

# 1.1 Formulae, equations and amount of substance

Name: \_\_\_\_\_ Class: \_\_\_\_\_ Date: \_\_\_\_\_

Total: 20 marks

**KEY WORDS** mole      • atom economy      • percentage yield  
• empirical formula      • molar volume

## Objective

Practise Topic 1: mole arithmetic, reacting masses, gas volumes, solution amounts, empirical formulae, yield and atom economy – the skills every WCH11 question leans on.

## 1 Key knowledge and worked examples

### ■ The three doors to n

$$n = \frac{m}{M} \quad n = \frac{V}{24 \text{ dm}^3} \quad (\text{RTP}) \quad n = cV$$

Here  $M$  is molar mass and  $\nu$  is the balanced product coefficient. For gases not at RTP,  $pV = nRT$  with  $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$  and Pascals throughout.

### ■ Worked example: a full combustion chain

A 7.6 g hydrocarbon forms 26.4 g  $\text{CO}_2$  and 3.6 g  $\text{H}_2\text{O}$  on complete combustion. The carbon in the sample becomes  $\text{CO}_2$ , and pairs of H atoms become  $\text{H}_2\text{O}$ .

$$n(\text{C}) = n(\text{CO}_2) = \frac{m(\text{CO}_2)}{M(\text{CO}_2)} = \frac{26.4 \text{ g}}{44.0 \text{ g mol}^{-1}} = 0.600 \text{ mol}$$

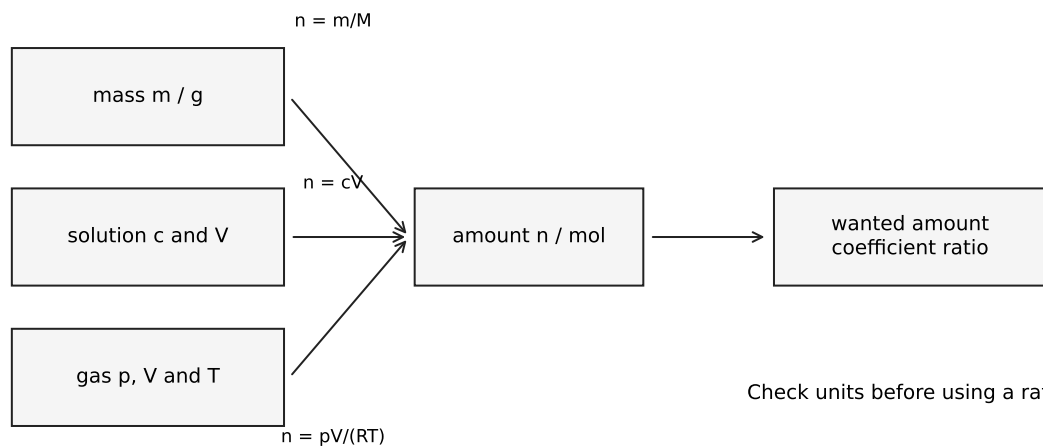
$$n(\text{H}) = 2n(\text{H}_2\text{O}) = \frac{2m(\text{H}_2\text{O})}{M(\text{H}_2\text{O})} = \frac{2 \times 3.6 \text{ g}}{18.0 \text{ g mol}^{-1}} = 0.400 \text{ mol}$$

Ratio C:H = 0.600:0.400 = 3:2, so the empirical formula is  $\text{C}_3\text{H}_2$ . Check element masses:  $m(\text{C}) = nM = 0.600 \times 12.0 = 7.20 \text{ g}$  and  $m(\text{H}) = nM = 0.400 \times 1.00 = 0.400 \text{ g}$ , adding to 7.60 g. A molecular formula also needs measured  $M_r$ .

## Yield and atom economy

$$\% \text{ yield} = \frac{\text{actual}}{\text{theoretical}} \times 100$$

$$\text{atom economy} = \frac{\nu_{\text{wanted}} M_r(\text{wanted})}{\sum \nu_i M_r(\text{product } i)} \times 100$$



## 2 Practice

**2.1** Calculate the number of atoms in 10 g of methane,  $\text{CH}_4$ . ( $A_r$ : H = 1.0, C = 12.0;  $L = 6.02 \times 10^{23}$ ) [2]

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**2.2** What volume of oxygen, measured at RTP, is needed for the complete combustion of 0.25 mol of butane? [2]

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**2.3** State what is meant by the term atom economy. [2]

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### 3 Exam-style questions

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**3.1** A 2.50 g fertiliser sample contains ammonium sulfate,  $(\text{NH}_4)_2\text{SO}_4$  ( $M_r = 132$ ), and inert sand. Excess sodium hydroxide releases all the ammonia from the salt. The ammonia reacts exactly with  $48.0 \text{ cm}^3$  of  $0.250 \text{ mol dm}^{-3}$  sulfuric acid. No ammonia escapes. Use  $(\text{NH}_4)_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{NH}_3 + 2\text{H}_2\text{O}$  and  $\text{H}_2\text{SO}_4 + 2\text{NH}_3 \rightarrow (\text{NH}_4)_2\text{SO}_4$  to calculate the percentage by mass of ammonium sulfate. [5]

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**3.2** Copper(II) nitrate,  $\text{Cu}(\text{NO}_3)_2$  ( $M_r = 188$ ), can be made by reacting copper(II) oxide with nitric acid. Calculate the maximum mass of copper(II) nitrate that can be produced from 4.0 g of copper(II) oxide with excess nitric acid ( $M_r = 80$ ), and the atom economy of the reaction if water is the only other product. [5]

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**3.3** A  $0.050 \text{ cm}^3$  drop of water is analysed. Calculate the number of molecules in the drop and the number of oxygen atoms. (density of water =  $1.0 \text{ g cm}^{-3}$ ) [4]

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