Week 3

A-Level Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

A-Level Chemistry Name: ________ Score: ________

1. The weighted mean mass of an element's atoms, compared to carbon-12, is the relative ________ mass.

   ____

2. One mole of any substance contains 6.02×10^{23} ________.

   ____

3. A balanced equation has the same number of each type of atom on both sides.

   ☐ True ☐ False

4. The simplest whole-number ratio of atoms in a compound is the ________ formula.

   ____

5. Percentage yield is the actual yield divided by the theoretical yield, times 100.

   ☐ True ☐ False

6. At room temperature and pressure, one mole of any gas occupies about ________ dm^3.

   ____

7. The relative atomic mass (Ar) of an element is:

   ☐ the weighted average mass of its atoms over all isotopes, compared with 1/12 of carbon-12

   ☐ the mass of its heaviest isotope

   ☐ its number of protons

   ☐ its mass in grams

8. One mole of any substance contains:

   ☐ 6.02×10^{23} particles

   ☐ 12 particles

   ☐ 100 particles

   ☐ exactly 1 gram of particles

9. A Group 2 element usually forms an ion with charge:

   ☐ +2

   ☐ +1

   ☐ −2

☐ −1

10. Ethane has empirical formula CH_3 and molecular formula C_2H_6. This shows:
    - ☐ the empirical formula is the simplest ratio; the molecular formula is the actual count
    - ☐ they are the same thing
    - ☐ the molecular formula is simpler
    - ☐ ethane has no formula

A-Level Chemistry

1. **atomic**

   Ar (relative atomic mass) accounts for the abundance of each isotope.

2. **particles**

   This number is the Avogadro constant.

3. **True**

   Atoms are neither created nor destroyed, so mass is conserved.

4. **empirical**

   The molecular formula is a whole-number multiple of the empirical formula.

5. **True**

   It measures how much product you actually obtained compared with the maximum possible.

6. **24**

   This is the molar gas volume at rtp (24 dm^3 per mole).

7. **the weighted average mass of its atoms over all isotopes, compared with 1/12 of carbon-12**

   Ar is the average over all isotopes (weighted by abundance), measured against 1/12 of a carbon-12 atom.

8. **6.02×10^{23} particles**

   A mole always contains the Avogadro number of particles, 6.02×10^{23}.

9. **+2**

   Group 2 elements lose two electrons to form 2+ ions; Group 17 form −1 ions.

10. **the empirical formula is the simplest ratio; the molecular formula is the actual count**

    Empirical = simplest whole-number ratio; molecular = the real number of atoms per molecule.

A-LEVEL CHEMISTRY • EXERCISE SHEET

2.1 Relative masses of atoms and molecules

Name: ____________ Class: ________ Date: __________ **Total: 11 marks**

KEY WORDS relative atomic mass 相对原子质量 • unified atomic mass unit 统一原子质量单位 • relative formula mass 相对式量 • relative molecular mass 相对分子质量 • isotope 同位素

Objective

Build the skills to answer exam questions on **relative masses of atoms and molecules** — the **unified atomic mass unit** 统一原子质量单位 and the relative masses A_r, M_r and relative formula mass.

You must be able to:

- define the unified atomic mass unit
- define relative atomic, isotopic, molecular and formula mass
- calculate A_r from isotopic abundances and M_r from a formula

1 Worked examples

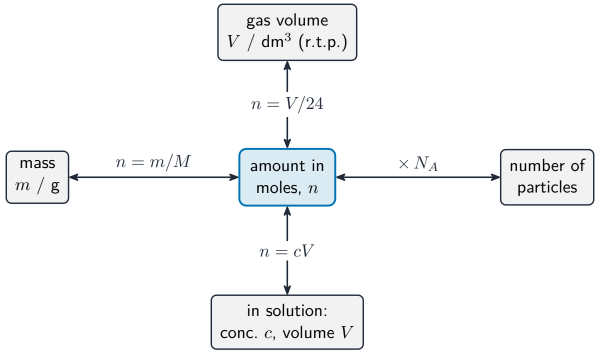
The relative masses

The **unified atomic mass unit** (u) is $\frac{1}{12}$ of the mass of a carbon-12 atom. Masses are then simple numbers relative to it.

- **relative atomic mass** A_r — the weighted average mass of an element's atoms, over all **isotopes** 同位素.
- **relative molecular mass** M_r — the sum of the A_r values of all atoms in a molecule.
- **relative formula mass** — the same, for an ionic compound.

$$A_r = \frac{(75 \times 35) + (25 \times 37)}{100} = 35.5$$

A_r is a weighted average: 75% ^{35}Cl + 25% ^{37}Cl → A_r = 35.5



Relative masses connect to amount in moles

Calculating M_r

For sulfuric acid, H_2SO_4 (A_r: H 1, S 32, O 16): $M_r = 2(1) + 32 + 4(16) = 98$.

2 Practice

2.1 Define **relative atomic mass**. [2]

2.2 Calculate the relative molecular mass of calcium carbonate, $CaCO_3$ (A_r: Ca 40, C 12, O 16). [1]

3 Exam-style questions

3.1 Why is the relative atomic mass of chlorine 35.5 and not a whole number? [1]

- **A** chlorine atoms are damaged
- **B** it is a weighted average of two isotopes
- **C** chlorine has half a neutron
- **D** the value is rounded

3.2 What is the relative formula mass of magnesium hydroxide, $Mg(OH)_2$ (A_r: Mg 24, O 16, H 1)? [1]

- **A** 41
- **B** 49
- **C** 58
- **D** 74

3.3 Magnesium has three isotopes: ^{24}Mg (79%), ^{25}Mg (10%) and ^{26}Mg (11%).

(a) Calculate the relative atomic mass of magnesium to 1 decimal place. [3]

(b) Explain why this value is not a whole number. [1]

3.4 Calculate the relative molecular mass of ethanol, C_2H_5OH (A_r: C 12, H 1, O 16). [2]

Solutions

2.1 the average mass of an element's atoms (over its isotopes) compared with $\frac{1}{12}$ of a carbon-12 atom.

2.2 $40 + 12 + 3(16) = 100$.

3.1 **B**. It is a weighted average of ^{35}Cl and ^{37}Cl.

3.2 **C**. $24 + 2(16 + 1) = 24 + 34 = 58$.

3.3 (a) $A_r = \dfrac{(24 \times 79) + (25 \times 10) + (26 \times 11)}{100} = \dfrac{2432}{100} = 24.3$.
(b) it is a weighted average of isotopes of different mass.

3.4 $2(12) + 6(1) + 16 = 24 + 6 + 16 = 46$.

40 A sample of magnesium contains the isotopes ^{24}Mg, ^{25}Mg and ^{26}Mg only.

The percentage abundance of ^{25}Mg and ^{26}Mg is the same.

The relative atomic mass of magnesium in the sample is 24.3.

What is the percentage abundance of ^{24}Mg?

A 10% **B** 20% **C** 60% **D** 80%

Important values, constants and standards

molar gas constant	$R = 8.31\,J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,C\,mol^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23}\,mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,C$
molar volume of gas	$V_m = 22.4\,dm^3\,mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,dm^3\,mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,mol^2\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,kJ\,kg^{-1}\,K^{-1}$ ($4.18\,J\,g^{-1}\,K^{-1}$)

The Periodic Table of Elements

Key: atomic number / atomic symbol / name / relative atomic mass

Group

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

40 A sample of gallium contains two isotopes only.

In every 10 atoms in the sample, there are 6 that have 38 neutrons and 4 that have 40 neutrons.

What is the relative atomic mass, A_r, of the gallium in the sample?

