Chapter 1
Moles and equations

Chapter outline

- Relative atomic mass, isotopic mass and formula mass based on the ^{12}C scale
- Empirical formula and molecular formula
- Using mass spectra to calculate relative atomic mass
- Constructing balanced equations
- Performing calculations involving moles, reacting masses, gas volumes and solution concentration

KEY TERMS

Avogadro constant, *L*: The number of defined particles (atoms, ions, molecules or electrons) in a mole of those particles. Its value is 6.02×10^{23}.

Empirical formula: The simplest ratio of the different atoms present in a molecule.

Mass spectrometer: An instrument for helping to deduce the relative isotopic abundance of elements and the structure of compounds.

Molar gas volume: The volume of one mole of gas at a defined temperature and pressure. At **r.t.p**. its value is 24.0 dm^3.

Molar mass: The mass of a mole of substance in grams.

Mole: The amount of substance that has the same number of particles (atoms, ions, molecules or electrons) as there are atoms in exactly 12 g of the ^{12}C isotope.

Molecular formula: The actual number of each type of atoms in a molecule.

Relative atomic mass: The weighted average mass of the atoms of an element on a scale on which an atom of the ^{12}C isotope has a mass of exactly 12 units.

Relative formula mass: The weighted average mass of one formula unit of a compound measured on a scale on which an atom of the ^{12}C isotope has a mass of exactly 12 units.

Relative isotopic mass: The mass of a particular isotope of an element on a scale on which an atom of the ^{12}C isotope has a mass of exactly 12 units.

Relative molecular mass: The weighted average mass of a molecule on a scale on which an atom of the ^{12}C isotope has a mass of exactly 12 units.

r.t.p.: Room temperature and pressure (1 atmosphere and 20 °C).

Spectator ion: Ion present in a reaction mixture which does not take part in the reaction.

State symbol: Symbol placed after each reactant and product to indicate whether they are solid (s), liquid (l), gas (g) or in aqueous solution (aq).

Stoichiometry: The mole ratio of the reactants and products in a chemical equation.

Exercise 1.1 Definitions

This exercise will familiarise you with some important definitions about relative masses, moles and the Avogadro constant.

It is important that you learn definitions carefully. Remember that:

- A mole is an amount of substance.
- You compare this amount with an atom of the ^{12}C isotope.
- Relative atomic masses are weighted averages.

Copy and complete these sentences using words from the list

adding **amount** **atomic** **atoms** **Avogadro** **carbon-12** **constant** **grams** **ionic** **isotope** **mole** **relative** **twelve** **weighted**

A **mole** is the _____ of substance that has the same number of defined particles as there are _____ in exactly _____ grams of the _____ isotope. This number of particles is called the _____ _____ . **Relative atomic mass** is the _____ average mass of atoms of an element on the scale where an atom of the ^{12}C _____ has a mass of 12 units. **Relative molecular mass** is found by _____ together the _____ _____ masses of the atoms in a compound. For _____ compounds we use the term **relative formula mass**. Another term is **molar mass** which is the mass of a _____ of substance in _____ .

Exercise 1.2 Mole calculations

This exercise will familiarise you with some basic calculations using the mole concept.

- $\text{moles} = \frac{\text{mass (in g)}}{\text{molar mass (in mol dm}^{-3}\text{)}}$.
- In part (a) remember to use the mole ratio.
- In part (a)(iv) you need to rearrange the equation: (mass (in g) = moles × molar mass (in mol dm^{-3}).

a Lead oxide, Pb_3O_4, is reduced by heating with excess carbon.

$$Pb_3O_4 + 4C \rightarrow 3Pb + 4CO$$

Use the following method to calculate the maximum mass of lead formed when 41.12 g of Pb_3O_4 is reduced.

Calculate:

i The molar mass of Pb_3O_4 (A_r values: Pb = 207.2, O = 16.0).

