5072 CHEMISTRY (NEW PAPERS WITH SPA)
TOPIC 3: FORMULAE, STOICHIOMETRY AND THE MOLE CONCEPT

5067 CHEMISTRY (NEW PAPERS WITH PRACTICAL EXAM)
TOPIC 3: FORMULAE, STOICHIOMETRY AND THE MOLE CONCEPT

LEARNING OUTCOMES
a) Define relative atomic mass A_r b) Define relative molecular mass M_r and calculate relative molecular mass (and relative formula mass) as the sum of relative atomic masses c) Calculate the percentage mass of an element in a compound when given appropriate information d) Calculate empirical and molecular formulae from relevant data e) Calculate stoichiometric reacting masses and volumes of gases (one mole of gas occupies 24 dm^3 at room temperature and pressure); calculations involving the idea of limiting reactants may be set (questions on the gas laws and the calculations of gaseous volumes at different temperatures and pressures will not be set) f) Apply the concept of solution concentration (in mol/dm^3 or g/dm^3) to process the results of volumetric experiments and to solve simple problems (appropriate guidance will be provided where unfamiliar reactions are involved) g) Calculate % yield and % purity

<table>
<tr><th>CONCEPT</th><th>SUB-CONCEPT</th><th>EXAMPLE</th></tr>
<tr><td rowspan="2">Relative Atomic Mass/ Relative Molecular Mass/ Percentage Mass/ Molar Mass</td>
<td>- The relative atomic mass/ relative molecular mass of an element is the average mass of one atom of the element/ substance compared with $\frac{1}{12}$ of a carbon-12 atom.</td>
<td>Anhydrous Copper (II) Sulphate, $CuSO_4 \cdot 5H_2O$
- It has 1 $^{64}_{29}S$ atom,1 $^{32}_{16}Cu$ atom, 4 $^{16}_{8}O$ atoms AND 5 H_2O atoms.
- H_2O consists of: 2 $^{1}_{1}H$ atoms and 1 $^{16}_{8}O$ atom.
- H_2O hence has a M_r of 2(1) + 16 = 18
- It has a M_r of 64 + 32 + 4(16) + 5(18) = 250
- The % of Cu in it is $\frac{64}{250}$ x 100% = 25.6%
- The % of H_2O in it is $\frac{5 \times 18}{250}$ x 100% = 36%</td></tr>
<tr><td>The mass in grams of 1 mole of substance is called its molar mass.
- 1 mole of substance has 6.23 x 10^{23} particles.
- The mass of 1 mole of substance is equal to its molecular formula
- To convert the number of moles to mass, one must multiply the number of moles by the M_r of the substance.</td>
<td>3.44 moles of $CuSO_4 \cdot 5H_2O$
- 3.44 x 250 = 860g</td></tr>
<tr><td>Empirical/ Molecular Formula</td>
<td>- The Empirical Formula shows the simplest number ratio of the different types of atoms in a compound.
- The Molecular Formula shows the actual number and kinds of atoms present in a compound, an integral multiple of the empirical formula.</td>
<td>An anaesthetic compound is found to contain elements carbon, hydrogen and chlorine. The percentages of by mass of these elements are C: 10.04%, H: 0.84%, Cl: 89.12%. One mole of this compound has a mass of 120g. Calculate its molecular formula.
<table>
<tr><th></th><th>C</th><th>H</th><th>Cl</th></tr>
<tr><td>Percentage by Mass</td><td>10.04%</td><td>0.84%</td><td>89.12%</td></tr>
<tr><td>Relative Atomic Mass, A_r</td><td>12</td><td>1</td><td>35.5</td></tr>
<tr><td>Number of moles</td><td>$\frac{10.04}{12}$ = 0.84</td><td>$\frac{0.84}{1}$ = 0.84</td><td>$\frac{89.12}{35.5}$ = 2.51</td></tr>
<tr><td>Divide by smallest Number (0.84)</td><td>1</td><td>1</td><td>3</td></tr>
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<table>
<tr><td></td><td></td><td><table><tr><td>Simplest Ratio</td><td>1</td><td>1</td><td>3</td></tr></table>∴ Empirical Formula: $CHCl_3$
n (Emprical Formula) = Molecular Formula
n (M_r of $CHCl_3$) = 120
n (119.5) = 120
n = 120/ 119.5
n ≈ 1
∴ Molecular Formula: $CHCl_3$</td></tr>
<tr><td>Masses/ Volumes of Gases</td><td>- The masses of gases are counted in the same way as it is counted for solids and liquids; that is to multiply the number of moles by the M_r of the substance.
- At room temperature of 25℃ and 1 atmosphere, one mole of gas has a volume of $24dm^3$.
  ➢ The volume of the gas is directly proportional to the number of moles.</td><td></td></tr>
<tr><td>Calculations from Equations</td><td>Calculations from chemical equations involve five main steps, although not all may be required in each calculation
Steps:
- Work out the number of moles of the known substance
- Construct or write down the balanced chemical equation
- List down the mole ratios of the substances to be found from the equations
- Calculate the number of moles of the substance to be found
- Work out the mass or volume or concentration of substance to be found.</td><td>Calculate the volume of Carbon Dioxide gas produced (At rtp) from the combustion of 2 moles of propane.
- Number of Moles of Propane
2 moles
- Balanced Chemical Equation
C_3H_8 (g) + $5O_2$ (g) → $3CO_2$ (g) + $4H_2O$ (g)
- Mole Ratio of substances
1 mole of C_3H_8 yield 3 moles of CO_2
- Calculation of number of moles of substance to be found
If 1 mole of C_3H_8 yields 3 moles of CO_2,
Then 2 moles of C_3H_8 yields 6 moles of CO_2
- Volume of CO_2 produced
6 x $24dm^3$ = $144dm^3$</td></tr>
<tr><td>Limiting</td><td>- Limiting Reactants or Reagents is the chemical that is</td><td>A mixture containing 1 mole of ethene and 4 moles</td></tr>
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Reagents/ Reactants	completely used up during the process. However, all others may and may not be totally used up.	of oxygen is ignited in a sealed container at 100℃. What was the total number of moles of gases at the end of the reaction? - **Number of Moles of Ethene and Oxygen** 1 mol C_2H_4 and 4 mol of O_2 - **Balanced Chemical Equation** C_2H_4 (g) + $3O_2$ (g) → $2CO_2$ (g) + $2H_2O$ (g) - **Mole Ratio of substances** 1 mole of C_2H_4 and 3 moles of O_2 yields 2 moles of CO_2 and 2 moles of H_2O (i.e. 4 moles of gases) - **Calculation of number of moles of substance to be found** Since we have only 1 mole of C_2H_4 but 4 moles of O_2, we can only produce 2 moles of CO_2 and 2 moles of H_2O. In addition, we would have 1 mole of O_2 left unreacted. Therefore, a total of 5 moles of gases is left at the end. Hence, the limiting reagent is C_2H_4 while O_2 is in excess.
Concentration/ Molarity of a Solution	- The concentration of a solution indicates the amount of solute present in $1dm^3$ of the solution. - Concentration of a solution = $\frac{\text{Mass of solute in grams}}{\text{Volume of solution in dm}^3}$ - In Chemistry, the concentration of a solution is expressed in **<u>molarity</u>** (symbol M), where M is in mol/dm^3 ➢ Molarity of a solution = $\frac{\text{Amount of Solute in moles}}{\text{Volume of solution in dm}^3}$ ➢ A molar solution contains 1 mole of solute in $1dm^3$ of solution ($1mol/dm^3$) - To convert between the two different types of concentrations, one may apply the formula:	A $20cm^3$ solution contains 5.0g of HCl. Calculate the molarity of the solution. - M_r of HCl = 1 + 35.5 = 36.5 - No of moles of HCl = $\frac{5.0}{36.5}$ = 0.137 - In $20cm^3$, there are 0.137 moles of HCl - Concentration in mol/dm^3 = $\frac{0.137\text{ mol}}{20cm^3}$ = $6.85mol/dm^3$

