Week 19

A-Level Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

A-Level Chemistry Name: _____ Score: _____

1. A functional group is:
   - ☐ the reactive part of a molecule that decides its properties
   - ☐ the carbon skeleton only
   - ☐ the number of atoms
   - ☐ the molecule's mass
2. Homolytic fission of a covalent bond produces:
   - ☐ two free radicals (one electron to each atom)
   - ☐ two ions
   - ☐ one molecule
   - ☐ no products
3. In an addition reaction:
   - ☐ two molecules join to make one
   - ☐ a molecule is split by water
   - ☐ a group is swapped
   - ☐ a small molecule is lost
4. An sp^3 carbon (four single bonds) is:
   - ☐ tetrahedral, 109.5°
   - ☐ planar, 120°
   - ☐ linear, 180°
   - ☐ bent, 104.5°
5. Isomers are compounds with:
   - ☐ the same molecular formula but a different arrangement of atoms
   - ☐ different molecular formulas
   - ☐ the same arrangement of atoms
   - ☐ no functional group
6. A group of atoms that gives an organic molecule its characteristic reactions is a _____ group.

_____

7. Breaking a bond so each atom keeps one electron is _____ fission.

_____

8. A carbon atom forming four single bonds is tetrahedral with bond angles of about 109.5°.

☐ True ☐ False

9. Compounds with the same molecular formula but different structures are structural _____.

_____

10. E/Z (cis-trans) isomerism arises because there is no rotation about a C=C double bond.

☐ True ☐ False

13. An introduction to AS Level organic chemistry

Answers · 答案

A-Level Chemistry

1. **the reactive part of a molecule that decides its properties**

   Molecules with the same functional group behave alike, because the group is the reactive part.

2. **two free radicals (one electron to each atom)**

   Homolytic = even split, one electron each → two radicals; heterolytic = uneven → two ions.

3. **two molecules join to make one**

   Addition combines two molecules into a single product (e.g. across a C=C bond).

4. **tetrahedral, 109.5°**

   Four single bonds (sp^3) give a tetrahedral shape at 109.5°.

5. **the same molecular formula but a different arrangement of atoms**

   Isomers share a molecular formula but differ in how the atoms are arranged.

6. **functional**

   e.g. –OH, –COOH.

7. **homolytic**

   It forms free radicals.

8. **True**

   Four bonding pairs repel equally.

9. **isomers**

   Chain, position and functional-group isomerism.

10. **True**

    The restricted rotation fixes the groups' positions.

A-LEVEL CHEMISTRY • EXERCISE SHEET

13.1 Formulas, functional groups and naming of organic compounds

Name: _____ Class: _____ Date: _____ **Total: 21 marks**

KEY WORDS alkane 烷烃 • functional group 官能团 • hydrocarbon 碳氢化合物 • nomenclature 命名法 • molecular formula 分子式

Objective

Build the skills to answer exam questions on **formulas, functional groups and naming** — **hydrocarbons** 碳氢化合物, **functional groups** 官能团, the types of formula, and systematic **nomenclature** 命名法.

You must be able to:

- define hydrocarbon and explain what a functional group is
- interpret and use general, molecular, structural, displayed and skeletal formulas
- name simple organic molecules systematically

1 Worked examples

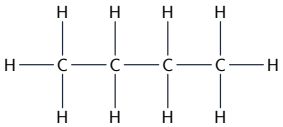
■ Functional groups and formulas

A **hydrocarbon** contains only C and H. A **functional group** is the reactive part that dictates a compound's properties (e.g. –OH in alcohols).

molecular C_4H_{10}

structural $CH_3CH_2CH_2CH_3$

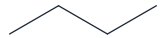
displayed



skeletal

The same molecule shown as molecular, structural, displayed and skeletal formulas

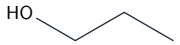
chain



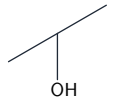
butane

2-methylpropane

positional

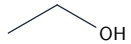


propan-1-ol

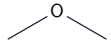


propan-2-ol

functional



ethanol (alcohol)



methoxymethane (ether)

Naming distinguishes structural isomers

- **general** (family pattern, e.g. alkanes C_nH_{2n+2}); **molecular** (C_4H_{10}); **structural** ($CH_3CH_2CH_2CH_3$); **displayed** (every bond drawn); **skeletal** (lines; C at corners).

■ Naming

Stem for carbons (meth/eth/prop/but/pent/hex = 1–6); ending for the functional group; numbers for positions. E.g. $CH_3CH(OH)CH_3$ = propan-2-ol.

