

Topic 3 – Quantitative chemistry

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3.1 Chemical measurements, conservation of mass and the quantitative interpretation of chemical equations

3.1.1 Conservation of mass and balanced chemical equations

Law of conservation of mass

- No atoms are lost or made during a chemical reaction
- So mass of products = mass of reactants

The student's results are shown in the table below.

	Mass in g
Beaker A and contents before mixing	127.60
Beaker B and contents before mixing	126.86
Beaker A and contents after mixing	153.09
Beaker B after mixing	101.37

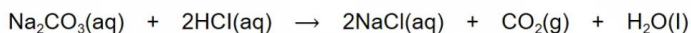
Use the data from the table to show that the law of conservation of mass is true.

[3 marks]

- Total mass before = $127.6 + 126.86 = 254.46$
- Total mass after = $153.09 + 101.37 = 243.46$
- So mass of products = mass of reactants

A fellow student also tests the law of conservation of mass and decides to use the same method but performs the experiment with a different reaction.

The equation for the reaction is:



This student's results appear to fail to support the law of conservation of mass.

Explain why this is so.

[3 marks]

- CO_2 is a gas
- Which escapes during the reaction
- So the mass at the end of the experiment is less expected as mass has been lost

Explain why an unbalanced chemical equation cannot correctly describe a chemical reaction (2)

- Must end up with the same no of atoms as at the start
- Otherwise matter is shown to be lost / gained
- Won't show correct amount of each element / compound

3.1.2 Relative formula mass

Relative formula mass (M_r)

Calculate the relative formula mass (M_r) of the compound lead nitrate $\text{Pb}(\text{NO}_3)_2$

Relative atomic masses (A_r): N = 14; O = 16; Pb = 207

[2 marks]

- $207 + 2 \times [14 + (3 \times 16)] = 331$

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In a balanced chemical equation

- Sum of Mr of reactants in the quantities = sum of Mr of products in the quantities

Why is there a change in mass?

- A reactant or product is a gas & its mass has not been taken into account

Percentage composition

$$\text{Percentage (\%)} = \frac{\text{mass or Mr of element}}{\text{mass or Mr of compound}} \times 100\%$$

How much Fe is there in FeSO₄?

Mr(Fe) = 56, Mr(FeSO₄) = 152

$$\text{Percentage (\%)} = \frac{\text{Mr of element}}{\text{Mr of compound}} \times 100\% = \frac{56}{152} \times 100\% = 36.8\%$$

3.1.3 Mass changes when a reactant or product is a gas

When a metal reacts with O₂

- Mass of the oxide produced is greater than the mass of the metal
- In thermal decompositions of metal carbonates
 - CO₂ is produced
 - Which escapes into the atmosphere
 - Leaving the metal oxide as the only solid product

The equation for the reaction is 2HCl(aq) + CaCO₃(s) → CaCl₂(aq) + H₂O(l) + CO₂(g). Explain why there is a loss in mass in this investigation (2)

- A gas is produced
- Which escapes from the flask

3.1.4 Chemical measurements

(Do practice questions)

3.2 Use of amount of substance in relation to masses of pure substances

3.2.1 Moles (HT only)

Moles

$$\text{mole (mol)} = \frac{\text{mass (g)}}{\text{Mr}}$$

Avogadro constant = 6.02 × 10²³

No of molecules = mole × 6.02 × 10²³

Mass of 1 mol of a substance

= relative atomic mass (Ar) in grams if substance is an element

= relative formula mass (Mr) in grams if substance is a compound

Reacting masses

Ex If I react 10g of CaCO₃ with excess HCl, what mass of CaCl₂ should I produce?



$$n(\text{CaCO}_3) = \frac{\text{mass (g)}}{\text{Mr}} = \frac{10}{100} = 0.1\text{mol}$$

$$0.1 = \frac{\text{mass (CaCl}_2)}{110}$$

$$\text{mass}(\text{CaCl}_2) = 11\text{g}$$

3.2.2 Amounts of substances in equations (HT only)

(Linked to other sub-topics)

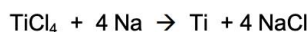
3.2.3 Using moles to balance equations (HT only)

(Linked to other sub-topics)

3.2.4 Limiting reactants (HT only)

0 8 7 In Stage 2, 40 kg of titanium chloride was added to 20 kg of sodium.

The equation for the reaction is:



Relative atomic masses (A_r): Na = 23 Cl = 35.5 Ti = 48

Explain why titanium chloride is the limiting reactant.

You **must** show your working.

