Chemical Composition

Reading:	Ch 8 sections 1 - 9	Homework:	8.2 questions 6, 8
	Ch 9 sections 1 - 6		8.3 questions 10*, 12, 14, 20*,22*
			8.4 questions 28*, 30, 32*, 34, 38, 40*
			8.5 questions 30, 32*, 34*, 36, 40*
			8.6 questions 46, 50,
			8.8 questions 58*, 60*, 78*, 80
			9.3 questions 20, 22*, 24, 26*, 30*, 32*
			9.5 questions 42, 46, 56

* = ‘important’ homework question

Solve the following everyday questions using ‘supermarket’, or (better still) ‘conversion factor’, math:

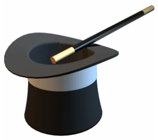
Question: If a dozen eggs weigh 1.50 pounds, then how many *dozen* eggs weigh 30.0 pounds?

Question: How many single eggs are there in 30.0 pounds of eggs?

Solving chemistry problems that involve converting between numbers of molecules and gram weights uses EXACTLY the same concepts as the above egg problem.

Pounds of eggs ↔ Dozens of eggs ↔ Number of eggs

The Mole



Just like the dozen, *the MOLE is just a number that represents a bigger number*. Since atoms and/or molecules are very small (i.e. to see a collection of atoms, say in your hand, you need a lot of them), the mole is a VERY large number :

1 dozen = 12 things (eggs)   1 mole = 6.02×10^{23} things (atoms)

<u>Task</u>: To get an idea about how many atoms there are in a mole of atoms, write 6.02×10^{23} as a regular number:

1 mole = ____

<u>Note</u>: The mole is sometimes called **Avogadro's number (N_A)**, so:

1 mole = $N_A = 6.02 \times 10^{23}$ things

<u>Nerd stuff</u>: When do you think *some* chemists celebrate mole day?

<u>Question</u>: If the population of the world is 5.7 billion (5.7×10^9) people, how many moles of people is this? <u>Hint</u>: this is a conversion problem.

<u>Discussion</u>: Why is the mole ($N_A = 6.02 \times 10^{23}$) such a 'strange' number? Why not just 1×10^{20} or something?

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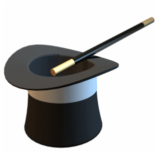
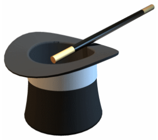


<u>Task</u>: Use the periodic table and the previous information to determine the following quantities:



Convert between grams, moles and number of atoms SEPARATELY using atomic mass values (Periodic table) and Avogadro's number respectively.

Grams ↔ Moles ↔ Number of atoms

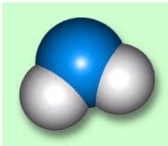
1. The *mass* of 2.0 moles of carbon atoms

2. The number of *moles* of carbon atoms in 6.0 g of C

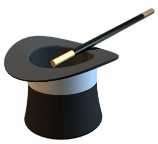
3. The *number of gold atoms* in 2.0 moles of Au

4. The number of *moles* of lead (Pb) atoms in 35.5 grams of lead.

5. The *number of Pb atoms* in 35.5 grams of lead



Question: What is the mass in amu of 1 molecule of water (H_2O).What is the mass of one *mole* of water molecules in grams?



Recall that a molecule is the 'sum of its parts' (atoms). Thus, simply add the masses of all the atoms in a molecule to find the molecule's FW in amu, *OR* the mass of 1 mole of molecules (MOLAR MASS, $\mathcal{M}$) in grams. THIS IS THE POWER OF THE MOLE(!)

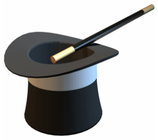
Note: The units of Molar mass ($\mathcal{M}$) are grams/mole (i.e. the number of grams in 1 mole of material).

Task: Calculate the Molar masses ($\mathcal{M}$) of the following compounds:

Carbon dioxide:

Diphosphorous pentoxide:

Calcium chloride:



Just like with atomic masses, Molar masses can be used to convert between grams, moles and number of molecules.

Grams ↔ Moles ↔ Number of molecules

Worked Example: How many molecules of sugar ($C_6H_{12}O_6$) are there in a 2.15 gram packet of sugar?