2 Practice

2.1 Define the term **hydrocarbon**. [1]

2.2 Give the molecular formula of the alkane with 5 carbons (using C_nH_{2n+2}). [1]

3 Exam-style questions

3.1 Which formula shows the simplest whole-number ratio of atoms? [1]

- **A** molecular
- **B** empirical
- **C** displayed
- **D** skeletal

3.2 What is the name of $CH_3CH_2CH_2OH$? [1]

- **A** propan-1-ol
- **B** propan-2-ol
- **C** propanal
- **D** propanoic acid

3.3 (a) Draw the skeletal formula of 2-methylbutane. [2]

(b) Give the structural formula of butan-2-ol. [1]

3.4 Explain why all members of a homologous series have similar chemical properties. [2]

3.5 A compound **Z** contains carbon, hydrogen and oxygen only. Burning 0.100 mol of **Z** completely gives 17.6 g of carbon dioxide and 7.20 g of water. The relative molecular mass of **Z** is 88.0.

(a) Determine the molecular formula of **Z**. [4]

(b) **Z** is an unbranched carboxylic acid. Give its structural formula and its systematic name. [2]

(c) Draw the displayed formula of a structural isomer of **Z** that is an ester, and name it. [3]

(d) Using **Z**, explain the difference between an empirical, a molecular and a structural formula. [3]

Solutions

2.1 a compound made up of only carbon and hydrogen atoms.

2.2 C_5H_{12}.

3.1 B. The empirical formula is the simplest whole-number ratio.

3.2 A. $CH_3CH_2CH_2OH$ is propan-1-ol.

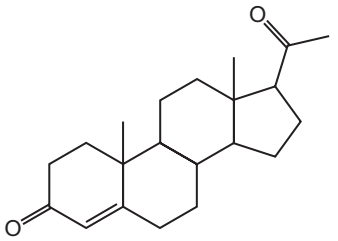
3.3 (a) a four-carbon zigzag with a methyl branch on the second carbon.
(b) $CH_3CH(OH)CH_2CH_3$.

3.4 they all have the same functional group, which determines their chemical reactions.

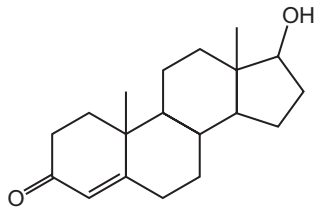
3.5 (a) $n(CO_2) = \frac{17.6}{44.0} = 0.400$ mol, so 4 C per molecule; $n(H_2O) = \frac{7.20}{18.0} = 0.400$ mol, giving 0.800 mol H, so 8 H per molecule; C_4H_8 has a mass of 56.0, leaving $88.0 - 56.0 = 32.0$, i.e. **2** oxygens; molecular formula $C_4H_8O_2$.
(b) $CH_3CH_2CH_2COOH$; **butanoic acid**.
(c) Any ester of formula $C_4H_8O_2$ drawn with every bond shown — e.g. methyl propanoate $CH_3CH_2COOCH_3$, or ethyl ethanoate $CH_3COOCH_2CH_3$.
(d) Empirical = simplest whole-number ratio, C_2H_4O; molecular = the actual number of each atom, $C_4H_8O_2$; structural = shows how the atoms are joined, $CH_3CH_2CH_2COOH$.

26 The skeletal formulas of two compounds are shown.

progesterone



testosterone



Which statements about progesterone and testosterone are correct?

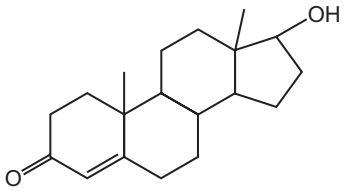
A They both contain a ketone group, and they both have geometrical isomers due to the C=C bond.

B They have the same molecular formula, and they both have geometrical isomers.

C They have the same number of chiral carbons, and they have the same molecular formula.

D They have the same number of chiral carbons, and they both contain a ketone group.

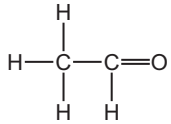
28 The diagram shows the skeletal formula of the hormone testosterone.



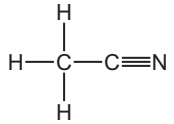
What is the molecular formula of testosterone?

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

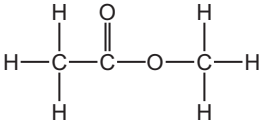
37 The structures of three organic compounds are shown.



1



2



3

Which compounds produce ethanoic acid when heated with HC*l*(aq)?

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

3 The alkanes are a homologous series of organic molecules. Alkanes are generally unreactive and are commonly used as fuels.

(a) Define homologous series.

.....

..... [2]

(b) Give two reasons to explain the general unreactivity of alkanes.

1 .....

2 .....

[2]

(c) Alkanes with low relative molecular mass, M_r, are more useful than those found in heavier crude oil fractions.

Name the process that is used to obtain alkanes with low M_r from heavier crude oil fractions.

..... [1]

(d) Hexane, C_6H_{14}, has four structural isomers.

Fig. 3.1 shows hexane and two of its structural isomers.