A 69.7 **B** 69.8 **C** 70.0 **D** 70.2

Important values, constants and standards

molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
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Key

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atomic symbol
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19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
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1 Chromium, Cr, and its compounds are widely used in many chemical reactions.

(a) Cr exists as four stable isotopes.

(i) The most common isotope of Cr is chromium-52.

Determine the number of protons, neutrons and electrons in an atom of chromium-52.

number of protons .... neutrons .... electrons ....
[1]

(ii) Describe how an atom of chromium-54 differs from an atom of chromium-52. Refer to numbers of particles in your answer.

....

.... [1]

(iii) The relative isotopic masses of the isotopes of Cr can be determined using mass spectrometry.

State what other information is needed to calculate the relative atomic mass, A_r, of Cr.

.... [1]

(iv) Atoms of ^{52}Cr, ^{53}Cr and ^{54}Cr make up more than 95% of naturally occurring chromium atoms. The A_r of naturally occurring Cr is 51.996.

Suggest what these statements imply about the relative isotopic mass of the fourth stable isotope of chromium.

.... [1]

(b) The shorthand electronic configuration of chromium is [Ar] $3d^5 4s^1$.

(i) Complete the full electronic configuration of chromium.

.... $3d^5 4s^1$ [1]

(ii) Deduce the total number of unpaired electrons in an atom of chromium.

.... [1]

(c) Acidified dichromate(VI) ions will convert methanal, CH_2O, to carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.

half-equation 1 $\quad CH_2O + H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

half-equation 2 $\quad Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

(i) Identify the species that is reduced in half-equation 2. Explain your answer.

.... [1]

(ii) The oxidation state of the carbon atom in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

.... [1]

(iii) Construct the ionic equation for the reaction of dichromate(VI) ions with methanal in acidic conditions.

.... [2]

(iv) Methanal is a liquid at –30 °C but carbon dioxide is a gas at this temperature. Explain why.

....

....

....

.... [2]

(d) In acidic conditions, a dynamic equilibrium is established between CrO_4^{2-}(aq) and $Cr_2O_7^{2-}$(aq).

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l) \qquad \Delta H > 0$$

(i) State what is meant by dynamic equilibrium.

....

.... [1]

(ii) Identify the condition necessary to establish dynamic equilibrium.

.... [1]

(iii) CrO_4^{2-}(aq) ions are yellow and $Cr_2O_7^{2-}$(aq) ions are orange.

State what is observed when the following changes are made to an equilibrium mixture of acidified CrO_4^{2-}(aq) and $Cr_2O_7^{2-}$(aq) ions.

Explain your answers.

- The equilibrium mixture is warmed gently.

  observation ....

  explanation ....

  ....

  ....

- Dilute HC*l*(aq) is added to the equilibrium mixture.

  observation ....

  explanation ....

  ....

  ....

[4]

(e) Chromium(IV) fluoride, CrF_4, is a covalent molecule that shows similar chemical properties to $SiCl_4$.

Suggest the type of reaction that occurs when CrF_4 is placed in water.

Construct a relevant equation for this reaction.

type of reaction ....

equation ....

[2]

[Total: 20]

A-LEVEL CHEMISTRY • EXERCISE SHEET

2.2 The mole and the Avogadro constant

Name: ____________ Class: ________ Date: __________ **Total: 9 marks**

KEY WORDS mole 摩尔 • avogadro constant 阿伏伽德罗常量 • solution 溶液 • molar mass 摩尔质量 • atom 原子

Objective

Build the skills to answer exam questions on **the mole and the Avogadro constant** — the **mole 摩尔**, the **Avogadro constant 阿伏伽德罗常量**, and the equation $n = m/M$.

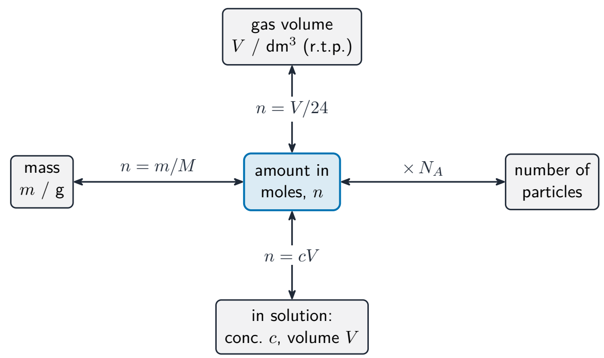
You must be able to:

- define the mole in terms of the Avogadro constant
- convert between mass, moles and number of particles

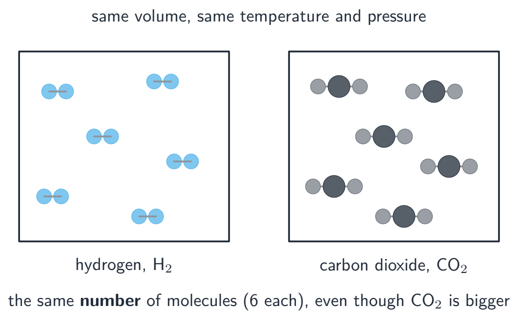
1 Worked examples

■ The mole

One **mole** is the amount of substance containing $N_A = 6.02 \times 10^{23}$ particles (the **Avogadro constant**). The particles may be atoms, molecules or ions — always say which.



The mole is the hub: convert to mass ($n = m/M$), particles ($\times N_A$), gas volume ($n = V/24$) or solution ($n = cV$)



Equal volumes of gas contain equal numbers of molecules

The mass of one mole equals the relative mass — the **molar mass** M (g mol^{-1}):

$$n = \frac{m}{M}$$

Example. Moles in 8.0 g of CH_4 ($M = 16$): $n = 8.0/16 = 0.50$ mol.

2 Practice

2.1 State the value of the Avogadro constant and what it counts. [2]

2.2 Calculate the number of moles in 36 g of water, H_2O ($M = 18$). [1]

3 Exam-style questions

3.1 How many molecules are in 2.0 mol of carbon dioxide? [1]

- **A** 3.0×10^{23}
- **B** 6.02×10^{23}
- **C** 1.2×10^{24}
- **D** 2.0×10^{23}

3.2 The mass of 0.25 mol of a compound is 22 g. Its molar mass is: [1]

- **A** 5.5 g mol^{-1}
- **B** 44 g mol^{-1}
- **C** 88 g mol^{-1}
- **D** 5.5×10^{23} g mol^{-1}

3.3 Calculate the number of moles in 5.85 g of sodium chloride, NaCl ($M = 58.5$). [2]

3.4 Calculate the number of chloride ions in 5.85 g of NaCl ($N_A = 6.02 \times 10^{23}$). [2]

Solutions

2.1 6.02×10^{23} mol^{-1}; the number of particles (atoms/molecules/ions) in one mole.

2.2 $n = 36/18 = 2.0$ mol.

3.1 C. $2.0 \times 6.02 \times 10^{23} = 1.2 \times 10^{24}$.

3.2 C. $M = m/n = 22/0.25 = 88$ g mol^{-1}.

3.3 $n = m/M = 5.85/58.5 = 0.100$ mol.

3.4 moles of NaCl = 0.100, so moles of Cl^- = 0.100; number = $0.100 \times 6.02 \times 10^{23} = 6.02 \times 10^{22}$.

2.3 Formulas

Name: ____________ Class: ________ Date: __________ **Total: 22 marks**

KEY WORDS empirical 实验式 • molecular 分子式 • relative molecular mass 相对分子质量 • equations 方程式 • balanced 配平

Objective

Build the skills to answer exam questions on **formulas** — writing formulas of ionic compounds, balancing **equations** 方程式 (including **ionic equations** 离子方程式), and finding **empirical** 实验式 and **molecular** 分子式 formulas.

