Cambridge

AS Level

Chemistry

CODE: (9701)

Chapter 13 and 14

Nitrogen and sulfur and Introduction to organic chemistry

Nitrogen gas

Nitrogen, a non-metallic element in Group 15, makes up 78% of Earth's atmosphere. It exists as diatomic molecules, N_2, and is unreactive in air. Nitrogen gas's lack of reactivity is due to its electronic configuration, which requires a triple covalent bond.

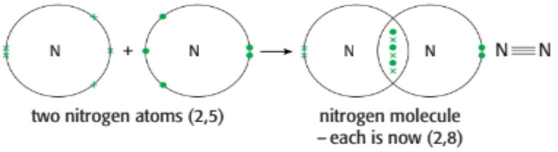


Figure 13.2 The bonding in a nitrogen molecule, N_2.

The triple covalent bond is very strong; its bond energy is almost 1000 $kJmol^{-1}$. It is difficult to break and so nitrogen gas will only react under extreme conditions.

Lightning provides the activation energy needed for this reaction to occur

$$N_2(g) + O_2(g) \longrightarrow \underset{\text{nitrogen(II) oxide}}{2NO(g)}$$

The nitrogen (II) oxide formed is further oxidised by oxygen in the air to give nitrogen (IV) oxide, NO_2.

$$2NO(g) + O_2(g) \longrightarrow \underset{\text{nitrogen(IV) oxide}}{2NO_2(g)}$$

Figure 13.3 Nitrogen oxides are formed when lightning strikes.

Nitrogen (IV) oxide dissolves in water droplets and forms nitric acid, which falls to earth in rain. This is a vital part of the natural nitrogen cycle:

$$2NO_2(g) + H_2O(l) + \tfrac{1}{2}O_2(g) \longrightarrow \underset{\text{nitric acid}}{2HNO_3(aq)}$$

Ammonia and ammonium compounds

Ammonia is a very important compound of nitrogen. It is an alkaline gas whose formula is NH3. In industry it is made on a large scale in the Haber process.

$$\underset{\text{nitrogen}}{N_2(g)} + \underset{\text{hydrogen}}{3H_2(g)} \overset{Fe}{\rightleftharpoons} \underset{\text{ammonia}}{2NH_3(g)}$$

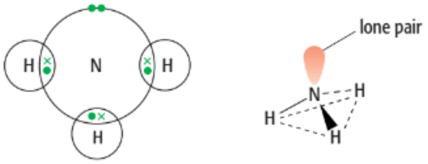


Figure 13.4 A dot-and-cross diagram showing the covalent bonding in an ammonia molecule and its pyramidal shape.

You have also learnt that nitrogen's lone pair can be donated to an H+ ion from an acid, forming a co-ordinate (or dative) covalent bond (see page 53). Ammonia is acting as a base in this reaction (because it is accepting an H+ ion):

$$NH_3(aq) + H^+(aq) \longrightarrow \underset{\text{ammonium ion}}{NH_4^+(aq)}$$

Ammonium chloride and calcium hydroxide, both in the solid state, are usually mixed then heated (see the apparatus in Figure 13.5).

$$2NH_4Cl(s) + Ca(OH)_2(s) \xrightarrow{\text{heat}} CaCl_2(s) + 2H_2O(l) + 2NH_3(g)$$

Uses of ammonia and ammonium compounds

The major nitrogen-based fertiliser is ammonium nitrate, NH_4NO_3. This is manufactured from ammonia and nitric acid:

$$NH_3(aq) + HNO_3(aq) \longrightarrow NH_4NO_3(aq)$$

The nitric acid used to make ammonium nitrate is itself made from ammonia in another chemical process. Fertiliser factories making ammonium nitrate often have three plants side by side, making:

- Ammonia in the Haber process
- Nitric acid from ammonia
- Ammonium nitrate from nitric acid and ammonia.

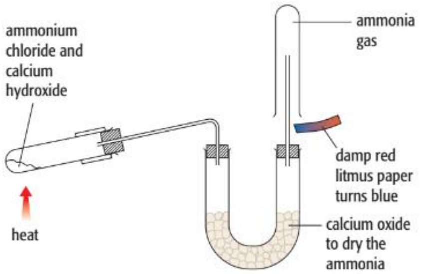


Figure 13.5 Preparing ammonia gas from an ammonium salt, NH_4Cl, and a base, $Ca(OH)_2$.