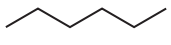
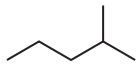
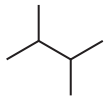
hexane	A	B	C	D
				

Fig. 3.1

(i) Complete Fig. 3.1 by drawing structures for **C** and **D**, the other two structural isomers of hexane. [2]

(ii) **A**, **B** and hexane have different boiling points.

Arrange **A**, **B** and hexane in order of increasing boiling point.

Explain your answer.

lowest ..... < ..... < ..... highest

.....

.....

....

[3]

(e) Hexane can be converted into compounds **E** and **F** at high temperature and pressure. Fig. 3.2 shows the reaction scheme involving hexane, **E** and **F**.

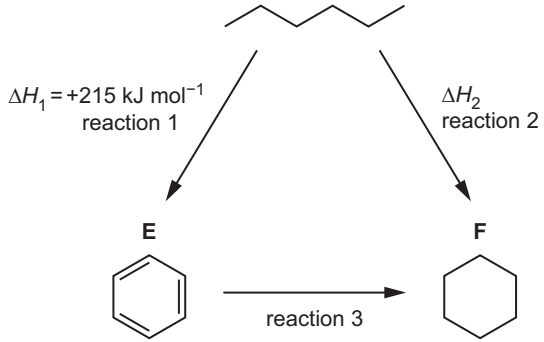


Fig. 3.2

(i) Identify a suitable reagent for reaction 3.

..... [1]

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

Table 3.1

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
	−156
	+48

ΔH_2 = ... kJ mol^{-1} [2]

(iii) Write an equation for the complete combustion of hexane.

..... [1]

[Total: 14]

A-LEVEL CHEMISTRY • EXERCISE SHEET

13.2 Characteristic organic reactions

Name: _____ Class: _____ Date: _____ **Total: 22 marks**

KEY WORDS addition 加成 • fission 断裂 • electrophile 亲电试剂 • homolytic fission 均裂 • nucleophile 亲核试剂

Objective

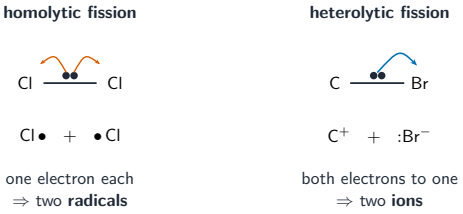
Build the skills to answer exam questions on **characteristic organic reactions** — bond **fission** 断裂, **nucleophiles** 亲核试剂 and **electrophiles** 亲电试剂, the reaction types, and mechanism terms.

You must be able to:

- use the terms homologous series, saturated/unsaturated, and homolytic/heterolytic fission
- define nucleophile, electrophile, and the reaction types (addition, substitution, etc.)
- describe the free-radical steps and name the main mechanisms

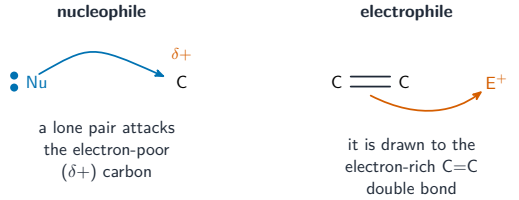
1 Worked examples

Breaking bonds



*Homolytic: one electron to each atom (two **free radicals** 自由基). Heterolytic: both electrons to one atom (two ions)*

Nucleophiles and electrophiles



A nucleophile (lone pair) attacks an electron-poor centre; an electrophile is drawn to an electron-rich one (e.g. C=C)

Reaction and mechanism types

addition (two → one), **substitution** (swap), **elimination** (lose a small molecule → double bond), **hydrolysis** (split by water), **condensation** (join + lose a small molecule). Free-radical reactions go by **initiation → propagation → termination**. Main mechanisms: free-radical substitution, electrophilic addition, nucleophilic substitution, nucleophilic addition. A **curly arrow** shows a pair of electrons moving.

2 Practice

2.1 Define a **nucleophile**. [1]

2.2 Name the type of bond fission that produces two free radicals. [1]

3 Exam-style questions

3.1 Heterolytic fission of a covalent bond produces: [1]

- **A** two free radicals
- **B** two ions
- **C** two atoms
- **D** a double bond

3.2 A reaction in which a small molecule is removed to form a C=C double bond is: [1]

- **A** addition
- **B** substitution
- **C** elimination
- **D** hydrolysis

3.3 (a) State the difference between homolytic and heterolytic fission. [2]

(b) Name the three steps of a free-radical mechanism. [3]

3.4 Explain why a C=C double bond is attacked by electrophiles. [2]

3.5 2-bromo-2-methylpropane, $(CH_3)_3CBr$, reacts with warm aqueous sodium hydroxide.

