HOLIDAY HOMEWORK 假期作业

AS-Level Chemistry

Exercise sheets and past-paper practice, topic by topic.

每个单元：练习卷 + 历年真题。

For class or self-study • no answer keys included.

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1 Atomic structure – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
atoms	原子			
nucleus	原子核			
electrons	电子			
protons	质子			
neutrons	中子			
shells	壳层			
proton	质子			
neutron	中子			
electron	电子			
proton number	质子数			
nucleon number	核子数			
ion	离子			
cation	阳离子			
anion	阴离子			
Isotopes	同位素			

English	中文	Write it 3 times (English)		
same chemical properties	化学性质			
physical properties	物理性质			
density	密度			

Recall

At IGCSE you learned that everything is made of **atoms** 原子, and that an atom has a tiny central **nucleus** 原子核 with **electrons** 电子 around it. Now we sharpen those ideas.

- The nucleus holds **protons** 质子 and **neutrons** 中子.
- Electrons sit in **shells** 壳层 around the nucleus.

Nothing here is harder than IGCSE — it just lines up the ideas the AS course starts with.

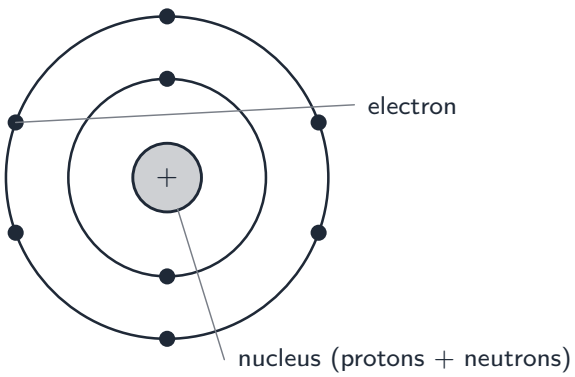
New ideas

Read these first, then do the Practice.

1 The three particles

An atom is mostly empty space: a tiny heavy nucleus, with light electrons moving in shells around it.

Particle	Relative charge	Relative mass
proton 质子	+1	1
neutron 中子	0	1
electron 电子	−1	$\frac{1}{1836}$ (≈ 0)



2 Proton number and nucleon number

- the **proton number** 质子数 (Z) is the number of protons (it names the element).
- the **nucleon number** 核子数 (A) is the number of protons **plus** neutrons.

So the number of neutrons is $A - Z$. In a neutral atom, the number of electrons = the number of protons = Z.

Worked example. Sodium $^{23}_{11}\mathrm{Na}$ has $Z = 11$ protons and $A = 23$, so $23 - 11 = 12$ neutrons; being neutral it has 11 electrons.

3 Ions

An **ion** 离子 is an atom that has lost or gained electrons:

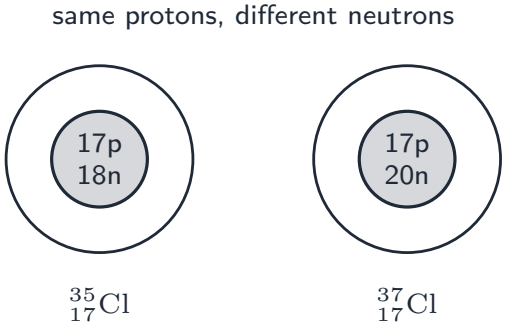
- a positive ion (**cation** 阳离子) has lost electrons (fewer electrons than protons).
- a negative ion (**anion** 阴离子) has gained electrons.

Worked example. $^{27}_{13}\mathrm{Al}^{3+}$ has 13 protons, $27 - 13 = 14$ neutrons, and $13 - 3 = 10$ electrons.

4 Isotopes

Isotopes 同位素 are atoms of the same element with the **same** number of protons but a **different** number of neutrons (same Z, different A).

- they have the **same chemical properties** 化学性质 (same electrons).
- they can have different **physical properties** 物理性质 such as **density** 密度 (different mass).



Watch out: almost all of an atom's mass sits in the nucleus — an electron weighs only about $\frac{1}{1836}$ as much as a proton, so the electrons add almost nothing to the mass.

Practice

Try these in order.

1.1 State the relative charge and relative mass of (a) a proton, (b) a neutron, (c) an electron. [3]

1.2 An atom has $Z = 17$ and $A = 35$. How many (a) protons, (b) neutrons, (c) electrons does it have? [3]

1.3 Define *proton number* and *nucleon number*. [2]

1.4 Work out the number of protons, neutrons and electrons in $^{24}_{12}Mg^{2+}$. [3]

1.5 What is meant by *isotopes*? [2]

1.6 Explain why two isotopes of an element have the same chemical properties. [2]

1.7 Challenge. Chlorine exists as ^{35}Cl and ^{37}Cl. Explain why the relative atomic mass of chlorine (35.5) is not a whole number. [2]

1 Helium forms an ion $^{3}_{2}He^{+}$.

Three statements about this ion are listed.

1 It contains two protons.

2 It contains three neutrons.

3 It contains one electron.

Which statements are correct?

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

3 Methanethiol, CH_3SH, burns as shown.

$$CH_3SH + 3O_2 \rightarrow CO_2 + SO_2 + 2H_2O$$

A sample of 10 cm^3 of methanethiol gas was reacted with 60 cm^3 of oxygen. Both samples were measured at room conditions.

What would be the final volume of the resultant mixture of gases measured at room temperature?

A 20 cm^3 **B** 30 cm^3 **C** 50 cm^3 **D** 70 cm^3

1 Manganese, Mn, and its compounds are widely used in many chemical reactions.

(a) Mn is usually found as a single isotope, manganese-55.

(i) Determine the number of protons, neutrons and electrons in an atom of manganese-55.

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

(ii) Define isotopes.

.....

..... [1]

(iii) A sample of manganese from the Moon is found to contain manganese-53 in addition to manganese-55.

State the two pieces of information needed to determine the relative atomic mass, A_r, of manganese in this sample.

1 .....

2 .....
[2]

(b) The shorthand electronic configuration of manganese is [Ar] $3d^5\ 4s^2$.

(i) Complete the full electronic configuration of manganese.

..... $3d^5\ 4s^2$ [1]

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

..... [1]

(c) Manganese(IV) oxide reacts with methanal, CH_2O, in acidic conditions to produce carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.

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

half-equation 2 $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$

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

.....

..... [1]

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

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

(iii) Construct the ionic equation for the reaction of manganese(IV) oxide with methanal in acidic conditions.

..... [2]

[Total: 10]

1 Atomic structure – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
shells	壳层			
sub-shells	亚层			
orbitals	轨道			
first ionisation energy	第一电离能			
nuclear charge	核电荷			
atomic radius	原子半径			
shielding	屏蔽			

Recall

From Part 1 you know electrons sit in **shells** 壳层. Here we look more closely at how they are arranged, and at the energy needed to remove one.

- At IGCSE you wrote electron arrangements like 2,8,1.
- Now we split shells into **sub-shells** 亚层 (s, p, d).

New ideas

Read these first, then do the Practice.

1 Shells, sub-shells and orbitals

Each shell ($n = 1, 2, 3, \dots$) is split into **sub-shells** 亚层 (s, p, d). Each sub-shell is made of **orbitals** 轨道, and each orbital holds up to **two** electrons.

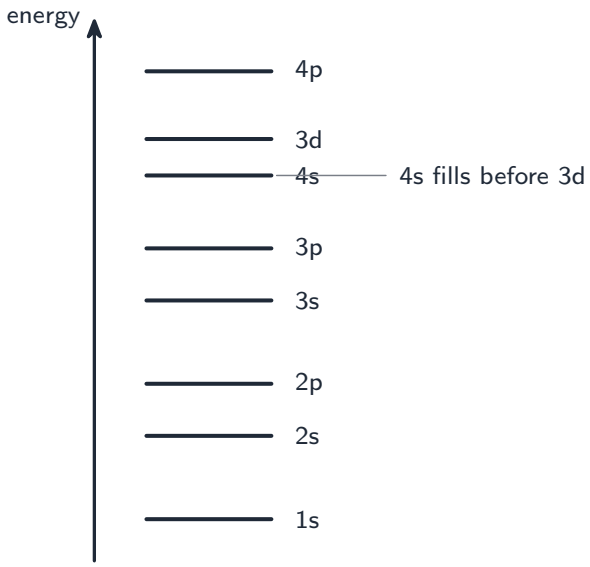
Sub-shell	Orbitals	Max electrons
s	1	2
p	3	6
d	5	10

2 Filling order

Electrons fill the lowest-energy sub-shell first:

$$1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p$$

The surprise: **4s fills before 3d** (it is slightly lower in energy).



Worked example. Iron (Fe, $Z = 26$): $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^6\,4s^2$, or in short $[Ar]\,3d^6\,4s^2$.

3 First ionisation energy

The **first ionisation energy** 第一电离能 is the energy to remove one electron from each atom in one mole of gaseous atoms:

$$X(g) \rightarrow X^+(g) + e^-$$

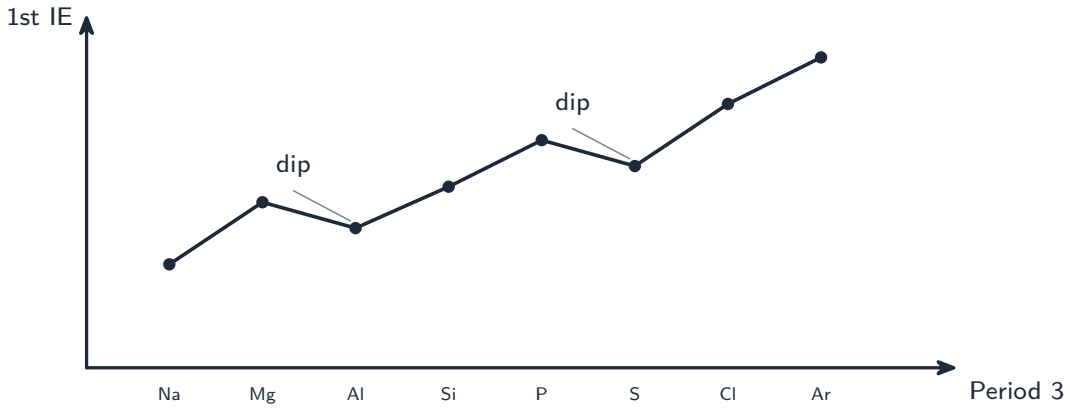
It depends on three factors:

- **nuclear charge** 核电荷 — more protons → stronger pull → higher.
- **atomic radius** 原子半径 — further out → weaker pull → lower.

- **shielding** 屏蔽 — more inner shells → weaker pull → lower.

■ 4 The trend across Period 3

Across a period the first ionisation energy generally **rises** (more nuclear charge, similar shielding). But there are two small **dips** — at Al and at S — which are evidence that sub-shells exist.



Watch out: although 4s fills *before* 3d, the 4s electrons leave *first* when the atom ionises — so Fe^{2+} is $[Ar]\,3d^6$, not $[Ar]\,3d^4\,4s^2$.

Practice

Try these in order.

1.1 How many electrons fill (a) an s sub-shell, (b) a p sub-shell, (c) a d sub-shell? [3]

1.2 Which fills first, 4s or 3d? [1]

1.3 Write the full electronic configuration of an atom with $Z = 20$ (calcium). [2]

1.4 Define the *first ionisation energy*, including a balanced equation for element X. [2]

1.5 Explain why the first ionisation energy generally rises across a period. [2]

1.6 Down a group, the first ionisation energy falls. Give two reasons why. [2]

1.7 Challenge. Across Period 3 the first ionisation energy dips at aluminium. Explain why aluminium's first ionisation energy is lower than magnesium's. [2]

1 What is the electronic configuration for the particle $^{27}_{13}Al^{+}$?

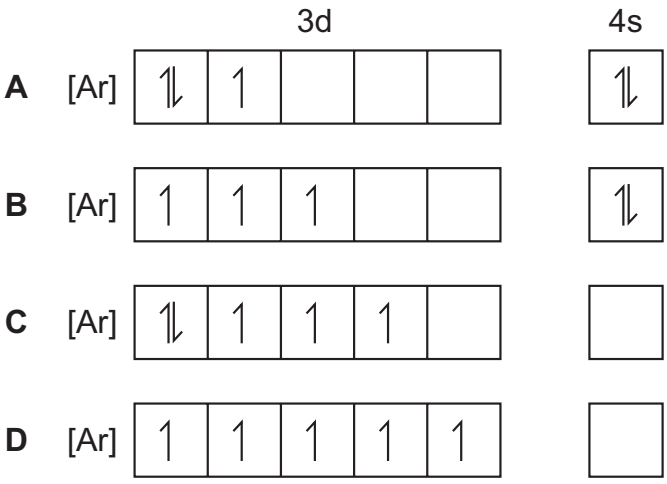
A $1s^2 2s^2 2p^6 3s^1 3p^1$

B $1s^2 2s^2 2p^6 3s^2$

C $1s^2 2s^2 2p^6 3s^2 3p^2$

D $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4s^1$

1 What is the electrons in boxes notation for the Fe^{3+} ion?



4 Which statement is correct?

A The relative atomic mass of a ^{35}Cl atom is 35.5.

B The relative molecular mass of O_2 is 16.0.

C The relative formula mass of $CaCO_3$ is 100.1.

D The relative isotopic mass of a ^{24}Mg atom is 24.3.

2 Which equation has an energy change that is equal to the first ionisation energy of bromine?

A $Br(g) \rightarrow Br^{+}(g) + e^{-}$

B $Br(g) \rightarrow Br^{-}(g) - e^{-}$

C $\frac{1}{2}Br_2(g) \rightarrow Br^{+}(g) + e^{-}$

D $\frac{1}{2}Br_2(g) \rightarrow Br^{-}(g) - e^{-}$

7 X and Y are different elements in Period 3.

Atoms of X and Y each have only one completely filled orbital in their highest occupied energy sub-shell.

Y has a greater first ionisation energy than X.

Which row shows the structure and bonding in X and Y?

	X	Y
A	giant metallic	giant metallic
B	giant metallic	simple molecular
C	giant covalent	simple molecular
D	simple molecular	simple molecular

2 Atoms, molecules and moles – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
relative atomic mass	相对原子质量			
mole	摩尔			
relative molecular mass	相对分子质量			
isotopes	同位素			
Avogadro constant	阿伏伽德罗常量			
molar mass	摩尔质量			

Recall

At IGCSE you used **relative atomic mass** 相对原子质量 and the idea of the **mole** 摩尔. Now we make those tools sharp, ready for AS calculations.

- Atoms are too light to weigh in grams, so we compare every mass to one standard.
- The mole lets us count huge numbers of particles by weighing.

Nothing here is harder than IGCSE — it just lines up the tools.

New ideas

Read these first, then do the Practice.

1 Relative masses

- the **relative atomic mass** 相对原子质量 (A_r) is the average mass of an element's atoms compared with $\frac{1}{12}$ of a carbon-12 atom.
- the **relative molecular mass** 相对分子质量 (M_r) is the sum of the A_r values of all the atoms in a molecule.

A_r is a **weighted average** over the **isotopes** 同位素. For chlorine (75% ^{35}Cl, 25% ^{37}Cl):

$$A_r = (0.75 \times 35) + (0.25 \times 37) = 35.5$$

$$A_r = (0.75 \times 35) + (0.25 \times 37) = 35.5$$

2 The mole and the Avogadro constant

One **mole** 摩尔 contains the **Avogadro constant** 阿伏伽德罗常量 of particles:

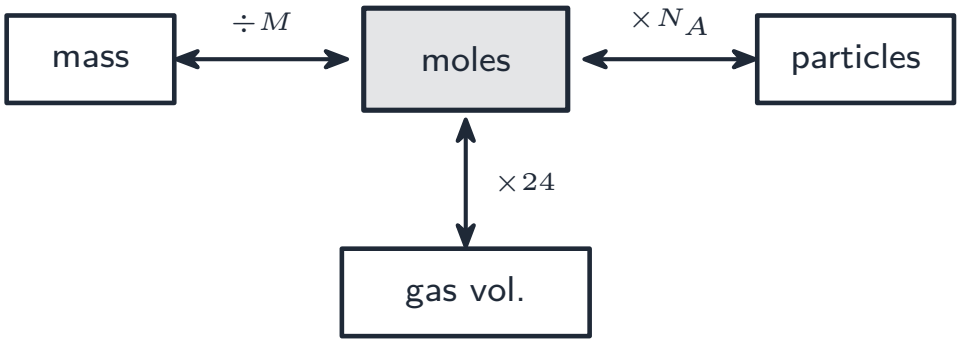
$$N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$$

The mass of one mole in grams equals the relative mass — the **molar mass** 摩尔质量 (M, in g mol^{-1}).

3 The key equation

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

where n = amount (mol), m = mass (g), M = molar mass.



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

Watch out: when finding M_r, multiply each atom's A_r by how many of that atom there are — H_2O is $2(1) + 16 = 18$, not $1 + 16$.

Practice

Try these in order. Use A_r: H = 1, C = 12, N = 14, O = 16, Na = 23.

2.1 State the value of the Avogadro constant, with its units. [1]

2.2 Work out the relative molecular mass, M_r, of (a) H_2O, (b) CO_2. [2]

2.3 How many moles are in 11.5 g of sodium ($A_r = 23$)? [2]

2.4 How many moles are in 36 g of water, H_2O? [2]

2.5 Bromine has two isotopes: 50% ^{79}Br and 50% ^{81}Br. Calculate its relative atomic mass. [2]

2.6 How many molecules are in 0.50 mol of carbon dioxide? [1]

2.7 Challenge. How many oxygen atoms are there in 8.8 g of carbon dioxide, CO_2

$(M = 44)$? [3]

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

The Periodic Table of Elements

Group																	
1	2											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	3	4	5	6	7	8	9	10	11	12	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 –

3 What contains 9.03×10^{23} oxygen atoms?

A 0.25 mol aluminium oxide

B 0.75 mol sulfur dioxide

C 1.5 mol sulfur trioxide

D 3.0 mol water

2 Atoms, molecules and moles – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
stoichiometry	化学计量			
limiting reagent	限量试剂			
excess	过量			
concentration	浓度			
solute	溶质			
titration	滴定			

Recall

From Part 1 you can use $n = m/M$. Here we use the mole to work out **reacting masses**, gas volumes and solution concentrations.

- A balanced equation gives the **mole ratio** of the reactants and products.
- At IGCSE you did titrations — now we calculate the concentration.

New ideas

Read these first, then do the Practice.

■ 1 Reacting masses

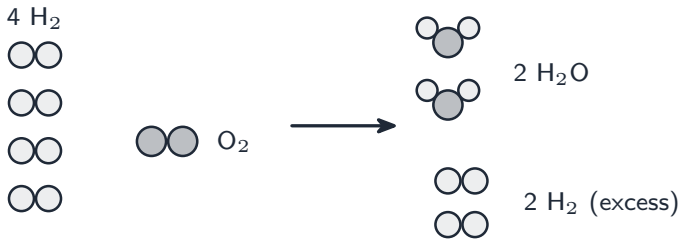
The numbers in a balanced equation give the **stoichiometry** 化学计量 (the mole ratio). To find a reacting mass: mass → moles → (use the ratio) → moles → mass.

Worked example. Mass of MgO from 4.8 g of Mg in $2Mg + O_2 \rightarrow 2MgO$ (A_r: Mg

= 24, O = 16): moles Mg = 4.8/24 = 0.20; ratio Mg : MgO = 1 : 1, so 0.20 mol MgO; mass = $0.20 \times 40 = 8.0$ g.

2 Limiting reagent

When two reactants are mixed, one runs out first — the **limiting reagent** 限量试剂. It decides how much product forms. The other is in **excess** 过量.



3 Gas volumes

At **room temperature and pressure** (r.t.p.), one mole of any gas takes up 24.0 dm^3:

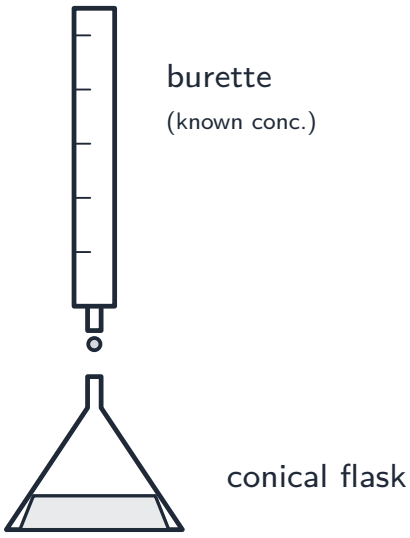
$$n = \frac{V}{24.0} \qquad (V \text{ in } dm^3)$$

4 Solution concentrations and titration

The **concentration** 浓度 (c, in mol dm^{-3}) is the amount of **solute** 溶质 per dm^3:

$$n = c \times V \qquad (V \text{ in } dm^3,\ 1000\ cm^3 = 1\ dm^3)$$

A **titration** 滴定 finds an unknown concentration by reacting it with a solution of known concentration.



Watch out: in $n = cV$ the volume must be in dm^3 — divide a cm^3 value by 1000 first (so 25.0 cm^3 = 0.0250 dm^3).

Practice

Try these in order. Use A_r: H = 1, C = 12, O = 16, Ca = 40.

2.1 State the volume of one mole of any gas at r.t.p. [1]

2.2 What volume does 0.25 mol of carbon dioxide occupy at r.t.p.? [2]

2.3 In $C + O_2 \rightarrow CO_2$, what mass of CO_2 forms from 6.0 g of carbon? [3]

2.4 What is meant by the *limiting reagent*? [1]

2.5 How many moles of solute are in 25.0 cm^3 of a 0.200 mol dm^{-3} solution? [2]

2.6 In a titration, 20.0 cm^3 of NaOH is neutralised by 25.0 cm^3 of 0.100 mol dm^{-3} HCl (1 : 1). Find the concentration of the NaOH. [3]

2.7 Challenge. 4.0 g of hydrogen (H_2, $M = 2$) reacts with 16 g of oxygen (O_2, $M = 32$) in $2H_2 + O_2 \rightarrow 2H_2O$. Show by calculation which reactant is the limiting reagent. [3]

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

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

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

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

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

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

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** $C_4H_8O_2$

3 Chemical bonding – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	**中文**	**Write it 3 times** (English)		
electrons	电子			
Electronegativity	电负性			
nuclear charge	核电荷			
atomic radius	原子半径			
shielding	屏蔽			
ionic bonding	离子键			
ions	离子			
covalent bonding	共价键			
metallic bonding	金属键			
delocalised electrons	离域电子			
coordinate bond	配位键			

Recall

At IGCSE you met **ionic**, **covalent** and **metallic** bonding. Now we explain *why* atoms pull on electrons, and draw the bonds more carefully.

- A bond is really about where the **electrons** 电子 go.
- Some atoms pull electrons harder than others.

Nothing here is harder than IGCSE — it just adds the right words.

New ideas

Read these first, then do the Practice.

1 Electronegativity

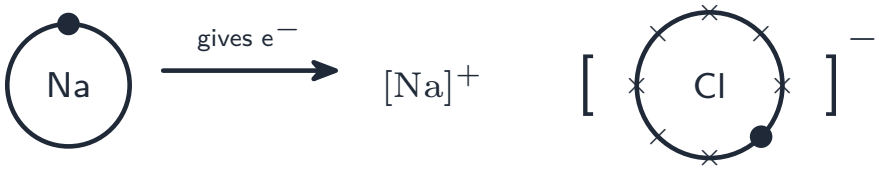
Electronegativity 电负性 is the power of an atom to attract the electrons in a bond towards itself. It depends on:

- **nuclear charge** 核电荷 — more protons pull harder.
- **atomic radius** 原子半径 — closer to the nucleus pulls harder.
- **shielding** 屏蔽 — more inner shells weaken the pull.

So it **rises** across a period and **falls** down a group. **Fluorine** is the most electronegative element.

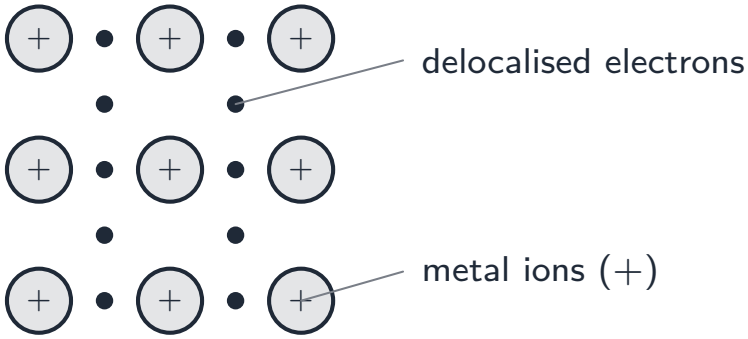
2 The three strong bonds

- **ionic bonding** 离子键 — the attraction between oppositely charged **ions** 离子 (a metal gives electrons to a non-metal).
- **covalent bonding** 共价键 — a **shared pair** of electrons between two atoms.
- **metallic bonding** 金属键 — positive metal ions in a "sea" of **delocalised electrons** 离域电子.