Concentrated nitric acid is utilized in explosive production, detergents, paints, pigments, dyes, and nylon manufacturing, with about 10% of ammonium nitrate used for explosives.

Figure 13.6 Ammonium nitrate is spread as pellets onto the soil.

Environmental problems caused by nitrogen compounds

Nitrate fertilisers

Nitrogen-based fertilizers, primarily ammonium nitrate and potassium nitrate, are soluble in water, causing environmental issues. Rainwater leaches nitrates into groundwater, leading to water plant growth in rivers and lakes, and algae growth, causing eutrophication.

Figure 13.7 Fertilisers leached from farmland have caused eutrophication in this river.

- A bloom of algae can spread across the surface, blocking out the light for other plant life in the water.
- When the plants and algae die, bacteria in the water feed on them, decomposing the plant material.
- The bacteria multiply rapidly with so much food available, using up the dissolved oxygen in the water.
- Fish extract dissolved oxygen from water, taken in through their gills. Without this dissolved oxygen they die, affecting the whole ecosystem.

Nitrogen oxides in the atmosphere

This chapter discusses the unreactive nature of nitrogen gas, which can be oxidized by lightning in extreme thunderstorm conditions. This reaction results in the formation of gaseous nitrogen oxides, such as nitrogen (II) oxide and nitrogen (IV) oxide, which can be found in car engines' cylinders.

The reactions below show the catalytic activity of the nitrogen oxides:

$$SO_2(g) + NO_2(g) \longrightarrow SO_3(g) + NO(g)$$

Then NO_2 is regenerated as NO reacts with oxygen in the air:

$$NO(g) + \frac{1}{2}O_2(g) \longrightarrow NO_2(g)$$

NO_2 catalyzes the oxidation of sulfur dioxide, reducing pollutants in motor vehicles. Catalytic converters in car exhaust systems reduce nitrogen oxides to harmless nitrogen gas, released from the vehicle's exhaust pipe.

$$2CO(g) + 2NO(g) \longrightarrow 2CO_2(g) + N_2(g)$$

Sulfur and its oxides

We have just seen how sulfur dioxide in the atmosphere can be oxidised by nitrogen(IV) oxide to form sulfur(VI) oxide (also known as sulfur trioxide). This reacts with water to form sulfuric acid, which is the main cause of acid rain.

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$$


Figure 13.8 This limestone carving has been chemically weathered by acid rain.

Acid rain has harmful effects on:

- Plants (especially trees)
- Rivers, streams and lakes (and the fish and other animals in these habitats)
- Buildings, statues (Figure 13.8) and metal structures.

Sulfuric acid

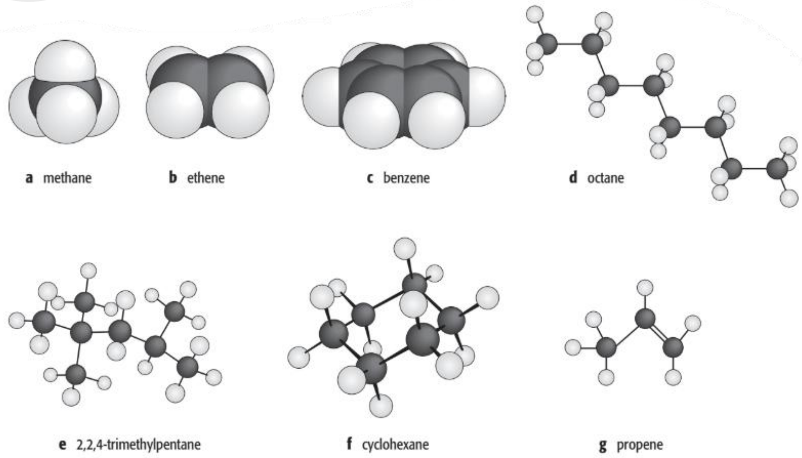
Sulfuric (VI) acid, H2SO4, is a crucial chemical used in various industries, including fertilizers, detergents, paints, pigments, dyes, synthetic fibers, chemicals, plastics, car batteries, tanning leather, and metal surface cleaning. Countries like Poland and the USA export sulfur, while impurities from fossil fuels can also be used in the Contact process.