You must be able to:

- write formulas of ionic compounds from ionic charges and oxidation numbers
- write and balance equations (including ionic equations) with state symbols
- calculate empirical and molecular formulas from data

1 Worked examples

Ionic formulas

$$A_r = \frac{(75 \times 35) + (25 \times 37)}{100} = 35.5$$

Formulae build from relative atomic masses

The total + charge balances the total − charge. Charges from the group: Group 1 +1, 2 +2, 13 +3, 15 −3, 16 −2, 17 −1. Learn: NO_3^-, CO_3^{2-}, SO_4^{2-}, OH^-, NH_4^+. E.g. iron(III) oxide = Fe_2O_3 (two Fe^{3+} balance three O^{2-}).

Equations and ionic equations

A balanced equation has the same atoms on both sides; add **state symbols** (s, l, g, aq). An **ionic equation** shows only what changes (no **spectator ions** 旁观离子): $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$.

■ **Empirical formula**

Divide each element's mass (or %) by its $A_r \to$ moles; divide by the smallest; round to whole numbers. **Example.** 40.0% C, 6.7% H, 53.3% O: moles $3.33 : 6.7 : 3.33 \to 1 : 2 : 1 \to CH_2O$. With M_r, scale up to the **molecular formula**.

2 Practice

2.1 Write the formula of (a) calcium nitrate and (b) aluminium sulfate. [2]

2.2 Write the ionic equation for the reaction of silver ions with chloride ions to form silver chloride. [1]

3 Exam-style questions

3.1 What is the formula of iron(III) sulfate? [1]

- **A** $FeSO_4$
- **B** Fe_2SO_4
- **C** $Fe_2(SO_4)_3$
- **D** $Fe_3(SO_4)_2$

3.2 A compound has empirical formula CH_2 and $M_r = 42$. Its molecular formula is: [1]

- **A** CH_2
- **B** C_2H_4
- **C** C_3H_6
- **D** C_4H_8

3.3 Balance this equation and add state symbols: $Mg + HCl \to MgCl_2 + H_2$. [2]

3.4 A compound contains 2.4 g of carbon, 0.4 g of hydrogen and 3.2 g of oxygen (A_r: C 12, H 1, O 16).

(a) Calculate its empirical formula. [3]

(b) The M_r of the compound is 60. Deduce its molecular formula. [1]

3.5 A 2.80 g sample of an oxide of iron is reduced completely by hydrogen, leaving 1.96 g of iron. (A_r: Fe 55.8, O 16.0)

(a) Calculate the empirical formula of the oxide, showing your working. [4]

(b) Write a balanced equation, with state symbols, for the reduction of this oxide by hydrogen. [2]

(c) The iron produced is dissolved in excess dilute sulfuric acid. Write the full equation and the ionic equation for this reaction. [3]

(d) A different oxide of iron has the empirical formula FeO. Explain why an empirical formula alone cannot give the molecular formula of a compound. [2]

Solutions

2.1 (a) $Ca(NO_3)_2$; (b) $Al_2(SO_4)_3$.

2.2 $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$.

3.1 C. Two Fe^{3+} balance three $SO_4^{2-} \rightarrow Fe_2(SO_4)_3$.

3.2 C. Empirical mass 14; $42/14 = 3 \rightarrow C_3H_6$.

3.3 $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$.

3.4 (a) moles: C $= 2.4/12 = 0.20$, H $= 0.4/1 = 0.40$, O $= 3.2/16 = 0.20$; divide by 0.20 $\rightarrow 1 : 2 : 1$; empirical formula CH_2O.
(b) empirical mass 30; $60/30 = 2 \rightarrow C_2H_4O_2$.

3.5 (a) mass of oxygen $= 2.80 - 1.96 = 0.84$ g; $n(\text{Fe}) = \frac{1.96}{55.8} = 0.0351$ mol and $n(\text{O}) = \frac{0.84}{16.0} = 0.0525$ mol; ratio $= 1 : 1.49 = 2 : 3$, so the empirical formula is Fe_2O_3.
(b) $Fe_2O_3(s) + 3H_2(g) \rightarrow 2Fe(s) + 3H_2O(g)$.
(c) $Fe(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2(g)$; ionic: $Fe(s) + 2H^+(aq) \rightarrow Fe^{2+}(aq) + H_2(g)$ — the sulfate is a spectator.
(d) The empirical formula gives only the **simplest whole-number ratio**; any molecule that is a whole-number multiple of that ratio has the same empirical formula, so the relative molecular mass is also needed.

17 Three equations are listed. x, y and z are all whole numbers.

1 $x\text{A}l + y\text{O}_2 \rightarrow z\text{A}l_2\text{O}_3$

2 $x\text{Mg} + y\text{O}_2 \rightarrow z\text{MgO}$

3 $x\text{Na} + y\text{O}_2 \rightarrow z\text{Na}_2\text{O}$

Which equations can be balanced if $x = 4$ and $z = 2$?

A 1 and 3 **B** 1 only **C** 2 only **D** 3 only

3 Cycloalkanes show similar chemical properties to alkanes but have the same empirical formula as alkenes.

(a) Define empirical formula.

....

.... [1]

(b) Cyclopentane, C_5H_{10}, has four cyclic structural isomers. One of these isomers is **C**, shown in Fig. 3.1.

Complete Fig. 3.1 to show two other cyclic structural isomers of C_5H_{10}.

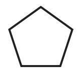
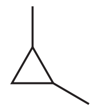
cyclopentane			**C**
			

Fig. 3.1

[2]

(c) Cyclopentane reacts with Cl_2 in the presence of ultraviolet light to form C_5H_9Cl.

(i) The reaction is initiated by the bond fission of Cl_2.

State the type of bond fission shown in the initiation step.

.... [1]

(ii) Complete the equations to show the two propagation steps that follow the initiation step.

propagation 1 C_5H_{10} + ... $\rightarrow$ $C_5H_9\bullet$ + ...

propagation 2 $C_5H_9\bullet$ + ... $\rightarrow$ ....
[2]

(iii) The final step is shown.

$$C_5H_9\bullet + Cl\bullet \rightarrow C_5H_9Cl$$

Give the name for this step in the reaction.

.... [1]

(d) Fig. 3.2 shows a reaction cycle involving cyclopentane, cyclopentene and C_5H_9Cl.

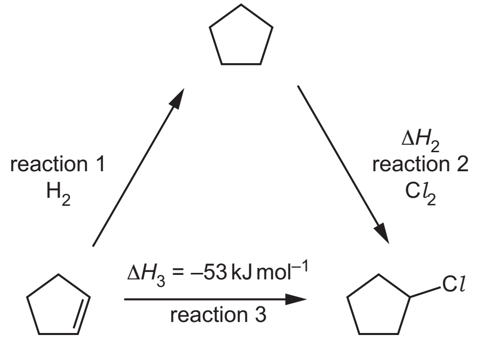


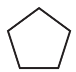
Fig. 3.2

(i) Identify a suitable reagent for reaction 3.

.... [1]

(ii) Use the data in Fig. 3.2 and in Table 3.1 to calculate the enthalpy change of reaction 2, ΔH_2.

Table 3.1

compound	enthalpy change of combustion, ΔH_c / $kJ\,mol^{-1}$
	–3292
	–3115
H_2	–286

ΔH_2 = ... $kJ\,mol^{-1}$ [2]

(e) Cyclopentene, C_5H_8, reacts with hot concentrated acidified $KMnO_4$ to form compound **W**, $C_5H_8O_4$.