3 Metallic bonding

The outer electrons are free to move through the whole metal. This is why metals **conduct electricity** and are strong.



4 Coordinate bonds

A **coordinate bond** 配位键 (dative bond) is a covalent bond where **both** shared electrons come from the **same** atom. Example: the lone pair on nitrogen forms the fourth N–H bond in the ammonium ion, NH_4^+.

Watch out: ionic and covalent are the two ends of a scale — the *bigger* the electronegativity difference between the atoms, the more ionic the bond; two identical atoms share the electrons equally (pure covalent).

Practice

Try these in order.

3.1 Define *electronegativity*. [1]

3.2 Which is the most electronegative element? [1]

3.3 State how electronegativity changes (a) across a period, (b) down a group. [2]

3.4 Define *ionic bonding*. [2]

3.5 Explain why metals conduct electricity, using the idea of delocalised electrons. [2]

3.6 What is a *coordinate (dative) bond*? [1]

3.7 Challenge. Using electronegativity, explain why the bond between sodium and chlorine is ionic, while the bond between the two chlorine atoms in Cl_2 is covalent. [2]

5 Which statement explains why sodium and potassium have different melting points?

A The attraction between cations and delocalised electrons is stronger in sodium.

B The attraction between cations and anions is stronger in sodium.

C The attraction between atoms is stronger in sodium.

D The attraction between nuclei and shared electron pairs is stronger in sodium.

6 NH_3 and HCN react together to form NH_4CN, an ionic compound.

Which row states the number of coordinate bonds and the number of π bonds in one formula unit of NH_4CN?

	number of coordinate bonds	number of π bonds
A	0	2
B	1	2
C	0	3
D	1	3

24 When dry ammonia and hydrogen chloride gases are mixed, a solid white ionic compound is formed.

Two statements are listed.

1 The formation of the ionic compound is a redox reaction.

2 During the formation of the ionic compound, the H–N–H bond angle increases.

Which statements are correct?

A both 1 and 2

B 1 only

C 2 only

D neither 1 nor 2

3 Chemical bonding – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	**中文**	**Write it 3 times** (English)		
covalent bond	共价键			
VSEPR theory	价层电子对互斥理论			
lone pair	孤对电子			
bonding pair	成键电子对			
bond angle	键角			
linear	直线形			
tetrahedral	四面体形			
pyramidal	三角锥形			
bent	角形			
dipole	偶极			
polar	极性			
intermolecular forces	分子间作用力			
London (dispersion) forces	伦敦色散力			
permanent dipole	永久偶极			
Hydrogen bonding	氢键			

English	中文	Write it 3 times (English)
boiling point	沸点	

Recall

From Part 1 you know a **covalent bond** 共价键 is a shared pair of electrons. Here we work out the **shape** of a molecule and the weak forces **between** molecules.

- The shape decides many of a substance's properties.
- Weak forces between molecules explain melting and boiling points.

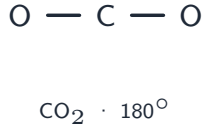
New ideas

Read these first, then do the Practice.

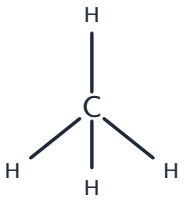
1 Shapes of molecules (VSEPR)

To find a shape, use **VSEPR theory** 价层电子对互斥理论: the electron pairs around the central atom push as far apart as possible. A **lone pair** 孤对电子 pushes harder than a **bonding pair** 成键电子对, squeezing the **bond angle** 键角.

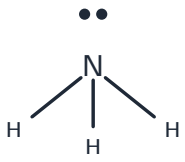
Molecule	Shape	Angle
CO_2	**linear** 直线形	180°
CH_4	**tetrahedral** 四面体形	109.5°
NH_3	**pyramidal** 三角锥形	107°
H_2O	**bent** 角形	104.5°



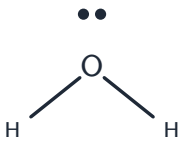
CO_2 · 180°



CH_4 · 109.5°



NH_3 · 107°



H_2O · 104.5°

2 Polarity and dipoles

When atoms of different electronegativity bond, the electrons sit closer to the more electronegative atom. One end is slightly negative ($\delta-$) and the other slightly positive ($\delta+$) — a **dipole** 偶极. If the dipoles do not cancel, the molecule is **polar** 极性.

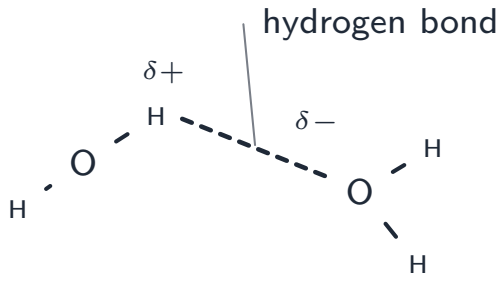
■ 3 Van der Waals' forces

These are the weak **intermolecular forces** 分子间作用力 *between* molecules:

- **London (dispersion) forces** 伦敦色散力 — brief dipoles from moving electrons; act between **all** molecules and get stronger with **more electrons**.
- **permanent dipole** 永久偶极 forces — between molecules that are always polar.

■ 4 Hydrogen bonding

Hydrogen bonding 氢键 is a strong special case: it forms when H is bonded to **N, O or F** and is attracted to a lone pair on an N, O or F atom nearby. It gives water its high **boiling point** 沸点, and makes ice **less dense** than water (so ice floats).



Watch out: hydrogen bonding only happens when H is bonded to N, O or F. A C–H bond does *not* hydrogen bond, so molecules like methane have only weak van der Waals' forces.

Practice

Try these in order.

3.1 What does VSEPR theory say about the electron pairs around a central atom? [1]

3.2 State the shape and bond angle of (a) CH_4, (b) CO_2. [2]

3.3 NH_3 has a smaller bond angle than CH_4. Explain why. [2]

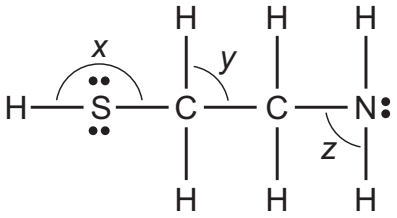
3.4 What is a *dipole*? [1]

3.5 London forces get stronger with more electrons. Explain what this means for boiling point down a group of similar molecules. [2]

3.6 State the three elements (bonded to hydrogen) that allow hydrogen bonding. [1]

3.7 Challenge. Water (H_2O) boils at a much higher temperature than hydrogen sulfide (H_2S), even though sulfur sits just below oxygen. Explain why. [2]

6 Three bond angles are labelled on the molecule shown.



: represents a lone pair of electrons

What is the order of **decreasing** size of the bond angles *x*, *y* and *z*?

	largest ⟶		smallest
A	*x*	*y*	*z*
B	*x*	*z*	*y*
C	*y*	*z*	*x*
D	*z*	*y*	*x*

5 In which set do all the molecules have all their atoms arranged in one plane?

A $AlCl_3$, BF_3, PH_3

B $AlCl_3$, CO_2, NH_3

C BF_3, C_2H_4, C_3H_6

D C_2H_4, CO_2, H_2O

7 The boiling point of water, H_2O, is higher than that of hydrogen sulfide, H_2S.

Which statement explains this difference in boiling points?

A The bond energy of O–H is greater than the bond energy of S–H.

B The intermolecular forces in H_2O are weaker than the intermolecular forces in H_2S.

C The S–H bond in H_2S is longer than the O–H bond in H_2O.

D There is significant intermolecular hydrogen bonding in H_2O but **not** in H_2S.

4 Gases and structures – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
ideal gas	理想气体			
colliding	碰撞			
pressure	压强			
real gas	实际气体			
kelvin	开尔文			

Recall

At IGCSE you learned that a gas is made of fast-moving particles spread far apart. Now we model a gas with numbers, using one neat equation.

- Gas particles move fast in all directions and hit the walls.
- We treat a gas as an **ideal gas** 理想气体 — a simple model.

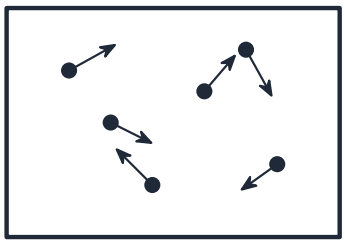
Nothing here is harder than IGCSE — it just adds one equation and the right words.

New ideas

Read these first, then do the Practice.

■ 1 Where gas pressure comes from

Gas molecules move fast and keep **colliding** 碰撞 with the walls of the container. Each hit gives a tiny push. The **pressure** 压强 is the overall result of all these collisions.



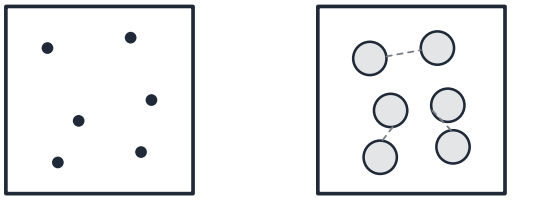
particles hit the walls

■ 2 The ideal gas model

An **ideal gas** 理想气体 assumes two things:

- the particles take up **zero volume**.
- there are **no forces** of attraction between the particles.

A **real gas** 实际气体 follows this best at **low pressure and high temperature**, and worst at high pressure and low temperature (when the particles are crowded).



ideal
(points, no forces)

real
(crowded, attractions)

■ 3 The ideal gas equation

$$pV = nRT$$

- p = pressure (Pa), V = volume (m^3), n = moles,
- T = temperature in **kelvin** 开尔文 (add 273 to °C), $R = 8.31$ J $K^{-1}mol^{-1}$.

Worked example. Volume of 0.50 mol at 27 °C (= 300 K) and 100 kPa (= 1.0×10^5 Pa):

$$V = \frac{nRT}{p} = \frac{0.50 \times 8.31 \times 300}{1.0 \times 10^5} = 0.0125 \text{ m}^3.$$

Watch out: in $pV = nRT$ everything must be in SI units — p in Pa, V in m^3, n in mol, and especially T in kelvin (add 273 to °C). Leaving T in °C is the most common slip.

Practice

Try these in order. Use $R = 8.31$ J K^{-1}mol^{-1}.

4.1 Explain, in terms of particles, how a gas creates pressure on the walls of its container. [2]

4.2 State the two assumptions of an ideal gas. [2]

4.3 Under what conditions does a real gas behave most like an ideal gas? [1]

4.4 Convert (a) 27 °C to kelvin, (b) 127 °C to kelvin. [2]

4.5 Find the volume of 2.0 mol of an ideal gas at 300 K and 1.0×10^5 Pa. [3]

4.6 Challenge. A 0.10 m^3 container holds an ideal gas at 1.0×10^5 Pa and 400 K. Find the amount, in moles, of gas present. [3]

11 1.00 g of nitrogen gas is stored in a 2.00 dm^3 vessel at 40.0 °C.

What is the pressure in the vessel?

A 5940 Pa **B** 11 900 Pa **C** 46 400 Pa **D** 92 900 Pa

8 A pure sample of a gas has a density of 2.62 g dm^{-3} at 101 000 Pa and 25 °C. The gas behaves ideally under these conditions.

Which expression gives the M_r of the gas?

A $\frac{101000 \times 0.001}{2.62 \times 8.31 \times 25}$

B $\frac{101000 \times 0.001}{2.62 \times 8.31 \times 298}$

C $\frac{2.62 \times 8.31 \times 25}{101000 \times 0.001}$

D $\frac{2.62 \times 8.31 \times 298}{101000 \times 0.001}$

4 Gases and structures – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
giant ionic	离子晶体			
simple molecular	分子晶体			
intermolecular forces	分子间作用力			
giant molecular	原子晶体			
covalent bonds	共价键			
giant metallic	金属晶体			
diamond	金刚石			
graphite	石墨			
delocalised electrons	离域电子			
melting point	熔点			

Recall

From Part 1 you know how a gas behaves. Here we look at **solids** and why their properties differ so much — it all comes down to **structure**.

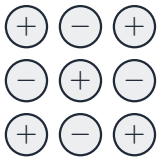
- At IGCSE you met giant ionic, simple molecular and giant covalent structures.
- The structure decides the melting point, conductivity and solubility.

New ideas

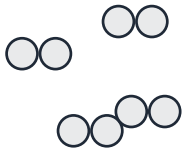
Read these first, then do the Practice.

■ 1 The four structures

Structure	Particles	Held by
giant ionic 离子晶体	ions in a lattice	strong ionic attraction
simple molecular 分子晶体	small molecules	weak **intermolecular forces** 分子间作用力
giant molecular 原子晶体	atoms in a network	strong **covalent bonds** 共价键
giant metallic 金属晶体	metal ions + electron sea	metallic bonding

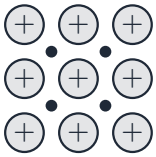


giant ionic



simple molecular

giant covalent

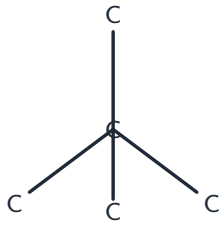


giant metallic

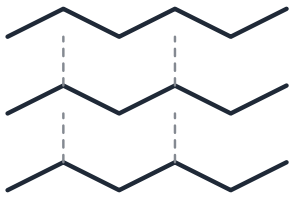
■ 2 Two forms of carbon

Both **diamond** 金刚石 and **graphite** 石墨 are giant covalent:

- **diamond** — each carbon bonds to **four** others in a rigid 3-D network. Very hard; does **not** conduct.
- **graphite** — carbon in flat layers; the layers slide (a lubricant), and spare **delocalised electrons** 离域电子 let it **conduct**.



diamond (3-D network)



layers

weak forces

graphite (layers)

■ 3 Properties follow the structure

- **melting point** 熔点 is high when strong forces (ionic, covalent, metallic) must be broken, and low when only weak forces break.
- **conducting** needs charged particles that can move — free ions (molten or dissolved) or delocalised electrons.
- ionic solids are usually **soluble** in water; molecular and giant covalent solids usu-

ally are not.

Watch out: when a simple molecular solid melts, only the *weak forces between* the molecules are broken — the strong covalent bonds *inside* each molecule stay intact. That is why the melting point is low.

Practice

Try these in order.

4.1 Name the four types of crystalline structure. [2]

4.2 Why does a simple molecular solid (like iodine) have a low melting point? [2]

4.3 Diamond and graphite are both made only of carbon. Explain why graphite conducts electricity but diamond does not. [2]

4.4 An ionic compound only conducts electricity when molten or dissolved, not when solid. Explain why. [2]

4.5 An unknown solid has a high melting point and conducts electricity as a solid. What type of structure is it? [1]

4.6 Challenge. Sodium chloride melts at 801 °C, but iodine melts at only 114 °C. Explain this large difference using their structures and bonding. [2]

8 Which row describes silicon dioxide?

	electrical conductivity in liquid state	solubility in water
A	non-conductor	insoluble
B	non-conductor	soluble
C	conductor	insoluble
D	conductor	soluble

5 Enthalpy changes – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
exothermic	放热			
endothermic	吸热			
enthalpy change	焓变			
activation energy	活化能			
bond energy	键能			

Recall

At IGCSE you learned that reactions can be **exothermic** 放热 (give out heat) or **endothermic** 吸热 (take in heat). Now we measure that energy and give it a symbol.

- The energy change at constant pressure is the **enthalpy change** 焓变, ΔH.
- We can read it off an energy diagram, or work it out from bonds.

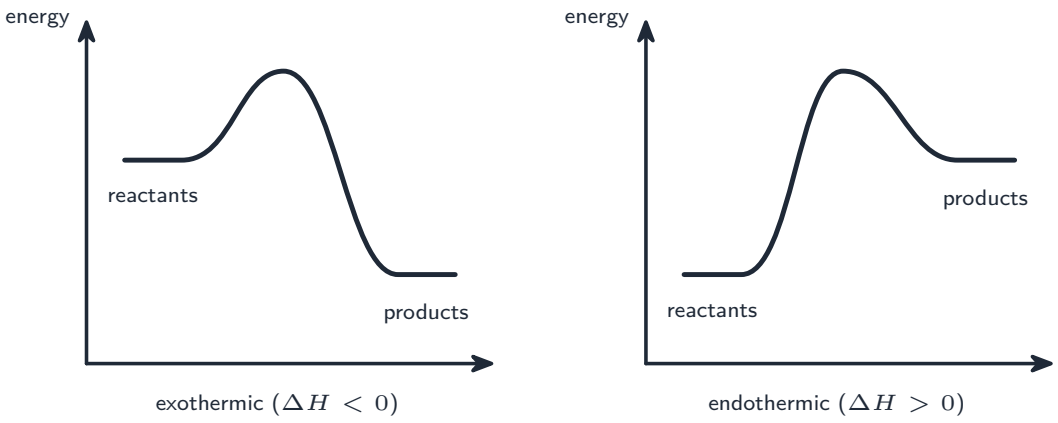
Nothing here is harder than IGCSE — it just adds the symbol ΔH and the bond method.

New ideas

Read these first, then do the Practice.

■ 1 Exothermic and endothermic

- **exothermic** 放热 — gives out heat; products **lower** than reactants; ΔH is **negative**.
- **endothermic** 吸热 — takes in heat; products **higher** than reactants; ΔH is **positive**.



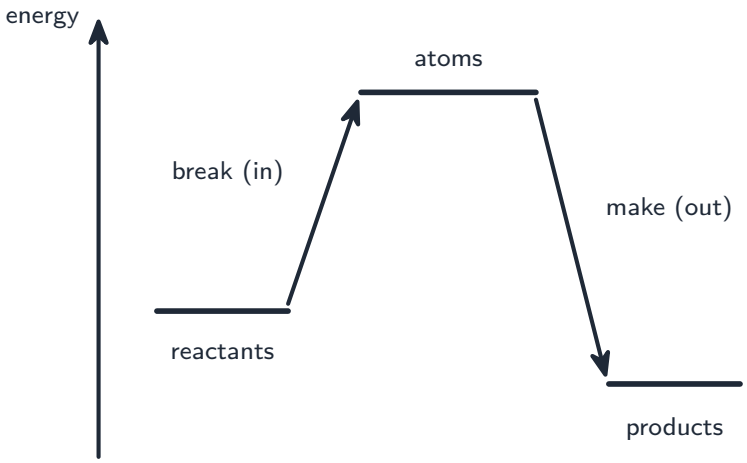
The height of the "hill" is the **activation energy** 活化能 — the least energy needed to start the reaction.

2 Energy from breaking and making bonds

- **breaking** a bond **takes in** energy.
- **making** a bond **gives out** energy.

$$\Delta H = \sum(\text{bonds broken}) - \sum(\text{bonds made})$$

The **bond energy** 键能 is the energy to break one mole of a bond (always positive).



Worked example. $H_2 + Cl_2 \rightarrow 2HCl$. Bond energies: H–H = 436, Cl–Cl = 242, H–Cl = 431.

$$\Delta H = (436 + 242) - (2 \times 431) = 678 - 862 = -184 \text{ kJ mol}^{-1}.$$

Watch out: use $\Delta H = \sum(\text{bonds broken}) - \sum(\text{bonds made})$ in that order. A *negative* answer means exothermic — more energy is released making bonds than is taken in

breaking them.

Practice

Try these in order.

5.1 State the sign of ΔH for (a) an exothermic, (b) an endothermic reaction. [2]

5.2 In an exothermic reaction, are the products higher or lower in energy than the reactants? [1]

5.3 What is meant by the *activation energy*? [1]

5.4 State whether (a) breaking a bond, (b) making a bond takes in or gives out energy. [2]

5.5 Use bond energies to find ΔH for $H_2 + Br_2 \rightarrow 2HBr$. Bond energies: H–H = 436, Br–Br = 193, H–Br = 366. [3]

5.6 Challenge. A reaction is found to have a negative ΔH. Explain what this tells you about the energy released in making bonds compared with the energy taken in breaking bonds. [2]

8 In an experiment, 1.60 g of a fuel is burnt. 45.0% of the energy released is absorbed by 200 g of water. The temperature of the water rises from 18.0 °C to 66.0 °C.

What is the total energy released per gram of fuel burnt?

A 25 100 J **B** 55 700 J **C** 89 200 J **D** 143 000 J

9 When 0.47 g of a hydrocarbon is completely burnt in air, the energy released heats 200 g of water from 23.7 °C to 41.0 °C.

What is the amount of energy absorbed, in Joules, by the water?

A $0.47 \times 4.18 \times 17.3$

B $0.47 \times 4.18 \times (273 + 17.3)$

C $200 \times 4.18 \times 17.3$

D $200 \times 4.18 \times (273 + 17.3)$

10 One commercially available ‘heat pad’ contains iron, activated carbon and water. The ‘heat pad’ is activated by air. This causes the pad to get hotter.

Which statement describes the chemical reaction occurring in the ‘heat pad’ when it is exposed to air?

A The reaction is endothermic and iron gains electrons.

B The reaction is endothermic and iron loses electrons.

C The reaction is exothermic and iron gains electrons.

D The reaction is exothermic and iron loses electrons.

5 Enthalpy changes – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)
Hess's law	盖斯定律	
specific heat capacity	比热容	
energy cycle	能量循环	

Recall

From Part 1 you know ΔH is the enthalpy change. Here we **measure** it in the lab and combine values using **Hess's law** 盖斯定律.

- A reaction that heats up water transfers a known amount of heat.
- Energy is conserved, so different routes give the same total.

New ideas

Read these first, then do the Practice.

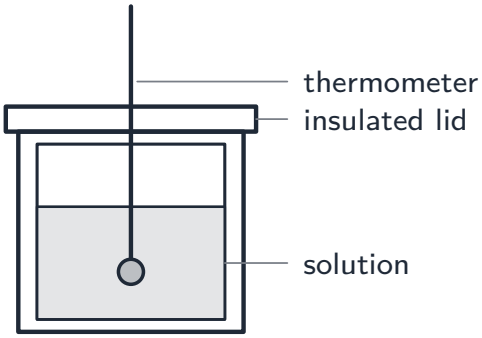
■ 1 Measuring enthalpy change

When a reaction heats a known mass of water or solution, the heat transferred is:

$$q = mc\,\Delta T$$

where m = mass (g), c = **specific heat capacity** 比热容, ΔT = temperature change. Per mole:

$$\Delta H = -\frac{mc\,\Delta T}{n}$$

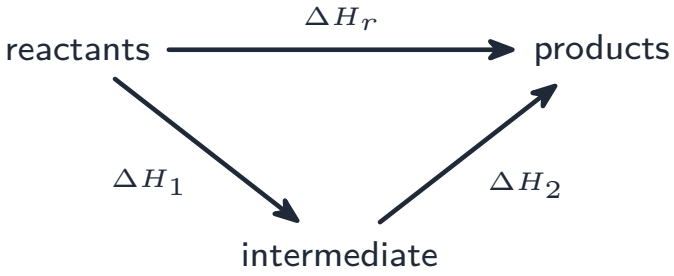


Worked example. Burning 0.50 g methanol ($M_r = 32$) heats 100 g water by 18 °C ($c = 4.18$): $q = 100 \times 4.18 \times 18 = 7520$ J; $n = 0.50/32 = 0.0156$ mol; $\Delta H_c = -7520/0.0156 \approx -480$ kJ mol^{-1}.

2 Hess's law

Hess's law 盖斯定律: the total enthalpy change is the **same** whichever route you take from reactants to products (because energy is conserved).

Draw an **energy cycle** 能量循环 with a direct route and an indirect route, then make both add up to the same total.



$$\Delta H_r = \Delta H_1 + \Delta H_2$$

It lets you find an enthalpy change you **cannot** measure directly, by using values you **can** measure.

Watch out: in $q = mc\Delta T$, the mass m is the mass of the *water (or solution) being heated*, not the mass of fuel. Then divide by the *moles of substance reacted* to get ΔH per mole.

Practice

Try these in order.