Chapter 14 - Introduction to organic chemistry

Representing organic molecules

Figure 14.2 shows two types of three-dimensional (3D) diagram representing a selection of organic molecules. **hydrocarbons**.

Hydrocarbons are compounds of carbon and hydrogen only. The colours used in the modelling of molecules are shown in Table 14.1.


a methane b ethene c benzene d octane

e 2,2,4-trimethylpentane f cyclohexane g propene

Figure 14.2 Examples of the variety of hydrocarbons. **a–c** These hydrocarbons are shown as space-filling models. Such models show the region of space occupied by the atoms and the surrounding electrons. **d–g** These hydrocarbons are shown as ball-and-stick models, which enable bonds between atoms to be seen clearly.

The **empirical formula** gives us the least detail. It tells us the simplest ratio of the different types of atoms present in the molecule. We can calculate empirical formulae from experimental data on the mass of each element, and hence the number of moles of each element, in a sample of a compound.

The **molecular formula** shows us the actual numbers of each type of atom in a molecule. To find this we need to know the relative molecular mass of the compound. The relative molecular mass of propene is 42.

Chemists can give more detail about a molecule by giving its **structural formula**. This tells us about the atoms bonded to each carbon atom in the molecule.

However**, all the bonds** within a molecule are shown in its **displayed formula**. We can think of this representation as a 2D, or flattened, version of the 'ball- and-stick' models shown in Figure 14.2. The displayed formula of propene is shown in Figure 14.3.

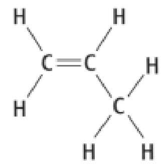


Figure 14.3 The displayed formula of propene, showing all the bonds in the molecule.

A simplified version of the displayed formula is called the **skeletal formula**. It has all the symbols for carbon and hydrogen atoms removed, as well as the carbon to hydrogen bonds. The carbon to carbon bonds are left in place. Figure 14.4 shows the skeletal formula of propene.

Figure 14.4 The skeletal formula of propene.

The displayed and skeletal formulae of an alcohol called butan-2-ol are shown in Figure 14.5. Notice that the H atom in an OH group is included in a skeletal formula.

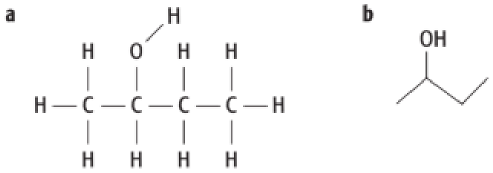
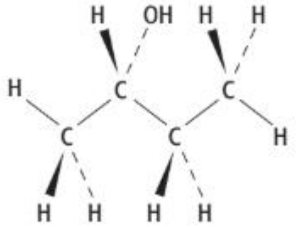


Figure 14.5 **a** The displayed formula of butan-2-ol; **b** the skeletal formula of butan-2-ol.

The 'zig-zag' in the carbon chain shown in a skeletal formula can be seen in the 3D representations of hydrocarbons in Figure 14.2. You will see more detailed 3D displayed formulae later in this chapter, when we look at optical isomers (see page 195). Figure 14.6 shows the 3D displayed formula of butan-2-ol.



the 'wedge' bond is sticking out of the plane of the paper and the 'dashed-line' bond is sticking into the plane of the paper

Figure 14.6 The 3D displayed formula of butan-2-ol.

With complex molecules, chemists sometimes find it useful to combine structural and skeletal formulae when representing a molecule. The molecule of cholesterol shown in Figure 14.7 is one such example.