Plan: Write down what you are given and what you can immediately figure out:

Mass sugar = 2.15 g

$\mathcal{M}_{C_6H_{12}O_6}$ = 6C + 12 H + 6 O
= 6(12.011 g/mol) + 12(1.01g/mol) + 6(16.00 g/mol)
= 180.2 g/mol

Use the conversion factor of $\boxed{1 \text{ mol } C_6H_{12}O_6 = 180.2 \text{ g}}$ to find # moles sugar in 2.15 g of sugar:

$$2.15\ \cancel{g} \times \frac{1\text{mol}}{180.2\ \cancel{g}} = \underline{0.0119 \text{ mols}}$$

Use the conversion factor of $\boxed{1 \text{ mol} = 6.02 \times 10^{23} \text{ molecules}}$ to find # molecules of sugar in 0.0119 mols. (2.15 g) of sugar:

$$0.0119\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23} \text{ molecules}}{1\ \cancel{\text{mol}}} = \underline{7.16 \times 10^{21} \text{ molecules}}$$

Remember: You CANNOT convert directly from grams to number of molecules. i.e. YOU MUST ALWAYS GO THROUGH MOLES:

Grams ↔ Moles ↔ Number of molecules

Things to remember:

Key relationships:

FW = sum of all atomic masses in a SINGLE molecular formula (amu/molecule)

$\mathcal{M}$ = sum of all atomic masses in any SINGLE molecular or ionic formula (grams/mole)

$$\mathcal{M} = \frac{\text{number grams material}}{\text{number moles of material}}$$

1 mole = 6.02×10^{23} particles

FW and $\mathcal{M}$ have identical numerical values but DIFFERENT units

You can write a conversion pyramid showing the relationship between $\mathcal{M}$, g and mols!

The relationship between $\mathcal{M}$, #grams and #moles is THE most frequently used equations in chemistry? Why?

Answer:

Observation(!):

Task: Determine the following quantities:

1. The number of *moles* of oxygen molecules in 5.0 g of oxygen gas

2. The weight *in grams* of 2.5 moles of P_2O_5 (s)

3. The *number* of water molecules in 330 grams of pure water

4. The mass in grams of 5.0×10^{24} molecules of CO_2 (g)

The Molar Volume

One mole of ANY gas occupies 22.4 Liters at STP (standard temperature and pressure, 0^{o}C, 1 atm.). This has two significant consequences:

1 mole = 22.4 L at STP for ANY gas

Gas Volume ↔ Moles ↔ Number of particles

<u>Task</u>: Use the above information to determine the number of atoms of He (g) in a party balloon of volume 35.6 L (assume STP).

Let's start the spider……

Applications

A. Determining Empirical and Molecular Formulas

Recall the definitions of *molecular formula* and *empirical formula*:

Molecular Formula: the actual number and type of atoms in a compound, e.g. hydrogen peroxide = H_2O_2

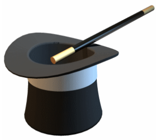
Empirical Formula: the lowest whole number ratio of each type of atom in a compound e.g. hydrogen peroxide = HO

Task: Complete the following table

Name	Molecular formula	Empirical formula
Dinitrogen tetroxide		
Benzene	C_6H_6	
Butane	C_4H_{10}	
Tetraphosphorous decoxide	P_4O_{10}	

Note: Empirical formulas most often pertain to molecular / covalent compounds, as ionic compounds' formulas are typically in their lowest ratio to begin with (i.e. a sample of NaCl (s) contains many more than two ions!)

<u>Worked Example</u>: A 1.271 g sample of Al(s) was allowed to react with chlorine. The mass of aluminum chloride produced was 6.280 g. Determine the empirical formula of aluminum chloride.



Recall that the Empirical formula is the lowest *whole number* ratio of each type of atom in a compound $\Rightarrow$ **find the moles of each type of atom and then find their ratio.**

<u>Step 1</u>. Write an *unbalanced* chemical equation (do not assume balancing numbers or formulas for these problems). Find the mass of the missing reactant by applying the conservation of mass law.

$$Al \quad + \quad Cl \quad \rightarrow \quad Al_xCl_y$$

1.271 g   6.280 g

<u>Step 2</u>. Find the *moles* of each reactant using the atomic masses from the periodic table.