5.1 Write the equation that gives the heat transferred to a mass of water. [1]

5.2 A reaction releases 5000 J and uses 0.10 mol of fuel. Find ΔH in kJ mol^{-1}. [2]

5.3 200 g of water rises by 10 °C ($c = 4.18$). Calculate the heat transferred, q. [2]

5.4 State Hess's law. [1]

5.5 Give one reason Hess's law is useful. [1]

5.6 Challenge. Burning 0.32 g of methane ($M_r = 16$) heats 200 g of water by 20 °C ($c = 4.18$). Find the enthalpy change per mole of methane. [3]

9 The data shown are needed for this question.

$\Delta H_f^{\ominus}(P_4O_{10}(s)) = -3012\,kJ\,mol^{-1}$

$\Delta H_f^{\ominus}(H_2O(l)) = -286\,kJ\,mol^{-1}$

$\Delta H_f^{\ominus}(H_3PO_4(s)) = -1279\,kJ\,mol^{-1}$

What is $\Delta H^{\ominus}$ for the reaction shown?

$$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(s)$$

A $-9844\,kJ\,mol^{-1}$

B $-388\,kJ\,mol^{-1}$

C $-97\,kJ\,mol^{-1}$

D $+2019\,kJ\,mol^{-1}$

6 Oxidation number and redox – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
oxidation	氧化			
reduction	还原			
redox	氧化还原			
oxidation number	氧化数			
oxidising agent	氧化剂			
reducing agent	还原剂			

Recall

At IGCSE you learned that **oxidation** 氧化 and **reduction** 还原 happen together in **redox** 氧化还原 reactions. Now we track them exactly using the **oxidation number** 氧化数.

- The oxidation number shows how many electrons an atom has lost or gained.
- Simple rules let you work it out for any atom.

Nothing here is harder than IGCSE — it just adds a counting tool.

New ideas

Read these first, then do the Practice.

1 Oxidation number rules

- an uncombined element is 0.
- a simple ion equals its charge (so Mg^{2+} is +2).
- Group 1 is +1, Group 2 is +2.
- **hydrogen** is +1, **oxygen** is −2, **fluorine** is −1.
- the numbers add up to 0 in a neutral compound, or to the charge in an ion.

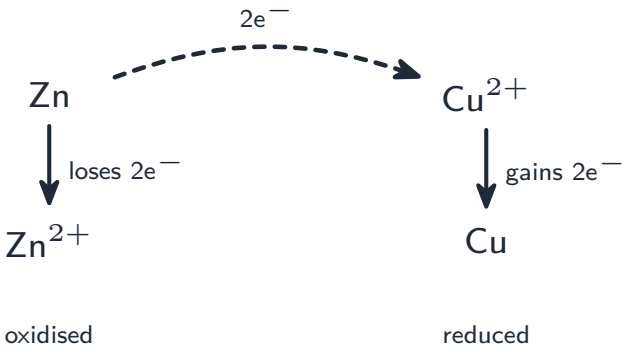
K	Mn	O	O	O	O
+1	+7	−2	−2	−2	−2

$$(+1) + (+7) + 4(-2) = 0$$

2 Redox is electron transfer

- **oxidation** 氧化 is **loss** of electrons — the oxidation number goes **up**.
- **reduction** 还原 is **gain** of electrons — the oxidation number goes **down**.

Remember **OIL RIG**: Oxidation Is Loss, Reduction Is Gain.



3 Oxidising and reducing agents

- an **oxidising agent** 氧化剂 takes electrons from another species (and is itself **reduced**).
- a **reducing agent** 还原剂 gives electrons to another species (and is itself **oxidised**).

Watch out: an oxidation number is *per atom* and always carries a sign (+2, not just 2). Multiply it by the number of those atoms before making the compound add up to zero (or to the ion's charge).

Practice

Try these in order.

6.1 State the oxidation number of (a) an uncombined element, (b) oxygen in most compounds. [2]

6.2 What does OIL RIG stand for? [2]

6.3 Work out the oxidation number of sulfur in SO_2 (O is -2). [2]

6.4 Work out the oxidation number of nitrogen in the nitrate ion, NO_3^-. [2]

6.5 In $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$, which species is oxidised? [1]

6.6 An oxidising agent is itself reduced. Explain why. [1]

6.7 Challenge. Work out the oxidation number of chromium in the dichromate ion, $Cr_2O_7^{2-}$ (O is -2). [2]

6 Oxidation number and redox – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
oxidation numbers	氧化数			
Disproportionation	歧化			

Recall

From Part 1 you can assign **oxidation numbers** 氧化数 and spot oxidation and reduction. Here we use the numbers to **balance** redox equations and meet a special case.

- Every electron lost by one species is gained by another.
- So the total rise in oxidation number equals the total fall.

New ideas

Read these first, then do the Practice.

■ 1 Balancing with oxidation numbers

1. find the element whose oxidation number **rises** (oxidised) and the one that **falls** (reduced).
2. the total rise must equal the total fall.
3. choose the ratio so they match, then balance the rest.

Fe: $+2 \rightarrow +3$ (rise 1)

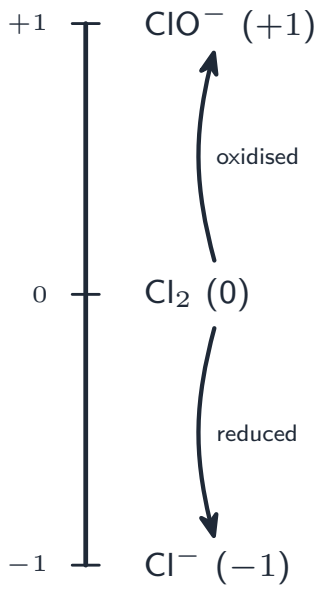
Mn: $+7 \rightarrow +2$ (fall 5)

total rise = total fall $\Rightarrow$ 5 Fe : 1 Mn

Worked example. Fe goes $+2 \rightarrow +3$ (rise 1); Mn goes $+7 \rightarrow +2$ (fall 5). To match, you need **5** Fe for every **1** Mn.

2 Disproportionation

Disproportionation 歧化 is a redox reaction in which the **same** element is both oxidised **and** reduced at once. For example, chlorine (0) in cold water goes to Cl^- (-1) **and** ClO^- ($+1$).



Watch out: in disproportionation the *same* element must both rise and fall in oxidation number. If two *different* elements change, it is ordinary redox, not disproportionation.

Practice

Try these in order.

6.1 In a redox reaction, what must be true about the total rise and total fall in oxidation number? [1]

6.2 In a reaction, an element's oxidation number changes from +2 to +3. (a) By how much does it change? (b) Is it oxidised or reduced? [2]

6.3 Manganese falls from +7 to +2, and iron rises from +2 to +3. How many iron atoms are needed for each manganese atom? [2]

6.4 What is meant by *disproportionation*? [2]

6.5 In $Cl_2 + H_2O \rightarrow HCl + HClO$, give the oxidation number of chlorine in (a) Cl_2, (b) HCl, (c) HClO. [3]

6.6 Challenge. When chlorine reacts with cold sodium hydroxide it forms NaCl and NaClO. Use oxidation numbers to explain why this is *disproportionation*. [2]

10 Which equation shows hydrogen acting as an oxidising agent?

A $H_2 + 2K \rightarrow 2K^+H^-$

B $H_2 + I_2 \rightarrow 2HI$

C $H_2 + Cu_2S + ZnO \rightarrow 2Cu + ZnS + H_2O$

D $3H_2 + N_2 \rightarrow 2NH_3$

3 The reaction of hydrogen sulfide with sulfur dioxide gives sulfur as one of the products.

The two relevant redox equations are shown.

$$H_2S(aq) \rightleftharpoons S(s) + 2H^+(aq) + 2e^-$$

$$SO_2(aq) + 4H^+(aq) + 4e^- \rightleftharpoons S(s) + 2H_2O(l)$$

How many moles of hydrogen sulfide are needed to react with sulfur dioxide to produce 1 mol of sulfur?

A $\frac{1}{3}$ mol **B** $\frac{2}{3}$ mol **C** $\frac{3}{2}$ mol **D** 2 mol

11 In which substance is the average oxidation number of sulfur the highest?

A S_8 **B** $Na_2S_4O_6$ **C** $Na_2S_2O_3$ **D** SO_2Cl_2

7 Equilibrium – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
reversible reactions	可逆反应			
equilibrium	平衡			
closed system	封闭系统			
dynamic equilibrium	动态平衡			
forward rate	正反应速率			
reverse rate	逆反应速率			
Le Chatelier's principle	勒夏特列原理			
catalyst	催化剂			

Recall

At IGCSE you met **reversible reactions** 可逆反应 (shown by ⇌). Now we look at the balance point — **equilibrium** 平衡 — and how to shift it.

- A reversible reaction goes both ways at once.
- In a closed system it settles into a steady balance.

Nothing here is harder than IGCSE — it just adds the right words and one rule.

New ideas

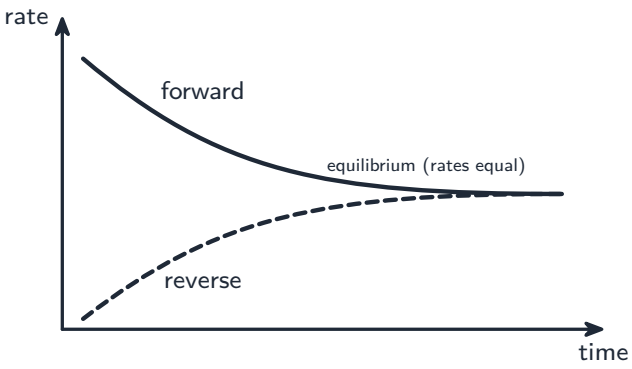
Read these first, then do the Practice.

1 Dynamic equilibrium

In a **closed system** 封闭系统, a reversible reaction reaches **dynamic equilibrium** 动态平衡 when:

- the **forward rate** 正反应速率 equals the **reverse rate** 逆反应速率.
- the concentrations of reactants and products stay **constant**.

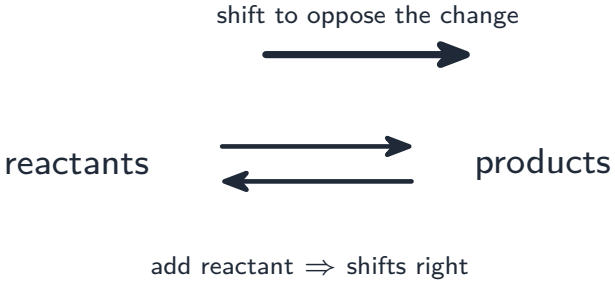
It is *dynamic* because both reactions are still happening — they just cancel out.



2 Le Chatelier's principle

Le Chatelier's principle 勒夏特列原理: if you change a system at equilibrium, the equilibrium moves to **oppose** the change.

Change	Equilibrium moves...
add more reactant	towards the products
increase pressure	towards fewer gas molecules
increase temperature	in the **endothermic** direction
add a **catalyst** 催化剂	no shift (just reaches it faster)



add reactant ⇒ shifts right

■ 3 The equilibrium constant

For $aA + bB \rightleftharpoons cC + dD$:

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

Only **temperature** changes the value of K_c.

Watch out: a catalyst does *not* shift the equilibrium — it speeds up both directions equally, so the system just reaches the same position faster. And K_c changes *only* with temperature.

Practice

Try these in order.

7.1 State the two conditions for a dynamic equilibrium. [2]

7.2 Why must the system be *closed* for equilibrium to be reached? [1]

7.3 State Le Chatelier's principle. [1]

7.4 For an exothermic reaction, which way does the equilibrium shift if you **raise** the temperature? [1]

7.5 Does adding a catalyst change the position of equilibrium? Explain. [2]

7.6 For $H_2 + I_2 \rightleftharpoons 2HI$ at equilibrium, $[H_2] = 0.20$, $[I_2] = 0.20$, $[HI] = 1.6$ mol dm^{-3}.

Find K_c. [2]

7.7 Challenge. For the exothermic reaction $N_2 + 3H_2 \rightleftharpoons 2NH_3$, state and explain the effect on the yield of ammonia of (a) increasing the pressure, (b) increasing the temperature. [3]

12 One molecule of haemoglobin, Hb, can bind with four molecules of oxygen according to the equation shown.

$$Hb(aq) + 4O_2(aq) \rightleftharpoons Hb(O_2)_4(aq)$$

When the equilibrium concentration of O_2 is 7.6×10^{-6} mol dm^{-3}, the equilibrium concentrations of Hb and $Hb(O_2)_4$ are equal.

What is the numerical value of K_c for this equilibrium?

A 3.0×10^{20} **B** 1.3×10^{5} **C** 7.6×10^{-6} **D** 3.3×10^{-21}

13 In the Contact process, sulfur dioxide and oxygen react to form sulfur trioxide.

In the Haber process, nitrogen and hydrogen react to form ammonia.

Which statement about these processes is correct?

A K_p for the Haber process has no unit.

B In the Contact process, the value of K_p falls when pressure is increased at constant T.

C The Haber process uses a homogeneous catalyst.

D When V_2O_5 is used in the Contact process, the position of equilibrium is unchanged.

12 Nitrogen dioxide decomposes on heating according to the equation shown.

$$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$$

When 4 mol of nitrogen dioxide were put into a 1 dm^3 container and heated to a constant temperature, the equilibrium mixture contained 0.8 mol of oxygen.

What is the value of the equilibrium constant, K_c, at the temperature of the experiment?

A $\frac{0.8^2 \times 0.8}{4^2}$ **B** $\frac{1.6 \times 0.8}{2.4^2}$ **C** $\frac{1.6^2 \times 0.8}{4^2}$ **D** $\frac{1.6^2 \times 0.8}{2.4^2}$

7 Acids and bases – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
acids	酸			
alkalis	碱			
protons	质子			
acid	酸			
proton donor	质子供体			
base	碱			
proton acceptor	质子受体			
alkali	碱			
dissociates	解离			
strong acid	强酸			
weak acid	弱酸			
Neutralisation	中和			
salt	盐			
titration curve	滴定曲线			
indicator	指示剂			

Recall

At IGCSE you met **acids** 酸 and **alkalis** 碱 and the **pH** scale. Now we define them by what they do with **protons** 质子 (H^+ ions).

- An acid gives away H^+; a base takes it.
- "Strong" and "weak" are about how fully an acid splits up.

New ideas

Read these first, then do the Practice.

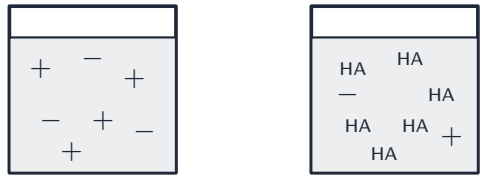
1 Brønsted–Lowry acids and bases

- an **acid** 酸 is a **proton donor** 质子供体 (gives H^+).
- a **base** 碱 is a **proton acceptor** 质子受体 (takes H^+). A soluble base is an **alkali** 碱.

2 Strong and weak

This is about how fully the acid **dissociates** 解离 (splits into ions) in water:

- a **strong acid** 强酸 is **fully** dissociated (almost all molecules split into ions).
- a **weak acid** 弱酸 is only **partly** dissociated (most stay whole).



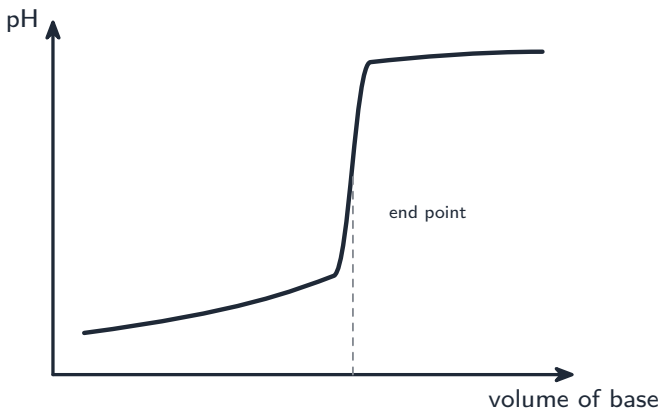
strong (all ions) weak (mostly HA)

At the **same concentration**, a strong acid has a **lower pH** and conducts electricity better (more ions).

3 Neutralisation and titration curves

Neutralisation 中和: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$, also forming a **salt** 盐.

A **titration curve** 滴定曲线 (pH against volume added) has a steep, almost vertical jump at the **end point**. Choose an **indicator** 指示剂 that changes colour inside that jump.



Watch out: *strong* (fully dissociated) is not the same as *concentrated* (a lot dissolved). A weak acid can be concentrated, and a strong acid can be dilute.

Practice

Try these in order.

7.1 Define an acid and a base in the Brønsted–Lowry theory. [2]

7.2 What is the difference between a *strong* and a *weak* acid? [2]

7.3 At the same concentration, which has the lower pH — a strong or a weak acid? [1]

7.4 Give two ways you could tell a strong acid from a weak acid in the lab. [2]

7.5 Write the ionic equation for neutralisation. [1]

7.6 Why does a strong acid conduct electricity better than a weak acid of the same concentration? [1]

7.7 Challenge. Equal concentrations of hydrochloric acid (strong) and ethanoic acid (weak) are compared. Explain why the hydrochloric acid has the lower pH. [2]

14 Photochromic glass, used for sunglasses, darkens when exposed to bright light and becomes more transparent again when the light is less bright. The darkness of the glass is due to the presence of silver atoms.

The following reactions are involved.

reaction 1 $Ag^+ + Cl^- \rightleftharpoons Ag + Cl$

reaction 2 $Cu^+ + Cl \rightarrow Cu^{2+} + Cl^-$

reaction 3 $Cu^{2+} + Ag \rightarrow Cu^+ + Ag^+$

Which statement about these reactions is correct?

A Cu^+ and Cu^{2+} ions act as catalysts.

B Cu^+ ions act as an oxidising agent in reaction 2.

C Reaction 3 increases the darkness of the glass.

D Silver atoms are reduced in reaction 3.

8 Rate of reaction – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
catalyst	催化剂			
collisions	碰撞			
collide	碰撞			
effective collision	有效碰撞			
non-effective collision	无效碰撞			
concentration	浓度			
pressure	压强			

Recall

At IGCSE you learned that reactions go faster with higher **concentration**, higher **temperature**, and a **catalyst** 催化剂. Now we explain *why*, using **collisions** 碰撞.

- Particles must collide to react.
- But not every collision works.

Nothing here is harder than IGCSE — it just explains the reasons.

New ideas

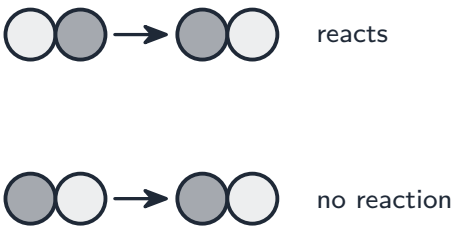
Read these first, then do the Practice.

1 Collisions

To react, particles must **collide** 碰撞. Only some collisions cause a reaction:

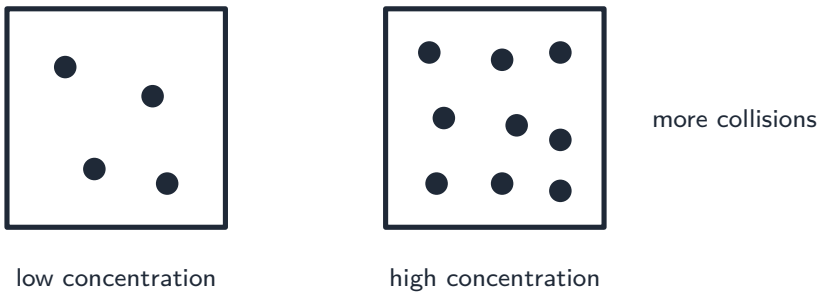
- an **effective collision** 有效碰撞 has **enough energy** *and* the **correct orientation** (direction).
- a **non-effective collision** 无效碰撞 has too little energy, or the wrong angle — nothing happens.

So the rate depends on the **frequency of effective collisions** (how many useful collisions happen each second).



2 Concentration and pressure

Increasing the **concentration** 浓度 of a solution (or the **pressure** 压强 of a gas) packs the particles closer. They collide **more often**, so there are more effective collisions each second — the rate rises.



Watch out: a faster rate needs more *effective* collisions per second. Simply colliding is not enough — the collision must also have enough energy *and* the correct orientation.

Practice

Try these in order.

8.1 What is meant by the *rate of reaction*? [1]

8.2 State the two things a collision needs to be *effective*. [2]

8.3 Explain why increasing the concentration of a reactant increases the rate. [2]

8.4 A reaction makes 48 cm^3 of gas in 24 s. Calculate the mean rate in $cm^3\,s^{-1}$. [2]

8.5 Increasing the pressure of a gas reaction speeds it up. Explain why, in terms of collisions. [2]

8.6 Challenge. Powdered marble reacts with acid much faster than the same mass of large marble chips. Explain why, in terms of collisions. [2]

14 20.0 cm^3 of hydrogen peroxide decomposes to water and oxygen in the presence of a suitable catalyst.

160 cm^3 of oxygen, measured at room conditions, is produced in 5.00 minutes.

What is the average rate of decomposition of hydrogen peroxide during this reaction period?

A $2.22 \times 10^{-5}\,mol\,s^{-1}$

B $4.44 \times 10^{-5}\,mol\,s^{-1}$

C $1.76 \times 10^{-4}\,mol\,s^{-1}$

D $2.67 \times 10^{-3}\,mol\,s^{-1}$

8 Rate of reaction – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
effective collisions	有效碰撞			
catalyst	催化剂			
activation energy	活化能			
Boltzmann distribution	玻尔兹曼分布			
enthalpy change	焓变			
homogeneous catalyst	均相催化剂			
heterogeneous catalyst	多相催化剂			

Recall

From Part 1 you know reactions need **effective collisions** 有效碰撞. Here we look at how **temperature** and a **catalyst** 催化剂 change the rate.

- The **activation energy** 活化能 is the least energy a collision needs.
- A graph called the Boltzmann distribution shows which molecules have enough.

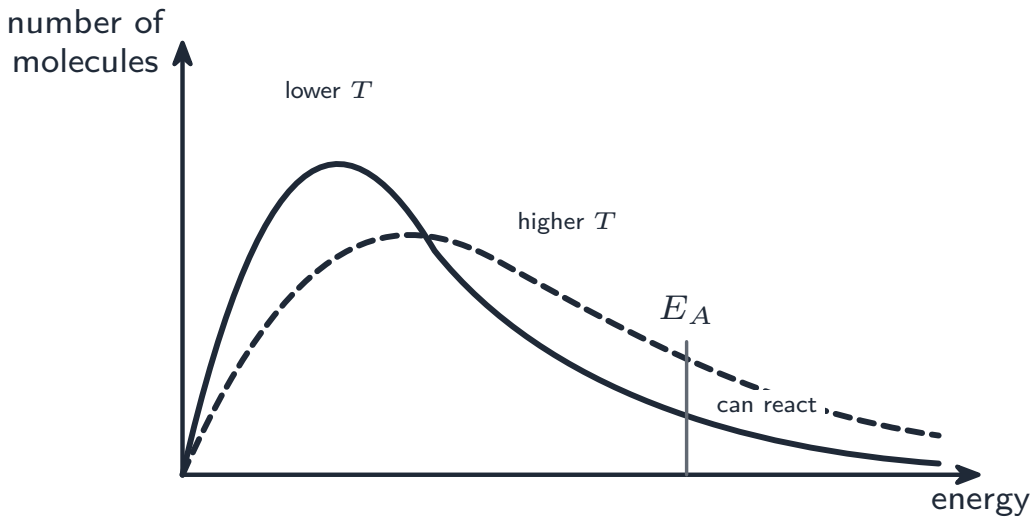
New ideas

Read these first, then do the Practice.

1 The Boltzmann distribution

The **Boltzmann distribution** 玻尔兹曼分布 shows how the molecules' energies are spread at one temperature. Only the molecules to the **right** of the **activation energy** 活化能 (E_A) have enough energy to react.

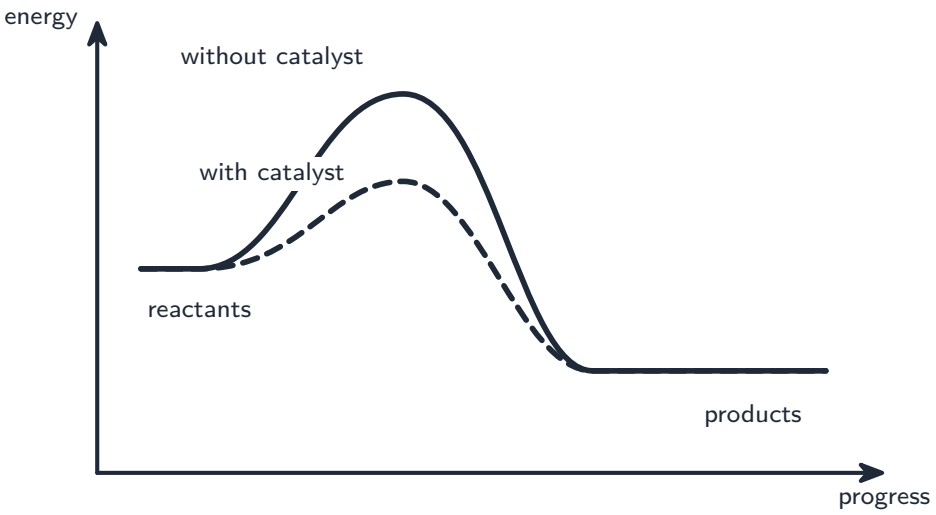
Raising the temperature **spreads the curve to the right**, so a **much larger fraction** of molecules now have energy above E_A — this is why a small temperature rise gives a big rise in rate.



