14–16 years

Practising calculations in chemistry

ROYAL SOCIETY OF CHEMISTRY

Education
Inspiring your teaching and learning

Learning objectives

1. Calculate the relative formula mass of a compound given its formula and appropriate relative atomic masses.
2. Calculate the percentage by mass of an element from a given formula.
3. Calculate masses of reactants and products from balanced equations using the mole equation.

Introduction

In chemistry, it is not enough just to know which substances react, we also need to know how much of each substance is involved. This part of chemistry is called quantitative chemistry.

By mastering these skills, you will gain a deeper understanding of how chemists use maths to make chemistry precise, reliable and useful in the real world.

Calculating relative formula mass

Worked example

Calculate the relative formula mass for:

$$CO_2$$

1 x carbon and 2 x oxygen

Relative atomic mass of carbon = 12

Relative atomic mass of oxygen = 16

1 x 12 = 12

2 x 16 = 32

12 + 32 = 44, so the relative formula mass of CO_2 is 44

Checkpoint one

On your mini whiteboard, calculate the relative formula mass for:

$$H_2O$$

2 x hydrogen and 1 x oxygen

Relative atomic mass of hydrogen = 1

Relative atomic mass of oxygen = 16

2 x 1 = 2

1 x 16 = 16

2 + 16 = 18, so the relative formula mass of H_2O is 18

Checkpoint two

On your mini whiteboard, calculate the relative formula mass for:

$$Fe_2O_3$$

2 x iron and 3 x oxygen

Relative atomic mass of carbon = 12

Relative atomic mass of oxygen = 16

2 x 56 = 112

3 x 16 = 48

112 + 48 = 160, so the relative formula mass of Fe_2O_3 is 160

Independent questions

Calculate the relative formula mass of:

1.1 Methane, CH_4

1.2 Sodium hydroxide, $NaOH$

1.3 Sulfuric acid, H_2SO_4

1.4 Zinc nitrate, $Zn(NO_3)_2$

Answer to Q1.1

1.1 Calculate the relative formula mass of **Methane, $\mathbf{CH_4}$**

1 x C and 4 x H

Relative atomic mass of carbon = 12

Relative atomic mass of hydrogen = 1

1 x 12 = 12

4 x 1 = 4

12 + 4 = 16

Answer to Q1.2

1. 2 Calculate the relative formula mass of **Sodium hydroxide, $NaOH$**

1 x Na, 1 x O and 1 x H

Relative atomic mass of sodium = 23

Relative atomic mass of oxygen = 16

Relative atomic mass of hydrogen = 1

1 x 23 = 23

1 x 16 = 16

1 x 1 = 1

23 + 16 + 1 = 40

Answer to Q1.3

1.3 Calculate the relative formula mass of **sulfuric acid, H_2SO_4**

2 x H, 1 x S and 4 x O

Relative atomic mass of hydrogen = 1

Relative atomic mass of sulfur = 32

Relative atomic mass of oxygen = 16

2 x 1 = 2

1 x 32 = 32

4 x 16 = 64

64 + 32 + 2 = 98

Answer to Q1.4

1.4 Calculate the relative formula mass of **zinc nitrate, $\mathbf{Zn(NO_3)_2}$**

1 x $\mathbf{Zn}$, 2 x $\mathbf{N}$ and 6 x $\mathbf{O}$

Relative atomic mass of zinc = 65

Relative atomic mass of nitrogen = 14

Relative atomic mass of oxygen = 16

1 x 65 = 65

2 x 14 = 28

6 x 16 = 96

65 + 28 + 96 = 189

Calculating percentage by mass

Worked example

Calculate the percentage mass of oxygen in magnesium oxide (MgO).

Relative atomic mass (A_r): $Mg = 24$, $O = 16$

1 atom of oxygen. Mass of atom is 16.

Total mass of MgO = 1 x Mg, 1 x O = 24 + 16 = 40

$$\% \text{ by mass} = \frac{A_r \text{ of element}}{M_r \text{ of compound}} \times 100 = \frac{16}{40} \times 100 = 40\%$$

Checkpoint one

On your mini whiteboard, calculate the percentage by mass of oxygen in sodium oxide (Na_2O).

Relative atomic mass (A_r): Na = 23, O = 16

1 atom of oxygen. Mass of atom is 16.