Moles Al =

Moles Cl =

Step 3. Substitute the # moles determined for each type of atom in the product's empirical formula.

Al Cl

Step 4. Find the lowest whole number ratio of each type of atom in the empirical formula. This is the final answer.

Al Cl

Finding the molecular formula from the empirical formula

Recall that the molecular formula is some whole number of times larger than the empirical formula (e.g. H_2O_2 compared to HO (x2)).

⇒ **the molecular formula will be 'heavier' than the empirical formula by the same factor (x2)**

Task: Work out the molecular masses of H_2O_2 and HO. What is their ratio?

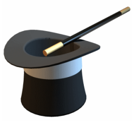
$\mathcal{M}_{\text{H2O2}}$ =

$\mathcal{M}_{\text{HO}}$ =

Ratio =

Find the ratio of the molecular formula to the empirical formula – this information tells you how much 'bigger' the molecular formula is than the empirical formula.

Worked Example: Ethylene glycol contains 38.7 % C, 9.7 % H and 51.6 % O. Calculate the empirical and molecular formula of ethylene glycol given its molar mass = 60 g/mol (60 amu/molecule)



When given the % by mass values of each atom in a compound assume a 100 g sample – the % and g values are then the same.

B. 'Slides and Ladders' – finding theoretical yield and % yield

Important Definitions:

Theoretical Yield: The amount of product, in grams, expected (calculated) for a reaction.

Actual Yield: The amount of product, in grams, recovered (weighed) for a reaction.

% Yield :

$$\% \text{ Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

Discussion: Are theoretical and actual yields ever the same (i.e. does % yield = 100%) in practice? What factors influence the % yield?

Finding the Theoretical Yield using 'Slides and Ladders'

Worked Example: If 5.00 g of Propane (C_3H_8(l)) is combusted in excess oxygen gas, what mass of water is expected to be formed? What mass and volume of CO_2 (g) (at STP) would you expect to collect?

Step 1. Write a balanced Chemical Equation *and*

[over]

Step 2. Set up g, $\mathcal{M}$ and mole 'ladder' grid

Step 3. Fill in the ladder grid with as much information as possible – this is typically supplied gram weights and molar mass data.

Step 4. Convert g $\rightarrow$ moles by 'climbing' down ladder(s) (g / $\mathcal{M}$ = moles).

Remember: Molar masses are calculated for **ONE** molecular formula only. I.E. ignore any balancing numbers when figuring out $\mathcal{M}$ values

Step 5. Convert moles reactant $\rightarrow$ moles product(s) by comparing balancing numbers and 'sliding' across.

Step 6. Convert moles product(s) $\rightarrow$ grams product(s) by 'climbing' up ladder(s) (moles x $\mathcal{M}$ = grams).

Note: moles of gas can be converted to Liters of gas using:

1 mole any gas = 22.4 L at STP

Group Tasks: Determine the following quantities

1. What mass of dissolved HCl is needed to completely react 5.00g of $CaCO_3$(s), according to the following *unbalanced* reaction? What volume of CO_2(g) is generated at STP?

   $CaCO_3(s) + \_\_ HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

2. What mass of magnesium oxide is recovered when 1.56 g of Mg(s) is burnt in air to give MgO(s)? What volume of oxygen gas is consumed during this process (assume STP).

3. A student recovers 1.59 g of $CaCO_3$ (s) from an experiment when they should have produced 2.32 g. What is the student's % yield for their reaction?

4. Task: Complete your lab assignment (Precipitating Calcium Phosphate), if you have not already done so

C. ‘Slides and Ladders’ – Limiting reactant problems

Analogy: Suppose you are making ham sandwiches. Each sandwich is made from 1 piece of ham and 2 pieces of bread:

i.e.: 1 ham + 2 bread → 1 sandwich

Questions:

How many sandwiches can you make from 5 pieces of ham and 18 slices of bread?

Which ingredient is there too much of (*excess, ‘XS’*)?

Which ingredient is there too little of (*limiting*)?

Which ingredient ultimately determines how many sandwiches can be made? Why?

How much of the XS ingredient remains unused?