[4 marks]

Mr of TiCl₄ = 190

$$n(\text{Na}) = \frac{\text{mass (g)}}{\text{Mr}} = \frac{20000}{23} = 870\text{mol}$$

$$n(\text{TiCl}_4) = \frac{\text{mass (g)}}{\text{Mr}} = \frac{40000}{190} = 211\text{mol}$$

Na is in excess as $n(\text{Na}) = 870\text{ mol}$ is more than 844 mol needed or $n(\text{TiCl}_4) = 211\text{ mol}$ is less than 217.5 mol needed

3.2.5 Concentration of solutions

(See 3.4 Using concentrations of solutions in mol/dm³ (chemistry only) (HT only))

3.3 Yield and atom economy of chemical reactions (chemistry only)

3.3.1 Percentage yield

Percentage yield

$$\text{Percentage yield (\%)} = \frac{\text{actual mass of product}}{\text{max mass of product}} \times 100\%$$

For a Stage 2 reaction the percentage yield was 92.3% The theoretical maximum mass of titanium produced in this batch was 13.5 kg. Calculate the actual mass of titanium produced. (2)

$$\text{Percentage yield (\%)} = \frac{\text{actual mass of product}}{\text{max mass of product}} \times 100\%$$

$$92.3\% = \frac{\text{actual mass of titanium}}{13.5} \times 100\%$$

Actual mass of titanium = 12.5kg

Factors that affect % yield

- Not all reactant is reacted
- Some product is lost when separated from reaction mixture
- Unexpected reaction

3.3.2 Atom economy

$$\text{Atom economy} = \frac{\text{Mr of desired product}}{\text{Total Mr of all reactants}} \times 100\%$$

0 2 . 5 An equation for the reaction is:



Calculate the percentage atom economy for the reaction to produce nickel.

Relative atomic masses (A_r): C = 12 Ni = 59

Relative formula mass (M_r): NiO = 75

Give your answer to 3 significant figures.

[3 marks]

$$\text{Atom economy} = \frac{\text{Mr of desired product}}{\text{Total Mr of all reactants}} \times 100\% = \frac{59}{87} \times 100\% = 67.8\%$$

Why is it important for percentage of atom economy of a reaction to be as high as possible (2)

- Important for sustainable development
- Economic reasons
- Waste products may be pollutants

Different results – additional product is made e.g. CO₂, H₂O

3.4 Using concentrations of solutions in mol/dm³ (chemistry only) (HT only)

$$\text{mole} = \text{concentration} \times \text{volume}$$

$$n = cv$$

n = number of moles (mol)

c = concentration of solution (mol/dm⁻³)

v = volume of solution (dm⁻³)

$$1\text{dm}^3 = 1000\text{cm}^3$$

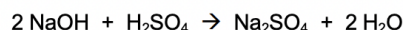
A student titrated 25.0 cm³ portions of dilute sulfuric acid with a 0.105 mol/dm³ sodium hydroxide solution.

0 9 . 3 Table 4 shows the student's results.

Table 4

	Titration 1	Titration 2	Titration 3	Titration 4	Titration 5
Volume of sodium hydroxide solution in cm ³	23.50	21.10	22.10	22.15	22.15

The equation for the reaction is:



Calculate the concentration of the sulfuric acid in mol/dm³

Use only the student's concordant results.

Concordant results are those within 0.10 cm³ of each other.

[5 marks]

$$\text{Average titre} = \frac{22.10+22.15+22.15}{3} = 22.13 \text{ cm}^3 = 0.02213 \text{ dm}^3$$

$$n(\text{NaOH}) = cv = 0.105 \times 0.02213 = 0.002324$$

$$n(\text{H}_2\text{SO}_4) = \frac{1}{2} \times 0.002324 = 0.001162$$

$$0.001162 = c(\text{H}_2\text{SO}_4) \times 0.025 = 0.0465 \text{ mol/dm}^3$$

3.5 Use of amount of substance in relation to volumes of gases (chemistry only) (HT only)

$$1 \text{ mole of gas} = 24 \text{ dm}^3 \quad 1 \text{ dm}^3 = 1000 \text{ cm}^3 \quad 1 \text{ m}^3 = 1000 \text{ dm}^3$$

$$\text{moles} = \frac{\text{volume (dm}^3\text{)}}{24 \text{ dm}^3}$$

A helium balloon has a volume of 48000 cm³. Calculate the moles of helium in the balloon. (2)

$$n(\text{He}) = \frac{\text{volume (dm}^3\text{)}}{24 \text{ dm}^3} = \frac{48}{24} = 2 \text{ mol}$$

All the formulae

$$\text{mole (mol)} = \frac{\text{mass (g)}}{M_r}$$

$$\text{moles} = \frac{\text{volume (dm}^3\text{)}}{24 \text{ dm}^3}$$

$$\text{Percentage (\%)} = \frac{\text{mass or } M_r \text{ of element}}{\text{mass or } M_r \text{ of compound}} \times 100\%$$

$$\text{mole} = \text{concentration} \times \text{volume}$$

$$n = cv$$

$$\text{Percentage yield (\%)} = \frac{\text{actual mass of product}}{\text{max mass of product}} \times 100\%$$

$$\text{Atom economy} = \frac{\text{Mr of desired product}}{\text{Total Mr of all reactants}} \times 100\%$$