(a) Name the type of reaction and its mechanism. [2]

(b) Explain what is meant by a *nucleophile*, and state which species is the nucleophile here. [2]

(c) The C–Br bond breaks heterolytically. Explain the term *heterolytic fission* and name the two species formed. [3]

(d) 1-bromobutane reacts by a different mechanism under the same conditions. Name that mechanism, and explain the difference in terms of the stability of the intermediate. [4]

Solutions

2.1 a species with a lone pair that is attracted to (attacks) an electron-poor / positive centre.

2.2 homolytic fission.

3.1 B. Heterolytic fission gives both electrons to one atom, producing two ions.

3.2 C. Removing a small molecule to form a double bond is elimination.

3.3 (a) homolytic — the bond splits evenly, one electron to each atom (two radicals); heterolytic — both electrons go to one atom (two ions).
(b) initiation; propagation; termination.

3.4 the C=C bond is an electron-rich region (high electron density); electrophiles are electron-deficient and are attracted to it.

3.5 (a) Nucleophilic substitution; by the S_N1 mechanism.
(b) A nucleophile is an electron-pair donor that attacks an electron-deficient, $\delta+$ carbon; here it is the hydroxide ion, OH^-.
(c) In heterolytic fission **both** bonding electrons go to one of the two atoms, so the bond breaks unevenly; it gives a bromide ion, Br^- and a tertiary carbocation, $(CH_3)_3C^+$.
(d) S_N2. The tertiary carbocation is stabilised by the electron-releasing inductive effect of **three** alkyl groups, which spread the positive charge; a primary carbocation has only one such group, so it is far less stable and does not form readily; the hydroxide therefore attacks the $\delta+$ carbon directly in a single step, from the side opposite the bromine.

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.

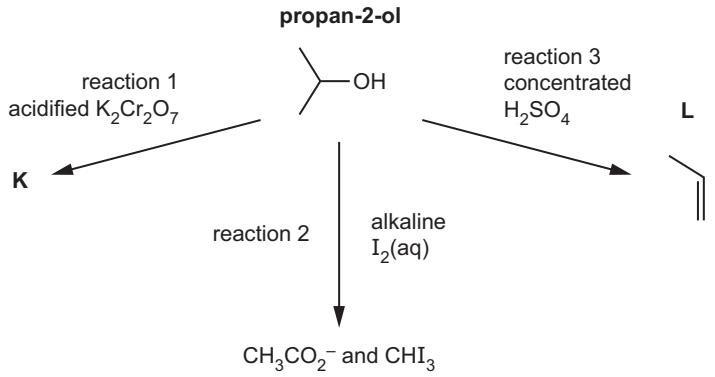


Fig. 3.1

(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.

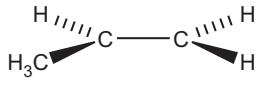


Fig. 3.2

[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.

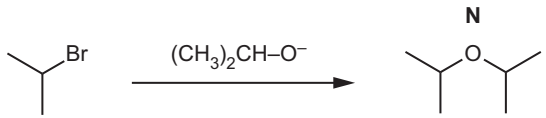


Fig. 3.3

(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]

3 Half-fill the 250 cm^3 beaker with water and place it on a tripod and gauze. Heat the water until boiling then switch off your Bunsen burner. This will be your hot water bath for use in **(b)(i)**. Start **(a)(i)** while the water is heating.

(a) **FA 4** is an aqueous solution containing three ions. One ion is **not** listed in the Qualitative analysis notes. **FA 5** is an aqueous solution containing two ions. The cation in **FA 5** is listed in the Qualitative analysis notes. The anions in both **FA 4** and **FA 5** contain sulfur.

(i) Carry out the following tests using a 1 cm depth of either **FA 4** or **FA 5** in a test-tube. Record your observations in Table 3.1.

Table 3.1

test	*observations*	
	FA 4	**FA 5**
Test 1 Add aqueous sodium hydroxide.		
Test 2 Add aqueous ammonia.		
Test 3 Add aqueous sodium carbonate.		
Test 4 Add aqueous barium chloride or aqueous barium nitrate.		
Test 5 Add acidified aqueous potassium manganate(VII).		

[5]

(ii) From your observations in **(a)(i)**, deduce the identities of the ions present in **FA 4** and **FA 5**. Give the formula of each ion in Table 3.2. If you are unable to identify an ion write 'unknown'.

Table 3.2

ions present	**FA 4**	**FA 5**
cations		
anions		

[3]

(b) (i) Both **FA 6** and **FA 7** are one of propan-1-ol, propan-2-ol, methanoic acid or ethanoic acid. You will carry out tests to investigate the identities of **FA 6** and **FA 7**. For each test use a 1 cm depth of **FA 6** or **FA 7** in a test-tube. Record your observations in Table 3.3.