2 Catalysts

A **catalyst** 催化剂 speeds up a reaction but is **not used up**. It gives a new route with a **lower activation energy**, so more collisions are effective.

- the **enthalpy change** 焓变 (ΔH) is **not** changed.
- a **homogeneous catalyst** 均相催化剂 is in the **same** state as the reactants.
- a **heterogeneous catalyst** 多相催化剂 is in a **different** state (e.g. a solid surface).



Watch out: a catalyst lowers the *activation energy* by giving an alternative route — it does *not* change ΔH (the reactant and product energies are unchanged), and it is not used up.

Practice

Try these in order.

8.1 What does the activation energy mean? [1]

8.2 On the Boltzmann distribution, which molecules are able to react? [1]

8.3 Explain why a small rise in temperature gives a large rise in rate. [2]

8.4 How does a catalyst speed up a reaction? [2]

8.5 Does a catalyst change the enthalpy change, ΔH, of a reaction? [1]

8.6 State the difference between a homogeneous and a heterogeneous catalyst. [2]

8.7 Challenge. Using the Boltzmann distribution, explain why a catalyst speeds up a reaction even at the *same* temperature. [2]

15 A mixture of gases reacts faster as its temperature increases.

Which row explains this?

	the activation energy remains unchanged	more particles have energy equal to or above the activation energy	there is an increase in the rate of successful collisions
A	false	false	false
B	true	true	true
C	false	true	true
D	true	false	false

15 The reversible reaction between methanol and ethanoic acid liquids is catalysed by adding a small volume of concentrated sulfuric acid.

Two statements about this reaction are listed.

1 The sulfuric acid is a homogeneous catalyst.

2 The sulfuric acid lowers the activation energy of the reverse reaction.

Which statements are correct?

A both 1 and 2

B 1 only

C 2 only

D neither 1 nor 2

14 When two aqueous solutions are mixed, the reaction between them is very slow.

An effective catalyst is added to the mixture without any change in temperature.

Which statement about this catalyst is correct?

A It increases the average energy of the reactant particles.

B It changes the distribution of energies of the reactant particles.

C It allows a greater number of reactant particles to react per unit time.

D It increases the number of reactant particles with the most probable energy.

9 Periodicity (Period 3) – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Periodic Table	元素周期表			
Periodicity	周期性			
atomic radius	原子半径			
nuclear charge	核电荷			
shielding	屏蔽			
giant metallic	金属晶体			
giant covalent	原子晶体			
simple molecular	分子晶体			
melting point	熔点			

Recall

At IGCSE you used the **Periodic Table** 元素周期表. Now we look closely at one row — **Period 3** (Na to Ar) — and see its properties change in a regular pattern.

- **Periodicity** 周期性 means properties repeat across each period.
- The pattern follows from the structure and bonding of each element.

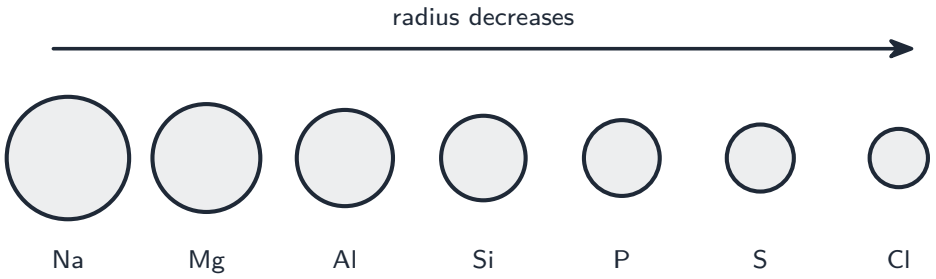
Nothing here is harder than IGCSE — it just lines up one row carefully.

New ideas

Read these first, then do the Practice.

■ 1 Atomic radius

Across Period 3 the **atomic radius** 原子半径 gets **smaller**. The **nuclear charge** 核电荷 rises (more protons), but the outer electrons go into the same shell with similar **shielding** 屏蔽, so they are pulled in tighter.

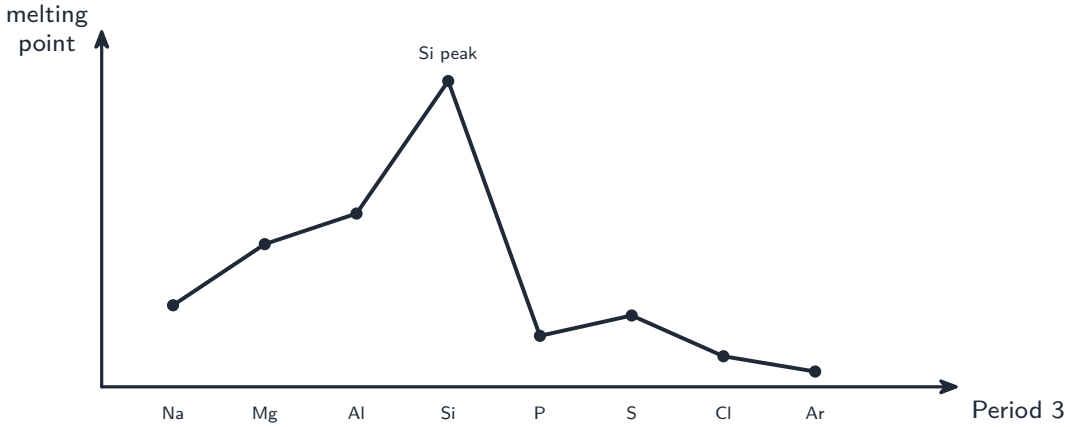


■ 2 Structure across the period

Elements	Structure	Melting point	Conducts?
Na, Mg, Al	**giant metallic** 金属晶体	high, rising	yes
Si	**giant covalent** 原子晶体	highest	no
P, S, Cl, Ar	**simple molecular** 分子晶体	low	no

■ 3 Melting point

The **melting point** 熔点 rises through the metals, peaks at **silicon** (strong covalent bonds to break), then drops sharply for the simple molecular elements (only weak forces break).



Watch out: across a period the atomic radius gets *smaller* (more nuclear charge,

same shell). Down a *group* it gets *bigger* (extra shells are added). Don't mix up the two trends.

Practice

Try these in order.

9.1 What is meant by *periodicity*? [1]

9.2 Describe and explain the trend in atomic radius across Period 3. [2]

9.3 Name the type of structure of (a) magnesium, (b) silicon, (c) sulfur. [3]

9.4 Silicon has the highest melting point in Period 3. Explain why. [2]

9.5 Why do sulfur and chlorine have low melting points? [2]

9.6 Challenge. Sodium has a larger atomic radius than chlorine, even though both are in Period 3. Explain why. [2]

16 The atomic radii and ionic radii for three elements in Period 3 are shown.

	atomic radius / nm	ionic radius / nm
element X	0.118	0.053
element Y	0.099	0.180
element Z	0.160	0.072

Using this data, which statement is correct?

A Element X has lower electrical conductivity than element Y.

B Element Y has a higher melting point than element X.

C Element Y and element Z react to form an ionic compound.

D Element Z forms ionic compounds by gaining electrons.

17 Sodium and sulfur react together to form sodium sulfide, Na_2S.

How do the atomic radius and ionic radius of sodium compare with those of sulfur?

	atomic radius	ionic radius
A	sulfur is greater	sodium is greater
B	sulfur is greater	sulfur is greater
C	sodium is greater	sodium is greater
D	sodium is greater	sulfur is greater

9 Periodicity (Period 3) – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
oxides	氧化物			
chlorides	氯化物			
basic	碱性			
amphoteric	两性			
acidic	酸性			
hydrolyse	水解			

Recall

From Part 1 you know Period 3 goes from metals (left) to non-metals (right). Here we see how that changes the **oxides** 氧化物 and **chlorides** 氯化物.

- Metal oxides are **basic**; non-metal oxides are **acidic**.
- One oxide in the middle is special: it reacts both ways.

New ideas

Read these first, then do the Practice.

■ 1 Acid–base nature of the oxides

Across Period 3 the oxides change from **basic** to **acidic**:

- **metal oxides** (Na_2O, MgO) are **basic** 碱性.
- **Al_2O_3** is **amphoteric** 两性 — it reacts with **both** acids and bases.

- **non-metal oxides** (P_4O_{10}, SO_3) are **acidic** 酸性.

2 Aluminium oxide is amphoteric

It behaves as a base with acids, and as an acid with bases — that is what **amphoteric** means.

3 Chlorides with water

- **ionic chlorides** (NaCl, $MgCl_2$) simply **dissolve**, giving a near-neutral solution.
- **covalent chlorides** ($SiCl_4$, PCl_5) **hydrolyse** 水解 (react with water), giving an **acidic** solution and **HCl** fumes.

Watch out: the oxides change from basic (metals) through amphoteric (Al_2O_3) to acidic (non-metals) — the trend follows the metal-to-non-metal change across the period.

Practice

Try these in order.

9.1 State whether each oxide is basic or acidic: (a) Na_2O, (b) SO_3. [2]

9.2 What does *amphoteric* mean? [1]

9.3 Which Period 3 oxide is amphoteric? [1]

9.4 Sodium chloride dissolves in water to a neutral solution, but phosphorus(V) chloride reacts with water. Explain this difference. [2]

9.5 Name the gas given off (as fumes) when a covalent chloride is added to water. [1]

9.6 Challenge. Predict which would raise the pH of water — magnesium oxide (MgO) or sulfur trioxide (SO_3) — and explain. [2]

18 Which oxide has a simple structure rather than a giant structure?

A MgO **B** Al_2O_3 **C** SiO_2 **D** P_4O_{10}

18 Compound X is an oxide of a Period 3 element.

Compound X is a white solid at 25 °C. It reacts with water to form an acidic solution.

What is compound X?

A aluminium oxide

B silicon dioxide

C sulfur dioxide

D phosphorus(V) oxide

23 Element E is in Period 3. It forms a chloride which reacts with a small amount of water to produce a white precipitate and steamy fumes. This precipitate is soluble in NaOH(aq) and in HCl(aq).

What is element E?

A magnesium

B aluminium

C silicon

D phosphorus

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 $CH_2O + H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

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

(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]

10 Group 2 – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)
Group	族	
more reactive	反应活性	

Recall

At IGCSE you learned that **Group** 族 elements share similar reactions, and that reactivity changes down a group. Now we look at **Group 2** — the metals magnesium, calcium, strontium and barium.

- They all have **two** outer electrons, lost to form **2+ ions**.
- Reactivity changes in a clear pattern down the group.

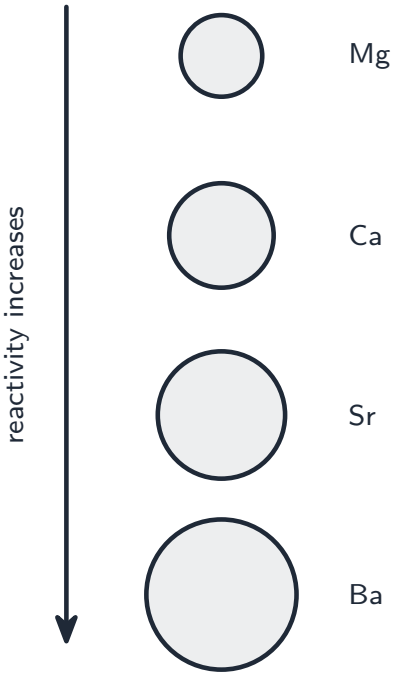
Nothing here is harder than IGCSE — it just lines up one group.

New ideas

Read these first, then do the Practice.

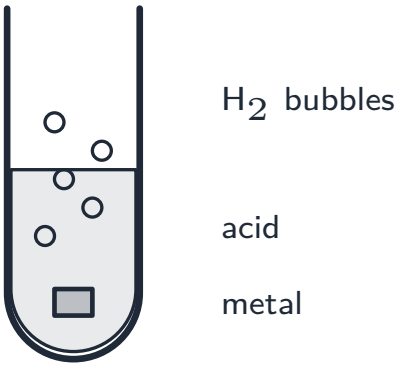
■ 1 Reactivity increases down the group

Going **down** Group 2, the atoms get **larger**, so the two outer electrons are held less tightly and are lost more easily. So the metals become **more reactive** 反应活性.



2 Reactions of the metals

- with **oxygen** → an **oxide**: $2Mg + O_2 \rightarrow 2MgO$.
- with **water** → a **hydroxide** + hydrogen: $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$.
- with **dilute acid** → a **salt** + hydrogen: $Mg + 2HCl \rightarrow MgCl_2 + H_2$.



The reaction with water gets **faster** down the group (more reactive metal).

Watch out: down Group 2 the reactivity *increases* (larger atoms lose their outer electrons more easily). This is the *opposite* of the halogens (Group 17), where reactivity *decreases* down the group.

Practice

Try these in order.

10.1 How many outer electrons does a Group 2 atom have, and what ion does it form? [2]

10.2 Describe and explain the trend in reactivity down Group 2. [3]

10.3 Write the equation for magnesium reacting with oxygen. [1]

10.4 Calcium reacts with water. Name the two products. [2]

10.5 Complete: $Mg + 2HCl \rightarrow$ _____ + _____. [2]

10.6 Challenge. Barium reacts with water much faster than magnesium. Explain why, in terms of atomic size and the outer electrons. [2]

10 Group 2 – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Thermal decomposition	热分解			
hydroxides	氢氧化物			
sulfates	硫酸盐			

Recall

From Part 1 you know the Group 2 metals. Here we heat their **compounds** and look at how easily they break apart and dissolve.

- **Thermal decomposition** 热分解 means breaking a compound by heating.
- The trends down the group are clear and worth learning.

New ideas

Read these first, then do the Practice.

■ 1 Thermal decomposition

Heating breaks the compounds apart:

- **carbonates** → oxide + carbon dioxide: $CaCO_3 \rightarrow CaO + CO_2$.
- **nitrates** → oxide + brown NO_2 + oxygen.

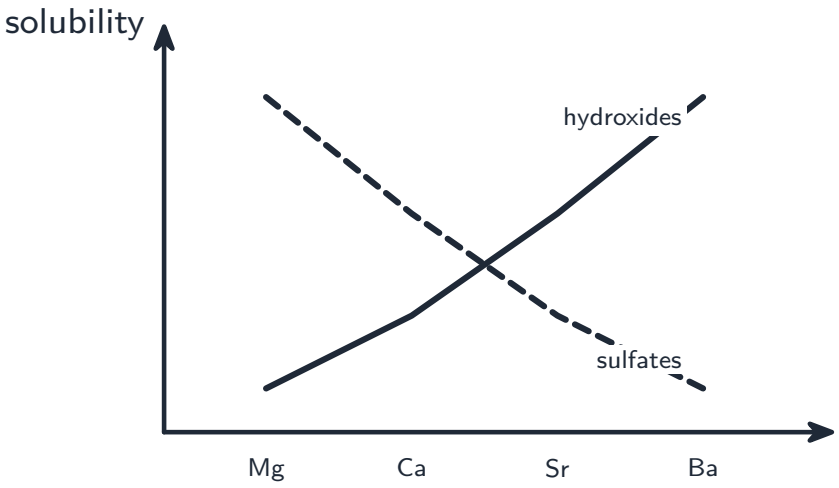
■ 2 Thermal stability increases down the group

A **larger** metal ion pulls **less** on the carbonate (or nitrate) ion, so it **distorts** it less and the compound is **harder** to break apart. So magnesium carbonate decomposes most easily, and barium carbonate is the hardest.

3 Solubility trends

Compound	Down the group
hydroxides 氢氧化物	become **more** soluble
sulfates 硫酸盐	become **less** soluble

(So $Mg(OH)_2$ is nearly insoluble but $Ba(OH)_2$ dissolves; $MgSO_4$ dissolves but $BaSO_4$ is insoluble.)



Watch out: thermal stability *increases* down the group — a *larger* cation distorts the anion *less*, so the carbonate is harder to break apart. The two solubility trends go opposite ways: hydroxides become more soluble, sulfates less soluble.

Practice

Try these in order.

10.1 What is meant by *thermal decomposition*? [1]

10.2 Write the equation for the thermal decomposition of calcium carbonate. [2]

10.3 State and explain the trend in thermal stability of the carbonates down Group 2. [3]

10.4 State the trend down the group in the solubility of (a) the hydroxides, (b) the sulfates. [2]

10.5 Which is more soluble, magnesium hydroxide or barium hydroxide? [1]

10.6 Challenge. Predict which decomposes at a *lower* temperature — magnesium carbonate or barium carbonate — and explain. [2]

20 Equal masses of $CaCO_3$, $Ca(NO_3)_2$, $BaCO_3$ and $Ba(NO_3)_2$ are thermally decomposed. The volume of gas produced in each experiment is measured under the same conditions.

Which compound will produce the greatest volume of gas?

A $CaCO_3$ **B** $Ca(NO_3)_2$ **C** $BaCO_3$ **D** $Ba(NO_3)_2$

19 When heated, magnesium nitrate decomposes.

Which equation for the thermal decomposition of magnesium nitrate is correct?

A $Mg(NO_3)_2 \rightarrow MgO + NO_2 + NO + O_2$

B $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO + 3O_2$

C $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$

D $3Mg(NO_3)_2 \rightarrow Mg_2N_3 + MgO + 3NO + 7O_2$

20 R is the aqueous solution of an ionic compound.

- A white precipitate is formed when R is added to $Sr(NO_3)_2(aq)$.
- No visible reaction is seen when R is added to dilute $HNO_3(aq)$.

What is the anion present in compound R?

A Cl^- **B** SO_4^{2-} **C** HCO_3^- **D** CO_3^{2-}

19 Magnesium nitrate, $Mg(NO_3)_2$, will decompose when heated to give a white solid and a mixture of gases. One of the gases released is oxygen.

29.7 g of anhydrous magnesium nitrate is heated until no further reaction takes place.

Which mass of oxygen is produced?

A 3.2 g **B** 6.4 g **C** 12.8 g **D** 19.2 g

11 The halogens – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
halogens	卤素			
volatility	挥发性			
van der Waals' forces	范德华力			
oxidising agent	氧化剂			

Recall

At IGCSE you met the **halogens** 卤素 (Group 17) and saw that a more reactive halogen can displace a less reactive one. Now we explain the trends.

- The halogens are **diatomic** molecules: Cl_2, Br_2, I_2.
- Their reactivity (as oxidising agents) changes down the group.

Nothing here is harder than IGCSE — it just adds the reasons.

New ideas

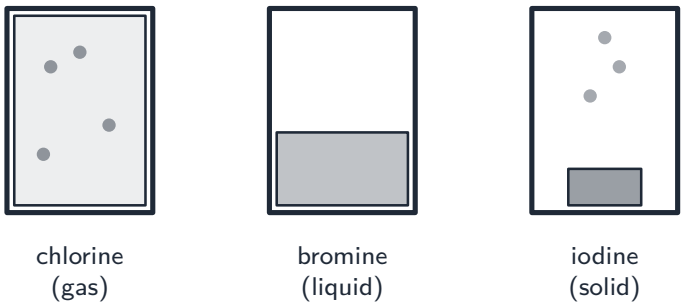
Read these first, then do the Practice.

■ 1 Colour, state and volatility

Halogen	At room temperature
chlorine	pale green **gas**
bromine	red-brown **liquid**
iodine	grey-black **solid**

The **volatility** 挥发性 (how easily it turns to vapour) **decreases** down the group.

The molecules get larger with more electrons, so the **van der Waals' forces** 范德华力 between them get stronger, raising the boiling point.

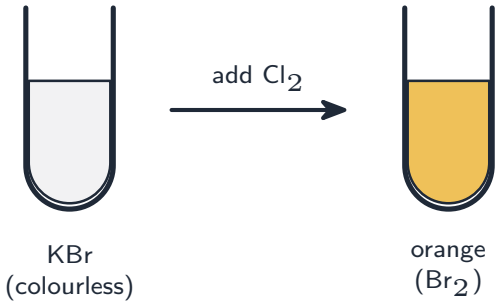


2 Oxidising power and displacement

Each halogen gains one electron to form a **1− ion**, acting as an **oxidising agent** 氧化剂. This power **decreases** down the group (larger atoms attract the extra electron less strongly).

So a more reactive halogen **displaces** a less reactive one from its salt:

$$Cl_2 + 2KBr \rightarrow 2KCl + Br_2$$



Watch out: a more reactive (more oxidising) halogen displaces a less reactive one — so chlorine displaces bromine and iodine, but iodine cannot displace chlorine.

Practice

Try these in order.

11.1 Give the colour and state of (a) chlorine, (b) iodine at room temperature. [2]

11.2 Describe and explain the trend in volatility down Group 17. [3]

11.3 Each halogen acts as an oxidising agent. Explain what this means in terms of electrons. [1]

11.4 State the trend in oxidising power down the group. [1]

11.5 Write the equation for chlorine reacting with potassium bromide, and state the colour change. [2]

11.6 Challenge. Predict whether bromine will displace iodine from potassium iodide. Write an equation if it reacts, and explain. [2]

1 The Group 17 elements are oxidising agents.

(a) **(i)** Explain how the Group 17 elements act as oxidising agents.

.....

..... [1]

(ii) Write an equation to show the reaction in which Cl_2 oxidises aluminium metal.

..... [1]

(iii) A student heats equal amounts of $I_2(g)$ and $H_2(g)$ in a sealed flask. The student leaves the contents to cool.

State what you would observe during the reaction.

..... [1]

(b) Cl_2 and Br_2 can each react with NH_3 to give N_2 and a hydrogen halide, HX.

$$3X_2 + 2NH_3 \rightarrow N_2 + 6HX \qquad X = Cl \text{ or } Br$$

The relative bond strengths of X–X and H–X determine the difference in enthalpy change of the two reactions.

(i) Describe and explain the difference in the X–X bond strengths of Cl_2 and Br_2.

.....

.....

.....

..... [2]

(ii) Describe the relative thermal stabilities of HCl and HBr.

..... [1]

(iii) Define enthalpy change of formation, ΔH_f.

.....

.....

..... [2]

(iv) Table 1.1 gives data relevant to the reaction of $Cl_2(g)$ with $NH_3(g)$.

Table 1.1

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$NH_3(g)$	–46
$HCl(g)$	–92

Use the data in Table 1.1 to calculate the enthalpy change of the reaction of $Cl_2(g)$ with $NH_3(g)$.

enthalpy change of reaction = ... kJ mol^{-1} [2]

(v) I_2 reacts with NH_3 to form NI_3.

Predict the shape of a molecule of NI_3. Explain your answer.

shape .....

explanation .....

.....

[2]

(c) Table 1.2 shows some information about reactions of NaCl, NaBr and NaI.

Table 1.2

	NaCl	**NaBr**	**NaI**
observation with $Ag^+(aq)$	white precipitate		
type of reaction with concentrated H_2SO_4	acid–base	acid–base, then redox	acid–base, then redox
observations with concentrated H_2SO_4			• black solid • yellow solid • effervescence

(i) Complete Table 1.2. [4]

(ii) Suggest an identity for the species that produces each observation in the reaction of NaI with concentrated H_2SO_4.

black solid .....

yellow solid .....

effervescence .....

[2]

(d) Table 1.3 gives some information about $MgCl_2$ and $SiCl_4$.

Table 1.3

	$MgCl_2$	**$SiCl_4$**
electrical conductivity when liquid	conducts	does **not** conduct
observation when added to water	dissolves	vigorous reaction

(i) Explain the difference between the electrical conductivity of liquid $MgCl_2$ and of liquid $SiCl_4$. Refer to bonding and relevant particles in your answer.

.....

.....

.....

.....

..... [2]

(ii) Suggest the pH of the solutions that form when each chloride is added to water.

$MgCl_2$ ..... $SiCl_4$ .....

[2]

22 What happens when iodine solution is added to a solution of sodium bromide?

A A reaction occurs without changes in oxidation state.