Total mass of Na_2O = 2 x Na, 1 x O = (2 x 23) + 16 = 62

% by mass = $\frac{16}{62} \times 100$ = 25.8%

Checkpoint two

On your mini whiteboard, calculate the percentage by mass of iron in iron oxide (Fe_2O_3).

Relative atomic mass (A_r): Fe = 56, O = 16

2 atoms of iron. Mass of iron is 2 x 56 = 112.

Total mass of Fe_2O_3 = 2 x Fe, 3 x O = (2 x 56) + (3 x16) = 160

% by mass = $\frac{112}{160} \times 100 = 70\%$

Independent questions

Calculate the percentage by mass of:

2.1 Carbon, C in methane, CH_4

2.2 Calcium, Ca in calcium carbonate, $CaCO_3$

2.3 Oxygen, O in sulfur dioxide, SO_2

2.4 Nitrogen, N in ammonium sulfate, $(NH_4)_2SO_4$

Answer to Q2.1

2.1 Calculate the percentage by mass of carbon, C in methane, CH_4

1 atom of carbon. Mass of carbon is 12.

Total mass of CH_4 = 1 x C, 4 x H = 12 + (4 x 1) = 16

% by mass = $\frac{12}{16} \times 100 = 75\%$

Answer to Q2.2

2.2 Calculate the percentage by mass of calcium, Ca in calcium carbonate, $CaCO_3$

1 atom of calcium. Mass of calcium is 40.

Total mass of $CaCO_3$ = 1 x Ca, 1 x C and 3 x O

= 40 + 12 + (3 x 16) = 100

% by mass = $\frac{40}{100} \times 100 = 40\%$

Answer to Q2.3

2.3 Calculate the percentage by mass of oxygen, O in sulfur dioxide, SO_2

2 atoms of oxygen. Mass of oxygen is 2 x 16 = 32.

Total mass of SO_2 = 1 x S, 2 x O = 32 + (2 x16) = 64

% by mass = $\frac{32}{64} \times 100 = 50\%$

Answer to Q2.4

2.4 Calculate the percentage by mass of nitrogen, N in ammonium sulfate, $(NH_4)_2SO_4$

2 atoms of nitrogen. Mass of nitrogen is 2 x 14 = 28.

Total mass of $(NH_4)_2SO_4$ = 2 x N, 8 x H, 1 x S and 4 x O =

(2 x 14) + (8 x 1) + 32 + (4 x16) = 132

% by mass = $\frac{28}{132} \times 100$ = 21.2%

Calculating mass from balanced equations
Worked example

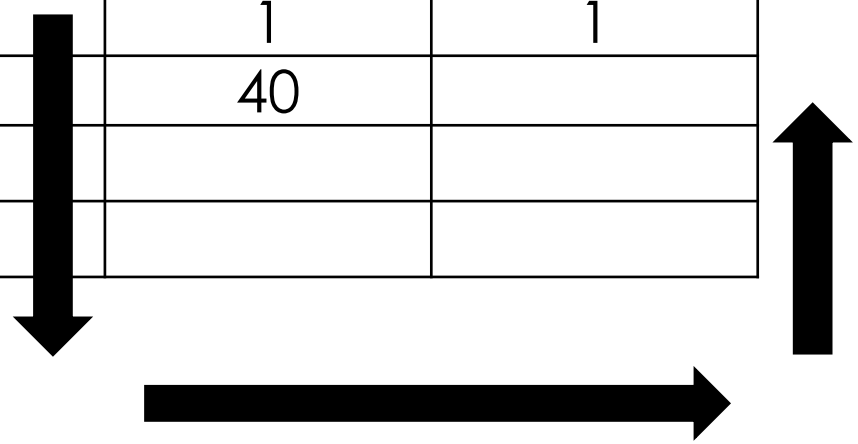
What mass of hydrogen is needed to react with 40 g of copper oxide?

$$CuO + H_2 \rightarrow Cu + H_2O$$

$$\textbf{moles} = \frac{\textbf{mass}}{M_r}$$

Step 1: fill out the table with the information from the question.

Substance	CuO	H_2
Ratio	1	1
Mass (g)	40	
M_r		
Moles		



Worked example

What mass of hydrogen is needed to react with 40 g of copper oxide?

$$CuO + H_2 \rightarrow Cu + H_2O$$

$$\textbf{moles} = \frac{\textbf{mass}}{M_r}$$

Step 2: work out the relative formula mass of CuO.

