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

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 ________. 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.

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

a Lead oxide, Pb$_3$O$_4$, is reduced by heating with excess carbon.

Pb$_3$O$_4$ + 4C $\rightarrow$ 3Pb + 4CO

Use the following method to calculate the maximum mass of lead formed when 41.12 g of Pb$_3$O$_4$ is reduced.

Calculate:
  - 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$_3$O$_4$ (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, 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. (\( \text{A, values: As} = 74.9, \ O = 16.0 \))
   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\(_2\)O\(_5\). Calculate the percentage by mass of arsenic in As\(_2\)O\(_5\). 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 = \( \frac{\text{volume (in dm}^3\text{)}}{24} \text{ or } \frac{\text{volume (in cm}^3\text{)}}{24000} \).

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

<table>
<thead>
<tr>
<th>gas</th>
<th>volume of gas</th>
<th>moles of gas / mol</th>
<th>mass of gas / g</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH(_3)</td>
<td>80.0 cm(^3)</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>SO(_2)</td>
<td>C dm(^3)</td>
<td>D</td>
<td>8.00 g</td>
</tr>
<tr>
<td>O(_2)</td>
<td>E cm(^3)</td>
<td>0.150 mol</td>
<td>F</td>
</tr>
</tbody>
</table>

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, values: Na = 23.0, O = 16.0, Cl = 35.5, H = 1.0)

<table>
<thead>
<tr>
<th>solute</th>
<th>moles or mass of solute</th>
<th>volume of solution</th>
<th>concentration of solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CuSO(_4)</td>
<td>0.12 mol</td>
<td>200 cm(^3)</td>
<td>R</td>
</tr>
<tr>
<td>HCl</td>
<td>S mol</td>
<td>1.5 dm(^3)</td>
<td>0.4 mol dm(^{-3})</td>
</tr>
<tr>
<td>ZnCl(_2)</td>
<td>0.25 mol</td>
<td>T cm(^3)</td>
<td>0.05 mol dm(^{-3})</td>
</tr>
<tr>
<td>NaOH</td>
<td>5.4 g</td>
<td>150 cm(^3)</td>
<td>U</td>
</tr>
<tr>
<td>NaCl</td>
<td>V g</td>
<td>0.20 dm(^3)</td>
<td>2.0 mol dm(^{-3})</td>
</tr>
</tbody>
</table>
Chapter 1: Moles and equations

b 20.0 cm³ of a solution of barium hydroxide, \( \text{Ba(OH)}_2 \), is exactly neutralised by 35.4 cm³ of 0.200 mol dm⁻³ hydrochloric acid.

\[ \text{Ba(OH)}_2 + 2\text{HCl} \rightarrow \text{BaCl}_2 + 2\text{H}_2\text{O} \]

Calculate

i The amount in moles of \( \text{HCl} \).

ii The amount in moles of \( \text{Ba(OH)}_2 \).

iii The concentration of \( \text{Ba(OH)}_2 \).

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, \( \text{Ba(NO}_3\text{)}_2 \), reacts with dilute sodium sulfate, \( \text{Na}_2\text{SO}_4 \). 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.

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).

\[ \text{calcium carbonate} + \text{hydrochloric acid} \rightarrow \text{calcium chloride} + \text{carbon dioxide} + \text{water} \]

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.
Exam-style questions

QUESTION 1

A sample of 3.60 g of malic acid, C₂H₄O₂(CO₂H)₂, was dissolved in 20.0 cm³ 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:

\[
C₂H₄O₂(CO₂H)₂ + 2NaOH → C₂H₄O₂(COONa)₂ + 2H₂O
\]

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

c 25 cm³ of a 0.0125 mol dm⁻³ solution of a metal hydroxide, X(OH)₁₉ was titrated with 0.05 mol dm⁻³ hydrochloric acid. It required 12.5 cm³ of acid to neutralise the hydroxide.

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

Total: 12 marks

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 × 10²³, \( A \) values: C = 12.0, O = 16.0) [3]

c 14 cm³ of butene gas, C₅H₁₀, reacts with exactly 84 cm³ of oxygen. 56 cm³ 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
QUESTION 3

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

<table>
<thead>
<tr>
<th>isotopic mass</th>
<th>relative abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>5.840</td>
</tr>
<tr>
<td>56</td>
<td>91.680</td>
</tr>
<tr>
<td>57</td>
<td>2.170</td>
</tr>
<tr>
<td>58</td>
<td>0.310</td>
</tr>
</tbody>
</table>

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

b Limonite is a mineral with the formula \( \text{Fe}_2\text{O}_3\cdot\text{H}_2\text{O} \). 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, \( \text{Fe}_2\text{O}_3 \), is reduced by excess carbon monoxide.

\[ \text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2 \]

Express your answer to 3 significant figures. (\( A_r \text{Fe} = 55.8, \text{O} = 16.0 \)) [3]

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

d Red hot iron reacts with steam to form \( \text{Fe}_3\text{O}_4 \) 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