STOICHIOMETRY AND MOLE CONCEPT
SUMMARY NOTES & PRELIM QUESTIONS

CONCEPT 1 BASIC MOLE CONCEPT CALCULATIONS

$$\text{Number of mole, } n = \frac{N}{L} = \frac{\text{number of particles}}{\text{Avogadro's constant, i.e. } 6\times10^{23}}$$

$$\text{Number of mole, } n = \frac{m}{M_r} = \frac{\text{mass (g)}}{\text{molar mass (g mol}^{-1})}$$

$$\text{Number of mole, } n = \frac{v}{V_m} = \frac{\text{volume of gas}}{\text{molar volume of gas, i.e. 24 dm}^3 \text{ at r.t.p.}}$$

$$\text{Number of mole, } n = CV = \text{concentration} \times \text{volume of solution}$$

1 Y3EOY/DHS/2008/I/20

Which one of the following contains the greatest number of atoms?

A 1 mole of zinc
B 18.0 g of water
C 48.0 dm^3 of hydrogen gas at r.t.p.
D 1.20×10^{24} atoms of oxygen

2 Which of the following quantities is equal to the Avogadro constant?

A The number of atoms in 24 dm^3 of nitrogen gas at r.t.p. conditions.
B The number of molecules in 1 dm^3 of oxygen at 298 K and 1 atm.
C The number of zirconium atoms in 962 g of tranquillityite, $Fe_3Zr_2Ti_3Si_3O_{24}$, of molar mass 961.8 g mol^{-1}.
D The number of ions in 29.3 g of sodium chloride.

CONCEPT 2 PERCENTAGE COMPOSITION

Steps to Find Percentage Mass of an Element in a Compound

Step 1: Calculate the mass of an element in a compound.

Step 2: Calculate the molar mass.

Step 3: Percentage mass of an element in a compound $= \frac{\text{mass of an element}}{\text{molar mass}}$

Purposes of Finding Percentage Mass of an Element in a Compound

- To calculate the mass of an element in a specified mass of compound, mixture or structure.
- To calculate the mass of compound, mixture or structure that contains a specified mass of an element.

3 An adult's bones weigh about 11 kg, and 50% of this mass is calcium phosphate, $Ca_3(PO_4)_2$. What is the mass of phosphorous in the bones of an average adult.

4 Copper is found in the mineral chalcopyrites, $CuFeS_2$. What mass of chalcopyrites must be melted to produce 100 tonnes of copper.

5 A garden fertiliser is said to have a phosphorous content of 30.0% "P_2O_5 soluble in water". What is the percentage by mass of phosphorous in the fertiliser?

CONCEPT 3 EMPIRICAL AND MOLECULAR FORMULAE (PURE CHEM ONLY)

Empirical formula gives the **simplest ratio** of the number of atoms in each element present in the compound.

Table to Calculate Using Mass Data

	$Element_1$	$Element_2$	$Element_3$
Mass			
Number of moles			
Division by the smallest number of moles			
Simplest ratio			

Molecular formula gives the **actual number** of the number of atoms in each element present in the compound.

$M_r = n \times$ sum of A_r in an empirical formula, where n is an integer

6 Compound **X** is an organic liquid which can be combined with other substances to be used as a cleaning agent. It contains 53.3% carbon, 11.1% hydrogen and 35.6% oxygen by mass. It is found that 75 cm^3 of liquid **X** contains 1 mol of compound **X**.

(a) Deduce the empirical formula of **X**.

(b) Given that the density of **X** is 1.20 g cm^{-3}, find the molecular formula of **X**.

7 An organic compound was known to contain carbon, hydrogen and oxygen. A 5.25 g sample was burnt completely in air. The products were water, 2.49 g, and carbon dioxide, 6.08 g. Determine:

(a) The empirical formula of the compound.

(b) The molecular formula knowing that the compound has a molar mass of 228 g.

8 In an experiment, 15 g of sodium sulfate crystals on being heated left a residue of 7.95 g of the anhydrous salt. Calculate:

(a) The percentage of water of crystallisation in the crystals.

(b) The value of "x" in the formula $Na_2SO_4.xH_2O$.

9 An oxide of the type XO_2 contains 36.8% of oxygen. Calculate the relative atomic mass of X.

CONCEPT 4 STOICHIOMETRY

A balanced chemical equation gives the **mole ratio** between the reactants and the products involved in the chemical reaction.

$$aA + bB \rightarrow cC + dD$$

Stoichiometry refers to the relationship, as specified by the **mole ratio**, between the reactions and products involved in a chemical reaction.

Steps Involved in Calculations Involving Stoichiometry:

Step 1: Write or refer to the balanced chemical equation for the reaction.