1 x Cu 1 x 63.5 = 63.5

1 x O 1 x 16 = 16

Total = 63.5 + 16 = 79.5

Substance	CuO	H_2
Ratio	1	1
Mass (g)	40	
M_r	79.5	
Moles		

Worked example

What mass of hydrogen is needed to react with 40 g of copper oxide?

$$CuO + H_2 \rightarrow Cu + H_2O$$

$$\textbf{moles} = \frac{\textbf{mass}}{M_r}$$

Step 3: work out the moles using:

$$\text{moles} = \frac{\text{mass}}{M_r}$$

$$\text{moles} = \frac{40}{79.5} = 0.503$$

Substance	CuO	H_2
Ratio	1	1
Mass (g)	40	
M_r	79.5	
Moles	0.503	

Worked example

What mass of hydrogen is needed to react with 40 g of copper oxide?

$$CuO + H_2 \rightarrow Cu + H_2O$$

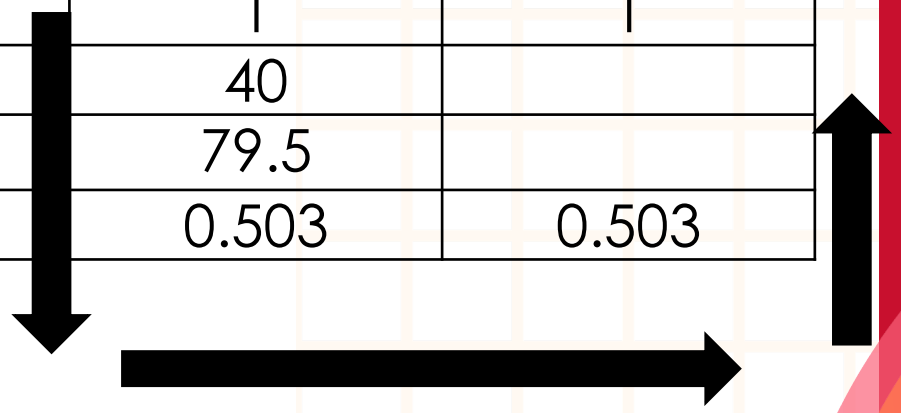
$$\textbf{moles} = \frac{\textbf{mass}}{M_r}$$

Step 4: manipulate the ratio.

Divide moles by ratio on the left. Multiply by ratio on the right to determine the moles.

Since this is a 1:1 ratio the number of moles is the same.

Substance	CuO	H_2
Ratio	1	1
Mass (g)	40	
M_r	79.5	
Moles	0.503	0.503



Worked example

What mass of hydrogen is needed to react with 40 g of copper oxide?

$$CuO + H_2 \rightarrow Cu + H_2O$$

$$\textbf{moles} = \frac{\textbf{mass}}{M_r}$$

Step 5: work out the relative formula mass of H_2

2 x H 2 x 1= 2

Substance	CuO	H_2
Ratio	1	1
Mass (g)	40	
M_r	79.5	2
Moles	0.503	0.503

Calculating mass from balanced equations – worked example

What mass of hydrogen is needed to react with 40 g of copper oxide?

$$CuO + H_2 \rightarrow Cu + H_2O$$

$$\textbf{moles} = \frac{\textbf{mass}}{M_r}$$

Step 6: work out mass using the mole equation:

$$\text{moles} = \frac{\text{mass}}{M_r}$$

$$0.503 = \frac{\text{mass}}{2}$$

Mass = 0.503 x 2 = 1.006 g

Substance	CuO	H_2
Ratio	1	1
Mass (g)	40	1.006
M_r	79.5	2
Moles	0.503	0.503

Checkpoint five

On your mini whiteboard:

Calculate the mass of carbon monoxide needed to react with 480 g of iron oxide.

$$Fe_2O_3 + 3\,CO \rightarrow 2Fe + 3CO_2$$

Use the table provided to support you. Remember, you must show your working.