B Bromide ions are oxidised; iodine atoms are reduced.

C Bromide ions are reduced; iodine atoms are oxidised.

D No reaction occurs.

23 Which statement is correct?

A Nitrogen is unreactive due to the absence of lone pairs in the molecule.

B Aqueous ammonia contains both $NH_3(aq)$ and $NH_4^+(aq)$. The $NH_4^+(aq)$ ion is a Brønsted–Lowry acid.

C High temperatures are needed to supply the energy to break the strong double bonds in nitrogen molecules when they react.

D Atmospheric SO_2 reacts with unburnt hydrocarbons to form a component of photochemical smog.

11 The halogens – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
halogens	卤素			
halide ions	卤离子			
silver nitrate	硝酸银			
ammonia	氨			
precipitate	沉淀			

Recall

From Part 1 you know the **halogens** 卤素 are oxidising agents. Here we look at their **halide ions** 卤离子 (Cl^-, Br^-, I^-) and how to tell them apart.

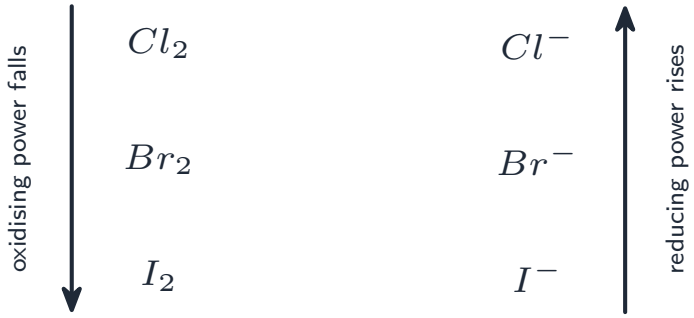
- A halide ion can **give** an electron, acting as a reducing agent.
- A silver nitrate test identifies which halide is present.

New ideas

Read these first, then do the Practice.

■ 1 Two opposite trends

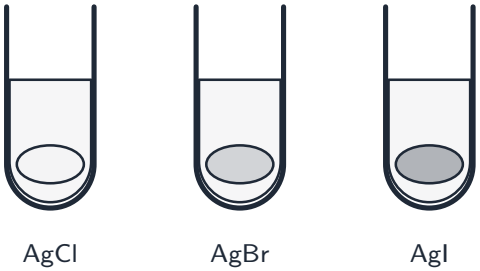
- the **oxidising power** of the halogens **decreases** down the group.
- the **reducing power** of the halide ions **increases** down the group (a larger ion holds its outer electron less tightly).



■ 2 The silver nitrate test

Add **silver nitrate** 硝酸银 solution to a halide, then **ammonia** 氨, and read off the **precipitate** 沉淀:

Halide	Precipitate	In ammonia
Cl^-	**white**	dissolves in dilute
Br^-	**cream**	dissolves only in concentrated
I^-	**yellow**	insoluble



white / cream / yellow

■ 3 With concentrated sulfuric acid

All give the hydrogen halide first; the **stronger reducing agents** are then oxidised:

- chloride → only **HCl** (no redox).
- bromide → also some brown $\mathbf{Br_2}$ and SO_2.
- iodide → $\mathbf{I_2}$ plus H_2S and SO_2 (I^- is the strongest reducing agent).

Watch out: the two trends are *opposite* — the oxidising power of the *halogens* falls down the group, while the reducing power of the *halide ions* rises down the group.

Practice

Try these in order.

11.1 State the trend down the group in the reducing power of the halide ions. [1]

11.2 Explain why reducing power increases down the group. [2]

11.3 Give the colour of the precipitate formed when silver nitrate is added to (a) Cl^-, (b) Br^-, (c) I^-. [3]

11.4 How could you use ammonia to confirm a white precipitate is silver chloride? [1]

11.5 With concentrated sulfuric acid, chloride gives only HCl, but iodide also gives iodine. Explain why. [2]

11.6 Challenge. A solution gives a cream precipitate with silver nitrate that dissolves only in concentrated ammonia. Identify the halide ion present, and explain how you know. [2]

21 Equation 1 and equation 2 show two different reactions of halide ion Q^- with concentrated sulfuric acid.

equation 1 $H_2SO_4 + Q^- \rightarrow HSO_4^- + HQ$

equation 2 $H_2SO_4 + 2Q^- + 2H^+ \rightarrow SO_2 + Q_2 + 2H_2O$

What is Q?

A Cl^- or Br^- **B** Br^- or I^- **C** Cl^- only **D** I^- only

22 X and Y are sodium salts of Group 17 elements.

When X reacts with concentrated sulfuric acid, hydrogen sulfide, H_2S, is produced.

When Y reacts with concentrated sulfuric acid, there is no change in the oxidation number of the sulfur.

Which statement is correct?

A Aqueous X reduces aqueous bromine.

B Aqueous Y reacts with aqueous silver nitrate to give a precipitate which is insoluble in concentrated aqueous ammonia.

C X and Y react separately with concentrated sulfuric acid to produce halogens.

D When X reacts with concentrated sulfuric acid, six halide ions are needed to reduce one sulfur atom to H_2S.

21 In an experiment, 0.600 mol of chlorine gas, Cl_2, is reacted with an excess of hot aqueous sodium hydroxide. One of the products is $NaClO_3$.

Which mass of $NaClO_3$ is formed?

A 21.3 g **B** 44.7 g **C** 63.9 g **D** 128 g

22 An excess of chlorine gas is bubbled into hot potassium hydroxide solution.

Which chlorine-containing species are present in the final solution?

A Cl^- and ClO^-

B Cl^- and ClO_3^-

C ClO^- and ClO_3^-

D ClO_3^- only

12 Nitrogen and its compounds – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
nitrogen	氮			
ammonia	氨			
lone pair	孤对电子			
triple bond	三键			
bond energy	键能			
non-polar	非极性			
base	碱			
proton	质子			
coordinate bond	配位键			
ammonium ion	铵离子			

Recall

At IGCSE you learned that air is mostly **nitrogen** 氮, and you met **ammonia** 氨 (NH_3). Now we explain why nitrogen barely reacts, and why ammonia is a base.

- Nitrogen gas is N_2 — two atoms joined by a strong bond.
- Ammonia has a **lone pair** 孤对电子 that makes it a base.

Nothing here is harder than IGCSE — it just adds the reasons.

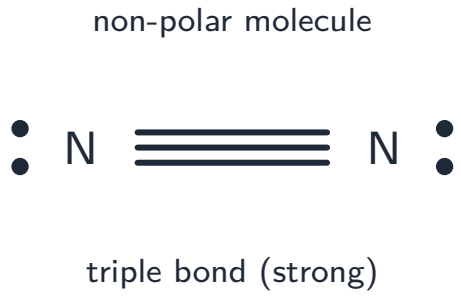
New ideas

Read these first, then do the Practice.

■ 1 Why nitrogen is unreactive

N_2 makes up most of the air but reacts with very little, for two reasons:

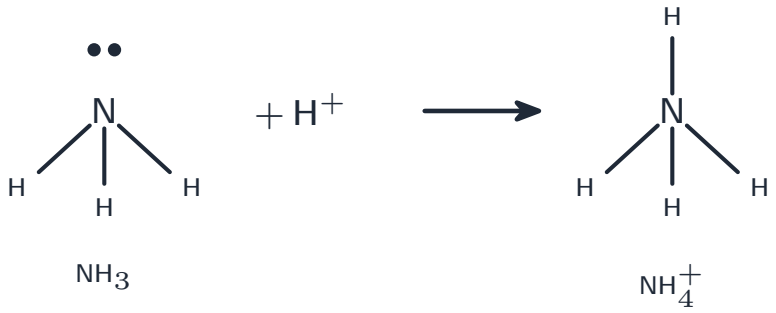
- the atoms are joined by a **triple bond** 三键 with a very high **bond energy** 键能 — hard to break.
- the molecule is symmetrical and **non-polar** 非极性, so nothing attracts other molecules to it.



■ 2 Ammonia as a base

Ammonia is a **base** 碱 because the **lone pair** 孤对电子 on its nitrogen can accept a **proton** 质子 (H^+):

$$NH_3 + H^+ \rightarrow NH_4^+$$



The new bond is a **coordinate bond** 配位键 (both electrons came from nitrogen). The **ammonium ion** 铵离子 NH_4^+ has four identical N–H bonds.

■ 3 Test for an ammonium salt

Warm an ammonium salt with sodium hydroxide to push out ammonia gas:

$$NH_4Cl + NaOH \rightarrow NaCl + NH_3 + H_2O$$

The sharp smell, and **damp red litmus turning blue**, confirms an ammonium salt.

Watch out: ammonia is a base because of its lone pair, which accepts an H^+ to form a coordinate bond. Once the ammonium ion has formed, all four N–H bonds are identical — you cannot tell the coordinate one apart.

Practice

Try these in order.

12.1 State the two reasons nitrogen gas is unreactive. [2]

12.2 What feature of ammonia allows it to act as a base? [1]

12.3 Write the equation for ammonia accepting a proton. [1]

12.4 The fourth N–H bond in the ammonium ion is a coordinate bond. Explain what this means. [2]

12.5 Describe the test for an ammonium salt and its result. [2]

12.6 Challenge. Ammonia (NH_3) can act as a base, but the ammonium ion (NH_4^+) cannot. Explain why, in terms of the lone pair. [2]

12 Nitrogen and its compounds – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
oxides of nitrogen	氮氧化物			
engine	发动机			
catalytic converter	催化转化器			
exhaust gases	尾气			
acid rain	酸雨			

Recall

From Part 1 you know nitrogen is unreactive — but at very high temperatures it does react. Here we meet the **oxides of nitrogen** 氮氧化物 and the pollution they cause.

- Inside a hot engine, nitrogen and oxygen combine.
- The oxides (NO, NO_2) cause smog and acid rain.

New ideas

Read these first, then do the Practice.

■ 1 Where the oxides come from

Oxides of nitrogen (NO_x) form when nitrogen and oxygen react at high temperature:

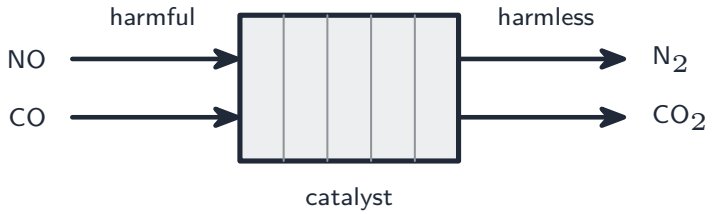
$$N_2 + O_2 \rightarrow 2NO$$

- **natural** — **lightning** gives enough energy.
- **man-made** — the high temperature inside a car **engine** 发动机.

■ 2 The catalytic converter

A **catalytic converter** 催化转化器 cleans the **exhaust gases** 尾气, letting the harmful gases react to form harmless ones:

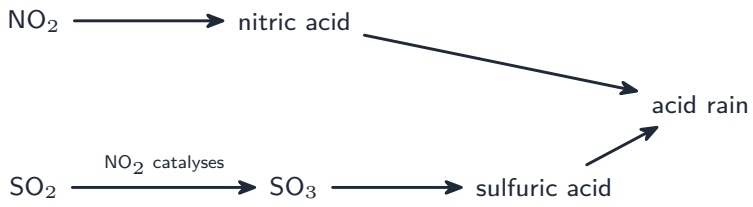
$$2NO + 2CO \rightarrow N_2 + 2CO_2$$



■ 3 Acid rain

The oxides also cause **acid rain** 酸雨:

- NO_2 dissolves in rain to form **nitric acid**.
- NO_2 also speeds up (catalyses) the change of SO_2 into SO_3, which forms **sulfuric acid**.



Watch out: in a catalytic converter the *harmful* gases (NO, CO) react together to make *harmless* ones (N_2, CO_2). The catalyst only speeds this up — it is not used up.

Practice

Try these in order.

12.1 Write the equation for nitrogen and oxygen forming nitrogen monoxide. [1]

12.2 State one natural and one man-made source of oxides of nitrogen. [2]

12.3 Write the equation for the reaction in a catalytic converter that removes NO and

CO. [2]

12.4 Name the harmless products formed in a catalytic converter. [2]

12.5 Explain the **two** ways oxides of nitrogen contribute to acid rain. [2]

12.6 Challenge. Explain why oxides of nitrogen form inside a hot car engine but not in ordinary air. [2]

16 Oxides of nitrogen, NO_x, are involved in formation of photochemical smog and acid rain.

Which oxides of nitrogen are involved in each of these processes?

	photochemical smog		acid rain	
	NO	NO_2	NO	NO_2
A	✓	✓	✓	✓
B	✗	✓	✗	✓
C	✓	✓	✗	✓
D	✗	✓	✓	✓

24 Four reaction mixtures are listed.

1 $(NH_4)_2SO_4(aq)$ and NaOH

2 $NH_4Cl(aq)$ and $Ba(OH)_2$

3 $NH_4Cl(aq)$ and Na_2O

4 $(NH_4)_3PO_4(aq)$ and HCl

Which reaction mixtures produce ammonia as a product?

A 1, 2 and 3 **B** 1 and 2 only **C** 2 and 3 only **D** 3 and 4 only

24 Which reagent, when mixed with ammonium sulfate and then heated, liberates ammonia?

A aqueous bromine

B dilute hydrochloric acid

C aqueous calcium hydroxide

D potassium dichromate(VI) in acidic solution

13 Introduction to organic chemistry – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
hydrocarbons	碳氢化合物			
functional group	官能团			
general	通式			
molecular	分子式			
structural	结构式			
displayed	展开式			
skeletal	骨架式			
homologous series	同系列			
saturated	饱和			
unsaturated	不饱和			
homolytic fission	均裂			
free radicals	自由基			
heterolytic fission	异裂			
ions	离子			

English	中文	Write it 3 times (English)		
nucleophile	亲核试剂			
electrophile	亲电试剂			

Recall

At IGCSE you met **hydrocarbons** 碳氢化合物 and drew molecules like methane. Now we organise organic chemistry — the ways to write a formula, and the **functional group** 官能团 that gives a family its reactions.

- A functional group is the **reactive part** of a molecule.
- Molecules with the same functional group react in the same way.

Nothing here is harder than IGCSE — it just adds the system.

New ideas

Read these first, then do the Practice.

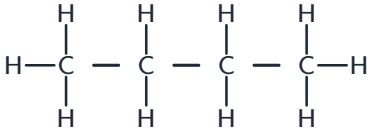
1 Types of formula

Formula	Shows
general 通式	the family pattern, e.g. alkanes C_nH_{2n+2}
molecular 分子式	the actual atoms, e.g. C_4H_{10}
structural 结构式	groups in order, e.g. $CH_3CH_2CH_2CH_3$
displayed 展开式	every atom and bond drawn
skeletal 骨架式	lines only; C at corners, H on C not shown

molecular: C_4H_{10}

structural: $CH_3CH_2CH_2CH_3$

displayed:



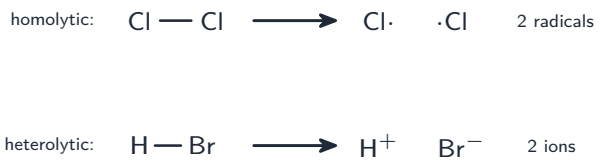
skeletal:

2 Homologous series

A **homologous series** 同系列 is a family with the same functional group and general formula, where each member differs by CH_2. A compound is **saturated** 饱和 (only single C–C bonds) or **unsaturated** 不饱和 (has a C=C).

3 Breaking bonds and attacking species

- **homolytic fission** 均裂 — splits evenly → two **free radicals** 自由基.
- **heterolytic fission** 异裂 — splits unevenly → two **ions** 离子.



- a **nucleophile** 亲核试剂 has a lone pair and attacks a positive (electron-poor) centre.
- an **electrophile** 亲电试剂 is attracted to an electron-rich centre (such as a C=C bond).

Watch out: a nucleophile *donates* a lone pair to an electron-poor ($\delta+$) centre; an electrophile *accepts* electrons from an electron-rich centre. Homolytic fission makes radicals, heterolytic makes ions.

Practice

Try these in order.

13.1 What is a *functional group*? [1]

13.2 Give the general formula of the alkanes. [1]

13.3 Each member of a homologous series differs from the next by what group? [1]

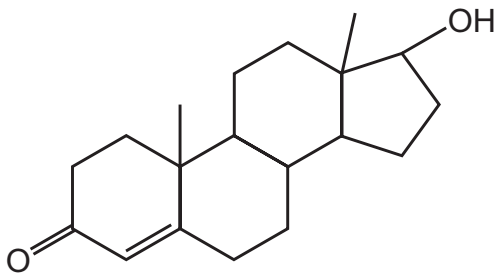
13.4 State the difference between homolytic and heterolytic fission. [2]

13.5 What is a *nucleophile*? [1]

13.6 Draw the skeletal formula of butane, C_4H_{10}. [1]

13.7 Challenge. In a C–Br bond the carbon carries a small positive charge. Explain why, and why this makes the carbon open to attack by a nucleophile. [2]

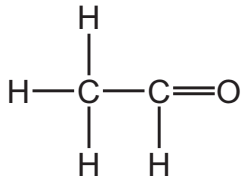
28 The diagram shows the skeletal formula of the hormone testosterone.



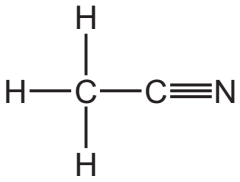
What is the molecular formula of testosterone?

A $C_{19}H_{28}O_2$ **B** $C_{17}H_{22}O_2$ **C** $C_{17}H_{24}O_2$ **D** $C_{19}H_{26}O_2$

37 The structures of three organic compounds are shown.



1



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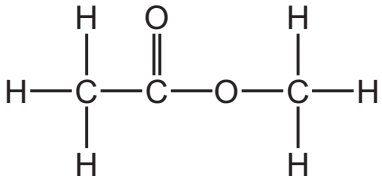


3

Which compounds produce ethanoic acid when heated with HCl(aq)?

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

3 Propan-2-ol, $(CH_3)_2CHOH$, is sometimes added to fuel to help it burn.

Fig. 3.1 shows some reactions of propan-2-ol.

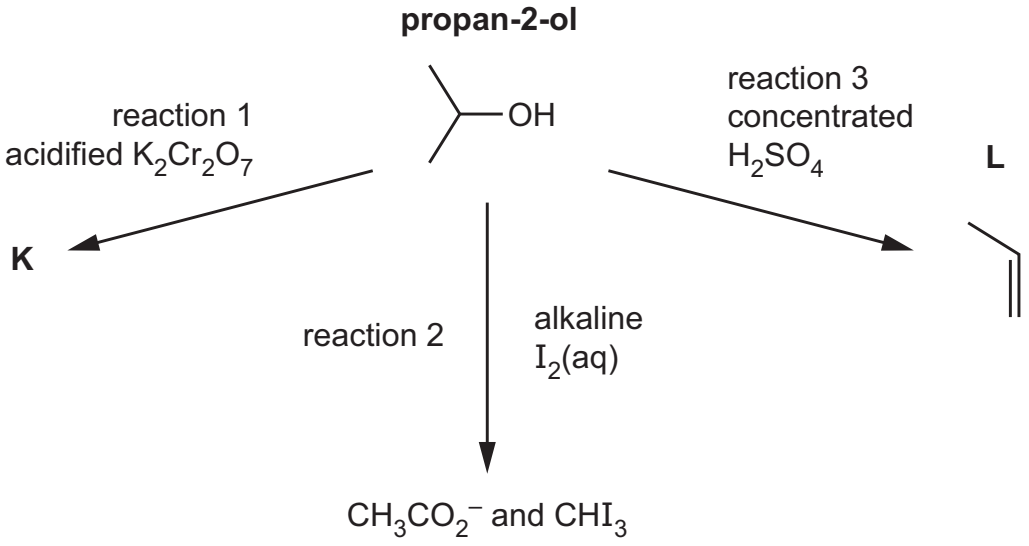


Fig. 3.1

(a) (i) Draw the structure of organic compound **K**.

[1]

(ii) State an observation you would make in reaction 2.

..... [1]

(iii) State the type of reaction that is shown in reaction 3.

..... [1]

(iv) Complete Fig. 3.2 to show the pi (π) bond in **L** that is formed from orbital overlap.

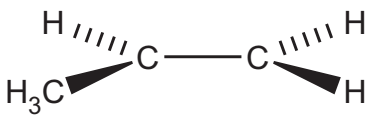


Fig. 3.2

[1]

(b) Propan-2-ol reacts with sodium to produce $(CH_3)_2CH–O^-$ anions.

These anions react with 2-bromopropane to form compound **N**, as shown in Fig. 3.3.

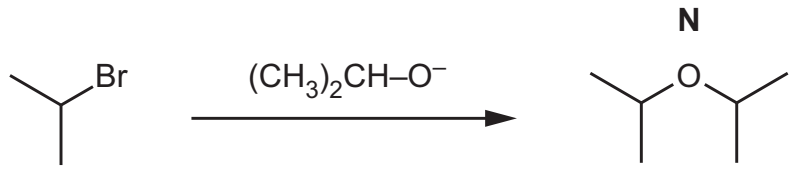


Fig. 3.3

(i) Write an equation for the reaction of propan-2-ol with sodium.

..... [1]

(ii) The reaction of 2-bromopropane with $(CH_3)_2CH–O^-$ anions follows an S_N1 mechanism.

Complete Fig. 3.4 to show this mechanism. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

Fig. 3.4

[3]

(iii) Suggest how the rate of the S_N1 reaction would change, if at all, if 2-chloropropane were used instead of 2-bromopropane.

Explain your answer.

.....

.....

..... [2]

(iv) **N** is also added to petrol to make it burn more smoothly.

Construct an equation for the complete combustion of **N**, $C_6H_{14}O$.

$C_6H_{14}O$ ..... [1]

[Total: 11]

13 Isomerism – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
isomers	异构体			
structural isomerism	结构异构			
chain isomerism	链异构			
positional isomerism	位置异构			
functional-group isomerism	官能团异构			
restricted rotation	受限旋转			
cis	顺式			
trans	反式			
chiral centre	手性中心			
enantiomers	对映体			

Recall

From Part 1 you know how to write organic formulas. Here we meet **isomers** 异构体 — molecules with the **same** molecular formula but a **different** arrangement.

- Same atoms, joined or arranged differently.
- This explains why two compounds can share a formula yet behave differently.

New ideas

Read these first, then do the Practice.

■ 1 Structural isomerism

In **structural isomerism** 结构异构 the atoms are joined in a different **order**. Three kinds:

- **chain isomerism** 链异构 — the carbon chain branches differently (e.g. butane vs 2-methylpropane).
- **positional isomerism** 位置异构 — the functional group is on a different carbon (e.g. propan-1-ol vs propan-2-ol).
- **functional-group isomerism** 官能团异构 — the atoms make a different functional group (e.g. an alcohol vs an ether).

■ 2 Cis–trans (geometrical) isomerism

A C=C double bond **cannot rotate** (**restricted rotation** 受限旋转). So groups are fixed on the **same** side (**cis** 顺式) or **opposite** sides (**trans** 反式).

cis (same side) trans (opposite)

■ 3 Optical isomerism

A **chiral centre** 手性中心 is a carbon with **four different** groups. It gives two **mirror-image** forms (**enantiomers** 对映体) that cannot be superimposed.

mirror images (enantiomers)

Watch out: cis–trans isomerism needs a C=C (no rotation) *with two different groups on each carbon*; optical isomerism needs a chiral carbon bonded to *four different*

groups.

Practice

Try these in order.

13.1 What are *isomers*? [1]

13.2 Name the three kinds of structural isomerism. [3]

13.3 Why can a C=C double bond not rotate? [1]

13.4 In cis–trans isomerism, what is the difference between the *cis* and *trans* forms? [2]

13.5 What makes a carbon a *chiral centre*? [1]

13.6 What name is given to the two mirror-image forms at a chiral centre? [1]

13.7 Challenge. But-2-ene ($CH_3CH{=}CHCH_3$) shows cis–trans isomerism, but but-1-ene ($CH_2{=}CHCH_2CH_3$) does not. Explain why. [2]

25 Two statements about a molecule of methanal are given.

1 It is planar.

2 It contains three σ bonds.

Which statements are correct?

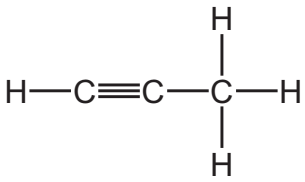
A both 1 and 2

B 1 only

C 2 only

D neither 1 nor 2

6 The diagram shows the bonding in a molecule of propyne.



Which types of hybridisation are shown by the carbon atoms in propyne?

