275 mL water (d = 1 g/mL) and excess NCl_3?

Answer: 5.09 mol NH_3

c. What mass of NCl_3 is required to produce 100 g ammonia?

Answer: 708 g NCl_3

d. Suppose 58 g NCl_3 and 15 g water were reacted. Which is the limiting reagent? What is the theoretical yield of ammonia and HOCl? (in moles and grams)

Answer: T.Y. of NH_3 = 0.278 mol (4.72 g); T.Y. of HOCl = 0.833 mol (43.7 g) HOCl

Referring to (d) above: If the yield of NH_3 were only 4.4 g, what is the percent yield?

Answer: %Yld = 93.2%

 Problem Club Question X. Phosphorus is made from reacting calcium phosphate with both silicon dioxide and elemental carbon to produce elemental phosphorus, P_4, carbon monoxide and calcium silicate, $CaSiO_3$.

a. Write the overall reaction and balance it.

Answer: $2\ Ca_3(PO_4)_2 + 6\ SiO_2 + 10\ C \longrightarrow P_4 + 10\ CO + 6\ CaSiO_3$

b. Suppose that we reacted 500.0 g calcium phosphate with 300.0 g silicon dioxide and 100.0 g carbon. Determine the limiting reagent.

Answer: L.R. is $Ca_3(PO_4)_2$

c. What mass of phosphorus is theoretically expected to be produced?

Answer: 99.8 g P_4

d. Suppose that the process is known to be typically 70% efficient. What mass of phosphorus can we realistically expect to get?

Answer: 70 g P_4

 Problem Club Question Y Answer: A

 Problem Club Question Z. Answer: A

Advice from a former student:

If I could give advice to next year's Chem 203 students, I would tell them to do the problem club worksheets given out in class. I print out the answers and work the problems *until I can get them right. I really like knowing if I am doing problems correctly, and I find it extremely useful in learning the material. The problem club worksheets also help students to understand what topics the professor is emphasizing in each chapter. I would also tell them that it can take some time to get used to the testing methods. I was very nervous on my first quiz and did not do as well as I would have liked. However, I have gotten used to the expectations and the quiz format and have become more confident as the semester has progressed.*

 Problem Club Question AA. Answer: B

 Problem Club Question BB. Answer: D

 Read Section 3.7 Concentrations of Reactants in Solution: Molarity

  Learning Objective 22: Define solution, solute, solvent.

  Learning Objective 23: Define molarity (molar solution, M).

  Learning Objective 24: Given mass of solute and volume of solution, determine molarity.

  Learning Objective 25: Given the volume of solution and the molar concentration (molarity), determine the number of moles or mass of the solute present.

  Learning Objective 26: Given the molar concentration and the moles or mass of solute, determine the volume of the solution.

 Do Problems 14 - 17 in this section

 Do the following end-of-chapter problems: 78, 80, 82, 84

 Problem Club Question CC. What is the molarity of a solution prepared by dissolving 2.5 moles of sugar in water to make 500.0-mL?

Answer: 5.0 M

 Problem Club Question DD. Sodium bicarbonate is used in baking and cooking. What is the molar concentration of sodium bicarbonate if you dissolved 28.5 g of the solid in enough water to make 200. mL solution?

Answer: 1.70 M

 Problem Club Question EE. What mass of sodium sulfate would you use in order to prepare 750-mL of a 0.800 M solution?

Answer: 85.2 g Na_2SO_4

 Problem Club Question FF. How many moles of HCl are present in 25.0-mL of 0.10278 M HCl?

Answer: 0.00257 mol HCl

Problem Club Question GG. What mass of $MgCl_2$ is required to prepare 2.00 L of 0.550 M solution?

(A) 1.10 g *(B) 28.9 g* *(C) 86.5 g* *(D) 105 g*

Answer: D

Problem Club Question HH. What is the molarity of a solution containing 11.7 g of NaCl in 400 mL of solution?

(A) 0.0290 M *(B) 0.500 M* *(C) 2.92 M* *(D) 5.00 M*

Answer: B

Read Section 3.8 Diluting Concentrated Solutions

Learning Objective 27: Use the expression $V_d \times M_d = V_c \times M_c$ to solve for an unknown volume or molar concentration.

Do Problems 18 and 19 at the end of the section

Do the following end-of-chapter problems: 30, 86

Problem Club Question II. Suppose that you diluted 50.0-mL of 0.4000 M NaOH to a total volume of 300.-mL. What is the new concentration?

Answer: 0.0667 M NaOH

Problem Club Question JJ. What volume of a 0.1222 M KOH solution should be used in order to prepare 1.0-L of a 0.00500 M solution?

Answer: V= 40.9 mL

Problem Club Question KK. What volume of a 0.20 M $AgNO_3$ solution is necessary to provide you with 20.0 mmol of silver?

