Stage 2

Algebra and equations

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Introduction

In maths, you have learned how to substitute values into equations and solve for unknowns. In chemistry, we use the same algebra – with formulas for quantities like concentration, density and moles. This session builds on those maths skills and applies them to chemical calculations.

Learning objectives

1. Understand the algebra needed for balancing chemical equations.
2. Substitute numerical values into formulas and expressions using appropriate units.
3. Change the subject of an equation.
4. Solve for unknowns in chemical equations and stoichiometry problems.

Balancing chemical equations

Activity

1. $Li + O_2 \rightarrow Li_2O$
2. $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$
3. $Fe_2O_3 + C \rightarrow Fe + CO_2$
4. $CH_4 + O_2 \rightarrow CO_2 + H_2O$
5. $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$

Balancing chemical equations – answers

Answers

1. $4Li + O_2 \rightarrow 2Li_2O$

2. $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$

3. $2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$

4. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

5. $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Substitution into formulas

Activity

1. A piece of copper has a mass of 89.0 g and a volume of 10.0 cm^3. Calculate its density.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

2. A learner dissolves 5.0 g of sodium chloride in water to make 2.0 dm^3 of solution. Calculate the concentration in g/dm^3.

$$\text{concentration} = \frac{\text{mass}}{\text{volume}}$$

3. A reaction produces 45 cm^3 of gas in 9 seconds. Calculate the mean rate of reaction.

$$\text{mean rate} = \frac{\text{volume of gas}}{\text{time}}$$

4. A solution has a concentration of 12.0 g/dm^3 and a volume of 0.25 dm^3. Calculate the mass of solute dissolved.

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

Substitution into formulas – answers

1. $\text{density} = \frac{\text{mass}}{\text{volume}}$

   $\text{density} = \frac{89.0}{10.0}$

   $\text{density} = 8.9\ \text{g/cm}^3$

2. $\text{concentration} = \frac{\text{mass}}{\text{volume}}$

   $\text{concentration} = \frac{5.0}{2.0}$

   $\text{concentration} = 2.5\ \text{g/dm}^3$

3. $\text{mean rate} = \frac{\text{volume of gas}}{\text{time}}$

   $\text{mean rate} = \frac{45}{9}$

   $\text{mean rate} = 5\ \text{cm}^3/\text{s}$

4. $\text{mass} = \text{concentration} \times \text{volume}$

   $\text{mass} = 12.0 \times 0.25$

   $\text{mass} = 3.0\ \text{g}$

Answers

Changing the subject – one calculation

Activity

Substitute first, then change the subject to find the unknown. Show your working.

1. $\text{density} = \frac{\text{mass}}{\text{volume}}$

A substance has a density of 3.5 g/cm^3 and a volume of 8.0 cm^3.

Find the mass.

2. $\text{concentration} = \frac{\text{mass}}{\text{volume}}$

A solution has a concentration of 4.0 g/dm^3 and a volume of 1.5 dm^3.

Find the mass of solute dissolved.

3. $\text{mean rate} = \frac{\text{volume of gas}}{\text{time}}$

A reaction has a mean rate of 6.0 cm^3/s and produces gas for 15 seconds.

Find the total volume of gas produced.

Changing the subject – one calculation – answers

Answers

1. $\text{density} = \frac{\text{mass}}{\text{volume}}$

   Substitute: $3.5 = \frac{\text{mass}}{8.0}$

   Multiply both sides by 8.0:

   $\text{mass} = 3.5 \times 8.0$

   $\text{mass} = 28.0\ \text{g}$

2. $\text{concentration} = \frac{\text{mass}}{\text{volume}}$

   Substitute: $4.0 = \frac{\text{mass}}{1.5}$

   Multiply both sides by 1.5:

   $\text{mass} = 4.0 \times 1.5$

   $\text{mass} = 6.0\ \text{g}$

3. $\text{mean rate} = \frac{\text{volume of gas}}{\text{time}}$

   Substitute: $6.0 = \frac{\text{volume of gas}}{15}$

   Multiply both sides by 15:

   $\text{volume of gas} = 6.0 \times 15$

   $\text{volume of gas} = 90\ \text{cm}^3$

Changing the subject – two calculations

Activity

Substitute first, then change the subject to find the unknown. These need two calculations. Show your working.

1. $\text{density} = \frac{\text{mass}}{\text{volume}}$

   A liquid has a density of 1.2 g/cm^3 and a mass of 36.0 g. Find the volume.

2. $\text{concentration} = \frac{\text{mass}}{\text{volume}}$

   A solution has a concentration of 6.5 g/dm^3 and contains 19.5 g of solute. Find the volume of the solution.