Table 3.3

test	*observations*	
	FA 6	**FA 7**
Test 1 Add a few drops of acidified aqueous potassium manganate(VII), then		
place the test-tube in the hot water bath.		
Test 2 Add a 2 cm depth of aqueous iodine followed by drops of aqueous sodium hydroxide until the colour just disappears.		
If no reaction is visible, place the test-tube in the hot water bath.		
Test 3 Add aqueous sodium carbonate.		

[3]

(ii) From your observations in **(b)(i)** deduce the identities of **FA 6** and **FA 7**. Give reasons for your answers.

FA 6 is .....

reasons .....

.....

FA 7 is .....

reasons .....

.....

[2]

(c) A student carrying out a similar set of tests identifies two unknown compounds to be ethanol and propanoic acid.

Write an equation for the reaction between these two compounds.

..... [1]

[Total: 14]

Qualitative analysis notes

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	**NH_3(aq)**
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless $[Ba^{2+}(aq)]$ is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless $[Ca^{2+}(aq)]$ is very low	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high $[Ca^{2+}(aq)]$
sulfite, SO_3^{2-}(aq)	gives white ppt. with B q) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white/pale yellow ppt. slowly with H^+

3 Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	'pops' with a lighted splint
oxygen, O_2	relights a glowing splint

A-LEVEL CHEMISTRY • EXERCISE SHEET

13.3 Shapes of organic molecules; sigma and pi bonds

Name: _____ Class: _____ Date: _____ **Total: 12 marks**

KEY WORDS planar 平面 • cyclic 环状 • hybridisation 杂化 • pi bond π 键

Objective

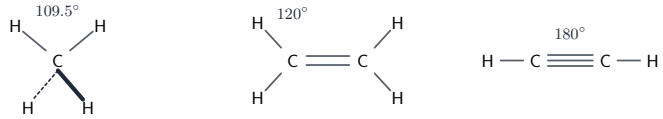
Build the skills to answer exam questions on **shapes of organic molecules** — **hybridisation** 杂化 (sp, sp^2, sp^3), **σ and π bonds**, and the term **planar** 平面.

You must be able to:

- describe organic molecules as straight-chained, branched or cyclic
- describe and explain the shape and bond angles at sp, sp^2 and sp^3 carbons
- describe the arrangement of σ and π bonds

1 Worked examples

Hybridisation and shape

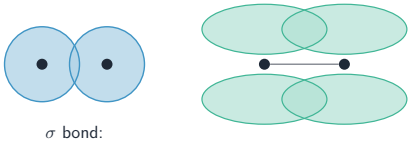


sp^3: 4 single bonds
tetrahedral

sp^2: 1 double + 2 single
planar (flat)

sp: 1 triple bond
linear

sp^3 = tetrahedral (109.5°); sp^2 = planar (120°); sp = linear (180°)



Hybridisation builds sigma and pi bonds

hybridisation	bonds	shape	angle
sp^3	4 single	tetrahedral	109.5°
sp^2	1 double + 2 single	planar	120°
sp	1 triple	linear	180°

Every single bond is a σ **bond** (direct overlap); a double bond is one σ + one π **bond** (sideways p-orbital overlap). Ethene is **planar** because its carbons are sp^2.

2 Practice

2.1 State the shape and bond angle around an sp^3 carbon. [2]

2.2 State how many σ and π bonds make up a C=C double bond. [2]

3 Exam-style questions

3.1 The carbon atoms in ethene, C_2H_4, are: [1]

- **A** sp hybridised, linear
- **B** sp^2 hybridised, planar
- **C** sp^3 hybridised, tetrahedral
- **D** sp^3 hybridised, planar

3.2 The bond angle around the carbon in methane is: [1]

- **A** 90°
- **B** 104.5°
- **C** 109.5°
- **D** 120°

3.3 (a) State the shape and bond angle around each carbon in ethyne, C_2H_2. [2]

(b) Explain why ethene is a planar molecule. [2]

3.4 Describe the σ and π bonds present in a molecule of ethene, C_2H_4. [2]

Solutions

2.1 tetrahedral; 109.5°.

2.2 1 σ bond and 1 π bond.

3.1 B. Ethene's carbons are sp^2 hybridised and the molecule is planar.

3.2 C. Methane's bond angle is 109.5°.

3.3 (a) linear; 180°.
(b) the carbons are sp^2 hybridised with 120° bond angles; all the atoms lie in one plane around the C=C double bond, so it is planar.

3.4 five σ bonds (4 C–H and 1 C–C) formed by direct overlap; one π bond from sideways overlap of p orbitals above and below the C=C.

5 The bonding between two atoms of nitrogen in an N_2 molecule involves the hybridisation of atomic orbitals to form sp orbitals.

