Using Balanced Equations

Balanced equations (full or ionic) can be used to calculate the mass, concentration or volume of a particular reactant or product.

The context for performing these calculations can vary greatly, but there are three basic steps to using balanced equations to calculate quantities.

Step 1 The question will include enough information for you to be able to calculate the number of moles of at least one reactant or product. You may need to calculate the number of moles of two reactants to find which is the limiting reactant.

Step 2 Use the stoichiometry of the balanced equation to determine the number of moles of the reactant or product for which you must calculate the quantity.

Step 3 Use the relevant equation to calculate the mass, concentration or volume of the desired reactant or product.

Read questions very carefully. You may find that it is necessary to carry out additional steps in these calculations. For example, you may be required to convert units, calculate mean titre volumes or to scale the number of moles in a sample of a substance to find the number of moles in a larger amount of the substance.

Remember that the accuracy of your answer will be limited by the accuracy of the measurements you have been given. So, if the least accurate measurement in your calculation has been given to two significant figures, it would be appropriate for your answer to be to two significant figures.

Useful Equations

moles and mass

$$\text{number of moles (mol)} = \frac{\text{mass of substance (g)}}{Ar \text{ or } Mr \text{ of substance } (\text{g mol}^{-1})} \times 100$$

moles and solutions

$$\text{number of moles (mol)} = \text{volume } (\text{dm}^3) \times \text{concentration } (\text{mol dm}^{-3})$$

moles and gases

at 298 K and 101 kPa the volume of 1 mole of gas = 24.0 dm^3

Examples

1. **Finding the mass of a reactant or product.**

Magnesium is used in the extraction of titanium.

$$2Mg(l) + TiCl_4(g) \longrightarrow Ti(s) + 2MgCl_2(l)$$

Calculate the mass, in kg, of magnesium that is required to produce 110 kg of titanium.

Give your answer to an appropriate number of significant figures.

Step 1

moles of Ti = $\frac{\text{mass of substance (g)}}{Ar \text{ or } Mr \text{ of substance (g mol}^{-1}\text{)}}$

110kg × 1000 = 110 000 g of Ti

Ar of Ti = 47.9

$\frac{110\ 000}{47.9}$ = 2296.450939 moles

Step 2

stoichiometric ratio Ti : Mg = 1 : 2

moles of Mg needed = 2296.450939 × 2 = 4592.901879 moles

Step 3

mass of Mg = number of moles × Ar

Ar of Mg = 24.3

4592.901879 × 24.3 = 111 607.5157 g

$\frac{111\ 607.5157 \text{ g}}{1000}$ = 111.6075157 kg

= 112 kg (3 s.f.)

2. Finding the concentration of a reactant or product.

A student carried out a titration to find the concentration of a sodium hydroxide solution.

$$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

25.0 cm^3 of sodium hydroxide solution was titrated with 0.450 mol dm^{-3} hydrochloric acid.

The student's results are shown below.

	Rough	Titre 1	Titre 2	Titre 3
Volume of Hydrochloric Acid (cm^3)	49.5	49.1	49.9	49.3

Calculate the concentration of the sodium hydroxide solution.

Give your answer to an appropriate number of significant figures.

Step 1

mean titre volume of HCl = $\frac{(49.1 + 49.3)}{2}$ = 49.2 cm^3

(Titre 1 and Titre 3 values have been selected to calculate the mean because they are concordant. Concordant results are values with a difference of 0.2 or less.)

moles of HCl in mean titre volume = volume (dm^3) × concentration (mol dm^{-3})

$\frac{49.2\ cm^3}{1000}$ = 0.0492 dm^3

0.0492 × 0.450 = 0.02214 moles

Step 2

stoichiometric ratio HCl : NaOH = 1 : 1

moles of NaOH in 25.0 cm^3 = 0.02214

Step 3

concentration of NaOH = $\frac{\text{number of moles}}{\text{volume } (dm^3)}$

volume of NaOH = $\frac{25.0\ cm^3}{1000}$ = 0.0250 dm^3

$\frac{0.02214}{0.0250}$ = 0.8856 mol dm^3

= 0.886 mol dm^{-3} (3 s.f.)

3. Finding the volume of an aqueous reactant or product.

When silver nitrate solution is added to a solution containing chloride ions, a white precipitate of silver chloride is produced.

$$AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$$

Calculate the volume, in cm^3, of 0.500 mol dm^{-3} sodium chloride solution that would produce 780 mg of silver chloride, when an excess of silver nitrate is added to it.

Give your answer to an appropriate number of significant figures.

Step 1

$$\text{moles of AgCl} = \frac{\text{mass of substance (g)}}{Ar \text{ or } Mr \text{ of substance } (\text{g mol}^{-1})}$$

$$\frac{780 \text{ mg}}{1000} = 0.780 \text{ g of AgCl}$$

$$Mr \text{ of AgCl} = (107.9 \times 1) + (35.5 \times 1) = 143.4$$

$$\frac{0.780}{143.4} = 0.005439330544 \text{ moles}$$

Step 2

stoichiometric ratio AgCl : NaCl = 1 : 1

moles of NaCl = 0.005439330544

Step 3

$$\text{volume of NaCl} = \frac{\text{number of moles}}{\text{concentration } (\text{mol dm}^{-3})}$$

$$\frac{0.005439330544}{0.500} = 0.01087866109 \text{ dm}^3$$

$$0.01087866109 \text{ dm}^3 \times 1000 = 10.87866109 \text{ cm}^3$$

$$= 10.9 \text{ cm}^3 \text{ (3 s.f.)}$$

4. **Finding the volume of a gaseous reactant or product at room temperature and pressure (298 K and 101 kPa).**

Calculate the volume, in cm^3, of hydrogen that could be produced when 32.7 g of zinc is added to 100 cm^3 of 0.500 mol dm^{-3} hydrochloric acid.

$$Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

Give your answer to an appropriate number of significant figures.

