CHEMISTRY 109 – Help Sheet #3
REVIEW (Part III): Stoichiometry (Part I)
***** Review the appropriate topics for your lecture*****
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https://clc.chem.wisc.edu *(Resources page)*

Nuggets: *Mole Calculations; Molar Mass; Mass %; Empirical/Molecular formulas; Finding an unknown metal M*

MOLE (abbreviated mol): a number equal to 6.022×10^{23} units = Avogadro's number; average atomic mass on Periodic Table (number below symbol) equals ***weight in grams for 1mol of that element*** *(e.g., 1mol C = 12.01g C)*

MOLAR MASS = mass of 1mol of substance in grams

Example 1: What is the molar mass of $(NH_4)_2O$? (AAM = average atomic mass)

Answer 1: 52.10g/mol {$2(AAM_N) + 8(AAM_H) + 1(AAM_O)$ =
2(14.01) + 8(1.01) + 1(16.00) = 52.10g $(NH_4)_2O$/1mol $(NH_4)_2O$ (or just 52.10g/mol)}

Example 2: What is the molar mass of $CuSO_4{\cdot}5H_2O$? (This is a hydrated compound.)

Answer 2: 249.72g/mol {$1(AAM_{Cu}) + 1(AAM_S) + 4(AAM_O) + 10(AAM_H) + 5(AAM_O)$ =
1(63.55) + 1(32.07) + 4(16.00) + 10(1.01) + 5(16.00) = 249.72g $CuSO_4{\cdot}5H_2O$/1mol $CuSO_4{\cdot}5H_2O$ (or just 249.72g/mol)}

MASS PERCENT of elements within a compound

$$\textbf{mass\%A} = \frac{\textbf{massA}}{\textbf{total mass}} \textbf{ x 100\%}$$

Example 3: What is the mass% of N in $Ca(NO_3)_2$?

Answer 3: 17.1%

1. Assume 1 mol → total mass = molar mass = 1(Ca) + 2(N) + 6(O) = 1(40.1) + 2(14.0) + 6(16.0) = 164.1g $Ca(NO_3)_2$
2. Find mass of N in 1 mol of $Ca(NO_3)_2$: 2mol N x (14.0g N/1mol N) = 28.0g N
3. $\text{mass\%N} = \frac{\text{mass N}}{\text{total mass}} \times 100\%$; $\text{mass\%N} = \frac{28.0}{164.1} \times 100\% = 17.1\%$

EMPIRICAL FORMULA: the simplest formula that shows the ratio between atoms within the compound

Determining empirical formula from mass percents:

1. Assume 100g
2. % → g
3. g → mol (if g originally given and not mass% → start at step 3!)
4. Write chemical formula; divide by smallest number of moles
5. Fractions: $^1/_2$ (0.5) → x2; $^1/_3$ or $^2/_3$ (0.33, 0.66) → x3; $^1/_4$ or $^3/_4$ (0.25, 0.75) → x4

Example 4: *What is the empirical formula for a compound with 43.64% phosphorous and 56.36% oxygen?*

Answer 4: P_2O_5

1. assume 100g
2. % → grams: P: 43.64% x 100g = 43.64g P; O: 56.36% x 100g = 56.36g O
3. g → mol: $43.64\text{g P}\left(\frac{1\text{mol P}}{30.97\text{g P}}\right) = 1.409\text{mol P}$; $56.36\text{g O}\left(\frac{1\text{mol O}}{16.00\text{g O}}\right) = 3.523\text{mol O}$
4. Write EF: $P_{1.409}O_{3.523}$ and divide by smallest number of mol: 1.490: $P_{\frac{1.409}{1.409}}O_{\frac{3.523}{1.409}} \Rightarrow P_1O_{2.500}$
5. Fractions, multiply by 2: $P_{(1 \times 2)}O_{(2.500 \times 2)} \rightarrow P_2O_5$ = EF

MOLECULAR FORMULA: the exact formula of a compound

For N_2O_4, the molecular formula is N_2O_4 and the empirical formula is NO_2

You can't determine the molecular formula from mass percent, only the empirical formula

Determine Molecular Formula from Empirical Formula and the Molar Mass

1. Determine *ratio*: $\frac{\text{molar mass of molecular formula}}{\text{molar mass of empirical formula}}$
2. Take empirical formula and multiply each subscript by the number from above *ratio*

Example 5: Using the prior example (Example 4), what is the molecular formula if the molar mass is 283.88g/mol?
Answer 5**:** P_4O_{10}

1. Determine ratio:

$$\frac{\text{molar mass}_{\text{molecular formula}}}{\text{molar mass}_{\text{empirical formula}}}$$; molar mass molecular formula is given in the problem = 283.88g/mol;