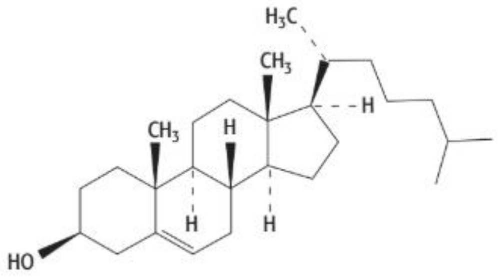
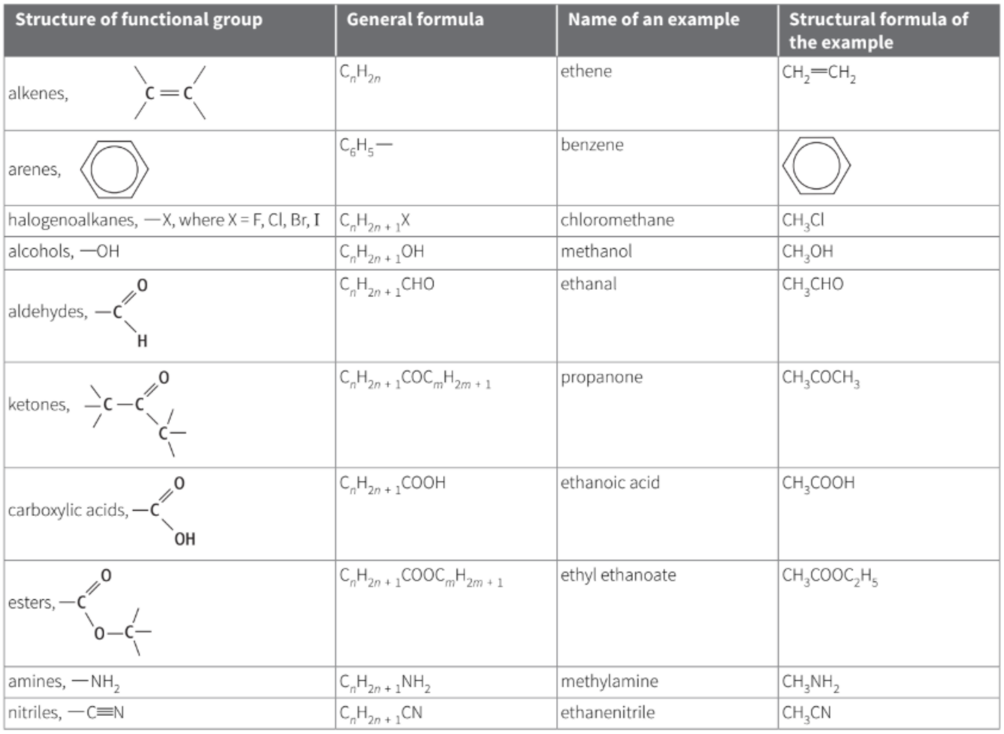


Figure 14.7 A useful way of combining structural and skeletal formulae.



Structure of functional group	General formula	Name of an example	Structural formula of the example
alkenes, C=C	C_nH_{2n}	ethene	$CH_2{=}CH_2$
arenes,	C_6H_5-	benzene	
halogenoalkanes, —X, where X = F, Cl, Br, I	$C_nH_{2n+1}X$	chloromethane	CH_3Cl
alcohols, —OH	$C_nH_{2n+1}OH$	methanol	CH_3OH
aldehydes,	$C_nH_{2n+1}CHO$	ethanal	CH_3CHO
ketones,	$C_nH_{2n+1}COC_mH_{2m+1}$	propanone	CH_3COCH_3
carboxylic acids,	$C_nH_{2n+1}COOH$	ethanoic acid	CH_3COOH
esters,	$C_nH_{2n+1}COOC_mH_{2m+1}$	ethyl ethanoate	$CH_3COOC_2H_5$
amines, —NH$_2$	$C_nH_{2n+1}NH_2$	methylamine	CH_3NH_2
nitriles, —C≡N	$C_nH_{2n+1}CN$	ethanenitrile	CH_3CN

Table 14.2 Some common functional groups.

Functional groups

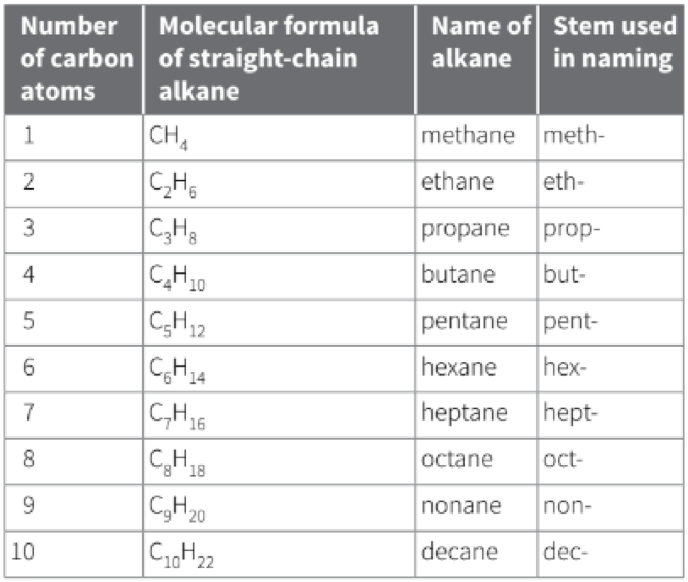
Within a class of compounds all the compounds consist of molecules with a particular atom, or grouping of atoms, called a **functional group**.