Substance	Fe_2O_3	CO
Ratio	1	3
Mass (g)	480	252
M_r	160	28
Moles	3	9

$M_r\,Fe_2O_3 = (2 \times 56) + (3 \times 16) = 160$

$$\text{moles} = \frac{\text{mass}}{M_r} = \frac{480}{160} = 3$$

A ratio of 1:3 is equal to a ratio of 3:9

$M_r\,CO = 12 + 16 = 28$

$\text{mass} = \text{moles} \times M_r = 9 \times 28 = 252$

Mass of CO = 252 g

Checkpoint six

On your mini whiteboard, :

Calculate the mass of aluminium that can be formed from 1020 g of aluminium oxide.

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Use the table provided to support you. Remember, you must show your working.

Substance	Al_2O_3	Al
Ratio	2	4
Mass (g)	1020	540
M_r	102	27
Moles	10	20

$M_r\ Al_2O_3 = (2 \times 27) + (3 \times 16) = 102$

$$\text{moles} = \frac{\text{mass}}{M_r} = \frac{1020}{102} = 10$$

A ratio of 2:4 is equal to a ratio of 10:20

$A_r\ Al = 27$

$$\text{mass} = \text{moles} \times A_r = 20 \times 27 = 540$$

Mass of Al = 540 g

Independent questions

3.1 What mass of calcium oxide is formed when 10 g of calcium carbonate is completely decomposed?

$$CaCO_3 \rightarrow CaO + CO_2$$

3.2 What mass of sulfur dioxide is produced when 2.4 g of sulfur is burnt?

$$S + O_2 \rightarrow SO_2$$

3.3 What mass of carbon is needed to react with 8 g of copper(II) oxide?

$$2CuO + C \rightarrow 2Cu + CO_2$$

3.4 What mass of iron(III) oxide is needed to react with carbon monoxide to produce 112 g of iron?

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

Answer to Q3.1

3.1 What mass of calcium oxide is formed when 10 g of calcium carbonate is completely decomposed?

$$CaCO_3 \rightarrow CaO + CO_2$$

Substance	$CaCO_3$	CaO
Ratio	1	1
Mass (g)	10	5.6
M_r	100	56
Moles	0.1	0.1

$M_r\ CaCO_3 = (1 \times 40) + (1 \times 12) + (3 \times 16) = 100$

$$\text{moles} = \frac{\text{mass}}{M_r} = \frac{10}{100} = 0.1$$

$M_r\ CaO = 40 + 16 = 56$

$$\text{mass} = \text{moles} \times M_r = 0.1 \times 56 = 5.6$$

Mass of CaO = 5.6 g

Answer to Q3.2

3.2 What mass of sulfur dioxide is produced when 2.4 g of sulfur is burnt?

$$S + O_2 \rightarrow SO_2$$

Substance	S	SO_2
Ratio	1	1
Mass (g)	2.4	4.8
M_r	32	64
Moles	0.075	0.075

$A_r\ S = 32$

$$\text{moles} = \frac{\text{mass}}{A_r} = \frac{2.4}{32} = 0.075$$

$M_r\ SO_2 = 32 + (2 \times 16) = 64$

$$\text{mass} = \text{moles} \times M_r = 0.075 \times 64 = 4.8$$

Mass of SO_2 = 4.8 g

Answer to Q3.3

3.3 What mass of carbon is needed to react with 8 g of copper(II) oxide?

$$2CuO + C \rightarrow 2Cu + CO_2$$

Substance	CuO	C
Ratio	2	1
Mass (g)	8	0.6
M_r	79.5	12
Moles	0.1	0.05

M_r CuO = (1 x 63.5) + (1 x 16) = 79.5

$$\text{moles} = \frac{\text{mass}}{M_r} = \frac{8}{79.5} = 0.1$$

A ratio of 2:1 is equal to a ratio of 0.1:0.05

A_r C = 12

$$\text{mass} = \text{moles} \times A_r = 0.05 \times 12 = 0.6$$

Mass of CaO = 0.6 g

Answer to Q3.4

Q3.4 What mass of iron(III) oxide is needed to react with carbon monoxide to produce 112 g of iron?

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

Substance	Fe	Fe_2O_3
Ratio	2	1
Mass (g)	112	160
M_r	56	160
Moles	2	1

A_r Fe = 56

$$\text{moles} = \frac{\text{mass}}{M_r} = \frac{112}{56} = 2$$

M_r Fe_2O_3 = (2 x 56) + (3 x 16) = 160

$$\text{mass} = \text{moles} \times M_r = 1 \times 160 = 160$$

Mass of Fe_2O_3= 160 g