- The number of significant figures in your answer should be the same as the least number of significant figures in the data.
- 326.7 is to 4 significant figures.
- 0.014 is to 2 significant figures.

ii The amount in moles of Pb_3O_4 (to 3 significant figures).

iii The amount in moles of lead produced.

iv Mass of lead produced (to 3 significant figures).

b 35.61 g of tin, reacts with exactly 42.60 g of chlorine, Cl_2, to form 78.21 g of tin(IV) chloride, $SnCl_4$.

i Calculate the number of moles of tin, chlorine and tin chloride. (A_r values: Sn = 118.7, Cl = 35.5)

ii Deduce the **stoichiometry** of the reaction.

iii Write a balanced equation for the reaction.

Exercise 1.3 Deducing formulae and composition by mass

This exercise will help you deduce empirical formula and molecular formula as well as percentage composition by mass.

Remember that % by mass $= \frac{\text{atomic mass} \times \text{number of moles of element}}{\text{molar mass of compound}}$

a When 14.98 g of arsenic are completely combusted, 19.78 g of an oxide of arsenic are formed.
Calculate

i The mass of oxygen in this oxide of arsenic.

ii The amount in moles of atoms of arsenic and oxygen which combine. (A_r values: As = 74.9, O = 16.0)

iii The empirical formula.

b The molar mass of this oxide of arsenic is 395.6 g. Deduce the molecular formula of this oxide of arsenic.

c The empirical formula of another oxide of arsenic is As_2O_5.
Calculate the percentage by mass of arsenic in As_2O_5. Give your answer to 3 significant figures.

Exercise 1.4 Using molar gas volume

This exercise helps you use the molar gas volume to deduce the stoichiometry of a reaction.

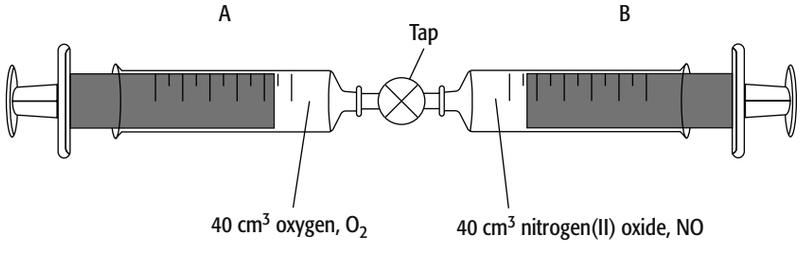
Remember that:

- The volume of one mole of gas at **r.t.p.** is 24 dm^3.
- Moles of gas $= \frac{\text{volume (in } dm^3)}{24}$ or $\frac{\text{volume (in } cm^3)}{24\,000}$.

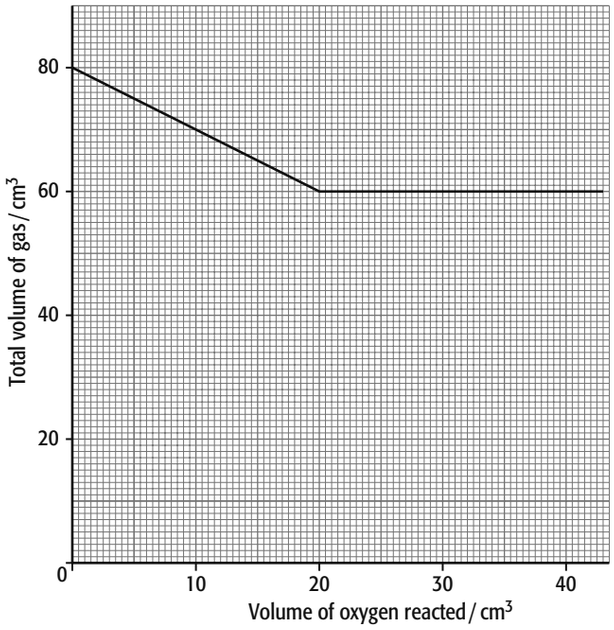
a Deduce the volume, number of moles or mass of gas represented by the letters A to F. (A_r values: P = 31.0, O = 16.0, S = 32.1, H = 1.00)

gas	volume of gas	moles of gas / mol	mass of gas / g
PH_3	80.0 cm^3	A	B
SO_2	C dm^3	D	8.00 g
O_2	E cm^3	0.150 mol	F

b Two syringes are set up as shown.