chemical properties of the compounds that contain that specific functional group.
The functional group in an alkene is the C= C double bond.
The functional group in a carboxylic acid is the
-----COOH group.

The **general formula** of the class of compounds is given in Table 14.2.

Naming organic compounds

Chemists have a system of naming organic compounds that can be applied consistently. This means that they can communicate with each other clearly when referring to organic compounds.



Number of carbon atoms	Molecular formula of straight-chain alkane	Name of alkane	Stem used in naming
1	CH_4	methane	meth-
2	C_2H_6	ethane	eth-
3	C_3H_8	propane	prop-
4	C_4H_{10}	butane	but-
5	C_5H_{12}	pentane	pent-
6	C_6H_{14}	hexane	hex-
7	C_7H_{16}	heptane	hept-
8	C_8H_{18}	octane	oct-
9	C_9H_{20}	nonane	non-
10	$C_{10}H_{22}$	decane	dec-

Table 14.3 The stems used in naming simple organic compounds that contain a hydrocarbon chain.

The stem of each name indicates how many carbon atoms are in the longest chain in one molecule of the compound.

Table 14.3 shows the names of the first ten alkanes and the stems used in naming other molecules.

The numbering starts at the end that produces the lowest possible numbers in the name (Figure 14.8).

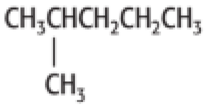

$\underset{CH_3}{CH_3CH}CH_2CH_2CH_3$

Figure 14.8 This is called 2-methylpentane, not 4-methylpentane.

If there is more than one of the same alkyl side-chain or functional group. we indicate how many by inserting di (for two), tri (for three) or tetra (for four) in front of its name. Figure 14.9 shows an example.

If there is more than one type of alkyl side-chain, they are listed in the name in alphabetical order (Figure 14.10). The alkyl groups appear in its name in alphabetical order.

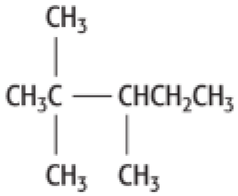

$CH_3\overset{CH_3}{\underset{CH_3}{C}}-\underset{CH_3}{CH}CH_2CH_3$

Figure 14.9 This is 2,2,3-trimethylpentane.

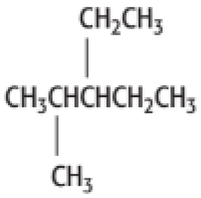

$CH_3\underset{CH_3}{CH}\overset{CH_2CH_3}{CH}CH_2CH_3$

Figure 14.10 This is 3-ethyl-2-methylpentane.

Table 14.2 lists compounds with common functional groups and uses a numbering system to indicate their position in a molecule. Examples include carboxylic acids and aldehydes. Aryl compounds, which contain at least one benzene ring, have six carbon atoms arranged in a hexagon.

At A level, alkyl groups bonded to a benzene ring do not require a number in the name, but with two or more, they must be indicated.

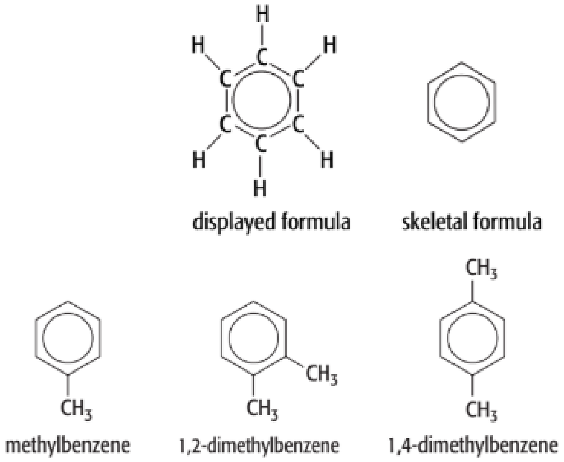


Figure 14.12 Naming aryl compounds.