Step 2: Check for and determine the limiting reagent.

- Identify key phrases in questions that suggest which reactants are in excess and which is limiting, such as "complete combustion", "an excess of acid is used" and "metal is reacted with sufficient amount of acid".
- If there is no such key phrases, determine the limiting reagent through calculations and comparison.

Step 3: Equate mole ratio of limiting reagent to the required product and solve.

10 The exothermic *thermite* reaction is applied in the welding of railway tracks as represented by the chemical reaction below. In the process, the molten iron (Fe) solidifies on cooling, thus welding the tracks together.

$3Fe_3O_4$ (s) + 8A*l* (s) → $4Al_2O_3$ (s) + 9Fe (*l*)

In a given reaction, 60 kg of the iron oxide were reacted with 15 kg of aluminium. Calculate the mass of molten iron formed in the reaction.

11 Under certain conditions, 0.84 g of nitrogen gas reacts with oxygen to form 1.8 g of a gaseous oxide of nitrogen. Find the equation for the reaction.

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Calcium sulfate can be prepared by:

i. Adding excess calcium oxide to warm dilute nitric acid.
ii. Adding excess sulfuric acid.
iii. Filtering the mixture.
iv. Washing the residue formed with deionised water and drying in an oven.

(a) What is the purpose of step (i)?

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(b) Explain why excess calcium oxide is used in step (i).

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(c) Name one possible impurity that might be removed when the residue is washed.

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(d) Explain why it is not advisable to prepare calcium sulfate by adding calcium oxide to sulfuric acid.

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(e) Write an equation for the reaction between calcium oxide and nitric acid.

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(f) A student wishes to prepare 10.0 g of calcium sulfate using the aforementioned method. Calculate the minimum mass of calcium oxide he would need to use.

13 10.0 dm^3 of chlorine and 30.0 dm^3 of hydrogen measured at r.t.p. react to form hydrogen chloride gas.

$$H_2\,(g) + Cl_2\,(g) \rightarrow 2\,HCl\,(g)$$

Calculate at r.t.p.:

(a) The limiting reactant.

(b) The volume of hydrogen chloride gas produced.

(c) The volume composition of the resultant mixture.

CONCEPT 5 CONCENTRATIONS OF SOLUTION

The **concentration** of a solution is measured in terms of the **amount of solute** (in g or mol) contained in a **given volume** of solution.

Formulae to Calculate Concentrations:

$$\text{Concentration in } \mathbf{g\ dm^{-3}} = \frac{\text{mass of solute (in g)}}{\text{volume of solution (in dm}^3\text{)}}$$

$$\textbf{Molarity}\text{, or concentration in } \mathbf{mol\ dm^{-3}} = \frac{\text{number of moles of solute (in mol)}}{\text{volume of solution (in dm}^3\text{)}}$$

Relationship between Concentrations in g dm^{-3} and mol dm^{-3}:

$$\text{Concentration in } \mathbf{g\ dm^{-3}} = \text{concentration in } \mathbf{mol\ dm^{-3}} \times \text{molar mass (g mol}^{-1}\text{)}$$

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0.300 g of magnesium metal was placed in excess hydrochloric acid. The equation for the reaction is

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

(a) Calculate the volume of hydrogen, measured at r.t.p., which was given off.

(b) If the concentration of the hydrochloric acid used in this experiment was 2.00 mol/dm^3, calculate the minimum volume of hydrochloric acid required to react completely with magnesium.

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Tartaric acid is found in both white and red wine. Tartaric acid exists as a white solid at room temperature. This acid is a dibasic acid and has a molecular formula of $H_6C_4O_6$.

(a) Explain what is meant by the term acid

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(b) The concentration of a solution of tartaric acid is 180 g/dm^3.

(i) Calculate the molarity of tartaric acid.

(ii) Calculate the number of moles of tartaric acid found in 20.0 cm^3 of the solution.

(iii) Calculate the number of moles of hydrogen ions in 1.00 dm^3 of tartaric acid.

(c) Copper(II) tartrate, $CuH_4C_4O_6$ is insoluble in water.

(i) Name the chemicals used to prepare copper(II) tartrate.

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(ii) Write an ionic equation with state symbols to show the formation of copper (II) tartrate.

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In an experiment, 20.0 cm^3 of 1.50 mol/dm^3 of aqueous copper(II) sulfate was mixed with 10.0 cm^3 of 2.00 mol/dm^3 of aqueous sodium hydroxide to form copper(II) hydroxide. The equation for the reaction is:

$$CuSO_4 + 2NaOH \rightarrow Cu(OH)_2 + Na_2SO_4$$

(a) Write the ionic equation, including state symbols, for the reaction between aqueous copper(II) sulfate and aqueous sodium hydroxide.