Small measured volumes of oxygen were pushed from syringe A into syringe B. The product is another gaseous oxide of nitrogen, NO_y. After each addition of oxygen, the tap was closed and the total volume of gases measured. The results are shown below.



i What volume of oxygen reacts with 40 cm^3 of nitrogen(II) oxide?

ii What volume of NO_y is formed?

iii Deduce the formula of NO_y

iv Write a balanced equation for the reaction.

Exercise 1.5 Solution concentration

This exercise gives you practice in calculating volumes, moles and concentrations. It also revises calculations from titration results.

Remember that:

- Concentration (in mol dm^{-3}) = $\frac{\text{amount (in mol)}}{\text{volume (in } dm^3\text{)}}$.
- In some questions you will have to rearrange this equation.

a Deduce the values represented by the letters R to V. (A_r values: Na = 23.0, O = 16.0, Cl = 35.5, H = 1.0)

solute	moles or mass of solute	volume of solution	concentration of solution
$CuSO_4$	0.12 mol	200 cm^3	R
HCl	S mol	1.5 dm^3	0.4 mol dm^{-3}
$ZnCl_2$	0.25 mol	T cm^3	0.05 mol dm^{-3}
NaOH	5.4 g	150 cm^3	U
NaCl	V g	0.20 dm^3	2.0 mol dm^{-3}

b 20.0 cm^3 of a solution of barium hydroxide, $Ba(OH)_2$, is exactly neutralised by 35.4 cm^3 of 0.200 mol dm^{-3} hydrochloric acid.

$$Ba(OH)_2 + 2HCl \rightarrow BaCl_2 + 2H_2O$$

Calculate

i The amount in moles of HCl.

ii The amount in moles of $Ba(OH)_2$.

iii The concentration of $Ba(OH)_2$.

Express your answers to 3 significant figures.

Exercise 1.6 Writing equations

This exercise provides practice in balancing equations, including ionic equations, as well as the use of state symbols.

Remember that when writing equations:

- You must not alter the formula of a compound.
- The number of atoms of each type must be the same on each side of the equation.
- Balance only by changing the numbers in front of particular compounds.

a Aqueous barium nitrate, $Ba(NO_3)_2$, reacts with dilute sodium sulfate, Na_2SO_4. A precipitate of barium sulfate is formed as well as one other aqueous compound.

i Write a balanced equation for this reaction. Include state symbols.

ii Convert the equation in part **i** into an ionic equation.

iii Name the **spectator ions** in this reaction.

b 2.50×10^{-2} mol of dilute hydrochloric acid reacts exactly with 1.25×10^{-2} mol of an insoluble oxide of iron. The products are aqueous iron(II) chloride and water.

Deduce the balanced equation for this reaction. Include state symbols.

c Convert the word equation below into a balanced ionic equation. Include state symbols for the substances at r.t.p. (calcium chloride is soluble in water).

calcium carbonate + hydrochloric acid → calcium chloride + carbon dioxide + water

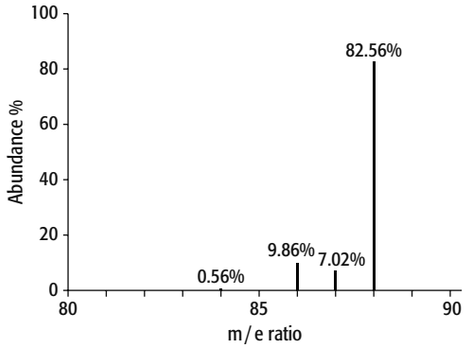
Exercise 1.7 Accurate relative molecular masses

The mass spectrometer gives information about the number and mass of the isotopes present in a sample of an element. In this exercise you will be using relative isotopic masses to calculate an accurate value for the relative atomic mass of strontium.