(i) Draw the structure of **W**.

[1]

(ii) The infrared spectrum of **W** is shown in Fig. 3.3.

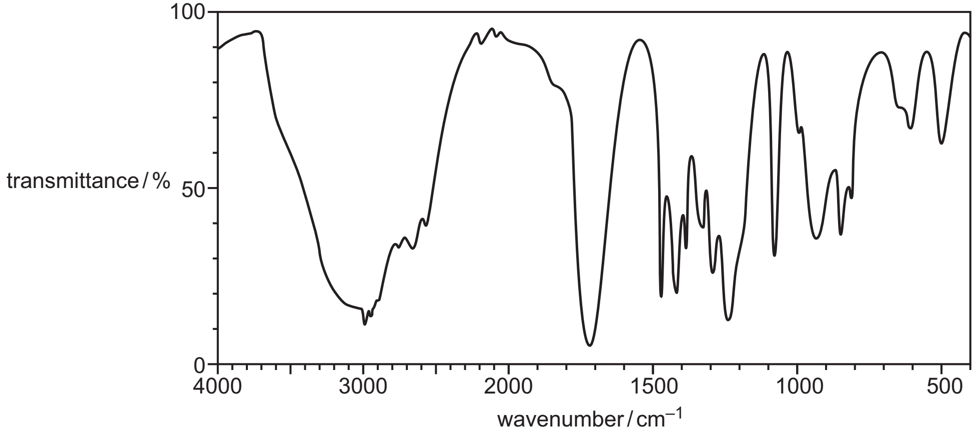


Fig. 3.3

Identify **two** absorptions in the infrared spectrum of **W** that would **not** be present in the infrared spectrum of cyclopentene.

- Write **1** or **2** on Fig. 3.3 against each of these two absorptions.
- Complete Table 3.2 to show which bond is responsible for each absorption that you have identified in Fig. 3.3.

Table 3.2

absorption	**1**	**2**
bond responsible		

[2]

Table 3.3

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

[Total: 13]

A-LEVEL CHEMISTRY • EXERCISE SHEET

2.4 Reacting masses and volumes

Name: ____________ Class: ________ Date: __________ **Total: 31 marks**

KEY WORDS limiting reagent 限量试剂 • titration 滴定 • percentage yield 产率 • stoichiometry 化学计量 • ion 离子

Objective

Build the skills to answer exam questions on **reacting masses and volumes** — **stoichiometry** 化学计量, **percentage yield** 产率, **limiting reagent** 限量试剂, gas volumes, and **titration** 滴定 calculations.

You must be able to:

- calculate reacting masses and percentage yield from a balanced equation
- identify the limiting reagent and calculate gas volumes ($n = V/24$)
- calculate solution concentrations from a titration ($n = cV$)

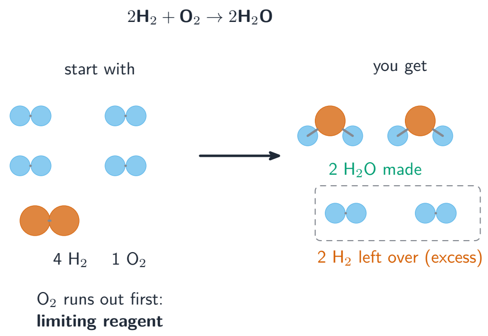
1 Worked examples

■ Reacting masses and percentage yield

Mole ratio comes from the equation. **Example.** Mass of MgO from 4.8 g Mg: $2Mg + O_2 \rightarrow 2MgO$. Moles Mg = 4.8/24 = 0.20; ratio 1:1 → 0.20 mol MgO; $m = 0.20 \times 40 = 8.0$ g.

$$\text{percentage yield} = \frac{\text{actual product}}{\text{maximum possible}} \times 100\%$$

■ Limiting reagent

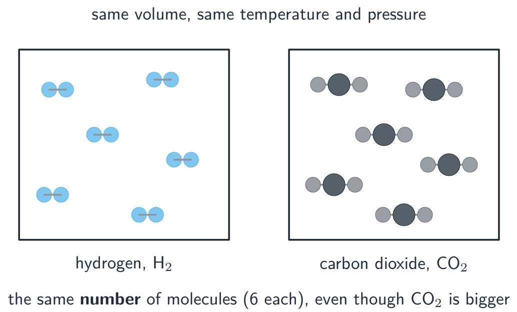


The limiting reagent runs out first and decides the product; the leftover is in excess

Find moles of each reactant, divide by its equation number — the smallest is the **limiting reagent**.

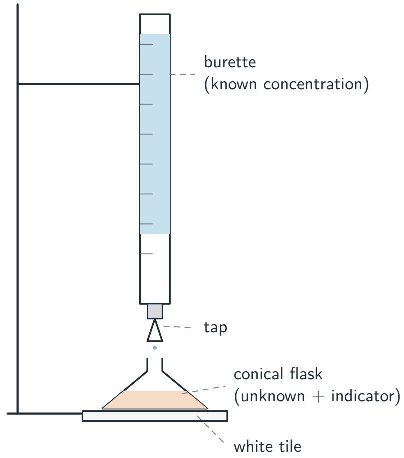
Gas volumes

At r.t.p. one mole of any gas = 24.0 dm^3, so $n = V/24.0$.



Equal gas volumes (same T, p) hold equal numbers of molecules

Titration ($n = cV$)



A titration finds an unknown concentration using a solution of known concentration

Example. 20.0 cm^3 of 0.100 mol dm^{-3} HCl neutralises 25.0 cm^3 NaOH (1:1). Moles HCl = 0.100 × 0.0200 = 2.00 × 10^{-3}; so NaOH conc = 2.00 × 10^{-3}/0.0250 = 0.0800 mol dm^{-3}.

The three routes through a mole calculation

Every quantitative question is the same shape: **convert to moles → use the equation's ratio → convert to the answer's unit.**

$$n = \frac{m}{M_r} \qquad n = c \times V(\text{dm}^3) \qquad n = \frac{V(\text{dm}^3)}{24.0}\ (\text{gas at r.t.p.}) \qquad pV = nRT$$

Gas volumes shortcut. At the same temperature and pressure, equal volumes contain equal numbers of moles (Avogadro), so for gases the equation's coefficients are **volume ratios directly** — no conversion needed. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ burns 24 cm^3 of methane in 48 cm^3 of oxygen and makes 24 cm^3 of carbon dioxide (the water is liquid at r.t.p. and is not counted).

Limiting reactant. Divide each reactant's moles by its coefficient; the **smallest** answer is limiting, and every product amount follows from it. The other reactant is in excess, and the leftover is the difference.

Percentage yield and atom economy are different questions and are often confused:

$$\text{percentage yield} = \frac{\text{actual moles of product}}{\text{theoretical moles}} \times 100 \qquad \text{atom economy} = \frac{M_r(\text{desired product})}{\sum M_r(\text{all products})} \times 100$$

Yield is about how well the reaction *ran*; atom economy is a property of the *equation* and is fixed before you start.

Worked example. 0.30 mol of H_2 reacts with 0.20 mol of O_2: $2H_2 + O_2 \rightarrow 2H_2O$. Find the limiting reactant, the water formed, and the excess left over.

1. H_2: $\frac{0.30}{2} = 0.15$; O_2: $\frac{0.20}{1} = 0.20$.
2. The smaller is hydrogen, so **hydrogen is limiting**.
3. Ratio $H_2 : H_2O = 2 : 2$, so 0.30 mol of water forms, which is $0.30 \times 18 = 5.4$ g.
4. Oxygen used = 0.15 mol, so $0.20 - 0.15 = 0.05$ mol of oxygen remains.