Which row is correct?

	formation of the σ bond between the nitrogen atoms in N_2	type of orbital which contains the lone pair of electrons on each nitrogen atom in N_2
A	an sp orbital from one atom overlaps with an sp orbital of the other atom	p
B	an sp orbital from one atom overlaps with an sp orbital of the other atom	sp
C	an s orbital from one atom overlaps with a p orbital of the other atom	p
D	an s orbital from one atom overlaps with a p orbital of the other atom	sp

25 Two statements about a molecule of methanal are given.

1 It is planar.

2 It contains three σ bonds.

Which statements are correct?

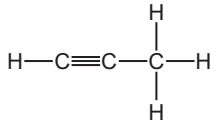
A both 1 and 2

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

A-LEVEL CHEMISTRY • EXERCISE SHEET

13.4 Isomerism: structural isomerism and stereoisomerism

Name: _____ Class: _____ Date: _____ **Total: 12 marks**

KEY WORDS isomerism 异构 • structural 结构 • stereoisomerism 立体异构 • structural isomerism 结构异构 • chiral 手性

Objective

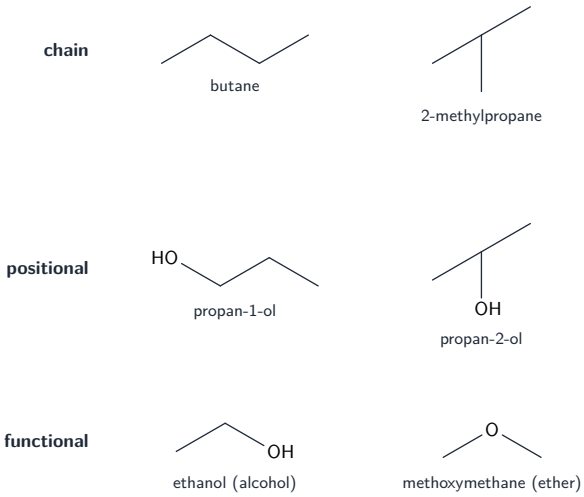
Build the skills to answer exam questions on **isomerism** 异构 — **structural** 结构 isomerism (chain, positional, functional group) and **stereoisomerism** 立体异构 (cis/trans and optical).

You must be able to:

- describe structural isomerism and its three kinds
- explain cis/trans isomerism in terms of restricted rotation at a C=C bond
- identify chiral centres and the geometrical isomerism in a given structure

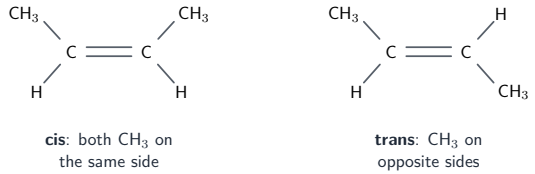
1 Worked examples

■ Structural isomerism

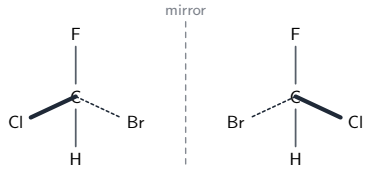


Chain, positional and functional-group isomerism — same molecular formula, different structure

■ Stereoisomerism



Cis/trans isomerism at a C=C: the π bond stops rotation, fixing groups on the same (cis) or opposite (trans) side



enantiomers: mirror images that cannot be superimposed
(the central carbon has 4 different groups)

*A **chiral centre** 手性中心 (carbon with four different groups) gives two mirror-image **enantiomers** 对映体*

2 Practice

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

2.2 State what is meant by a **chiral centre**. [1]

3 Exam-style questions

3.1 Cis/trans isomerism is possible because: [1]

- **A** single bonds cannot rotate
- **B** the π bond in C=C prevents rotation
- **C** the molecule is ionic
- **D** the carbons are sp^3 hybridised

3.2 Which compound has a chiral centre? [1]

- **A** $CH_3CH_2CH_3$
- **B** $CH_3CHBrCH_2CH_3$
- **C** CH_3CH_2OH
- **D** CH_2Cl_2

3.3 (a) Draw the cis and trans isomers of but-2-ene, $CH_3CH{=}CHCH_3$. [2]

(b) Explain why but-2-ene shows cis/trans isomerism but but-1-ene does not. [2]

3.4 2-hydroxypropanoic acid is $CH_3CH(OH)COOH$. State, with a reason, whether it has a chiral centre. [2]

Solutions

2.1 chain; positional; functional group isomerism.

2.2 a carbon atom bonded to four different groups.

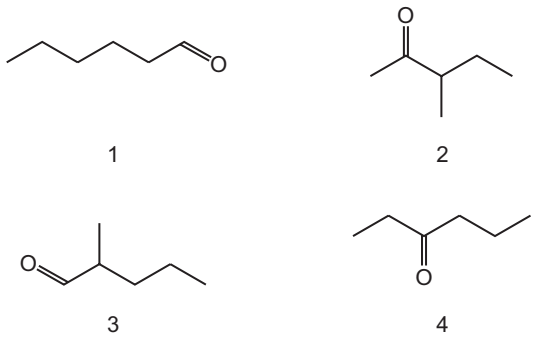
3.1 B. The π bond in the C=C prevents rotation.