Step 1

moles of Zn = $\dfrac{\text{mass of substance (g)}}{Ar \text{ or } Mr \text{ of substance (g mol}^{-1})}$

Ar of Zn = 65.4

$\dfrac{32.7}{65.4}$ = 0.500 moles

moles of HCl = volume (dm^3) × concentration (mol dm^{-3})

$\dfrac{100 \text{ cm}^3}{1000}$ = 0.100 dm^3

0.100 × 0.500 = 0.050 moles

HCl is the limiting reactant.

Step 2

stoichiometric ratio HCl : H_2 = 2 : 1

moles of H_2 = $\dfrac{0.0500}{2}$ = 0.025 moles

Step 3

at 298 K and 101 kPa the volume of 1 mole of gas = 24.0 dm^3

volume of H_2 = number of moles × 24.0 dm^3

0.025 × 24.0 = 0.600 dm^3

0.600 dm^3 × 1000 = 600 cm^3

= 600 cm^3 (3 s.f.)

5. **Finding the volume of a gaseous reactant or product that is not at room temperature or pressure.**

Soda bread can be made using buttermilk, bicarbonate of soda and flour. Lactic acid in the buttermilk reacts with the bicarbonate of soda (sodium hydrogen carbonate), which produces carbon dioxide, causing the dough to rise as it bakes.

$$C_3H_6O_3(l) + NaHCO_3(s) \longrightarrow NaC_3H_5O_3(s) + H_2O(g) + CO_2(g)$$

lactic acid	sodium hydrogen carbonate	sodium lactate	water	carbon dioxide

Calculate the maximum volume, in cm^3, of carbon dioxide that could be produced when 3.15 g (approximately 1 teaspoon) of bicarbonate of soda is mixed with an excess of the other ingredients and baked in an oven at 190 °C for 30 minutes.

The pressure inside the oven is 101 kPa. You may assume that the temperature of the dough and the air inside the oven are equal. The gas constant, R = 8.31 J K^{-1} mol^{-1}.

Give your answer to an appropriate number of significant figures.

Step 1

moles of $NaHCO_3 = \dfrac{\text{mass of substance (g)}}{Ar \text{ or } Mr \text{ of substance (g mol}^{-1})}$

Mr of $NaHCO_3 = (23.0 \times 1) + (1.0 \times 1) + (12.0 \times 1) + (16.0 \times 3) = 84.0$

$\dfrac{3.15}{84.0} = 0.0375$ moles

Step 2

stoichiometric ratio $NaHCO_3 : CO_2 = 1 : 1$

moles of $CO_2 = 0.0375$ moles

Step 3

volume of $CO_2 = \dfrac{nRT}{P}$

T = 190 °C + 273 = 463 K

p = 101 kPa × 1000 = 101 000 Pa

$\dfrac{0.0375 \times 8.31 \times 463}{101\,000} = 0.001428538366$ m^3

0.001428538366 m^3 × 1 000 000 = 1428.538366 cm^3

= 1430 cm^3 (3 s.f.)

6. Finding the percentage by mass of an element within a compound.

Most nails are made of steel. Steel is an alloy of iron.

One nail with a mass of 1.65 g was completely dissolved in a small amount of acid to produce a solution containing Fe^{2+} ions. The solution was made up to 250 cm^3 with distilled water.

A 25 cm^3 sample of the solution containing iron was titrated with 0.025 mol dm^{-3} potassium manganate(VII). The mean titre was 12 cm^3.

$$5Fe^{2+}(aq) + MnO_4^-(aq) + 8H^+(aq) \longrightarrow 5Fe^{3+}(aq) + Mn^{2+}(aq) + 4H_2O(l)$$

Calculate the percentage by mass of iron in the nail.

Give your answer to an appropriate number of significant figures.

Step 1

moles of MnO_4^- = volume (dm^3) × concentration (mol dm^{-3})

$\frac{12\ cm^3}{1000} = 0.012\ dm^3$

0.012 × 0.025 = 0.0003 moles

Step 2

stoichiometric ratio MnO_4^- : Fe^{2+} = 1 : 5

moles of Fe^{2+} in 25 cm^3 sample of solution = 0.0003 × 5 = 0.0015 moles

moles of Fe^{2+} in 250 cm^3 of solution = 0.0015 × 10 = 0.015 moles

Step 3

mass of Fe^{2+} in 250 cm^3 of solution = number of moles × Ar

Ar of Fe = 55.8

0.015 × 55.8 = 0.837 g of Fe

percentage by mass of iron = $\frac{\text{mass of Fe}}{\text{total mass of nail}} \times 100$

$\frac{0.837}{1.65} \times 100 = 50.72727273\%$

= 51% (2 s.f.)