2 Practice

2.1 Calculate the mass of carbon dioxide made when 10 g of calcium carbonate decomposes: $CaCO_3 \rightarrow CaO + CO_2$ (M_r: $CaCO_3$ 100, CO_2 44). [2]

2.2 Calculate the volume of 0.50 mol of gas at r.t.p. [1]

2.3 Calculate the volume of oxygen, at r.t.p., needed to burn 50 cm^3 of propane completely. [2]

2.4 State the difference between percentage yield and atom economy. [2]

2.5 0.40 mol of N_2 reacts with 0.90 mol of H_2 to make ammonia. Identify the limiting reactant. [2]

3 Exam-style questions

3.1 24 cm^3 of methane is burned completely in oxygen: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. What volume of CO_2 is made (same conditions)? [1]

- **A** 12 cm^3
- **B** 24 cm^3
- **C** 48 cm^3
- **D** 96 cm^3

3.2 0.30 mol of H_2 reacts with 0.20 mol of O_2: $2H_2 + O_2 \rightarrow 2H_2O$. The limiting reagent is: [1]

- **A** hydrogen
- **B** oxygen
- **C** water
- **D** neither — they react exactly

3.3 In a titration, 25.0 cm^3 of sulfuric acid is exactly neutralised by 20.0 cm^3 of 0.100 mol dm^{-3} NaOH: $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$.

(a) Calculate the moles of NaOH used. [1]

(b) Calculate the concentration of the sulfuric acid. [3]

3.4 8.0 g of methanol is made from a reaction whose maximum possible yield is 12.8 g. Calculate the percentage yield. [2]

3.5 Ammonia is manufactured by the Haber process: $N_2 + 3H_2 \rightleftharpoons 2NH_3$. In one run, 2.80 kg of nitrogen is mixed with 0.750 kg of hydrogen. (A_r: N 14.0, H 1.0.)

(a) Calculate the amount, in mol, of each reactant. [2]

(b) Determine which reactant is limiting, showing your reasoning. [2]

(c) Calculate the maximum mass of ammonia that could be formed. [3]

(d) The plant actually collects 1.02 kg of ammonia. Calculate the percentage yield. [2]

(e) Calculate the atom economy of this reaction for ammonia, and explain why it takes that value. [3]

(f) Calculate the volume that the unreacted excess reactant would occupy at r.t.p. [2]

Solutions

2.1 moles $CaCO_3 = 10/100 = 0.10$; ratio 1:1 $\rightarrow$ 0.10 mol CO_2; $m = 0.10 \times 44 = 4.4$ g.

2.2 $V = 0.50 \times 24.0 = 12$ dm^3.

2.3 $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$, so the volume ratio is $1 : 5$; $50 \times 5 = 250$ cm^3.

2.4 Percentage yield compares the product actually obtained with the theoretical maximum, so it measures how well the reaction ran; atom economy compares the mass of the desired product with the total mass of all products, and is fixed by the equation itself.

2.5 N_2: $\frac{0.40}{1} = 0.40$; H_2: $\frac{0.90}{3} = 0.30$; the smaller value is hydrogen, so hydrogen is limiting.

3.1 B. Ratio $CH_4 : CO_2$ is 1:1, so 24 cm^3 of CO_2.

3.2 A. $0.30/2 = 0.15$ for H_2 vs $0.20/1 = 0.20$ for O_2; H_2 gives the smaller value, so hydrogen is limiting.

3.3 (a) $n = 0.100 \times 0.0200 = 2.00 \times 10^{-3}$ mol.
(b) ratio H_2SO_4 : NaOH is 1:2, so moles $H_2SO_4 = 1.00 \times 10^{-3}$; $c = n/V = 1.00 \times 10^{-3}/0.0250 = 0.0400$ mol dm^{-3}.

3.4 $\frac{8.0}{12.8} \times 100 = 62.5\%$.

3.5 (a) $n(N_2) = \frac{2800}{28.0} = 100$ mol; $n(H_2) = \frac{750}{2.0} = 375$ mol.
(b) N_2: $\frac{100}{1} = 100$; H_2: $\frac{375}{3} = 125$; nitrogen gives the smaller value, so nitrogen is limiting.
(c) Ratio $N_2 : NH_3 = 1 : 2$, so $n(NH_3) = 200$ mol; $M_r(NH_3) = 17.0$; $m = 200 \times 17.0 = 3400$ g $= 3.40$ kg.
(d) $\frac{1.02}{3.40} \times 100 = 30.0\%$.
(e) Ammonia is the only product, so the atom economy is 100%; every atom of both reactants ends up in the desired product, which is characteristic of an addition or combination reaction.
(f) Hydrogen used $= 3 \times 100 = 300$ mol, so $375 - 300 = 75$ mol remains; $V = 75 \times 24.0 = 1800$ dm^3.

4 Methane and steam react to produce hydrogen.

$$CH_4(g) + 2H_2O(g) \rightarrow CO_2(g) + 4H_2(g)$$

0.80 g of methane and 1.35 g of steam react. One of the reactants is used up.

Which volume of hydrogen, measured at room conditions, will be produced?

A 1.80 dm^3 **B** 3.60 dm^3 **C** 4.80 dm^3 **D** 7.20 dm^3

4 A solution containing 4.4 g of an organic acid is exactly neutralised by 25.0 cm^3 of 2.0 mol dm^{-3} sodium hydroxide. The acid has one COOH group in each molecule.

What is the empirical formula of the acid?

A CH_2O **B** C_2H_4O **C** $C_3H_6O_3$ **D** $C_4H_8O_2$

1 Hydrated ethanedioic acid is a diprotic acid with the formula $(COOH)_2\bullet\mathbf{x}H_2O$ where **x** is an integer.

Ethanedioic acid reacts with manganate(VII) ions when heated.

$$5(COOH)_2(aq) + 2MnO_4^-(aq) + 6H^+(aq) \rightarrow 10CO_2(g) + 2Mn^{2+}(aq) + 8H_2O(l)$$

You will determine the value of **x** in $(COOH)_2\bullet\mathbf{x}H_2O$ by titrating a solution containing ethanedioic acid with manganate(VII) ions.

- **FA 1** is 6.20 g dm^{-3} aqueous ethanedioic acid, $(COOH)_2\bullet\mathbf{x}H_2O$.
- **FA 2** is 0.0200 mol dm^{-3} potassium manganate(VII), $KMnO_4$.
- **FA 3** is 1.0 mol dm^{-3} sulfuric acid, H_2SO_4.

(a) Method

- Fill the burette with **FA 2**.
- Pipette 25.0 cm^3 of **FA 1** into a conical flask.
- Use the measuring cylinder to add approximately 20 cm^3 of **FA 3** to the conical flask.
- Place the conical flask on a tripod and gauze and heat carefully until the temperature of the solution is approximately 70 °C.
- Remove the flame.
- Carefully lift the hot conical flask and place it on the white tile under the burette.
- Add **FA 2** drop-wise for the first 2–3 cm^3. Any initial pink colouring may take several seconds to disappear.
- If the reaction mixture turns brown, reheat it to about 70 °C. If the brown colour disappears, continue the titration. If the brown colour remains, discard the contents of the flask and begin a new titration.
- The end-point is reached when a permanent pale pink colour is formed.
- Perform a rough titration with **FA 2**. Record your burette readings in the space below.

The rough titre is .... cm^3.