Bonding in organic molecules

The ability of a carbon atom to bond to other carbon atoms, and the shapes of the molecules formed, can be explained by looking closely at the bonding involved.

Sigma (σ) bonds

By forming **single covalent bonds** with four other atoms, a carbon atom can gain the electronic configuration of the noble gas neon. These single covalent bonds are known as **sigma (σ) bonds.**

The electron pair in a σ bond is located in a lobe between atoms, bonding them through electrostatic attraction. In organic compounds, each carbon atom forms four σ bonds, repelling each other and forming a tetrahedral arrangement with a 109.5° bond angle.

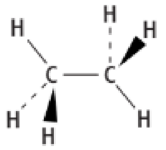


Figure 14.13 The bond angles are all close to 109.5° in an ethane molecule. The two carbon atoms, each forming four sigma bonds, are said to be sp^3 hybridised (see page 57).

Pi (π) bonds

Carbon can also form double bonds between its atoms in organic molecules, as well as forming single bonds. A C= C double bond, as found in alkenes such as ethene, is made up of a σ bond and a **pi (π) bond.**

The two lobes that make up the π bond lie above and below the plane of the atoms in an ethene molecule.

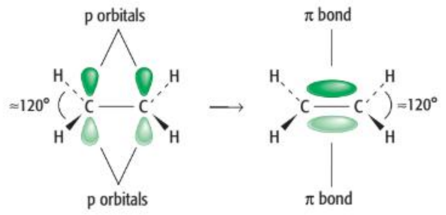


Figure 14.14 The overlap of p orbitals results in a π bond. Ethene is described as a **planar** molecule. The two carbon atoms are said to be sp^2 hybridised (see page 57). All the carbon and hydrogen atoms in the ethene molecule lie in the same plane.

Structural isomerism

We have seen how a compound's molecular formula tells us the number and type of each atom in one molecule of the compound. However, for a given molecular formula there may be different ways of arranging these atoms.

Such compounds with the same molecular formula but different structural formulae are called structural isomers.

Structural isomers have the same molecular formula but different structural formulae.

There are three types of structural isomerism:
1 position isomerism
2 functional group isomerism
3 chain isomerism.

1 Position isomerism

In position isomerism, it is the position of the functional group that varies in each isomer.

You need to take care when drawing the structural or displayed formula of different isomers not to repeat the same structure. Remember that there is free rotation about C= C single bonds.

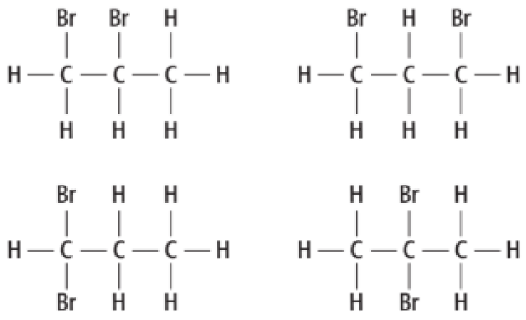


Figure 14.15 An example of position isomerism.

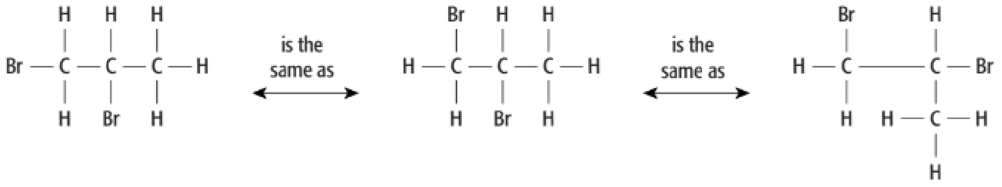
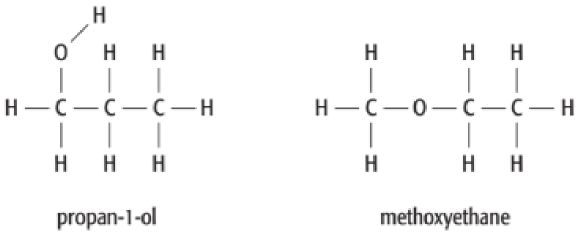


Figure 14.16 These are different ways of representing the **same molecule** because of free rotation about C—C single bonds.