3. $\text{mean rate} = \frac{\text{volume of gas}}{\text{time}}$

   A reaction has a mean rate of 8.0 cm^3/s and produces 200 cm^3 of gas. How long does the reaction take?

Changing the subject – two calculations – answers

Answers

1. $\text{density} = \frac{\text{mass}}{\text{volume}}$

   Substitute: $1.2 = \frac{36.0}{\text{volume}}$

   Multiply both sides by volume:

   $1.2 \times \text{volume} = 36.0$

   Divide both slides by 1.2:

   $\text{volume} = \frac{36.0}{1.2}$

   $\text{volume} = 30.0\ \text{cm}^3$

2. $\text{concentration} = \frac{\text{mass}}{\text{volume}}$

   Substitute: $6.5 = \frac{19.5}{\text{volume}}$

   Multiply both sides by volume:

   $6.5 \times \text{volume} = 19.5$

   Divide both sides by 6.5:

   $\text{volume} = \frac{19.5}{6.5}$

   $\text{volume} = 3.0\ \text{dm}^3$

3. $\text{mean rate} = \frac{\text{volume of gas}}{\text{time}}$

   Substitute: $8.0 = \frac{200}{\text{time}}$

   Multiply both sides by time:

   $8.0 \times \text{time} = 200$

   Divide both sides by 8.0:

   $\text{time} = \frac{200}{8.0}$

   $\text{time} = 25\ \text{s}$

Putting it all together

Activity

The next two questions combine balancing, substitution and changing the subject.

1. Magnesium reacts with hydrochloric acid:

$$\mathrm{Mg} + \mathrm{HCl} \rightarrow \mathrm{MgCl_2} + \mathrm{H_2}$$

a) Balance this equation.

b) A learner uses 4.86 g of magnesium chloride ($\mathrm{MgCl_2}$) dissolved in 0.6 dm^3 of water. Calculate the concentration in g/dm^3.

$$\text{concentration} = \frac{\text{mass}}{\text{volume}}$$

Putting it all together 2

Activity

This question combines balancing, substitution and changing the subject.

2. Calcium carbonate decomposes when heated:

$$CaCO_3 \rightarrow CaO + CO_2$$

a) Is this equation already balanced? Explain how you know.

b) A learner heats 40.0 g of calcium carbonate. The calcium oxide produced has a mass of 22.4 g. Calculate the mass of carbon dioxide produced. Remember: **mass of reactants = mass of products**

c) The carbon dioxide occupies a volume of 8.0 dm^3. Calculate its density.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Putting it all together – answers

Answers

Question 1

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

$MgCl_2$ has 2 Cl, so we need $2HCl$ on the left.

Check: Mg: $1 = 1$, H: $2 = 2$, Cl: $2 = 2$

b) $\text{concentration} = \frac{\text{mass}}{\text{volume}}$

$\text{concentration} = \frac{4.86}{0.6}$

$\text{concentration} = 8.1\ \text{g/dm}^3$

Question 2

a) Yes, the equation is already balanced.

b) mass of reactants = mass of products

$40.0 = 22.4 + \text{mass of } CO_2$

$\text{mass of } CO_2 = 40.0 - 22.4$

$\text{mass of } CO_2 = 17.6\ \text{g}$

c) $\text{density} = \frac{\text{mass}}{\text{volume}}$

$\text{density} = \frac{17.6}{8.0}$

$\text{density} = 2.2\ \text{g/dm}^3$

Discussing algebra in chemistry

Activity

A piece of metal has a mass of 156 g. Its density is 7.8 g/cm^3.

Three learners are calculating the volume. $\text{density} = \frac{\text{mass}}{\text{volume}}$

Which learner has answered correctly? Explain why the other two learners are wrong.

Learner A

$$d = \frac{m}{V}$$
$$7.8 = \frac{156}{V}$$
$$V = 156 \times 7.8$$
$$V = 1216.8\ \text{cm}^3$$

Learner B

$$d = \frac{m}{V}$$
$$7.8 = \frac{156}{V}$$
$$7.8 \times V = 156$$
$$V = \frac{156}{7.8}$$
$$V = 20\ \text{cm}^3$$

Learner C

$$d = \frac{m}{V}$$
$$7.8 = \frac{V}{156}$$
$$V = 7.8 \times 1567.8$$
$$V = 1216.8\ \text{cm}^3$$

Discussing algebra in chemistry – answer

Answer

Learner B is correct.

$V = \frac{156}{7.8}$

$V = 20\ \text{cm}^3$

Learner A is incorrect because they used the wrong inverse operation.

Learner C is incorrect because they substituted the values the wrong way round.

Learner B

$$d = \frac{m}{V}$$

$$7.8 = \frac{156}{V}$$

$$7.8 \times V = 156$$

$$V = \frac{156}{7.8}$$

$$V = 20\ \text{cm}^3$$