- Carry out as many titrations as you think necessary to obtain consistent results.
- Make sure any recorded results show the precision of your practical work.
- Record all your burette readings and the volume of **FA 2** added in each accurate titration.

Results

I	
II	
III	
IV	
V	
VI	
VII	

[7]

(b) From your accurate titration results, calculate a suitable mean value to be used in your calculations.

Show clearly how you obtained this value.

25.0 cm^3 of **FA 1** required .... cm^3 of **FA 2**. [1]

(c) Calculations

(i) Give your answers to **(c)(ii)**, **(c)(iii)** and **(c)(iv)** to the appropriate number of significant figures. [1]

(ii) Calculate the amount, in mol, of manganate(VII) ions, MnO_4^-, in the volume of **FA 2** calculated in **(b)**.

amount of MnO_4^- = ... mol [1]

(iii) Calculate the amount, in mol, of ethanedioic acid that reacts with the manganate(VII) ions in **(c)(ii)**.

amount of $(COOH)_2$ = ... mol

Hence calculate the concentration, in mol dm^{-3}, of ethanedioic acid in **FA 1**.

concentration of $(COOH)_2$ = ... mol dm^{-3} [2]

(iv) Calculate the relative molecular mass, M_r, of the ethanedioic acid in **FA 1**.

M_r = ... [1]

(v) Calculate the value of **x** in $(COOH)_2 \cdot xH_2O$.

Show your working.

x = ... [1]

(d) Explain why it is necessary to add **FA 3** in each titration.

....

.... [1]

[Total: 15]

2 Hydrated zinc sulfate has the formula $ZnSO_4$•**y**H_2O where **y** is an integer.

Hydrated zinc sulfate decomposes when heated, losing only its water of crystallisation and becoming anhydrous.

You will determine the value of **y** in $ZnSO_4$•**y**H_2O by heating the hydrated salt until it becomes anhydrous.

FA 4 is hydrated zinc sulfate, $ZnSO_4$•**y**H_2O.

(a) Method

- Weigh the crucible with its lid. Record the mass in the space for Results.
- Add between 3.20 g and 3.40 g of **FA 4** to the crucible.
- Weigh the crucible with its lid and **FA 4**. Record the mass.
- Place the crucible on the pipeclay triangle. Gently heat the crucible and contents for approximately 2 minutes with the lid on.
- Remove the lid. Heat the crucible and contents strongly for approximately 4 minutes.
- Replace the lid and leave the crucible and residue to cool for at least 5 minutes.

You may wish to begin work on Question 3 while the crucible is cooling.

- Weigh the crucible with its lid and its contents. Record the mass.
- Remove the lid. Heat the crucible strongly for approximately 3 minutes.
- Replace the lid and leave the crucible and residue to cool for at least 5 minutes.
- Weigh the crucible with its lid and its contents. Record the mass.
- Calculate the mass of **FA 4** used and the mass of residue obtained. Record the masses.

Results

I	
II	
III	
IV	
V	

[5]

(b) Calculations

(i) Calculate the amount, in mol, of anhydrous zinc sulfate residue formed in the decomposition of **FA 4**.

amount of $ZnSO_4$ = ... mol

Calculate the amount, in mol, of water of crystallisation lost.

amount of H_2O = ... mol [2]

(ii) Calculate the value of **y** in the formula $ZnSO_4$•**y**H_2O.

Show your working.

y = ... [2]

(c) A student suggests using this thermal decomposition method to investigate the number of moles of water of crystallisation in hydrated ethanedioic acid. The teacher says that this method is unsuitable.

Suggest why this method is unsuitable.

....

.... [1]

[Total: 10]

Qualitative analysis

For each test you should record all your observations in the spaces provided.

Examples of observations include:

- colour changes seen
- the formation of any precipitate and its solubility (where appropriate) in an excess of the reagent added
- the formation of any gas and its identification (where appropriate) by a suitable test.

You should record clearly at what stage in a test an observation is made.

Where no change is observed, you should write 'no change'.

Where reagents are selected for use in a test, the name or correct formula of the element or compound must be given.

If any solution is warmed, a boiling tube must be used. If a solid is heated, a hard-glass test-tube must be used.

Rinse and reuse test-tubes and boiling tubes where possible.

No additional tests should be attempted.

2 In this experiment you will determine the percentage by mass of a sodium halide impurity present in a sample of sodium hydrogencarbonate by titration.

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

FB 4 is an aqueous solution made by dissolving 17.20 g of the impure sodium hydrogencarbonate in each dm^3 of solution.
FB 5 is 0.200 mol dm^{-3} hydrochloric acid, HC*l*.
FB 6 is methyl orange indicator.

(a) Method

- Fill the burette with **FB 5**.
- Pipette 25.0 cm^3 of **FB 4** into a conical flask.
- Add several drops of **FB 6** to the conical flask.
- Perform a rough titration and record your burette readings in the space below.

The rough titre is .... cm^3.

- Carry out as many accurate titrations as you think necessary to obtain consistent results.
- Make sure any recorded results show the precision of your practical work.
- Record all your burette readings and the volume of **FB 5** added in each accurate titration.

Keep FB 4 for use in Question 3.

Results

I	
II	
III	
IV	
V	
VI	
VII	

[7]

(b) From your accurate titration results, calculate a suitable mean value to be used in your calculations.
Show clearly how you obtained this value.

25.0 cm^3 of **FB 4** required .... cm^3 of **FB 5**. [1]

(c) Calculations

(i) Give your answers to **(c)(ii)** and **(c)(iii)** to an appropriate number of significant figures. [1]

(ii) Use your answer to **(b)** to calculate the amount, in mol, of hydrochloric acid in your mean titre.

amount of HC*l* = ... mol

Hence determine the amount, in mol, of sodium hydrogencarbonate present in 25.0 cm^3 of **FB 4**.

amount of $NaHCO_3$ = ... mol [1]

(iii) Calculate the mass of sodium hydrogencarbonate present in each dm^3 of solution.

mass of $NaHCO_3$ = ... g

Hence calculate the percentage by mass of the sodium halide impurity in **FB 4**.
Show your working.

percentage by mass = ... % [2]

(d) A student carries out the experiment in Question 1 using the impure sodium hydrogencarbonate dissolved to make **FB 4**.
State how this affects the value of ΔH_1 determined in **1(b)(iii)** compared to the value the student would get if pure sodium hydrogencarbonate were used.

....

....

State what assumption you have made about the sodium halide impurity.

....

....

[2]

[Total: 14]

Qualitative analysis

For each test you should record all your observations in the spaces provided.

Examples of observations include:
- colour changes seen
- the formation of any precipitate and its solubility (where appropriate) in an excess of the reagent added
- the formation of any gas and its identification (where appropriate) by a suitable test.

You should record clearly at what stage in a test an observation is made.

Where no change is observed, you should write ‘no change’.

Where reagents are selected for use in a test, the name or correct formula of the element or compound must be given.

If any solution is warmed, a boiling tube must be used. If any solid is heated a hard-glass test-tube must be used.

Rinse and reuse test-tubes and boiling tubes where possible.

No additional tests should be attempted.

1 The concentration of aqueous chloride ions can be found by titration with aqueous silver nitrate, $AgNO_3(aq)$.

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

The indicator used is aqueous potassium chromate(VI), $K_2CrO_4(aq)$.

As $AgNO_3(aq)$ is added to aqueous chloride ions, a white precipitate of $AgCl(s)$ is formed.

When all the chloride ions have reacted, further addition of $AgNO_3(aq)$ leads to the formation of a red precipitate of silver chromate(VI), $Ag_2CrO_4(s)$. The first appearance of the red precipitate shows the end-point of the titration.