Answer: V= 0.10 L

Read Section 3.9 Solution Stoichiometry

Learning Objective 28: Perform stoichiometry calculations involving solutions. See the objectives involving balanced equations and stoichiometry.

Learning Objective 29: Determine the volume of a reactant solution required for a given equation involving solutions.

Do Problems 20 - 21 in this section

Do the following end-of-chapter problems: 88, 90

Problem Club Question LL. When solutions of lead nitrate, $Pb(NO_3)_2$ and sodium chloride are reacted, a precipitate forms which is known to be $PbCl_2$. The reaction is:

$$Pb(NO_3)_2 + 2\ NaCl \longrightarrow PbCl_2 + 2\ NaNO_3$$

Answer: 75 mL

What volume of 0.0800 M NaCl is needed to completely precipitate 30.0-mL of 0.1000 M $Pb(NO_3)_2$?

Problem Club Question MM. Calcium carbonate reacts with hydrochloric acid to produce calcium chloride, water and carbon dioxide.
a. Write the balanced equation for the reaction.
b. What volume of a 0.200-M HCl solution is necessary to react completely with a 5.0-g sample of calcium carbonate?

Answer: (a) $CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$
(b) 499 mL

Skip Section 3.10 Titration (this will be covered in great detail next semester)

Read Section 3.11 Percent Composition and Empirical Formulas

Learning Objective 30: Calculate the percent composition of each element given in a chemical formula.

Do Problems 23 and 124 at the end of the section

Do the following end-of-chapter problem: 92

Problem Club Question NN. The active ingredient in many common antiperspirants is aluminum chlorohydrate, $Al_2(OH)_5Cl$. Calculate the mass percent of each element present in this ingredient.

Answer: 30.93% Al; 45.86% O; 2.89% H; 20.32% Cl

Read Section 3.12 Determining Empirical Formulas: Elemental Analysis

Learning Objective 31: Presented with the percent composition of an unknown compound, determine the empirical formula.

Do Problems 25 — 27 at the end of the section

Do the following end-of-chapter problems: 32, 37, 94, 96, 98, 100

Problem Club Question OO. Pepto-Bismol, sold as a cure for an upset stomach contains an active ingredient called bismuth subsalicylate. Bismuth subsalicylate analyzes for 23.22 % C, 1.39 % H, 57.72 % Bi and 17.68 % O. What is the simplest formula of bismuth subsalicylate?

Answer: $C_7H_5BiO_4$

Problem Club Question PP. Toluene is now widely used as a solvent. It has a sweet aroma that you can smell in liquid paper or white-out and in model glues. Combustion of 1.000 g toluene, which contains only C and H, produces 3.344 g carbon dioxide. What is the simplest formula of toluene?

Answer: C_7H_8

Problem Club Question QQ. Calculate the simplest formula of citric acid which is known to contain C, H, and O and analyzes as follows: 37.51% C and 4.20% H.

Answer: $C_6H_8O_7$

Problem Club Question RR. Wintergreen (properly named methyl salicylate) contains C, H, and O and is used in some chewing gums and is the active ingredient in BenGay. When a 5.287 g sample of wintergreen was combusted in excess oxygen, it produced 12.24 g CO_2 and 2.522 g water. What is the empirical formula of wintergreen?

Answer: $C_8H_8O_3$

Problem Club Question SS. (ACS-style) Answer: *A*

Problem Club Question TT. Answer: *A*

Problem Club Question UU. Answer: *C*

Problem Club Question VV. Answer: *D*

Read Section 3.13 Determining Molecular Masses: Mass Spectrometry

Learning Objective 32: Presented with the percent composition and the approximate molar mass of an unknown compound, determine the molecular formula.

Do Problems 18 and 19 at the end of the section

Problem Club Question WW. Hexamethylenediamine, used to produce nylon, contains C, H, and N and has a molar mass of approximately 110 - 120 g/mol. When 6.315 g of hexamethylenediamine are burned in oxygen, 14.354 g CO_2 and 7.833 g water are obtained. Calculate simplest and molecular formula.

Answer: $C_6H_{16}N_2$

Problem Club Question XX. Nicotine, the highly addictive carcinogen found in tobacco, shows it contains 74.0% C, 8.65% H and the remainder is N. Its molar mass is approximately 160 g/mol. What is the empirical and molecular formula?

Answer: $C_{10}H_{14}N_2$

Problem Club Question YY. Epsom salt is $MgSO_4{\cdot}xH_2O$. When Epsom salt is heated to 250 ^oC all of the water of hydrations are driven off. On heating 1.687-g sample of Epsom salt, 0.824-g $MgSO_4$ remains. How many molecules of water occur per formula unit?

Answer: x = 7