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(b) By calculation, determine the limiting reagent in the above reaction.

(c) Calculate the mass of copper(II) hydroxide produced.

(d) State 2 observations at the end of the reaction.

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(e) Copper(II) hydroxide can be converted back to copper(II) sulfate by adding dilute sulfuric acid. A minimum of 10.0 cm^3 of dilute sulfuric acid was needed to completely react with all the copper(II) hydroxide formed in (c).

Calculate the molarity of dilute sulfuric acid used.

CONCEPT 6 DILUTION

Dilution is the process of adding solvent to a known volume of the solution to lower concentration, with the amount of solute remaining the same after dilution.

$$C_1V_1 = C_2V_2$$

17 What volume of water must be added to 200 cm^3 of 8.00 mol/dm^3 sulfuric acid so that its final concentration is 2.00 mol/dm^3?

CONCEPT 7 VOLUMETRIC ANALYSIS

Volumetric analysis is a method of quantitative analysis which depends essentially on the accurate measurement of the volumes of two reacting solutions.

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In a titration, 25.0 cm^3 of dilute sulfuric acid was used to react completely with 20.0 cm^3 of 0.400 mol/dm^3 aqueous sodium hydroxide.

$$2\ NaOH\ (aq) + H_2SO_4\ (aq) \rightarrow Na_2SO_4\ (aq) + 2\ H_2O\ (l)$$

(a) Calculate the number of moles of sodium hydroxide that reacted.

(b) Calculate the number of moles of sulfuric acid that reacted with the sodium hydroxide.

(c) What is the concentration of sulfuric acid in g/dm^{-3}?

19 25.0 cm^3 of a solution containing 4.20 g/dm^3 of sodium hydroxide is neutralised by 26.50 cm^3 of acid containing 8.37 g/dm^3 of HXO_3. Calculate:

(a) The molarity of the acid.

(b) The relative atomic mass of X and identify X.

CONCEPT 8 PERCENTAGE YIELD AND PURITY (PURE CHEM ONLY)

Formulae to Calculate Percentage Yield

$$\text{Percentage Yield} = \frac{\text{actual mass obtained}}{\text{theoretical mass}} \times 100$$

Formulae to Calculate Percentage Purity:

$$\text{Percentage Purity} = \frac{\text{mass of the pure compound}}{\text{mass of the impure mixture}} \times 100$$

20 10 cm^3 of 1 mol/dm^3 silver nitrate solution was added to an excess of potassium iodide solution. The silver iodide precipitated was filtered, dried, and weighed. The measured mass was 2 g.

Find the percentage yield of silver iodide formed by precipitation.

21 10 cm^3 of 1 mol/dm^3 silver nitrate solution was added to an excess of potassium iodide solution. The silver iodide precipitated was filtered, dried, and weighed. The measured mass was 2 g.

Find the percentage yield of silver iodide formed by precipitation.

Answers

1 C
2 D
3 1.10 kg
4 289 tonnes
5 13.1%
6 (a) C_2H_5O
(b) $C_4H_{10}O_2$
7 (a) $C_2H_4O_3$
(b) $C_6H_{12}O_9$
8 (a) 47%
9 55
10 3.49×10^4 g
11 $N_2 + O_2 \rightarrow 2NO$
12 (a) To produce $CaNO_3$.
(b) To ensure all HNO_3 is reacted to prevent contamination.
(c) Nitric acid or sulfuric acid.
(d) $CaSO_4$ is insoluble, hence able to coat onto surface of CaO and inhibits further reaction between unreacted CaO and H_2SO_4.
(e) $CaO + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$
(f) 4.12 g
13 (a) Cl_2 is limiting.
(b) 20.0 dm^3
(c) 20.0 dm^3 of HCl and 20.0 dm^3 of H_2.
14 (a) 0.300 dm^3
(b) 0.0125 dm^3
15 (a) Produces H^+ in aqueous solution.
(b) (i) 1.20 mol dm^{-3}
(ii) 0.0240 mol
(iii) 2.40 mol
(c) (i) Tartrate ion solution and copper ion solution.
(ii) Cu^{2+} (aq) + $H_4C_4O_6^{2-}$ (aq) $\rightarrow$ $CuH_4C_4O_6$ (s)
16 (a) Cu^{2+} (aq) + $2OH^-$ (aq) $\rightarrow$ $Cu(OH)_2$ (s)
(b) NaOH
(c) 0.975 g
(d) Blue precipitate formed. Blue solution turns light blue or remains blue.
17 600 cm^3
18 (a) 0.00800 mol
(b) 0.00400 mol
(c) 15.7 g/dm^3
19 (a) 0.0991 mol dm^{-3}
(b) Cl
20 85.1%