A student carries out an experiment to determine the number of molecules of water of crystallisation, *x*, in hydrated barium chloride, $BaCl_2 \cdot xH_2O(s)$.

(a) The student makes $250.0\,cm^3$ of $0.0500\,mol\,dm^{-3}$ $AgNO_3(aq)$ to use for the titration.

(i) Calculate the mass of solid silver nitrate, $AgNO_3(s)$, needed to make $250.0\,cm^3$ of $0.0500\,mol\,dm^{-3}$ $AgNO_3(aq)$.

Give your answer to **two** decimal places.

mass of $AgNO_3(s)$ = ... g [1]

(ii) Describe how the student should make $250.0\,cm^3$ of $0.0500\,mol\,dm^{-3}$ $AgNO_3(aq)$ starting from the mass of $AgNO_3(s)$ calculated in **(a)(i)** in a $50\,cm^3$ beaker.

Give the name and size of any key apparatus used.

Write your answer using a series of numbered steps.

....

....

....

....

....

....

.... [3]

(b) The student uses the following method.

step 1 Dissolve 1.58 g of $BaCl_2 \cdot xH_2O(s)$ to form $250\,cm^3$ of aqueous solution. Label this solution **A**.

step 2 Transfer $20.0\,cm^3$ of solution **A** into a conical flask.

step 3 Add aqueous sodium sulfate, $Na_2SO_4(aq)$, to the flask and swirl the mixture to remove barium ions from the solution.

step 4 Add 2–3 drops of $K_2CrO_4(aq)$ indicator to the flask.

step 5 Titrate the contents of the flask against $0.0500\,mol\,dm^{-3}$ $AgNO_3(aq)$.

step 6 Repeat steps 2 to 5 to collect sufficient data for analysis.

(i) Suggest a suitable piece of apparatus for transferring $20.0\,cm^3$ of solution **A** in step 2.

.... [1]

(ii) Suggest why barium ions are removed in step 3 before performing the titration.

....

.... [1]

(iii) Suggest why chemically resistant gloves should be worn to carry out step 4.

.... [1]

(c) The student's results are shown in Table 1.1.

Table 1.1

	rough titration	titration 1	titration 2	titration 3
burette reading (final) / cm^3	20.10	40.55	20.75	20.90
burette reading (initial) / cm^3	0.00	20.25	0.05	0.30
titre / cm^3	20.10	20.30	20.70	20.60

The student uses the titres from titrations 2 and 3 shown in Table 1.1 to calculate a mean titre value of $20.65\,cm^3$.

(i) Explain why only these two values are used.

.... [1]

(ii) Calculate the percentage error in the titre volume for titration 3.
Show your working.

percentage error = ... [1]

(d) The equation for the reaction of silver nitrate with barium chloride is shown.

$$2AgNO_3(aq) + BaCl_2(aq) \rightarrow Ba(NO_3)_2(aq) + 2AgCl(s)$$

(i) Calculate the amount, in mol, of $AgNO_3(aq)$ in the mean titre of $20.65\,cm^3$.

amount of $AgNO_3$ = ... mol [1]

(ii) Calculate the amount, in mol, of $BaCl_2(aq)$ in $250\,cm^3$ of solution **A**.

amount of $BaCl_2$ = ... mol [1]

(iii) Calculate the value of x in the formula $BaCl_2 \bullet xH_2O$.

x = ... [2]

(e) Another student uses a different experimental method to check the value of x obtained by the method described in **(b)**.

Give a **brief** description of another method, not involving titration, that could be used to determine the value of x in the formula $BaCl_2 \bullet xH_2O(s)$. Write your answer using a series of numbered steps.

Your plan should include details of the following:
- the apparatus and method you would use
- the measurements you would make.

You are provided with standard laboratory apparatus.

....

....

....

....

....

....

....

....

.... [3]

[Total: 16]

2 A student carries out an experiment to determine the concentration of aqueous sulfate ions, $SO_4^{2-}(aq)$, in a sample of lake water.

(a) The student uses the following method.

step 1 Transfer $25.00\,cm^3$ of the lake water sample to a beaker and record its conductivity as shown in Fig. 2.1.

step 2 Add $5.00\,cm^3$ of $0.100\,mol\,dm^{-3}$ aqueous barium hydroxide, $Ba(OH)_2(aq)$, to the beaker.

step 3 Stir the mixture and record the conductivity of the contents of the beaker as shown in Fig. 2.1.

step 4 Repeat steps 2 and 3 until a total of $40.00\,cm^3$ of $0.100\,mol\,dm^{-3}$ $Ba(OH)_2(aq)$ has been added to the beaker.

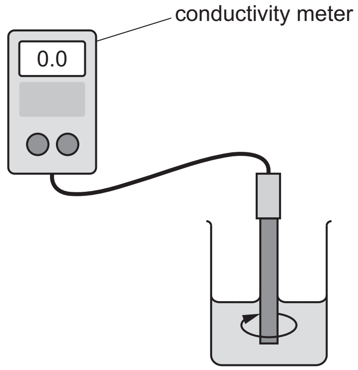


Fig. 2.1

(i) Suggest a suitable piece of apparatus to transfer $25.00\,cm^3$ of the lake water sample to the beaker in step 1.

.... [1]

(ii) $0.100\,mol\,dm^{-3}$ $Ba(OH)_2(aq)$ is an irritant to skin and eyes. Other than wearing safety goggles, state **one** safety precaution that the student should take when conducting this experiment.

.... [1]

(b) The student's results are given in Table 2.1.

A correction can be applied to the conductivity values to take into account dilution of the solution as its volume increases using the following equation.

$$\text{corrected conductivity} = \text{measured conductivity} \times \frac{(\text{total volume in beaker})}{25.00}$$

Table 2.1

reading number	volume of $0.100\,mol\,dm^{-3}$ $Ba(OH)_2(aq)$ added to beaker / cm^3	total volume in beaker / cm^3	measured conductivity / $\mu S\,cm^{-1}$	corrected conductivity / $\mu S\,cm^{-1}$
1	0.00	25.00	37000	37000
2	5.00		23000	27600
3	10.00		12000	16800
4	15.00		2300	3680
5	20.00		5000	
6	25.00		12000	
7	30.00		18000	
8	35.00		21000	
9	40.00		24500	

(i) Complete Table 2.1. [2]

(ii) Identify the independent variable in this experiment.

.... [1]

(c) Plot a graph on the grid in Fig. 2.2 to show the relationship between corrected conductivity and volume of 0.100 mol dm^{-3} $Ba(OH)_2$ added to beaker.

Use a cross (×) to plot each data point.

Draw a line of best fit using readings 1 to 4 and another line of best fit using readings 5 to 9. Extend the lines so that they intersect.