	Molarity of a solution = $\frac{\text{Concentration of solution}}{M_r \text{ of solution}}$	
Percentage Yield	- The quantity of product formed when all the limiting reagents react is called the Theoretical Yield. This may be calculated from the Chemical equation. - The amount of product actually obtained through experimentation is called the Actual Yield. - Percentage Yield = $\frac{\text{Actual Yield}}{\text{Theoretical Yield}}$ x 100%	50cm^3 of 0.105 mol/dm^3 of $CaCl_2$ (aq) was treated with an excess of $AgNO_3$ (aq). White AgCl was formed and the precipitate weighed after drying. A mass of 1.45g was recorded. What was the Percentage Yield? - **Number of Moles Of $CaCl_2$** $\frac{50}{1000}$ x 0.105 = 0.00525 mol - **Balanced Chemical Equation** $CaCl_2$ (aq) + $2AgNO_3$ (aq) → 2AgCl (s) + $Ca(NO_3)_2$ (aq) - **Mole Ratio of substances** 1 mol of $CaCl_2$ yields 2 moles of AgCl - **Calculation of number of moles of substance to be formed** If 1 mol of $CaCl_2$ yields 2 moles of AgCl, Then 0.00525 mol of $CaCl_2$ yields 0.0105 mol of AgCl - **Theoretical Yield/ Mass of AgCl** 0.0105 x M_r of AgCl = 0.0105 x (108 + 35.5) = 1.507g - **Percentage Yield** $\frac{1.45}{1.507}$ x 100% = 96.2%
Percentage Purity	- Percentage Purity indicates the amount of pure substances present in a sample of chemical substance. - Percentage Purity = $\frac{\text{Mass of Pure Substance in Sample}}{\text{Mass of Sample}}$ x 100%	4.35g of MnO_2 was added to 1.0mol/dm^3 of HCl. 48cm^3 of the acid was needed to react with MnO_2 in the given sample. Calculate the percentage purity of MnO_2. - **Number of Moles Of HCl** $\frac{48}{1000}$ x 1.0 = 0.048 mol - **Balanced Chemical Equation** MnO_2 (s) + 4HCl (aq) → $MnCl_2$ (aq) + $2H_2O$

		(l) + Cl_2 (g) - **Mole Ratio of substances** 1 mole of MnO_2 requires 4 moles of HCl to react. - **Calculation of number of moles of pure MnO_2** 0.048 mol of HCl used, Hence $\frac{0.048}{4}$ = 0.012 moles of MnO_2 present - **Mass of Pure MnO_2** 0.012 x M_r of MnO_2 = 0.012 x 87 = 1.044g - **Percentage Purity of MnO_2** $\frac{1.044}{4.35}$ x 100% = 24%