A sp, sp^2 and sp^3

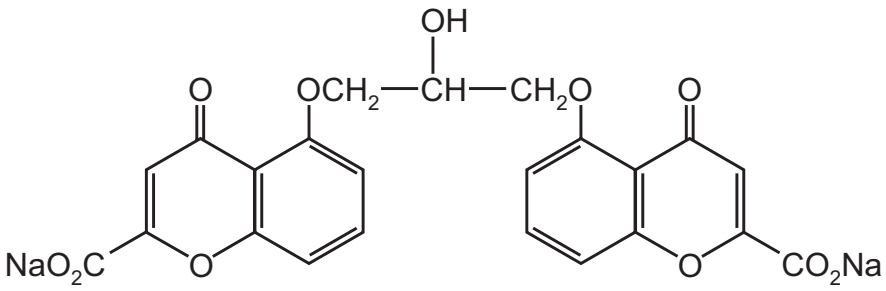
B sp and sp^3 only

C sp^2 and sp^3 only

D sp^2 only

26 The structure of disodium cromoglycate is shown.

disodium cromoglycate

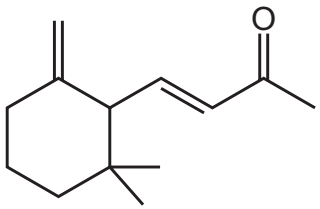


How many chiral centres are there in this molecule?

A 0 **B** 1 **C** 2 **D** 3

26 The structure of the compound γ-ionone is shown.

γ-ionone



Including γ-ionone, how many stereoisomers exist with this molecular formula?

A 1 **B** 2 **C** 4 **D** 8

14 Alkanes – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
alkanes	烷烃			
complete combustion	完全燃烧			
incomplete combustion	不完全燃烧			
carbon monoxide	一氧化碳			
ultraviolet light	紫外线			
free-radical substitution	自由基取代			
initiation	引发			
propagation	增长			
termination	终止			
polarity	极性			

Recall

At IGCSE you learned that **alkanes** 烷烃 are saturated hydrocarbons that **burn** as fuels. Now we look at their combustion and their one important reaction with halogens.

- Alkanes have only single bonds (general formula C_nH_{2n+2}).
- They are fairly **unreactive** because their bonds are strong and non-polar.

Nothing here is harder than IGCSE — it just adds a mechanism.

New ideas

Read these first, then do the Practice.

1 Combustion

- **complete combustion** 完全燃烧 (plenty of oxygen) → carbon dioxide + water.
- **incomplete combustion** 不完全燃烧 (too little oxygen) → water + toxic **carbon monoxide** 一氧化碳 (CO) + soot.

$$\text{complete: alkane} + O_2 \rightarrow CO_2 + H_2O$$

$$\text{incomplete: alkane} + \text{less } O_2 \rightarrow CO + \text{soot} + H_2O$$

2 Free-radical substitution

Alkanes react with chlorine (or bromine) in **ultraviolet light** 紫外线 by **free-radical substitution** 自由基取代, in three steps:

- **initiation** 引发 — UV splits the halogen into **radicals**: $Cl_2 \rightarrow 2\,Cl\cdot$
- **propagation** 增长 — radicals react and make new radicals: $Cl\cdot + CH_4 \rightarrow CH_3\cdot + HCl$, then $CH_3\cdot + Cl_2 \rightarrow CH_3Cl + Cl\cdot$
- **termination** 终止 — two radicals join, ending the chain.

$$\begin{aligned}
&\text{initiation:} && Cl_2 \rightarrow 2\,Cl\cdot \\
&\text{propagation:} && Cl\cdot + CH_4 \rightarrow CH_3\cdot + HCl \\
& && CH_3\cdot + Cl_2 \rightarrow CH_3Cl + Cl\cdot \\
&\text{termination:} && Cl\cdot + CH_3\cdot \rightarrow CH_3Cl
\end{aligned}$$

3 Why alkanes are unreactive

Their C–H and C–C bonds are strong and have little **polarity** 极性, so there is no charge to attract an attacking species.

Watch out: free-radical substitution needs UV light and gives a *mixture* of products (mono-, di-, tri-substituted). The dot in Cl· marks an unpaired electron — a radical, not an ion.

Practice

Try these in order.

14.1 Give the general formula of the alkanes. [1]

14.2 Name the products of (a) complete, (b) incomplete combustion of an alkane. [2]

14.3 Why is carbon monoxide dangerous? (one reason) [1]

14.4 Name the three steps of free-radical substitution, in order. [3]

14.5 Write the initiation step for the reaction of chlorine in UV light. [1]

14.6 Explain why alkanes are unreactive towards polar reagents. [2]

14.7 Challenge. When methane reacts with chlorine in UV light, the product is a mixture, not just chloromethane. Explain why. [2]

29 The fumes from the exhausts of petrol-burning cars contain the following pollutants.

1 unburnt hydrocarbons

2 nitrogen dioxide

3 carbon monoxide

Which pollutants are removed by oxidation in a catalytic converter?

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

25 Two hydrocarbons, $CH_3CHC(CH_3)CH_3$ and $CH_3CH(CH_3)CH_2CH_3$, react separately with chlorine in the presence of ultraviolet light.

In each reaction, free-radical substitution occurs.

Which row is correct?

	identity of the hydrocarbon that can also undergo electrophilic addition	a termination stage of the free-radical substitution of the saturated hydrocarbon
A	$CH_3CHC(CH_3)CH_3$	$CH_3CH(CH_3)CH_2CH_2\bullet + Cl\bullet \rightarrow CH_3CH(CH_3)CH_2CH_2Cl$
B	$CH_3CHC(CH_3)CH_3$	$CH_3CHC(CH_3)CH_2\bullet + Cl\bullet \rightarrow CH_3CHC(CH_3)CH_2Cl$
C	$CH_3CH(CH_3)CH_2CH_3$	$CH_3CH(CH_3)CH_2CH_2\bullet + Cl\bullet \rightarrow CH_3CH(CH_3)CH_2CH_2Cl$
D	$CH_3CH(CH_3)CH_2CH_3$	$CH_3CHC(CH_3)CH_2\bullet + Cl\bullet \rightarrow CH_2CHC(CH_3)CH_2Cl$

14 Alkenes – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Alkenes	烯烃			
C=C double bond	双键			
electrophilic addition	亲电加成			
bromine water	溴水			
addition polymerisation	加成聚合			
polymer	聚合物			

Recall

From Part 1 you know alkanes are unreactive. **Alkenes** 烯烃 are different — they have a reactive **C=C double bond** 双键 (general formula C_nH_{2n}).

- The C=C double bond is the functional group.
- It makes alkenes react readily by **addition**.

New ideas

Read these first, then do the Practice.

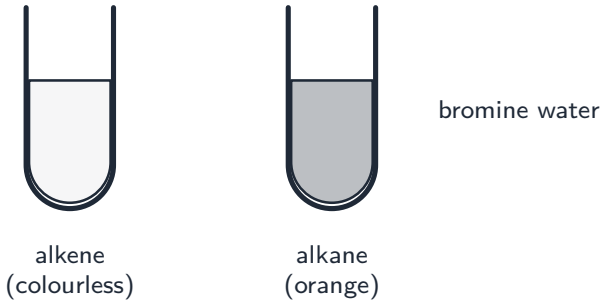
■ 1 Electrophilic addition

Most alkene reactions are **electrophilic addition** 亲电加成 across the C=C bond:

Reagent	Product
H_2 (Ni catalyst)	an alkane
steam (H_2O, H_3PO_4 catalyst)	an alcohol
a hydrogen halide (HX)	a halogenoalkane
a halogen (Br_2)	a di-substituted alkane

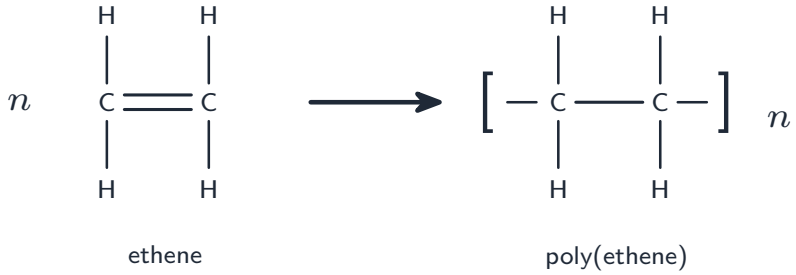
2 The test for a C=C bond

Shake the compound with orange **bromine water** 溴水. An **alkene decolourises** it (turns it colourless); an alkane does not.



3 Addition polymerisation

In **addition polymerisation** 加成聚合, many alkene molecules open their double bonds and join into one long chain — a **polymer** 聚合物 — with no other product. Ethene gives poly(ethene).



Watch out: alkenes react by *addition* — the C=C opens and groups add across it (unlike alkanes, which only substitute). In the bromine-water test the orange colour goes *colourless* with an alkene.

Practice

Try these in order.

14.1 Give the general formula of the alkenes, and name their functional group. [2]

14.2 Name the product when an alkene reacts with (a) hydrogen, (b) steam. [2]

14.3 Describe the bromine-water test and its result for an alkene. [2]

14.4 Why does an alkene decolourise bromine water but an alkane does not? [2]

14.5 What is *addition polymerisation*? [2]

14.6 Name the polymer made from ethene. [1]

14.7 Challenge. Predict the product when ethene ($CH_2{=}CH_2$) reacts with bromine (Br_2), and explain what happens to the double bond. [2]

27 Which intermediate ion forms in the greatest amount during the addition of HBr to propene?

A $CH_3CH^+CH_3$

B $CH_3CH_2CH_2^+$

C $CH_3CH^-CH_2Br$

D $CH_3CHBrCH_2^-$

27 What is the major product when 2-methylpent-2-ene reacts with hydrogen bromide?

A 1-bromo-2-methylpentane

B 2-bromo-2-methylpentane

C 3-bromo-2-methylpentane

D 4-bromo-2-methylpentane

28 Pent-2-ene is reacted with cold, dilute, acidified manganate(VII) ions.

What is the major product?

A $CH_3CH_2CH(OH)CH(OH)CH_3$

B $CH_3CH_2COCOCH_3$

C a mixture of $CH_3CH_2CH(OH)CH_2CH_3$ and $CH_3CH_2CH_2CH(OH)CH_3$

D CH_3CH_2COOH and CH_3COOH

15 Halogenoalkanes – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
halogenoalkanes	卤代烷			
polar	极性			
nucleophile	亲核试剂			
primary	伯			
secondary	仲			
tertiary	叔			
nucleophilic substitution	亲核取代			
alcohol	醇			
nitrile	腈			
amine	胺			
silver nitrate	硝酸银			
precipitate	沉淀			

Recall

You met **halogenoalkanes** 卤代烷 when an alkane or alkene reacts with a halogen. A halogenoalkane has a **C–X bond** (X = a halogen) in place of a C–H bond.

- The C–X bond is **polar** 极性, so the carbon is slightly positive ($\delta+$).
- This $\delta+$ carbon is open to attack by a **nucleophile** 亲核试剂.

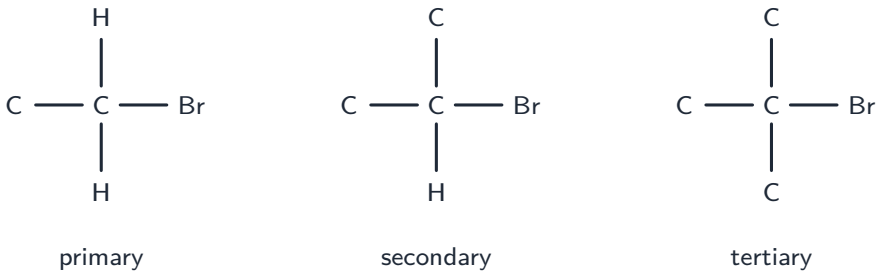
Nothing here is harder than IGCSE — it just adds the reactions.

New ideas

Read these first, then do the Practice.

1 Three classes

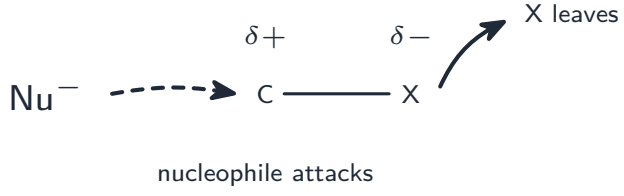
A halogenoalkane is **primary** 伯, **secondary** 仲 or **tertiary** 叔, set by how many carbons are joined to the carbon holding the halogen (one, two or three).



2 Nucleophilic substitution

A **nucleophile** 亲核试剂 (a lone-pair species) attacks the $\delta+$ carbon and replaces the halogen — a **nucleophilic substitution** 亲核取代:

Reagent	Product
NaOH(aq), heat	an **alcohol** 醇
KCN in ethanol	a **nitrile** 腈 (adds a carbon)
NH_3 in ethanol	an **amine** 胺



■ 3 Identifying the halogen

Warm with **silver nitrate** 硝酸银 in ethanol; the silver halide **precipitate** 沉淀 colour shows which halogen (white AgCl, cream AgBr, yellow AgI).

Watch out: primary/secondary/tertiary is decided by how many *carbons* are joined to the carbon holding the halogen — not by the number of halogen atoms. The nucleophile always attacks that $\delta+$ carbon.

Practice

Try these in order.

15.1 What is a halogenoalkane? [1]

15.2 What decides whether a halogenoalkane is primary, secondary or tertiary? [1]

15.3 Why is the carbon of the C–X bond open to attack by a nucleophile? [2]

15.4 Name the product when a halogenoalkane reacts with (a) NaOH(aq), (b) NH_3 in ethanol. [2]

15.5 Describe how you would identify the halogen in a halogenoalkane. [2]

15.6 Challenge. A halogenoalkane is warmed with KCN (a source of CN^-) in ethanol. Name the type of reaction, and explain why the product has one *more* carbon than the halogenoalkane. [2]

15 Halogenoalkanes – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
alkene	烯烃			
substitution	取代			
elimination	消去			
C–X bond energy	键能			

Recall

From Part 1 you know a halogenoalkane reacts with NaOH to give an alcohol. But the **same** halogenoalkane can instead lose HX to make an **alkene** 烯烃 — the conditions decide which.

- Different solvents send the reaction down different routes.
- Reactivity also depends on which halogen is present.

New ideas

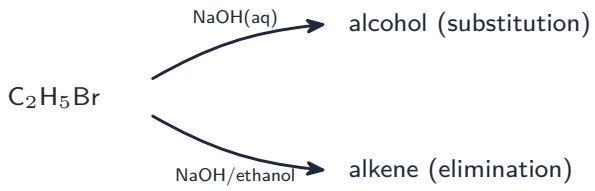
Read these first, then do the Practice.

■ 1 Substitution vs elimination

The conditions decide the reaction:

- NaOH in **water**, heat → **substitution** 取代 → an alcohol.
- NaOH in **ethanol**, heat → **elimination** 消去 → an alkene.

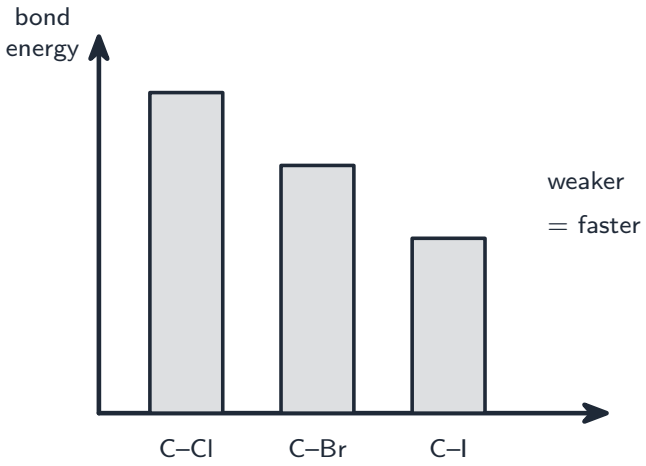
$$C_2H_5Br + NaOH \rightarrow C_2H_4 + NaBr + H_2O$$



2 Reactivity and the C–X bond

How fast a halogenoalkane reacts depends on the **C–X bond energy** 键能 (bond strength):

- the **C–I** bond is **weakest**, so iodoalkanes react **fastest**.
- the **C–Cl** bond is **strongest** of the three, so chloroalkanes react **slowest**.



So with silver nitrate, the iodoalkane gives its precipitate first.

Watch out: the *same* halogenoalkane gives an alcohol (substitution) in *aqueous* NaOH, but an alkene (elimination) in *ethanolic* NaOH — the solvent decides the route. And the weakest bond (C–I) reacts fastest.

Practice

Try these in order.

15.1 State the conditions that make a halogenoalkane react by (a) substitution, (b) elimination. [2]

15.2 What product is formed by the elimination reaction? [1]

15.3 Write the equation for bromoethane reacting with NaOH in ethanol. [2]

15.4 Which reacts faster, an iodoalkane or a chloroalkane? Explain why. [2]

15.5 Which C–X bond is the strongest of C–Cl, C–Br and C–I? [1]

15.6 Challenge. 1-chlorobutane and 1-iodobutane are each warmed with aqueous silver nitrate. Predict which gives a precipitate first, and explain. [2]

31 1,4-dibromobutane reacts with an excess of ethanolic sodium hydroxide until no further reaction takes place.

What is the relative formula mass of the major organic product?

A 54 **B** 56 **C** 74 **D** 90

30 Which reaction mixture produces a nitrile?

A halogenoalkane with KCN in ethanol

B halogenoalkane with NH_3 in ethanol

C ketone with 2,4-DNPH

D carboxylic acid with NH_3 in water

27 Structural and stereoisomerism should be considered when answering this question.

A mixture of 1-chlorobutane and 2-chlorobutane is heated with an excess of NaOH in ethanol.

How many different organic molecules will be produced?

A 1 **B** 2 **C** 3 **D** 4

38 When bromoethane, C_2H_5Br, is heated with NaOH in ethanol, which type of reaction occurs?

A electrophilic substitution

B elimination

C nucleophilic substitution, mainly via an S_N1 mechanism

D nucleophilic substitution, mainly via an S_N2 mechanism

16 Alcohols – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
ethanol	乙醇			
alcohol	醇			
primary	伯			
secondary	仲			
tertiary	叔			
dehydration	脱水			
carboxylic acid	羧酸			
ester	酯			
oxidation	氧化			

Recall

At IGCSE you met **ethanol** 乙醇, the alcohol in drinks and fuel. An **alcohol** 醇 has the **–OH** (hydroxyl) functional group.

- The –OH group gives the family its reactions.
- Like halogenoalkanes, alcohols come in three classes.

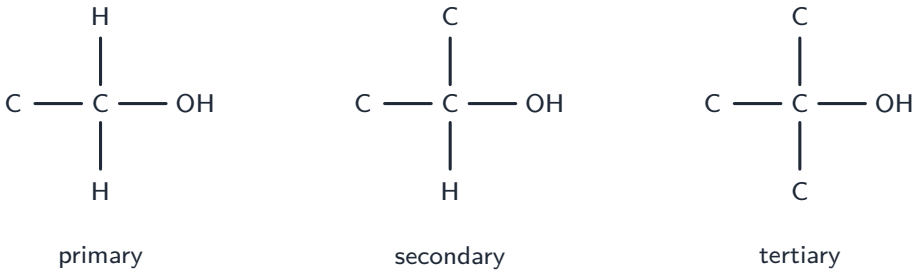
Nothing here is harder than IGCSE — it just adds the reactions.

New ideas

Read these first, then do the Practice.

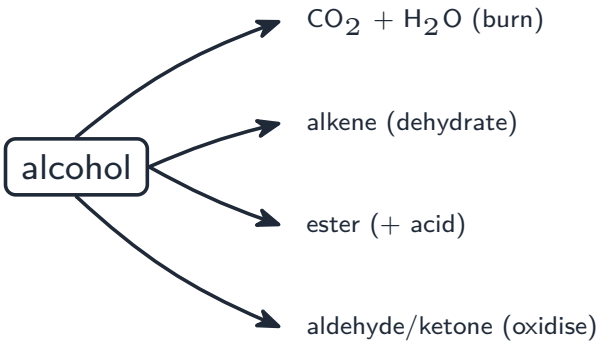
■ 1 Three classes

An alcohol is **primary** 伯, **secondary** 仲 or **tertiary** 叔, set by how many carbons are joined to the carbon holding the **–OH**.



■ 2 Reactions of alcohols

- **combustion** — burn in oxygen → CO_2 + water.
- **with sodium** — react with sodium metal → hydrogen + a sodium alkoxide.
- **dehydration** 脱水 — hot Al_2O_3 (or conc. acid) removes water → an **alkene**.
- **esterification** — with a **carboxylic acid** 羧酸 (conc. H_2SO_4 catalyst) → an **ester** 酯.
- **oxidation** 氧化 — with acidified $K_2Cr_2O_7$ (Part 2).



Watch out: an alcohol's class (primary/secondary/tertiary) is set by the number of carbons on the C–OH carbon — exactly like halogenoalkanes — and it controls the product of oxidation (Part 2).

Practice

Try these in order.

16.1 Name the functional group of an alcohol. [1]

16.2 What decides whether an alcohol is primary, secondary or tertiary? [1]

16.3 Name the products when an alcohol reacts with sodium metal. [2]

16.4 What is formed when an alcohol is dehydrated? [1]

16.5 An alcohol reacts with a carboxylic acid (with a sulfuric acid catalyst). Name the product. [1]

16.6 Write the products of the complete combustion of ethanol. [1]

16.7 Challenge. Propan-1-ol and propan-2-ol share the formula C_3H_8O. Classify each as primary or secondary, and explain. [2]

16 Alcohols – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
potassium dichromate(VI)	重铬酸钾			
aldehyde	醛			
carboxylic acid	羧酸			
ketone	酮			
distillation	蒸馏			
reflux	回流			

Recall

From Part 1 you know the three classes of alcohol. Here we **oxidise** them — and the product tells you which class you have.

- The class decides what oxidation gives.
- The apparatus (distillation or reflux) controls how far it goes.

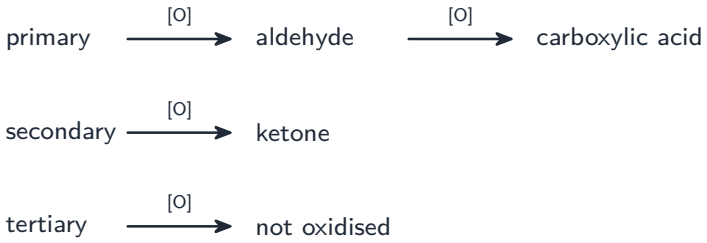
New ideas

Read these first, then do the Practice.

■ 1 Oxidation by class

Oxidise with acidified **potassium dichromate(VI)** 重铬酸钾 ($K_2Cr_2O_7$):

Class	Product
primary	an **aldehyde** 醛 (by distillation), then a **carboxylic acid** 羧酸 (by reflux)
secondary	a **ketone** 酮
tertiary	**not oxidised**



A quick test: acidified dichromate turns **orange to green** with a primary or secondary alcohol, but **stays orange** with a tertiary alcohol.

2 Distillation vs reflux

- **distillation** 蒸馏 removes the aldehyde **as it forms**, before it can be oxidised further → stops at the aldehyde.
- **reflux** 回流 keeps boiling and returning the vapour, so the alcohol is **fully** oxidised → the carboxylic acid.

Watch out: distillation *stops* at the aldehyde (it is removed as it forms); reflux goes *all the way* to the carboxylic acid. A tertiary alcohol is not oxidised at all, so the dichromate stays orange.

Practice

Try these in order.

16.1 Name the reagent used to oxidise an alcohol. [1]

16.2 State the oxidation product of (a) a secondary alcohol, (b) a tertiary alcohol. [2]

16.3 A primary alcohol can be oxidised to two different products. Name them and the method for each. [2]

16.4 What colour change does acidified dichromate show with a primary alcohol? [1]

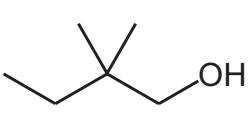
16.5 Explain why distillation stops the oxidation at the aldehyde. [2]

16.6 Challenge. An unknown alcohol is warmed with acidified dichromate, and the orange colour does *not* change. Identify the class of the alcohol and explain. [2]

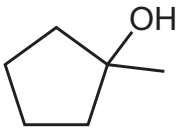
39 Some properties of compound X are listed.

- 1.0 mol X reacts with exactly 8.5 mol oxygen when completely combusted.
- X does **not** react when heated with acidified $KMnO_4$.