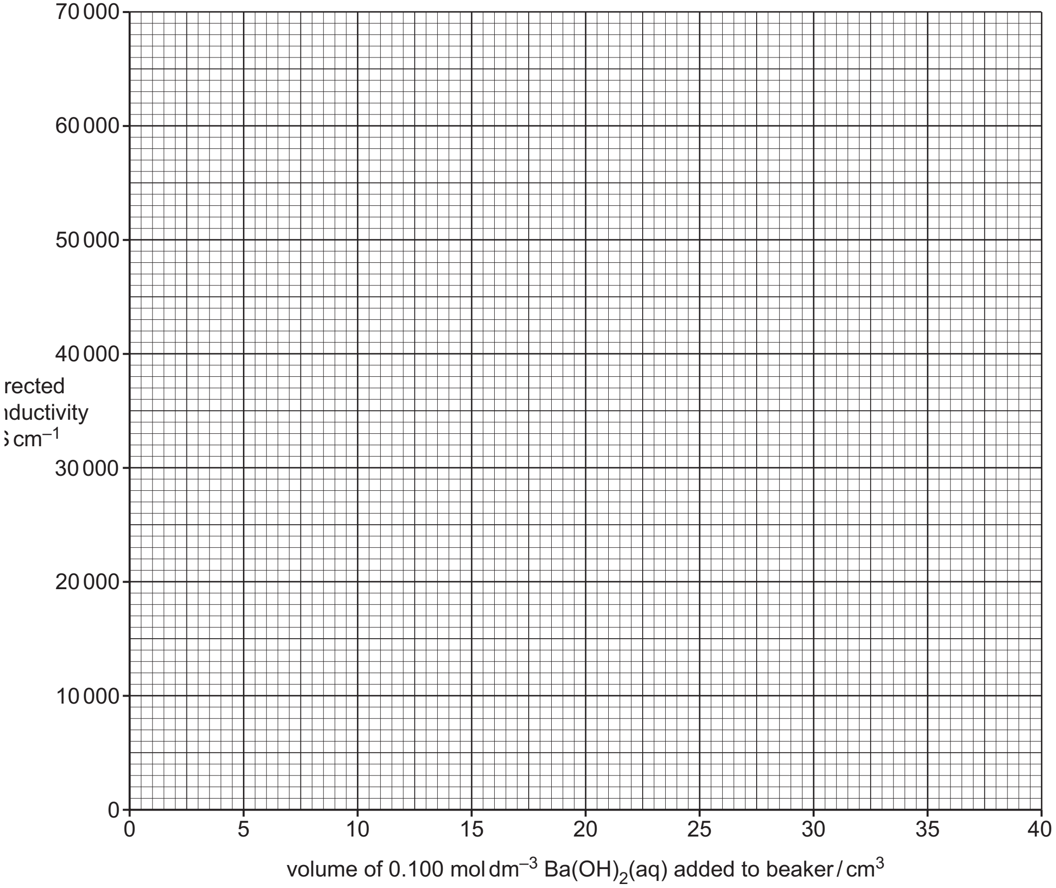


Fig. 2.2

[2]

(d) The point on the graph where the two lines intersect indicates the volume of 0.100 mol dm^{-3} $Ba(OH)_2$(aq) required to react exactly with the SO_4^{2-}(aq) present in 25.00 cm^3 of lake water being tested.

(i) Use the graph in Fig. 2.2 to determine the volume of 0.100 mol dm^{-3} $Ba(OH)_2$(aq) required to react exactly with SO_4^{2-}(aq) in the lake water sample.

volume required = ... cm^3 [1]

(ii) The equation for the reaction taking place in the beaker is shown.

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$$

Use your answer in **(d)(i)** to calculate the concentration of SO_4^{2-}(aq) in the lake water sample.

concentration of SO_4^{2-}(aq) = ... mol dm^{-3} [1]

(e) The concentration of SO_4^{2-}(aq) in a sample of water can also be determined by measuring the mass of precipitate produced when excess $Ba(OH)_2$(aq) is added to the sample.

The student suggests the following method.

step 1 Place 25.0 cm^3 of the water sample in a conical flask.

step 2 Add excess 0.100 mol dm^{-3} $Ba(OH)_2$(aq) to the flask.

step 3 Filter the contents of the flask.

step 4 Dry the residue in a warm oven.

step 5 Measure the mass of residue.

(i) Draw a labelled diagram to describe the arrangement of apparatus that would be needed to complete step 3.

[1]

(ii) Suggest a step that the student should add between steps 3 and 4 to improve this method.

.... [1]

(iii) Describe what the student can do to ensure that the residue weighed in step 5 is completely dry.

....

.... [1]

(iv) The mass of residue is used to calculate the concentration of SO_4^{2-}(aq).

Suggest the effect, if any, on the concentration of SO_4^{2-}(aq) that is calculated if the residue is **not** completely dried in step 4.

Explain your answer.

effect on concentration of SO_4^{2-}(aq) calculated ....

explanation ....

....

[1]

[Total: 13]

Important values, constants and standards

molar gas constant	$R = 8.31\ J\ K^{-1}\ mol^{-1}$
Faraday constant	$F = 9.65 \times 10^4\ C\ mol^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23}\ mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\ C$
molar volume of gas	$V_m = 22.4\ dm^3\ mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\ dm^3\ mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\ mol^2\ dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\ kJ\ kg^{-1}\ K^{-1}$ ($4.18\ J\ g^{-1}\ K^{-1}$)

The Periodic Table of Elements

Group

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
								1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0												5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3												13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1		21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6		39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3		57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –		89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

Key: atomic number / **atomic symbol** / name / relative atomic mass

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

1 Iron is an element that is essential in the human diet. Some people need to take iron supplement tablets to ensure an adequate intake of iron.

You will investigate the mass of iron in an iron supplement tablet by titrating a solution with potassium manganate(VII).

$$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$$

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$$

FB 1 is an aqueous solution of iron supplement tablets made by dissolving 14 tablets in 1.00 dm^3 of solution. The iron in each tablet is iron(II) sulfate, $FeSO_4 \bullet 7H_2O$.
FB 2 is 0.0100 $mol\,dm^{-3}$ acidified aqueous potassium manganate(VII), $KMnO_4$.
FB 3 is dilute sulfuric acid, H_2SO_4.

(a) Method

- Fill a burette with **FB 2**.
- Pipette 25.0 cm^3 of **FB 1** into a conical flask.
- Use the 25 cm^3 measuring cylinder to add 10.0 cm^3 of **FB 3** to the conical flask.
- Perform a rough titration and record your burette readings in the space below.

The rough titre is .... cm^3.

- Carry out as many accurate titrations as you think necessary to obtain consistent results.
- Make sure any recorded results show the precision of your practical work.
- Record, in a suitable form in the space below, all your burette readings and the volume of **FB 2** added in each accurate titration.

Rinse the burette with distilled water and leave to drain while you continue Question 1.

Results

I	
II	
III	
IV	
V	
VI	
VII	

[7]

(b) From your accurate titration results, calculate a suitable mean value to use in your calculations. Show clearly how you obtain the mean value.

25.0 cm^3 of **FB 1** required .... cm^3 of **FB 2**. [1]

(c) Calculations

(i) Give your answers to **(c)(ii)**, **(c)(iii)** and **(c)(iv)** to an appropriate number of significant figures. [1]

(ii) Calculate the amount, in mol, of manganate(VII) ions in the volume of **FB 2** in **(b)**.

amount of MnO_4^- = ... mol [1]

(iii) Use your answer to **(c)(ii)** and the equations at the start of the question to calculate the concentration, in mol dm^{-3}, of iron(II) ions in **FB 1**.

concentration of Fe^{2+} = ... mol dm^{-3} [1]

(iv) Use your answer to **(c)(iii)** to calculate the concentration, in g dm^{-3}, of iron(II) ions in **FB 1**.

concentration of Fe^{2+} = ... g dm^{-3} [1]

(v) The manufacturer of the iron supplement tablets used to make **FB 1** claims that each tablet contains a minimum of 150 mg of Fe^{2+}.

Use your answer to **(c)(iv)** and the information given about **FB 1** to determine whether this claim is correct. Show your working.

[1]

(d) A student used all the **FB 3** and suggests that dilute hydrochloric acid would be a suitable replacement.
Suggest whether the student is correct or not. Explain your answer.

....

....

.... [1]

[Total:14]