When calculating accurate relative atomic masses:

- Multiply each isotopic mass by its % abundance.
- Add these figures and divide by 100.

The mass spectrum shows the relative abundance of the isotopes present in a sample of strontium.



a Write the symbol for the lightest isotope present.

b Use the data in the mass spectrum to calculate the relative atomic mass of strontium. Express your answer to 3 significant figures.

- In part (a) the term *describe* means that you have to give details of the procedure.
- In part (b) remember to take the mole ratio of acid to alkali into account.
- When doing calculations make sure that you show all your working.
- Remember not to round up to the correct number of significant figures until the end of the calculation.

Exam-style questions

QUESTION 1

A sample of 3.60 g of malic acid, $C_2H_4O(CO_2H)_2$, was dissolved in 20.0 cm^3 of distilled water. The solution was titrated with 0.125 mol dm^{-3} aqueous sodium hydroxide.

a Describe how you would carry out this titration. [4]

b The equation for the reaction is

$$C_2H_4O(COOH)_2 + 2NaOH \rightarrow C_2H_4O(COONa)_2 + 2H_2O$$

Calculate the volume of aqueous sodium hydroxide used. Express your answer to 3 significant figures. [4]

c 25 cm^3 of a 0.0125 mol dm^{-3} solution of a metal hydroxide, $X(OH)_y$ was titrated with 0.05 mol dm^{-3} hydrochloric acid. It required 12.5 cm^3 of acid to neutralise the hydroxide.

Deduce the value of y and write a balanced equation for the reaction. [4]

Total: 12 marks

- In part (a) make sure that you give an accurate definition.
- In part (b) you need to make sure that you are calculating the number of atoms and not molecules.
- In part (c) remember that equal volumes of gases have equal numbers of moles of molecules.

QUESTION 2

a What is meant by the term *Avogadro constant*? [1]

b How many oxygen atoms are there in 0.0011 g of carbon dioxide? ($L = 6.02 \times 10^{23}$, A_r values: C = 12.0, O = 16.0) [3]

c 14 cm^3 of butene gas, C_xH_y, reacts with exactly 84 cm^3 of oxygen. 56 cm^3 of carbon dioxide is formed. Deduce the formula of butene. Show all working. [4]

d **i** A compound has the following percentage composition by mass: C 37.25%, H 7.75%, Cl 55%. Deduce the empirical formula. [3]

ii What further information is needed to deduce the molecular formula of this compound? [1]

Total: 12 marks

- Part (a) involves calculation of relative atomic mass.
- In calculations (b) and (c) make sure that you show all working clearly, e.g.

$$\text{moles of } Fe_2O_3 = \frac{mass}{M_r}$$

QUESTION 3

The table shows the relative abundances of the four naturally occurring isotopes of iron.

isotopic mass	relative abundance
54	5.840
56	91.680
57	2.170
58	0.310

a Calculate the relative atomic mass of iron to 3 significant figures. [3]

b Limonite is a mineral with the formula $Fe_2O_3.H_2O$. Calculate the percentage by mass of iron in limonite. [3]

c **i** Calculate the maximum mass of iron formed when 798 g of iron(III) oxide, Fe_2O_3, is reduced by excess carbon monoxide.

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

Express your answer to 3 significant figures. (A_r values Fe = 55.8, O = 16.0) [3]

ii Calculate the volume of carbon dioxide formed at r.t.p. [2]

d Red hot iron reacts with steam to form Fe_3O_4 and hydrogen. Write a balanced equation for this reaction. [2]

e Iron reacts with aqueous copper(II) sulfate. The products are copper and aqueous iron(II) sulfate. Construct the ionic equation for this reaction including state symbols. [2]

Total: 15 marks