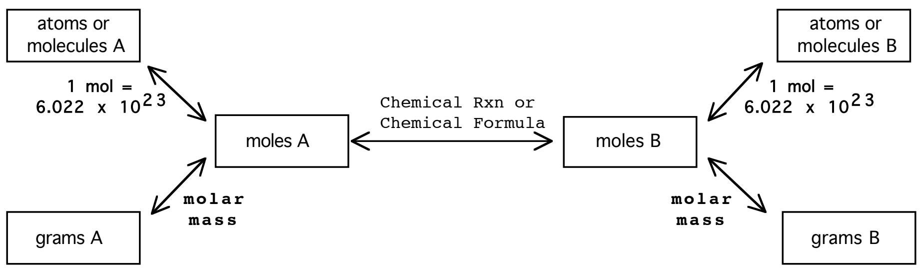
molar mass empirical formula (calculate this) = 2(P) + 5(O) = 2(30.97) + 5(16.00) = 141.8g/mol

$$\frac{\text{molar mass}_{\text{molecular formula}}}{\text{molar mass}_{\text{empirical formula}}} = \frac{283.88\text{g / mol}}{141.8\text{g / mol}} = 2.01$$

2. Multiply empirical formula by ratio: $P_{(2 \times 2)}O_{(5 \times 2)} = P_4O_{10}$ = molecular formula

CONVERTING BETWEEN MOL, GRAMS, AND ATOMS/MOLECULES

Use the flow chart to guide you for basic mole calculations



Example 6*:* How many grams of N are in 88.0g N_2O?

Answer 6*:* 56.0g N {This is a grams A → grams B calculation; requires 3 conversions (counting the steps in the flow chart); in the calculation below, *the fractions in the parentheses have units on the bottom to cancel the prior units and units on the top that you want to end up with:*

$$88.0\text{gN}_2\text{O}\left(\frac{1\text{molN}_2\text{O}}{44.0\text{gN}_2\text{O}}\right)\left(\frac{2\text{molN}}{1\text{molN}_2\text{O}}\right)\left(\frac{14.0\text{gN}}{1\text{molN}}\right) = 56.0\text{gN}$$

(note: after 1st fraction/parentheses the units are mol A; after 2nd fraction/parentheses the units are mol B; after 3rd fraction/parentheses the units are gB); it is often helpful to cancel out units (not numbers) to check to make sure the set-up is correct:

$$88.0\cancel{\text{gN}_2\text{O}}\left(\frac{1\cancel{\text{molN}_2\text{O}}}{44.0\cancel{\text{gN}_2\text{O}}}\right)\left(\frac{2\cancel{\text{molN}}}{1\cancel{\text{molN}_2\text{O}}}\right)\left(\frac{14.0\text{gN}}{1\cancel{\text{molN}}}\right) = 56.0\text{gN}$$

Example 7*:* A single molecule weighs 4.98 x 10^{23}g. What molecule is it?

a. NO_2 b. CO_2 c. H_2O d. NO e. CO

Answer 7: d {Determine the molar mass of the molecule and compare to the molar masses of the possible choices.

Step 1. $$\left(\frac{4.98 \times 10^{-23}\text{g}}{\text{molecule}}\right)\left(\frac{6.022 \times 10^{23}\text{molecules}}{\text{mol}}\right) = 29.99\text{g / mol}$$

Step 2. Find molar masses of chemicals given: NO_2 = 46g/mol; CO_2 = 44g/mol; H_2O = 18g/mol; NO = 30g/mol; CO = 28g/mol

Unknown molecule is NO which has a molar mass that matches the calculated molar mass from Step 1}

FINDING "M" IN A FORMULA: This is a specific type of mole calculation.

Example 8: 25.00g of MCl_3 is broken into its elements and produces 17.57g Cl_2. What ***element*** is M?

Answer 8: Sc {Find the molar mass of the unknown metal M using $\text{molar mass M} = \frac{\text{grams M}}{\text{mol M}}$ and then look it up on the Periodic Table

Step 1. Find grams M: $g_{total} = gM + gCl \rightarrow gM = 25.00 - 17.57 = 7.43g$ M;

Step 2. Find mol M using gCl_2 and chemical formula: $$17.57\text{gCl}_2\left(\frac{1\text{molCl}_2}{70.90\text{gCl}_2}\right)\left(\frac{2\text{molCl}}{1\text{molCl}_2}\right)\left(\frac{1\text{molM}}{3\text{molCl}}\right) = 0.1652\text{mol M}$$

Step 3. $$\text{molar mass M} = \frac{\text{grams M}}{\text{mol M}} = \frac{7.43\text{g M}}{0.1652\text{mol M}} = 44.97\text{g / mol}$$ → Sc from the periodic table}

Example 9: 1.500g of M_2CO_3 was heated releasing 0.623g CO_2. What is M? (Chemicals with carbonate, CO_3^{-2} are more challenging!)