3.2 B. The second carbon in $CH_3CHBrCH_2CH_3$ has four different groups.

3.3 (a) cis — both CH_3 groups on the same side of the C=C; trans — on opposite sides. (b) but-2-ene has a different group (H and CH_3) on each double-bond carbon, so cis/trans is possible; but-1-ene has two H atoms on the end carbon, so the groups can be swapped without making a new isomer.

3.4 yes; the second carbon is bonded to four different groups (CH_3, OH, H, COOH), so it is a chiral centre.

25 The diagrams show skeletal formulas of some isomers of $C_6H_{12}O$.



Which statement is correct?

A 1 and 3 are chain isomers of each other and positional isomers of each other.

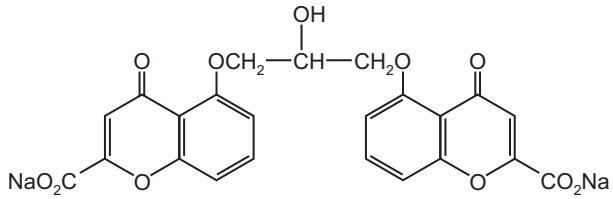
B 2 and 3 are functional group isomers of each other and both have a chiral centre.

C 1 and 4 are functional group isomers of each other and both have a chiral centre.

D 2 and 4 are positional isomers of each other and functional group isomers of each other.

26 The structure of disodium cromoglycate is shown.

disodium cromoglycate

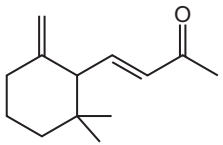


How many chiral centres are there in this molecule?

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

4 Fig. 4.1 shows a possible synthesis of propene, C_3H_6.

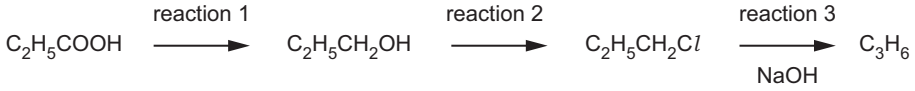


Fig. 4.1

(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).

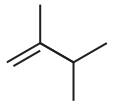
1 .....

2 .....

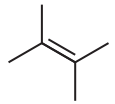
[2]

(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**.

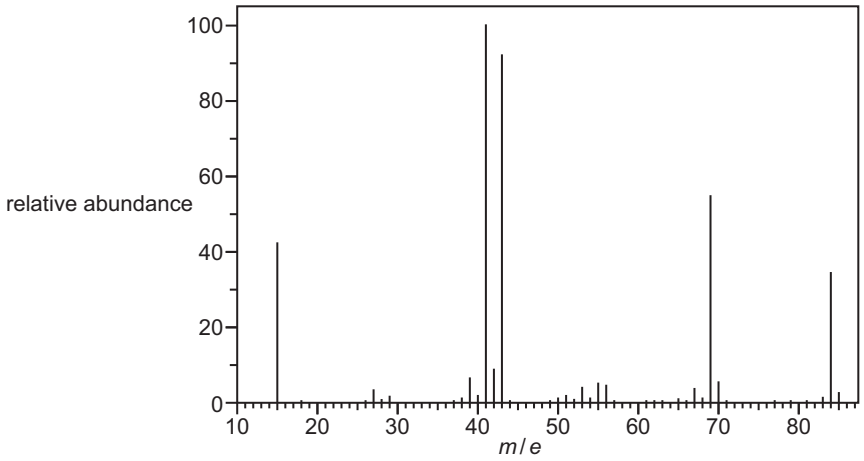


Fig. 4.2

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 $[M+1]^+$ 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

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												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 –

4 Fig. 4.1 shows how propane, C_3H_8, can be converted to propanoic acid, CH_3CH_2COOH.

$$C_3H_8 \xrightarrow{\text{reaction 1}} CH_3CH_2CH_2Cl \xrightarrow{\text{reaction 2}} CH_3CH_2CH_2OH \xrightarrow{\text{reaction 3}} CH_3CH_2COOH$$

Fig. 4.1

(a) Reaction 1 in Fig. 4.1 takes place in the presence of sunlight.

$$C_3H_8 + Cl_2 \rightarrow CH_3CH_2CH_2Cl + HCl$$

The reaction takes place via initiation, propagation and termination steps.

(i) Name the mechanism shown by reaction 1.

..... [1]

(ii) Complete the mechanism for reaction 1.