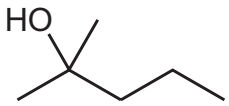
What are the possible identities of X?



1



2



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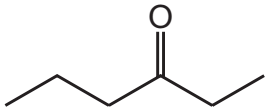


4

A 1 and 3 **B** 2 and 4 **C** 3 only **D** 4 only

32 Which reaction mixture produces a primary alcohol as the major product?

A propanone with $NaBH_4$

B propene with steam in the presence of H_3PO_4

C butanoic acid with $LiAlH_4$

D ethene with hot concentrated acidified $KMnO_4$

17 Aldehydes and ketones – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
aldehyde	醛			
ketone	酮			
C=O carbonyl	羰基			
reduction	还原			
hydrogen cyanide	氰化氢			
nucleophilic addition	亲核加成			

Recall

From the Alcohols sheet you know that oxidising an alcohol can give an **aldehyde** 醛 or a **ketone** 酮. Both contain the **C=O carbonyl** 羰基 group.

- They are made by oxidising alcohols.
- The carbonyl carbon is slightly positive, so it is attacked by nucleophiles.

Nothing here is harder than IGCSE — it just adds the reactions.

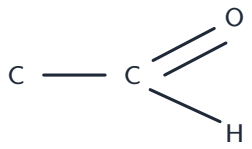
New ideas

Read these first, then do the Practice.

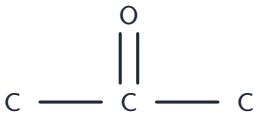
1 Aldehyde vs ketone

Both have the **C=O** group, but in a different place:

- in an **aldehyde** 醛 the C=O carbon is on the **end** of the chain (it also has an H) — written –CHO.
- in a **ketone** 酮 the C=O carbon is in the **middle**, between two carbons.



aldehyde (end)



ketone (middle)

2 Making and reducing them

- oxidise a **primary** alcohol (with distillation) → an **aldehyde**.
- oxidise a **secondary** alcohol → a **ketone**.
- **reduction** 还原 ($NaBH_4$ or $LiAlH_4$) turns them back into alcohols.

3 Nucleophilic addition

The reaction with **hydrogen cyanide** 氰化氢 (HCN) is a **nucleophilic addition** 亲核加成. The carbonyl carbon is $\delta+$ (oxygen pulls the electrons):

1. the **CN^-** nucleophile attacks the $\delta+$ carbon.
2. the C=O breaks, leaving a negative oxygen (O^-).
3. the O^- takes an H^+ to finish the product.

CN^- attacks

hydroxynitrile

Watch out: an aldehyde has its C=O at the *end* of the chain (–CHO); a ketone has it in the *middle*. The HCN reaction is *addition* — the C=O opens and nothing leaves (unlike substitution).

Practice

Try these in order.

17.1 Name the functional group in aldehydes and ketones. [1]

17.2 State where the C=O group sits in (a) an aldehyde, (b) a ketone. [2]

17.3 Which class of alcohol is oxidised to a ketone? [1]

17.4 What is formed when an aldehyde is reduced? [1]

17.5 Why is the carbonyl carbon open to attack by a nucleophile? [2]

17.6 Name the type of mechanism when HCN reacts with a carbonyl compound. [1]

17.7 Challenge. Explain why the reaction of a carbonyl compound with HCN is called nucleophilic *addition* rather than substitution. [2]

17 Aldehydes and ketones – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	**中文**	**Write it 3 times** (English)
Fehling's reagent	斐林试剂	
Tollens' reagent	托伦试剂	

Recall

From Part 1 you know aldehydes and ketones both have a **C=O** group. Here we learn the **tests** that detect a carbonyl, and that tell an aldehyde from a ketone.

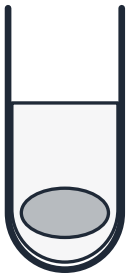
- One test detects **any** carbonyl.
- Two more use the fact that aldehydes are easily oxidised but ketones are not.

New ideas

Read these first, then do the Practice.

■ 1 Detecting any carbonyl

Add **2,4-DNPH** reagent (2,4-dinitrophenylhydrazine). An **orange precipitate** confirms an aldehyde **or** a ketone.



orange

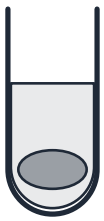
precipitate

2,4-DNPH

2 Telling an aldehyde from a ketone

Aldehydes are easily **oxidised** to carboxylic acids; ketones are not. Two tests use this:

Test	Aldehyde	Ketone
Fehling's reagent 斐林试剂 (blue)	brick-red precipitate	no change
Tollens' reagent 托伦试剂 (colourless)	silver mirror	no change



Fehling's
(brick-red)

Tollens'
(silver mirror)

So a positive Fehling's or Tollens' test means an **aldehyde**; no change means a **ketone**.

Watch out: 2,4-DNPH (orange precipitate) detects *any* carbonyl. Fehling's (brick-red) and Tollens' (silver mirror) are positive *only* for aldehydes — a ketone gives no change.

Practice

Try these in order.

17.1 Which reagent detects any aldehyde or ketone, and what is seen? [2]

17.2 Why can Fehling's and Tollens' tests tell an aldehyde from a ketone? [2]

17.3 State what is seen when an **aldehyde** is warmed with (a) Fehling's reagent, (b) Tollens' reagent. [2]

17.4 A compound gives an orange precipitate with 2,4-DNPH but no change with Tollens'. What type of compound is it? [1]

17.5 Name the product when an aldehyde is oxidised. [1]

17.6 Challenge. A liquid gives an orange precipitate with 2,4-DNPH and a silver mirror with Tollens' reagent. Identify the type of compound, and explain how each result leads to your answer. [2]

38 Seven aldehydes and ketones

- contain only **one** oxygen atom per molecule
- have four or fewer carbon atoms in their structures.

Alkaline I_2(aq) is added to each of these carbonyl compounds separately.

How many of these carbonyl compounds produce a yellow precipitate with alkaline I_2(aq)?

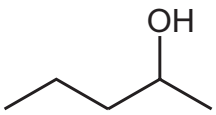
A 1 **B** 2 **C** 3 **D** 4

34 An organometallic lithium compound, RLi, contains the nucleophile R^-.

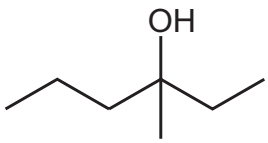
CH_3CH_2Li reacts with pentan-2-one. The mechanism is nucleophilic addition. The first step produces an anion which is then protonated to form the final product.

Which organic product is formed?

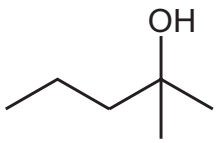
A



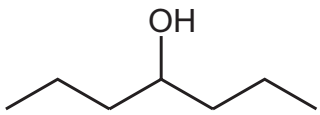
B



C



D



35 Butanone, $CH_3CH_2COCH_3$, and HCN mixed with a little KCN react together in a nucleophilic addition reaction.

Which description of the mechanism of this nucleophilic addition reaction is correct?

A The π bond pair of C=O accepts H^+ from HCN and then CN^- acts as a nucleophile.

B A π bond pair from CN^- attacks the δ+ C and HCN then donates H^+ to O.

C The lone pair on O accepts H^+ from HCN and then CN^- acts as a nucleophile.

D A lone pair from CN^- attacks the δ+ C and then O^- accepts H^+ from HCN.

18 Carboxylic acids – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
ethanoic acid	乙酸			
carboxylic acid	羧酸			
weak acid	弱酸			
alcohol	醇			
aldehyde	醛			
reflux	回流			
nitrile	腈			
ester	酯			
salt	盐			
alkali	碱			
carbonate	碳酸盐			

Recall

At IGCSE you met **ethanoic acid** 乙酸 in vinegar — a **carboxylic acid** 羧酸. It has the **–COOH** (carboxyl) functional group and is a **weak acid** 弱酸.

- It reacts like any acid — with metals, alkalis and carbonates.
- It is made by oxidising a primary alcohol or an aldehyde.

Nothing here is harder than IGCSE — it just organises the reactions.

New ideas

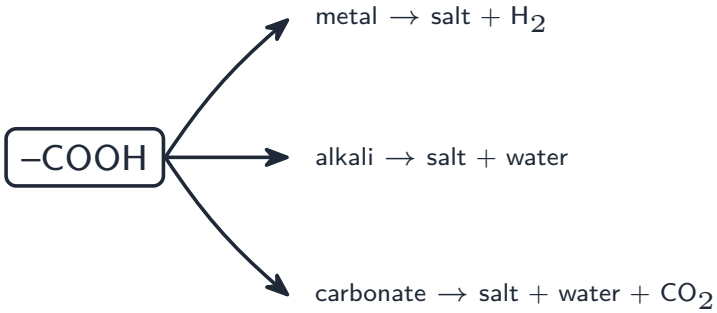
Read these first, then do the Practice.

1 Making carboxylic acids

- **oxidise** a primary **alcohol** 醇 or an **aldehyde** 醛 (acidified $K_2Cr_2O_7$, with **reflux** 回流).
- **hydrolyse** a **nitrile** 腈 or an **ester** 酯, then acidify.

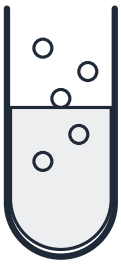
2 Carboxylic acids behave as acids

Reacts with	Products
a reactive **metal**	a **salt** 盐 + hydrogen
an **alkali** 碱	a salt + water
a **carbonate** 碳酸盐	a salt + water + **CO_2** (the fizz is a test)



3 The carbonate test

Add a carboxylic acid to a carbonate: it **fizzes**, giving off carbon dioxide. This is a test for the –COOH group.



CO_2 fizz

acid + carbonate

Watch out: carboxylic acids are *weak* acids (only partly dissociated), yet they still react with metals, alkalis and carbonates. The fizz with a carbonate is a useful test for the –COOH group.

Practice

Try these in order.

18.1 Name the functional group of a carboxylic acid. [1]

18.2 How is a carboxylic acid made from a primary alcohol? [2]

18.3 Name the products when a carboxylic acid reacts with (a) a reactive metal, (b) an alkali. [2]

18.4 Write the equation for ethanoic acid reacting with sodium carbonate. [2]

18.5 Describe the test for a carboxylic acid using a carbonate. [2]

18.6 Challenge. Ethanoic acid is a weak acid, yet it still fizzes with sodium carbonate. Explain how a weak acid can still react in this way. [2]

34 Three mixtures are heated under reflux.

Which mixtures will produce sodium propanoate as one product?

1 CH_3CH_2CHO + $NaBH_4(aq)$

2 $CH_3CH_2CH_2OH$ + $Na(s)$

3 CH_3CH_2CN + $NaOH(aq)$

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

33 $HOCH_2CHO$ is heated under reflux with an excess of acidified $K_2Cr_2O_7$ until there is no further reaction.

What is the final product of this reaction?

A HOOCCHO

B $HOCH_2COOH$

C HOOCCOOH

D $HOOCCH_2COOH$

36 Which organic starting material could be used in a single reaction to produce propanoic acid?

A ethanenitrile

B propan-2-ol

C propanal

D propyl ethanoate

18 Esters – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)
carboxylic acid	羧酸	
alcohol	醇	
ester	酯	
hydrolysis	水解	
condensation	缩合	

Recall

From Part 1 you know a **carboxylic acid** 羧酸 has –COOH. When it reacts with an **alcohol** 醇, it makes a sweet-smelling **ester** 酯 (the –COO– group).

- Esters give fruits and perfumes their smell.
- They can be split apart again by water (**hydrolysis** 水解).

New ideas

Read these first, then do the Practice.

■ 1 Making an ester (esterification)

An **ester** 酯 forms in a **condensation** 缩合 reaction between an alcohol and a carboxylic acid, with a concentrated H_2SO_4 catalyst. A **water** molecule is lost, and the reaction is reversible:

$$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

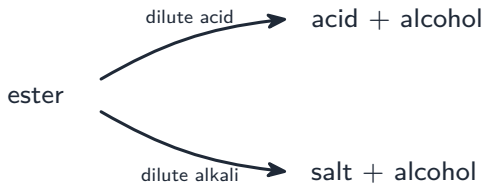
$$CH_3COOH + C_2H_5OH \xrightarrow{H_2SO_4} \text{ester} + H_2O$$

the –OH and –H leave as water

2 Hydrolysis of an ester

Hydrolysis 水解 splits the ester apart. The conditions change the products:

- **dilute acid** + heat (reversible) → the **carboxylic acid** + the **alcohol**.
- **dilute alkali** + heat (not reversible) → the **carboxylate salt** + the **alcohol**.



Watch out: esterification is a *condensation* (water is lost) and is *reversible*. Acid hydrolysis simply reverses it (acid + alcohol), but *alkali* hydrolysis is *not* reversible — it gives the carboxylate salt plus the alcohol.

Practice

Try these in order.

18.1 Name the functional group of an ester. [1]

18.2 What two types of compound react to form an ester, and what catalyst is used? [2]

18.3 Esterification is a *condensation* reaction. What small molecule is lost? [1]

18.4 Name the products when an ester is hydrolysed by (a) dilute acid, (b) dilute alkali. [2]

18.5 Why might you smell an ester product as "sweet" or "fruity"? [1]

18.6 Challenge. Esterification is reversible and reaches an equilibrium. Suggest one way to increase the yield of the ester, and explain. [2]

35 Which compound is a product of the hydrolysis of $CH_3CO_2CH_2C_2H_5$ using aqueous sodium hydroxide?

A $CH_3CO_2^-Na^+$

B CH_3CO_2H

C $C_2H_5CH_2O^-Na^+$

D $C_2H_5CH_2CO_2^-Na^+$

36 The structural formula of compound P is $CH_3CH_2COOCH_2CH_3$.

P can be formed by reacting together two organic compounds in the presence of a suitable catalyst.

Which pair of compounds could react together to produce P?

A ethanoic acid and propanoic acid

B ethanoic acid and propan-1-ol

C ethanol and propanoic acid

D ethanol and propan-1-ol

19 Amines – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
amine	胺			
lone pair	孤对电子			
nucleophile	亲核试剂			
primary amine	伯胺			
halogenoalkane	卤代烷			
ammonia	氨			
nucleophilic substitution	亲核取代			

Recall

An **amine** 胺 is like ammonia (NH_3) with one hydrogen replaced by a carbon chain — it has the $-\mathbf{NH_2}$ group. Like ammonia, it has a **lone pair** 孤对电子 on the nitrogen.

- That lone pair makes an amine a **base** and a **nucleophile** 亲核试剂.
- Amines are made from halogenoalkanes.

Nothing here is harder than IGCSE — it just adds one reaction.

New ideas

Read these first, then do the Practice.

1 The amine group

A **primary amine** 伯胺 has the **–NH_2** group on a carbon chain (e.g. $C_2H_5NH_2$). The nitrogen keeps its **lone pair**.

2 Making a primary amine

Heat a **halogenoalkane** 卤代烷 with **ammonia** 氨 in ethanol, under pressure:

$$C_2H_5Br + NH_3 \rightarrow C_2H_5NH_2 + HBr$$

This is a **nucleophilic substitution** 亲核取代: the lone pair on the ammonia nitrogen attacks the $\delta+$ carbon and pushes out the halogen.

3 Use an excess of ammonia

Use **excess ammonia**, or the amine you make can react again (it is also a nucleophile) to give secondary and tertiary amines.

Watch out: the amine forms by nucleophilic *substitution* — the nitrogen's lone pair attacks the $\delta+$ carbon and the halogen leaves. Use *excess* ammonia, or the amine (also a nucleophile) reacts on to give secondary and tertiary amines.

Practice

Try these in order.

19.1 Name the functional group of an amine. [1]

19.2 What gives the amine nitrogen its ability to act as a nucleophile? [1]

19.3 Write the equation for bromoethane reacting with ammonia. [2]

19.4 Name the type of mechanism for this reaction. [1]

19.5 Why is an excess of ammonia used? [2]

19.6 Challenge. Both ammonia and ethylamine ($C_2H_5NH_2$) have a lone pair on nitrogen, but ethylamine is a slightly *stronger* base. Suggest why. [2]

38 Butylamine can be produced by the reaction of butanenitrile with hydrogen in the presence of a suitable catalyst.

Which volume of hydrogen, measured at room conditions, is required to react completely with 0.500 g of butanenitrile?

A 145 cm^3 **B** 174 cm^3 **C** 289 cm^3 **D** 348 cm^3

19 Nitriles – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
nucleophilic substitution	亲核取代			
nitrile	腈			
halogenoalkane	卤代烷			
potassium cyanide	氰化钾			
hydrolysis	水解			
carboxylic acid	羧酸			
reduction	还原			
amine	胺			

Recall

From Part 1 you used a **nucleophilic substitution** 亲核取代 to make an amine. The **cyanide ion** (CN^-) can do the same — and it has a special bonus: it **adds a carbon** to the chain.

- A **nitrile** 腈 has the –CN group.
- Nitriles are a useful "hub" — they convert to acids or amines.

New ideas

Read these first, then do the Practice.

1 Making a nitrile

Heat a **halogenoalkane** 卤代烷 with **potassium cyanide** 氰化钾 (KCN) in ethanol:

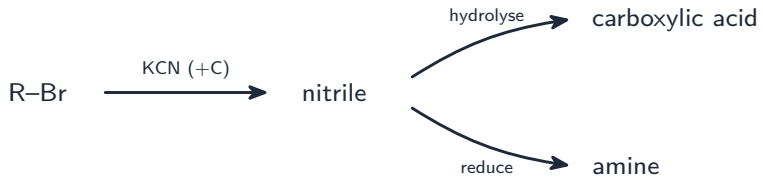
$$C_2H_5Br + KCN \rightarrow C_2H_5CN + KBr$$

This is a nucleophilic substitution with **CN^-** as the nucleophile. It is useful because it **adds one carbon** to the chain.

2 The nitrile hub

A **nitrile** 腈 can be changed two ways:

- **hydrolysis** 水解 (warm with dilute acid) turns –CN into –COOH → a **carboxylic acid** 羧酸.
- **reduction** 还原 (H_2 and a catalyst) turns –CN into $–CH_2NH_2$ → an **amine** 胺.



3 Two ways cyanide adds a carbon

R–Br + KCN → nitrile (substitution)

C=O + HCN → hydroxynitrile (addition)

- **KCN** + a halogenoalkane → a **nitrile** (substitution).
- **HCN** + an aldehyde/ketone → a **hydroxynitrile** (addition).

Watch out: cyanide adds a carbon two different ways — KCN + a halogenoalkane gives a nitrile by *substitution*; HCN + a carbonyl gives a hydroxynitrile by *addition*. The nitrile is a hub: hydrolyse it to an acid, or reduce it to an amine.

Practice

Try these in order.

19.1 Write the equation for bromoethane reacting with KCN. [2]

19.2 Why is making a nitrile a useful step in organic synthesis? [1]

19.3 Name the product when a nitrile is (a) hydrolysed, (b) reduced. [2]

19.4 State the reagent and the type of mechanism for making a nitrile from a halogenoalkane. [2]

19.5 HCN reacts with a ketone. Name the product and the type of mechanism. [2]

19.6 Challenge. A chemist needs to turn bromoethane (2 carbons) into propanoic acid (3 carbons). Outline a two-step route, naming the reagent for each step. [3]

4 Compounds **P** and **Q** are structural isomers.

Fig. 4.1

(a) (i) Define structural isomerism.

.....

..... [2]

(ii) **P** shows geometrical isomerism.

Draw the geometrical isomer of **P**. Explain why the two isomers are **not** identical.

geometrical isomer of **P**

explanation .....

.....

.....
[2]

(iii) Both **P** and **Q** react with aqueous bromine.

Name the mechanism of this reaction.

..... [1]

(iv) **Q** is oxidised by hot concentrated acidified $KMnO_4(aq)$, forming two different organic products.

Construct an equation for this reaction. Use [O] to represent an atom of oxygen from the oxidising agent.

$(CH_3)_2C=CHCH_3$ ..... [2]

(v) **Q** reacts with HBr(g) to produce two structural isomers, **R** and **S**, as shown in Fig. 4.2.

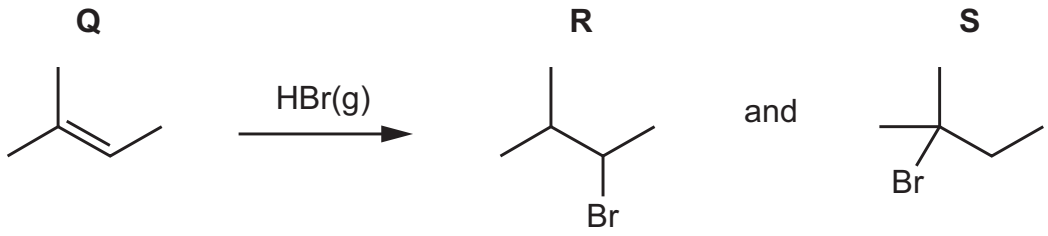


Fig. 4.2

State and explain why isomer **S** is the major product of the reaction.

.....

.....

..... [2]

(vi) The mass spectrum of **R** shows peaks at *m/e* = 150 and *m/e* = 152.

Suggest structures for the ions responsible for these peaks.

peak at *m/e* = 150	peak at *m/e* = 152

[2]

(b) Fig. 4.3 shows a synthesis starting from **T**, a different isomer of **R** and **S**.

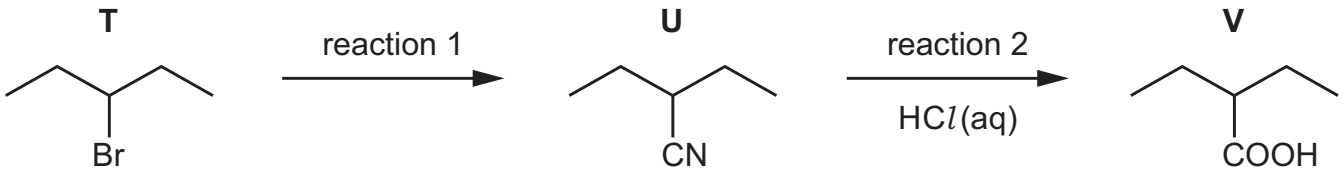


Fig. 4.3

(i) Identify the reagent and conditions for reaction 1.

..... [1]

(ii) Reaction 2 is a hydrolysis reaction.

Construct an equation for reaction 2.

$(C_2H_5)_2CHCN$ ..... [1]

(iii) **V** reacts with propan-2-ol in the presence of a catalytic amount of H_2SO_4 to form organic compound **W**.

Complete Table 4.1 to give details of this reaction.

Table 4.1

	reaction of **V** with propan-2-ol
type of reaction	
functional group formed	
molecular formula of organic product **W**	

[3]

[Total: 16]

Important values, constants and standards

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

The Periodic Table of Elements

Group																	
1	2											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	3	4	5	6	7	8	9	10	11	12	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 –

20 Addition polymerisation – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)
alkene	烯烃	
repeat unit	重复单元	
monomer	单体	
polymer	聚合物	
addition polymerisation	加成聚合	

Recall

From the Alkenes sheet you know that many **alkene** 烯烃 molecules can join into one long chain. Here we look more closely at the **repeat unit** 重复单元 and how to read it.

- A small starting molecule is a **monomer** 单体.
- The long chain that forms is a **polymer** 聚合物.

Nothing here is harder than IGCSE — it just adds the repeat unit.

New ideas

Read these first, then do the Practice.

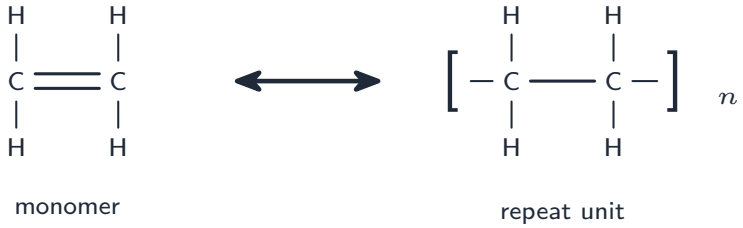
■ 1 Addition polymerisation

In **addition polymerisation** 加成聚合, many **monomers** (each with a **C=C** double bond) open their double bonds and join end to end into one long **polymer**, with **no other product**.

2 The repeat unit

The **repeat unit** 重复单元 is the small part copied along the chain. To find it: take the monomer, change the C=C to a single **C–C**, and draw a bond going out at each end.

$$n\,CH_2{=}CH_2 \rightarrow -(CH_2{-}CH_2)_n-$$



For **PVC**: $n\,CH_2{=}CHCl \rightarrow -(CH_2{-}CHCl)_n-$.