$M_2CO_3(s) \rightarrow M_2O(s) + CO_2(g)$

Answer 9: Na {determine molar mass of M = gM/mol M;

determine mol M using gCO_2 and chemical formula: $0.623g\ CO_2\left(\frac{1mol\ CO_2}{44.01g\ CO_2}\right)\left(\frac{1mol\ CO_3}{1mol\ CO_2}\right)\left(\frac{2mol\ M}{1mol\ CO_3}\right) = 0.02831mol\ M$

determine gM (start by finding gram CO_3): $0.623g\ CO_2\left(\frac{1mol\ CO_2}{44.01g\ CO_2}\right)\left(\frac{1mol\ CO_3}{1mol\ CO_2}\right)\left(\frac{60.01g\ CO_3}{1mol\ CO_3}\right) = 0.8495g\ CO_3$

$1.500g = gM + gCO_3 = gM + 0.8495$; $gM = 0.6505g\ M$; molar mass $M = \frac{grams\ M}{mol\ M} = \frac{0.6505g\ M}{0.02831mol\ M} = 22.98g/mol \rightarrow$ Na from the periodic table}

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1. *(Hint: No calculation is needed.)*

a. Given 5.0g samples of H_2O, N_2O, and F_2O, which of these samples has the ***most moles***?

b. Which of these samples has the ***most molecules***?

c. Which of these samples has the ***most atoms***?

2. How many ***molecules of water*** will be found in 5.00ml $H_2O(l)$? Assume the density of water is 0.997 g/ml.

3. a. Mercury, Hg, has a molar mass of 201g/mol. What does ***one atom*** of Hg weigh?

b. Acetone, CH_3COCH_3, has a molar mass of 58.1g/mol. What does ***one molecule*** of acetone weigh?

4. The mass of a single isotopic version of O_2 is measured and found to weigh 5.978 x 10^{-23} grams. Which is the correct isotopic version of O_2?

a. $^{16}O^{16}O$ b. $^{16}O^{17}O$ c. $^{16}O^{18}O$ d. $^{17}O^{18}O$ e. $^{18}O^{18}O$

5. What is the ***mass percent of nitrogen*** in ammonium carbonate, $(NH_4)_2CO_3$?

6. Which compound has the ***highest*** mass percent of oxygen?

a. CO b. CO_2 c. CO_3^{-2} d. H_2O e. all have the same

7. The composition of adipic acid is 49.3% C, 6.90% H, and 43.8% O and the molar mass is 146 g/mol. What is the empirical and molecular formula of adipic acid?

8. 15.00g of a metal chloride, MCl_2, is completely broken into its elements and produces 9.583g Cl_2. Identify the metal, M.

9. A metal oxide, M_2O, is 93.10% by mass metal, M. Calculate the ***atomic mass*** of the metal.

ANSWERS

1. a. H_2O {since H_2O has the smallest molar mass and the masses are the same, it will have the most moles}

b. H_2O {since H_2O has the most moles, it will have the most molecules}

c. H_2O {since H_2O has the most moles and all the molecules have the same number of atoms per molecule, H_2O will have the most atoms}

2. 1.67 x 10^{23} molecules of water {D = m/V; m = D(V) = (0.997g/ml)(5.00) = 4.985gH_2O;

$$4.985g\ H_2O\left(\frac{1mol\ H_2O}{18.02g\ H_2O}\right)\left(\frac{6.022 \times 10^{23} molecules\ H_2O}{1mol\ H_2O}\right) = 1.666 \times 10^{23} molecules\ H_2O$$ }

3. a. 3.34×10^{-22}g/atom Hg $\{\left(\frac{201\text{g Hg}}{1\text{mol Hg}}\right)\left(\frac{1\text{mol Hg}}{6.022 \times 10^{23}\text{atoms Hg}}\right) = 3.338 \times 10^{-22}\text{g / atom Hg}$;

more simply: $\left(\frac{\text{molar mass}}{6.022 \times 10^{23}}\right) = \left(\frac{201\text{g Hg}}{6.022 \times 10^{23}\text{atoms Hg}}\right) = 3.338 \times 10^{-22}\text{g / atom Hg}\}$

b. 9.65×10^{-23}g/molecule CH_3COCH_3

$\{\left(\frac{58.1\text{g } CH_3COCH_3}{1\text{mol } CH_3COCH_3}\right)\left(\frac{1\text{mol } CH_3COCH_3}{6.022 \times 10^{23}\text{molecules } CH_3COCH_3}\right) = 9.648 \times 10^{-23}\text{g / molecule } CH_3COCH_3$;

more simply: $\left(\frac{\text{molar mass}}{6.022 \times 10^{23}}\right) = \left(\frac{58.1\text{g } CH_3COCH_3}{6.022 \times 10^{23}\text{molecules } CH_3COCH_3}\right) = 9.648 \times 10^{-23}\text{g / molecules } CH_3COCH_3\}$