Construct equations to describe the steps of the mechanism.

initiation $Cl_2 \rightarrow 2Cl\bullet$

propagation 1 .....

propagation 2 .....

termination ..... $\rightarrow CH_3CH_2CH_2Cl$ [3]

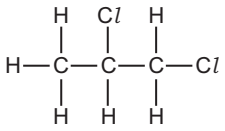
(iii) Reaction 1 is initiated by the bond fission of Cl_2.

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

..... [1]

(iv) Compound **Q** is a by-product of reaction 1.

Q



Name **Q**.

..... [1]

(v) The molecular formula of **Q** is $C_3H_6Cl_2$.

Identify the types of structural isomerism and stereoisomerism that a molecule with molecular formula $C_3H_6Cl_2$ can show.

type of structural isomerism .....

type of stereoisomerism ..... [2]

(b) State the reagent and solvent required for reaction 2.

..... [1]

(c) Reaction 3 takes place when $CH_3CH_2CH_2OH$ is heated under reflux with acidified potassium dichromate(VI) solution.

(i) State the colour change that takes place in the reaction mixture.

..... [1]

(ii) Construct an equation to represent reaction 3. Use [O] to represent an atom of oxygen from the oxidising agent.

..... [1]

(d) CH_3CH_2COOH reacts with an unsaturated alcohol **R** to form unsaturated ester **S**.

(i) State the **type** of reaction that forms **S**.

..... [1]

(ii) The infrared spectrum of **S** is shown in Fig. 4.2.

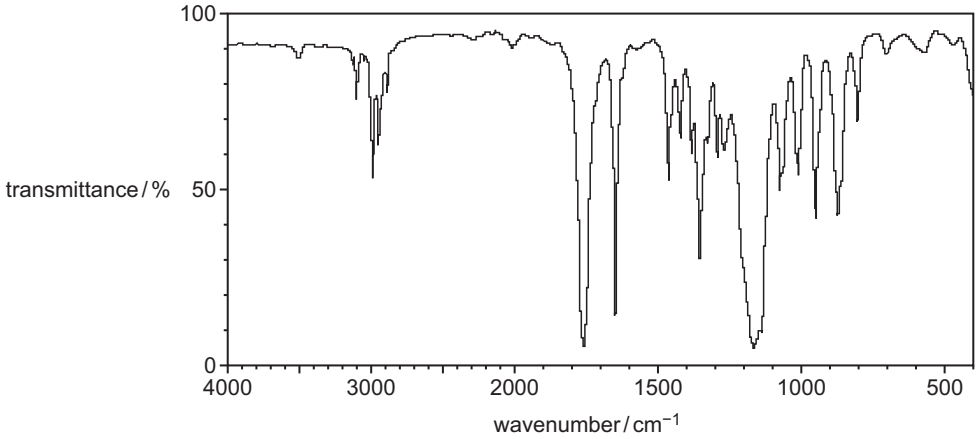


Fig. 4.2

Three absorptions in the infrared spectrum in Fig. 4.2 confirm that **S** is an ester and is unsaturated.

- Write **1**, **2** or **3** on Fig. 4.2 against each of these three absorptions.
- Complete Table 4.1 to show which bond is responsible for each absorption that you have identified in Fig. 4.2.

Table 4.1

absorption	**1**	**2**	**3**
bond responsible			

[3]

Table 4.2

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

(iii) The mass spectrum of **S** shows the following peaks.

Table 4.3

peak	relative abundance
M^+	4.7
$[M+1]^+$	0.31

Use Table 4.3 to calculate the number of carbon atoms in **S**.

number of carbon atoms in **S** = ... [1]

[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	$e = -1.60 \times 10^{-19}\,\text{C}$
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ionic product of water	$K_w = 1.00 \times 10^{-14}\,\text{mol}^2\,\text{dm}^{-6}$ (at 298 K (25 °C))
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								1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0												5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3												13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

Key

atomic number
atomic symbol
name
relative atomic mass

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

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.

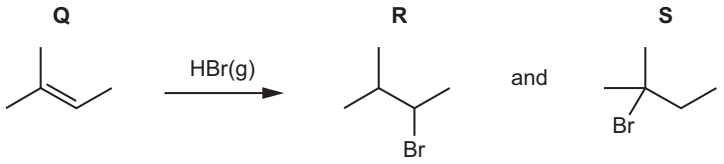

Fig. 4.2

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**.

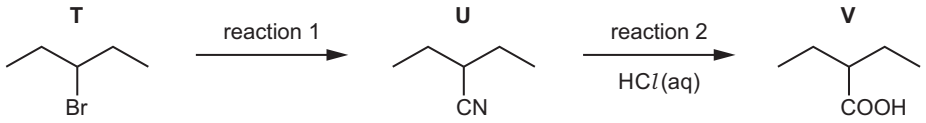

Fig. 4.3

(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	$R = 8.31\,J\,K^{-1}\,mol^{-1}$
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
			Key: atomic number / atomic symbol / name / relative atomic mass														
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
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