3 Finding the monomer

To go the other way, take one repeat unit and **put the C=C double bond back** — that gives you the monomer.

Watch out: for the repeat unit, change the C=C to C–C and draw a bond out at *each* end (inside brackets, with n). To get back to the monomer, put the C=C double bond back in.

Practice

Try these in order.

20.1 What is the difference between a *monomer* and a *polymer*? [2]

20.2 What feature must a monomer have for addition polymerisation? [1]

20.3 Draw the repeat unit of poly(ethene). [1]

20.4 In addition polymerisation, what other product is made besides the polymer? [1]

20.5 The repeat unit of a polymer is $-(CH_2-CHCl)-$. Draw the monomer. [1]

20.6 Challenge. The monomer propene is $CH_2{=}CHCH_3$. Draw the repeat unit of poly(propene). [2]

20 Addition polymerisation – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
poly(ethene)	聚乙烯			
non-biodegradable	不可生物降解			
recycle	回收			
incinerate	焚烧			

Recall

From Part 1 you know addition polymers like **poly(ethene)** 聚乙烯 and **PVC** are long chains of carbon. Their strength and stability are useful — but they make them hard to throw away.

- The same strong C–C chain that makes plastics useful makes them hard to break down.
- Disposal is a real environmental problem.

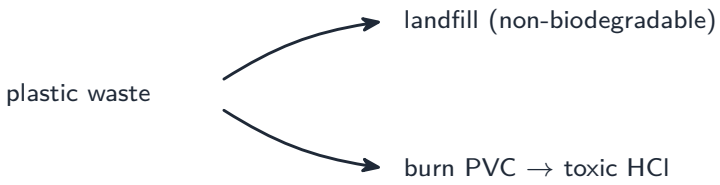
New ideas

Read these first, then do the Practice.

■ 1 Why disposal is hard

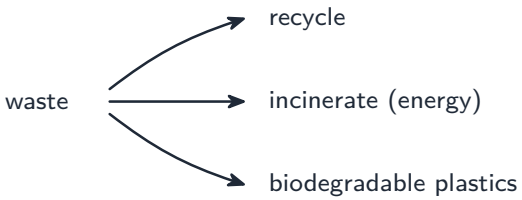
Poly(alkene)s are very hard to get rid of:

- they are **non-biodegradable** 不可生物降解 — microbes cannot break them down, so they stay in the ground for a very long time.
- **burning** them can release harmful gases — for example, burning **PVC** gives off toxic **hydrogen chloride** (HCl).



2 Ways to deal with the waste

- **recycle** 回收 — sort, melt and remould the plastic.
- **incinerate** 焚烧 — burn it (with the heat used for energy), but the gases must be cleaned.
- develop **biodegradable** plastics that microbes **can** break down.



Watch out: poly(alkene)s are non-biodegradable *because* their C–C and C–H bonds are strong and unreactive — the very property that makes them durable and useful. Burning PVC also releases toxic HCl.

Practice

Try these in order.

20.1 What does *non-biodegradable* mean? [1]

20.2 Why are poly(alkene)s non-biodegradable? [2]

20.3 Name the toxic gas given off when PVC is burned. [1]

20.4 State two ways to deal with plastic waste. [2]

20.5 Suggest one advantage of developing biodegradable plastics. [1]

20.6 Challenge. Explain why the very property that makes poly(alkene)s useful as materials also makes them a disposal problem. [2]

32 A small section of a polymer produced from two monomers is shown.

$$–CH_2–C(CH_3)_2–CH(CH_3)–CH_2–$$

What are the two monomers?

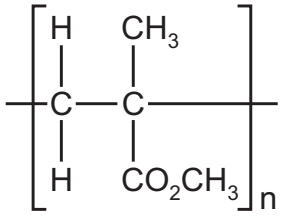
A but-1-ene and propene

B but-2-ene and propene

C ethene and pent-2-ene

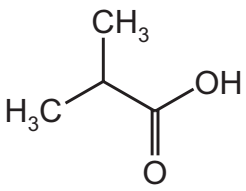
D methylpropene and propene

39 PMMA is a rigid polymer. The repeat unit of PMMA is shown.



Which monomer is used to make PMMA?

A



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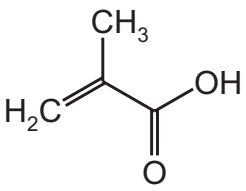
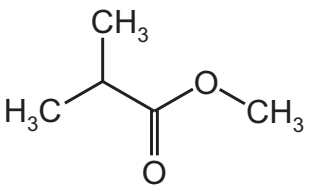
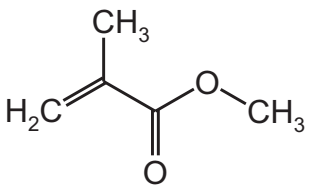


C



D



21 Organic synthesis – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
alkene	烯烃			
halogenoalkane	卤代烷			
alcohol	醇			
aldehyde	醛			
ketone	酮			
carboxylic acid	羧酸			

Recall

This topic adds **no new reactions**. It asks you to **join up** the reactions you already know — to identify functional groups and to see how they interconvert.

- A molecule may have **more than one** functional group.
- Standard tests tell you which groups are present.

Nothing here is harder than IGCSE — it just connects the pieces.

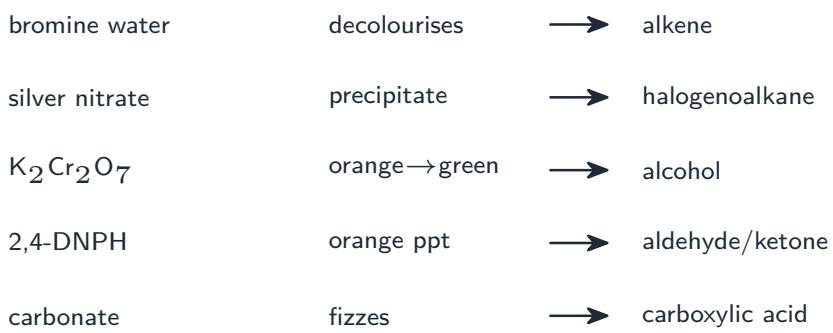
New ideas

Read these first, then do the Practice.

1 Identifying functional groups

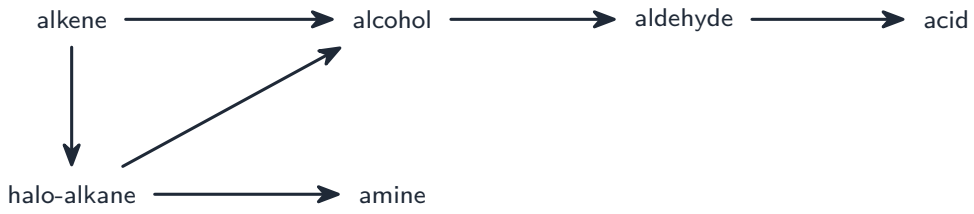
Each test gives a characteristic result that points to one group:

Test	Observation	Group
bromine water	decolourises	C=C (**alkene** 烯烃)
silver nitrate	precipitate	**halogenoalkane** 卤代烷
$K_2Cr_2O_7$	orange → green	1°/2° **alcohol** 醇
2,4-DNPH	orange precipitate	**aldehyde** 醛 or **ketone** 酮
carbonate	fizzes (CO_2)	**carboxylic acid** 羧酸



2 A map of the reactions

Each reaction turns one functional group into another. Learn it as a **map** you can travel around: alkene ⇄ alcohol ⇄ aldehyde ⇄ carboxylic acid, with halogenoalkane and amine branches.



Watch out: match each test to its group — bromine water decolourises for an alkene, 2,4-DNPH gives an orange precipitate for *any* carbonyl, a carbonate fizzes for a carboxylic acid. (Tollens'/Fehling's then single out the *aldehyde*.)

Practice

Try these in order.

21.1 A compound decolourises bromine water. What functional group does it have? [1]

21.2 Which test, and result, identifies a carboxylic acid? [2]

21.3 A compound gives an orange precipitate with 2,4-DNPH but no silver mirror with Tollens'. What is it? [1]

21.4 Name the reagent that turns an alkene into an alcohol. [1]

21.5 Name the product when a halogenoalkane reacts with NaOH(aq). [1]

21.6 Challenge. A compound decolourises bromine water *and* fizzes with sodium carbonate. Name the two functional groups it must contain. [2]

21 Organic synthesis – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
synthetic route	合成路线			
functional group	官能团			
reagent	试剂			
nitrile	腈			
by-products	副产物			

Recall

From Part 1 you have a **map** of the reactions. Here we use it to **plan a route** from a starting material to a target molecule, in several steps.

- Compare the target with the start: what has changed?
- Work **backwards** from the target, one reaction at a time.

New ideas

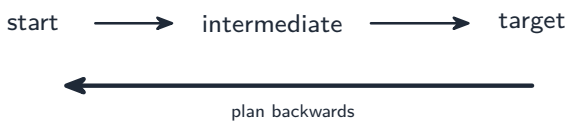
Read these first, then do the Practice.

■ 1 Planning a route

To devise a **synthetic route** 合成路线:

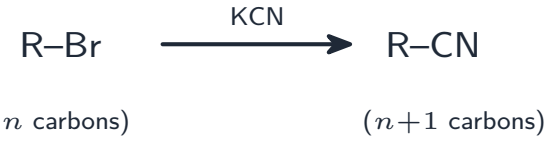
1. compare the target with the start — what changed (the **functional group** 官能团? the number of carbons?).
2. work **backwards** from the target: which single reaction could make it, and from what?

3. repeat until you reach the start.
4. write each step with its **reagent** 试剂 and conditions.



2 Adding a carbon

If you need to **add a carbon** to the chain, the **KCN** step is the key — it is the only AS reaction that lengthens the chain (halogenoalkane → **nitrile** 腈).



3 Analysing a route

For each step given, state the **type of reaction** (oxidation, reduction, substitution, addition or elimination) and the **reagent**. Watch for **by-products** 副产物 (e.g. making an amine also gives further-substituted amines, so the yield is low).

Watch out: plan a route by working *backwards* from the target, one reaction at a time. Remember the KCN step is the *only* AS reaction that adds a carbon to the chain.

Practice

Try these in order.

21.1 When planning a synthesis, which direction do you usually work — forwards from the start, or backwards from the target? [1]

21.2 Which reagent is the key to **adding a carbon** to the chain? [1]

21.3 To turn ethene into ethanol, give the reagent and conditions. [2]

21.4 Classify each reaction type: (a) alkene + H_2 → alkane, (b) alcohol → alkene + water. [2]

21.5 Plan a two-step route from ethene to ethanoic acid (give the product of each step). [2]

21.6 Challenge. Outline how to turn bromomethane (CH_3Br, 1 carbon) into ethanoic acid (CH_3COOH, 2 carbons), naming the reagent for each step. [3]

22 Analysis (spectroscopy) – Part 1

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Infrared spectroscopy	红外光谱			
absorbs	吸收			
wavenumber	波数			

Recall

You now know the functional groups. **Infrared spectroscopy** 红外光谱 is a tool that helps you **find** which group a molecule has — without any chemical test.

- Each kind of bond absorbs infrared light at its own frequencies.
- Where a bond absorbs strongly, the spectrum shows a **dip**.

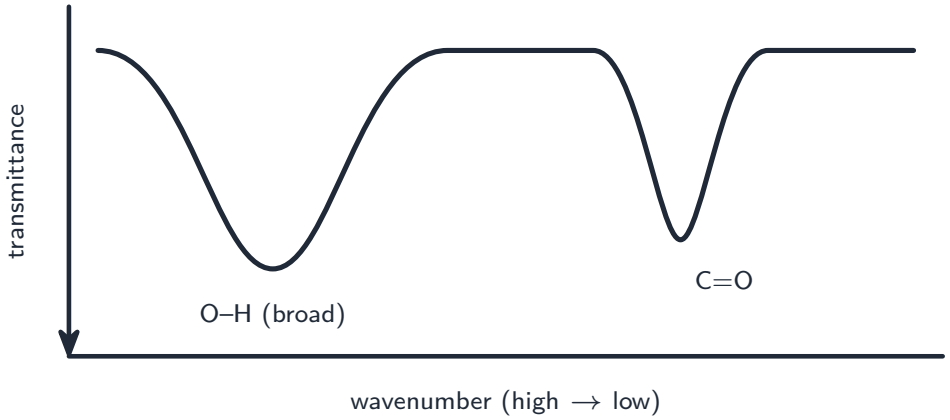
Nothing here is harder than IGCSE — it just reads a graph.

New ideas

Read these first, then do the Practice.

■ 1 How it works

Each kind of bond soaks up (**absorbs** 吸收) infrared at its own range of frequencies. The position is measured in **wavenumber** 波数 (cm^{-1}). You are **given a data table**, so you do not memorise the numbers — you just match the dips to bonds.



2 Key absorptions

Bond	Wavenumber (cm^{-1})
O–H (alcohol)	3200–3650 (broad)
C=O	~1700
O–H (acid)	2500–3000 (very broad) + a C=O dip

O–H (alcohol)	$3200–3650 cm^{-1}$
C=O	$\sim 1700 cm^{-1}$
O–H (acid)	$2500–3000 \text{ (broad)} cm^{-1}$

3 Checking a reaction

If propene has been turned into propan-2-ol, the **C=C dip should disappear** and an **O–H dip should appear** — so the spectrum confirms the change.

Watch out: you are *given* the IR data table — match the dips to bonds rather than memorising numbers. Note the alcohol O–H (broad, 3200–3650) sits higher than the acid O–H (very broad, 2500–3000), which also comes with a C=O dip.

Practice

Try these in order.

22.1 In what unit is the position of an infrared absorption measured? [1]

22.2 Do you need to memorise the absorption numbers? Explain. [1]

22.3 A broad dip at 3200–3650 cm^{-1} shows which bond? [1]

22.4 A dip at about 1700 cm^{-1} shows which bond? [1]

22.5 An alcohol is oxidised to a carboxylic acid. What new dip would you expect in the infrared spectrum? [1]

22.6 Challenge. An infrared spectrum has a strong dip at about 1700 cm^{-1} *and* a very broad dip at 2500–3000 cm^{-1}. Suggest the functional group present, and explain. [2]

40 The purity of a compound can be determined using infrared spectroscopy.

The table gives the characteristic infrared absorption frequencies for some selected bonds.

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

Propan-2-ol is made by hydration of propene. A sample of the product is obtained.

Which feature of the infrared spectrum of the product would show that **no** propene remains in the product?

A absorption in the 2900 cm^{-1} region

B strong absorption below 1000 cm^{-1}

C the lack of absorption at or near 1250 cm^{-1}

D the lack of absorption at or near 1550 cm^{-1}

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											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	3	4	5	6	7	8	9	10	11	12	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 –

22 Analysis (spectroscopy) – Part 2

Name: _____ Class: _____ Date: _____

Vocabulary 词汇

Write each word three times. 把每个单词抄写三遍。

English	中文	Write it 3 times (English)		
Mass spectrometry	质谱			
mass-to-charge ratio	质荷比			
molecular ion peak	分子离子峰			
fragmentation	碎裂			
fragment	碎片			

Recall

Mass spectrometry 质谱 is another analysis tool. It turns a molecule into ions and sorts them by their **mass-to-charge ratio** 质荷比 (m/e).

- The spectrum is a set of peaks at different m/e values.
- The tallest-mass peak tells you the molecule's mass.

New ideas

Read these first, then do the Practice.

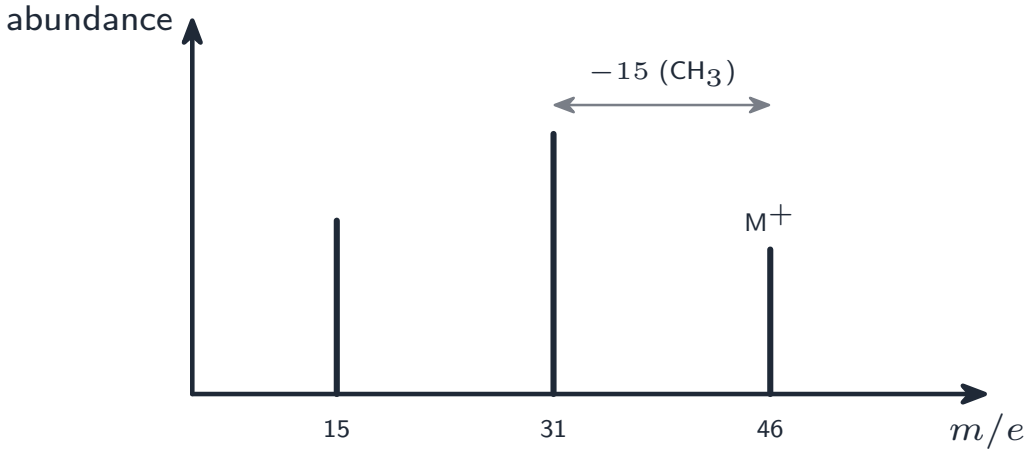
■ 1 The molecular ion peak

The peak at the **highest** m/e is the **molecular ion peak** 分子离子峰 (M^+). It gives the **relative molecular mass** (M_r) of the whole molecule.

2 Fragmentation

The molecule also breaks into smaller pieces — **fragmentation** 碎裂. The **gap** between two peaks gives the mass of the piece lost, so you can suggest each **fragment** 碎片:

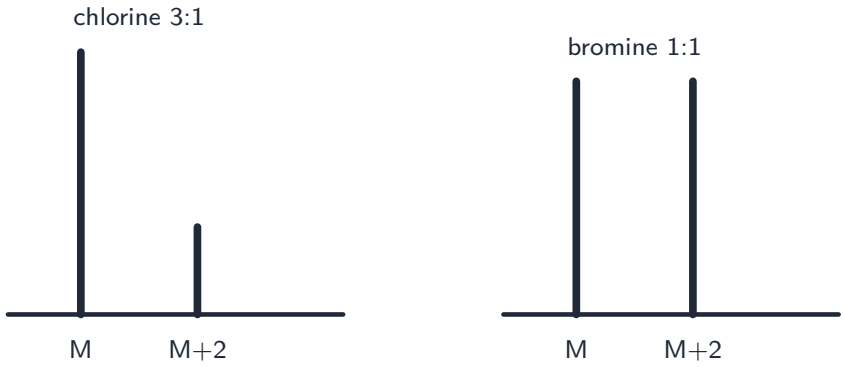
- a loss of **15** = a CH_3 group.
- a loss of **29** = CHO or C_2H_5.



3 The [M+2] peak shows a halogen

An **[M+2]** peak two mass units above M^+ shows chlorine or bromine:

- one **chlorine** gives an [M+2] about **one third** the height of M^+ (a **3:1** ratio).
- one **bromine** gives an [M+2] about the **same** height as M^+ (a **1:1** ratio).



Watch out: the molecular ion (highest m/e) gives M_r; the *gap* between peaks gives the mass *lost* (the fragment), not the fragment's own peak. An [M+2] peak means chlorine (3:1) or bromine (1:1).

Practice

Try these in order.

22.1 What does the molecular ion peak (M^+) tell you? [1]

22.2 Where on the spectrum is the molecular ion peak found? [1]

22.3 A spectrum shows peaks at $m/e = 46$ and 31. What fragment was lost, and what is it? [2]

22.4 An [M+2] peak is the same height as the M^+ peak. Which halogen is present? [1]

22.5 What peak ratio shows that one chlorine atom is present? [1]

22.6 Challenge. A spectrum has its molecular ion at $m/e = 78$ and an [M+2] peak at $m/e = 80$ of about the *same* height. Suggest the halogen present, and explain. [2]

4 Fig. 4.1 shows a possible synthesis of propene, C_3H_6.

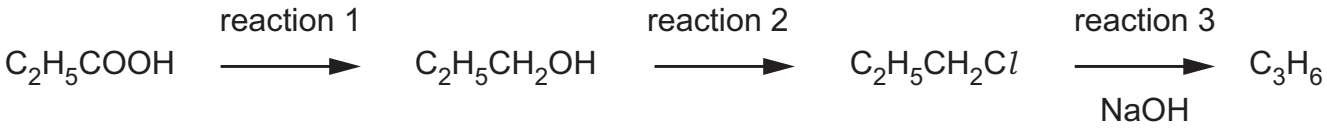


Fig. 4.1

(a) (i) Identify the type of reaction that occurs in reaction 1.

..... [1]

(ii) Suggest a suitable reagent for reaction 2.

..... [1]

(iii) Reaction 3 is an elimination reaction.

Write an equation for this reaction and identify the solvent and conditions used.

equation .....

solvent and conditions .....
[2]

(iv) $C_2H_5CH_2OH$ can be directly converted to C_3H_6.

Suggest the reagent and conditions for this conversion.

..... [1]

(b) Under suitable conditions, propene polymerises to form poly(propene).

Poly(propene) exhibits stereoisomerism.

(i) Identify the type of polymerisation that forms poly(propene) from propene.

..... [1]

(ii) Define stereoisomerism.

.....

..... [2]

(iii) Draw a section of poly(propene), showing **two** repeat units.

Use your diagram to identify the type of stereoisomerism shown by poly(propene). Explain your answer.

section of poly(propene)

.....

.....

.....

.....

[3]

(iv) State **two** difficulties associated with the disposal of poly(propene).

1 .....

2 .....

[2]

(c) Under different conditions, two molecules of propene can combine to form compounds **X** and **Y**.

X **Y**

(i) Name **X**.

..... [1]

(ii) Fig. 4.2 shows the mass spectrum of either compound **X** or compound **Y**.

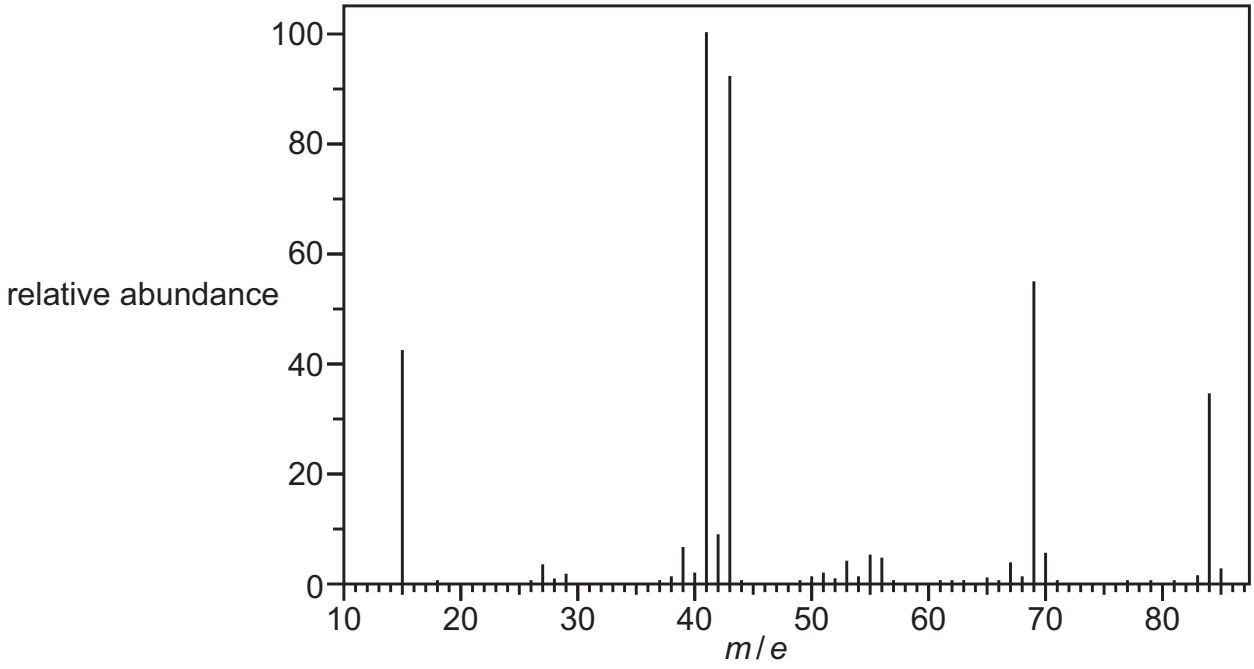


Fig. 4.2

Identify which of **X** and **Y** gives this mass spectrum.

Give **one** reason for your answer, referring to the fragmentation pattern.

.....

.....

..... [1]

(iii) The molecular ion peak in the spectrum in Fig. 4.2 has relative abundance 34.7.

Calculate the relative abundance of the $[M+1]^+$ peak in this spectrum.

relative abundance of [M peak = ... [1]

Important values, constants and standards

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

The Periodic Table of Elements

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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	3	4	5	6	7	8	9	10	11	12	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 –