Similarly…

<u>Recall</u>: Reactants ALWAYS combine in the ratio defined by their respective balancing numbers:

$$1\ AgNO_3(aq) + 1\ NaCl(aq) \rightarrow 1\ AgCl(s) + 1\ NaNO_3(aq)$$

i.e. 1 mole of $AgNO_3(aq)$ will react exactly with 1 mole of NaCl(aq)

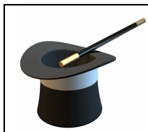
<u>Problem</u>: It is VERY difficult to add exactly the right ratio of reactants in the lab ⇒

There will be too *much* of one reactant (the excess (XS) reactant)

There will be too *little* of one reactant (the limiting reactant)

<u>Discussion questions</u>: If 10 moles of $AgNO_3(aq)$ is added to 15 moles of NaCl(aq), then:

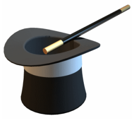
1. Which reactant is INXS?
2. Which reactant is limiting?
3. How many moles of AgCl(s) would be formed?
4. How many moles of NaCl(aq) would remain unreacted?



Compare the 'Ideal' (from the balanced equation) and the 'Real' (given) ratio of reactants to determine which is the limiting reactant ($AgNO_3(aq)$)

Since the LIMITING reactant will run out first, it determines the amount of product that can be formed (as well as the amount of XS reactant that is left behind)

<u>Questions</u>: Work out the mass of each product formed in the following reactions, assuming 10.0 grams of each reactant are initially mixed together.



Use a regular slides and ladders approach, but 'slide' across (to find moles of product) using the molar ratio determined by the ***limiting reactant***.

Use conversions factors to find out the number of moles required to react with one of the reactants in 'NON 1:1 problems'

1. $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

2. $CaCO_3(s)$ + __ $HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

D. Concentration of Solutions

Discussion: When you finish this class chances are good you'll head out to a local bar for a well deserved 'adult beverage'. Assuming the bar you visit is running a special where you can buy a pint of beer ***or*** a pint of wine for the same price, which do you choose and why?

Answer:

Concentration = Molarity (M) = number moles of *solute* per Liter of *solution*

i.e. Molarity = $\frac{\text{Moles Solute}}{\text{Liters Solution}}$ Units: mol/L or just M

Where:

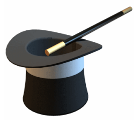
SOLUTION = SOLUTE + SOLVENT

Example:

PEPSI =

Task: Think up two more examples illustrating the components of a solution.

Question and Demo: What is the concentration of a solution made by dissolving 2.845 g of sugar ($C_6H_{12}O_6$) in water and making the final volume up to 150 mL?



Remember that Moles, Concentration and Volume are all related for a solution. Sketch a 'triangle' to help you solve concentration problems.

Question: What mass of NaCl is contained within 0.50 L of a 6.0 M NaCl(aq) solution?

Since CV = moles for any solution, concentration (C) and solution volume (V) terms can also be used in 'slides and ladders' problems featuring solutions.

Example: What mass of $CaCO_3$(s) would be completely reacted with 100 mL of 2.0 M HCl? What volume of CO_2 (g) would be collected at STP?

$$CaCO_3(s) \quad + \quad 2\ HCl(aq) \quad \rightarrow \quad CaCl_2(aq) \quad + \quad CO_2(g) \quad + \quad H_2O(l)$$

g	C			
$\mathcal{M}$	V			
mol	mol			

The Importance of the mole

Most of the equations we have met in this handout feature # moles as a variable. Thus, moles can in many ways be considered the chemists' link between macro and micro scale quantities.

Task: Write down as many equations you can featuring the mole. Use this information to construct a flow chart illustrating how all these conversions 'go through' moles

"Slides and Ladders"

The following question was taken from your 3rd practice midterm:

Question 1 (25 points): For the following *unbalanced* chemical reaction, determine the quantities listed below (Hint: balance the reaction first):

$$Fe(s) \quad + \quad O_2(g) \quad \rightarrow \quad Fe_2O_3(s)$$

A. The mass of iron (III) oxide produced when 2.56 g of solid iron is burnt in excess oxygen gas:

B. The number of oxygen molecules consumed in part (a)

Extra Credit: State to which one of the five general classes of reaction the above processes belongs.