4. e $\{\left(\frac{5.978 \times 10^{-23}\text{g}}{\text{molecule } O_2}\right)\left(\frac{6.022 \times 10^{23}\text{molecules } O_2}{1\text{mol } O_2}\right) = \frac{36.00\text{g}}{\text{mol}} O_2$; now compare the 36 to the mass or mass numbers of the different isotopic versions; “a” = 32g/mol; “b” = 33g/mol; “c” = 34g/mol; “d” = 35g/mol; “e” = 36g/mol}

5. 29.2% {mass% N = (mass N/total mass) x 100%; assume 1 mol $\rightarrow$ molar mass = total mass = 96.09g;

mass $N = 1\text{mol } (NH_4)_2CO_3\left(\frac{2\text{mol N}}{1\text{mol } (NH_4)_2CO_3}\right)\left(\frac{14.01\text{g N}}{1\text{mol N}}\right) = 28.02\text{g N}$; mass% N = (28.02/96.09) x 100% = 29.16%}

6. d {since there is “more” O in CO_3^{-2} than in CO or CO_2, CO and CO_2 can be eliminated; now determine the %O in H_2O and CO_3^{-2} with two calculations; for H_2O: mass% O = mass O/total mass x 100% = 16/18 x 100% = 89%;
for CO_3^{-2}: mass% O = mass O/total mass x 100% = 48/60 x 100% = 80%}

7. $C_3H_5O_2$ is the empirical formula; $C_6H_{10}O_4$ is the molecular formula {assume 100g;

$49.3\text{g C}\left(\frac{1\text{mol C}}{12.01\text{g C}}\right) = 4.105\text{mol C}$; $6.90\text{g H}\left(\frac{1\text{mol H}}{1.008\text{g H}}\right) = 6.845\text{mol H}$; $43.8\text{g O}\left(\frac{1\text{mol O}}{16.00\text{g O}}\right) = 2.738\text{mol O}$

$C_{4.105}H_{6.845}O_{2.738}$; divide by 2.738: $C_{\frac{4.105}{2.738}}H_{\frac{6.845}{2.738}}O_{\frac{2.738}{2.738}} = C_{1.499}H_{2.500}O_1$; fraction of 0.5 $\rightarrow$ $^1/_2$ $\rightarrow$ x2:

$C_{(1.499 \times 2)}H_{(2.500 \times 2)}O_{(1 \times 2)} = C_{2.998}H_5O_2 = \mathbf{C_3H_5O_2 = EF}$; molar mass EF = 73.07g/mol;

$\text{ratio} = \frac{\text{molar mass}_{\text{molecular formula}}}{\text{molar mass}_{\text{empirical formula}}} = \frac{146}{73.07} = 1.998 = 2$; multiply EF by 2; $C_{(3 \times 2)}H_{(5 \times 2)}O_{(2 \times 2)} = \mathbf{C_6H_{10}O_4 = MF}$}

8. Ca {Need to determine average atomic mass (AAM) of M; to do this you need g M and mol M;
g_{total} = gM + gCl $\rightarrow$ gM = 15.00 – 9.583 = 5.417g M;

mol M: $9.583\text{g } Cl_2\left(\frac{1\text{mol } Cl_2}{70.90\text{g } Cl_2}\right)\left(\frac{2\text{mol Cl}}{1\text{mol } Cl_2}\right)\left(\frac{1\text{mol M}}{2\text{mol Cl}}\right) = 0.1352\text{mol M}$;

molar mass $M = \frac{\text{grams M}}{\text{mol M}} = \frac{5.417\text{g M}}{0.1352\text{mol M}} = 40.07\text{g / mol}$ $\rightarrow$ Ca from the periodic table}

9. 107.9g/mol {Need to determine molar mass of M; to do this you need g M and mol M;
assume 100g $\rightarrow$ 93.10gM; if 93.10% is M, then 100.00%-93.10% = 6.90%O $\rightarrow$ 6.90g O;

$6.90\text{g O}\left(\frac{1\text{mol O}}{16.00\text{g O}}\right)\left(\frac{2\text{mol M}}{1\text{mol O}}\right) = 0.8625\text{mol M}$; molar mass $M = \frac{\text{grams M}}{\text{mol M}} = \frac{93.10\text{g M}}{0.8625\text{mol M}} = 107.94\text{g / mol}$ }