

1.1.1 Concentrations, gas equations and limiting amounts

Name: _____ Class: _____ Date: _____

Total: 24 marks

KEY WORDS molar mass • concentration • limiting reagent

Objective

Choose consistent units for concentration, ppm and gas calculations, then use a balanced equation. Original practice for specification 1.3–1.8.

1 Key knowledge and worked examples

■ Concentration is an amount divided by a volume

Mass concentration = mass/solution volume; amount concentration = amount/solution volume. For 5.85 g NaCl in 0.500 dm³, with $M = 58.5 \text{ g mol}^{-1}$:

$$n = m/M = 5.85/58.5 = 0.100 \text{ mol}$$

$$c = n/V = 0.100/0.500 = 0.200 \text{ mol dm}^{-3}$$

Mass concentration is 11.7 g dm⁻³. State which concentration you calculated. For gases, use $n = pV/(RT)$ with Pa, m³ and K. Parts per million is the stated fraction $\times 10^6$.

■ Remove spectator ions only after balancing

$\text{Zn(s)} + \text{CuSO}_4(\text{aq}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{Cu(s)}$ becomes $\text{Zn(s)} + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{Cu(s)}$. Sulfate ions remain unchanged.

2 Practice

2.1 Define relative formula mass and molar mass. Explain why sodium chloride has a formula mass rather than a molecular mass. [3]

2.2 Dissolve 4.00 g NaOH and make the solution up to 250 cm³. Use $M = 40.0 \text{ g mol}^{-1}$. Calculate both amount concentration and mass concentration. [4]

2.3 Air contains 0.0420% carbon dioxide by volume. Calculate its concentration in ppm by volume. [2]

3 Exam-style questions

3.1 A volatile liquid of mass 0.230 g becomes 100 cm³ of vapour at 373 K and 1.00×10^5 Pa. Use $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$. Calculate its molar mass, assuming ideal behaviour. [4]

3.2 A mixture contains 0.0600 mol aluminium and 0.0600 mol chlorine. Use $2\text{Al} + 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3$. Identify the limiting reactant, calculate the amount of product, and calculate the amount of aluminium left. [4]

3.3 A student adds aqueous sodium carbonate to aqueous calcium chloride. A white solid forms. Write a balanced full equation and the net ionic equation with state symbols, and identify the spectator ions. [4]

3.4 A process has theoretical product mass 4.00 g but gives 3.20 g isolated dry product. Calculate percentage yield. Explain why a 100% atom-economy reaction can still give this yield. [3]

Solutions

Original authored marking guidance; award equivalent balanced working.

2.1 Relative formula mass is the sum of relative atomic masses in the formula, a dimensionless ratio. Molar mass is mass per mole, with units such as g mol^{-1} . Sodium chloride has a giant ionic lattice rather than discrete NaCl molecules.

2.2 $V = 250/1000 = 0.250 \text{ dm}^3$; $n = m/M = 4.00/40.0 = 0.100 \text{ mol}$.

$$c = n/V = 0.100/0.250 = 0.400 \text{ mol dm}^{-3}$$

Mass concentration = $m/V = 4.00/0.250 = 16.0 \text{ g dm}^{-3}$.

2.3 Fraction = $0.0420/100 = 0.000420$. ppm = $0.000420 \times 10^6 = 420$. Do not multiply the percentage itself by 10^6 .

3.1 $V = 100 \times 10^{-6} = 1.00 \times 10^{-4} \text{ m}^3$.

$$n = \frac{pV}{RT} = \frac{1.00 \times 10^5 \times 1.00 \times 10^{-4}}{8.31 \times 373} = 0.00323 \text{ mol}$$

$M = m/n = 0.230/0.00323 = 71.3 \text{ g mol}^{-1}$. The gas equation requires the absolute temperature already supplied in K.

3.2 Available amount/coefficient is $0.0600/2 = 0.0300$ for aluminium and $0.0600/3 = 0.0200$ for chlorine. Chlorine limits. Product amount = $0.0600 \times 2/3 = 0.0400 \text{ mol}$; aluminium left = $0.0600 - 0.0400 = 0.0200 \text{ mol}$.

3.3 $\text{Na}_2\text{CO}_3(\text{aq}) + \text{CaCl}_2(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + 2\text{NaCl}(\text{aq})$. $\text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s})$. Na^+ and Cl^- are spectator ions; the white solid is calcium carbonate.

3.4 Yield = $3.20/4.00 \times 100 = 80.0\%$. Atom economy concerns the balanced reaction products, while incomplete reaction or isolation losses can lower actual yield even if no by-product is formed.