2 Functional group isomerism

In functional group isomerism there are different functional groups present. For example, given the molecular formula C_3H_8O we can draw both an alcohol and an ether (Figure 14.17).

These two isomers have different functional groups and so have very different chemical properties.



propan-1-ol methoxyethane

Figure 14.17 An example of functional group isomerism.

3 Chain isomerism

Chain isomers differ in the structure of their carbon ‘skeleton’. For example, butane and methylpropane are chain isomers, both with the molecular formula of C_4H_{10} (Figure 14.18).

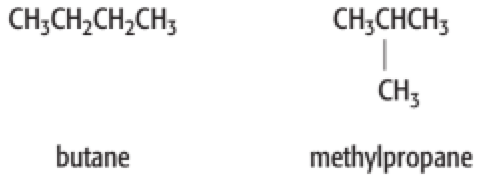


Figure 14.18 An example of chain isomerism.

Stereoisomerism

In stereoisomerism we have compounds whose molecules have the same atoms bonded to each other but with different arrangements of the atoms in space.

There are two types of stereoisomerism:
1 cis–trans isomerism
2 optical isomerism.

1 Cis–trans isomerism

Unlike a C =C single bond, there is no free rotation about a C= C double bond. This results in the possibility of a different type of isomerism in unsaturated organic compounds. Figure 14.19 gives an example.

cis-1,2-dibromoethene *trans*-1,2-dibromoethene

Figure 14.19 An example of *cis–trans* isomerism.

Cis-1,2-dibromoethene and trans-1,2-dibromoethene are stereoisomers with different arrangements of atoms in space, resulting in different compounds with different physical properties and chemical properties. These structures can be observed in unsaturated compounds, as shown in Figure 14.20.

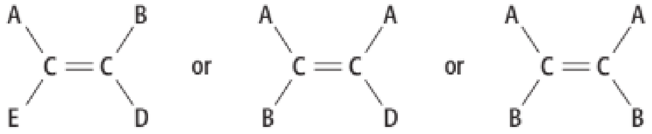


Figure 14.20 These three arrangements can result in *cis–trans* isomerism because there is restricted rotation about the C=C double bond.

2 Optical isomerism

The two different molecules are mirror images of each other and cannot be superimposed (Figure 14.21). The carbon atom with the four different groups attached is called the **chiral centre** of the molecule.

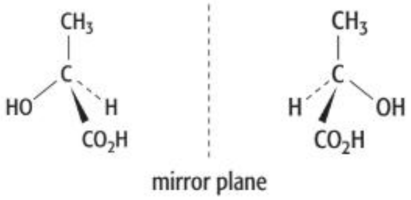


Figure 14.21 These two molecules are optical isomers, sometimes referred to as enantiomers. Trying to superimpose the two isomers is like trying to superimpose your left hand on top of your right hand – it can’t be done.

Organic reactions – mechanisms

Chemists find it useful to explain organic reactions by summarising the overall reaction in a series of steps called a reaction mechanism.

There are two ways in which covalent bonds can break:
- homolytic fission
- heterolytic fission.

Homolytic fission

In this type of bond breaking, both the atoms at each end of the bond leave with one electron from the pair that formed the covalent bond. This is shown in Figure 14.22, using the simple example of a hydrogen chloride molecule.

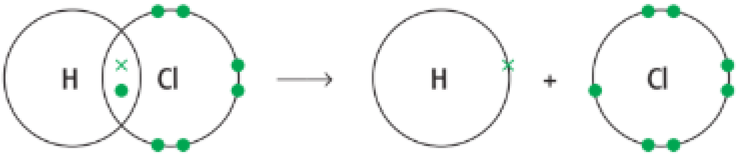


Figure 14.22 Homolytic fission of a covalent bond.

The species produced when a bond breaks homolytically are called **free radicals.** We can show the formation of free radicals by using an equation:

$$HCl \longrightarrow H\bullet + Cl\bullet$$

H• and Cl• are free radicals. All free radicals have an unpaired electron (represented by the dot) and are very reactive.

You can read more about a free-radical reaction on page 207.

■■ This type of reaction involves the formation of the free radicals in an **initiation step**. This requires an input of energy to break a covalent bond, resulting in two free radicals.

■■ The radicals formed can then attack reactant molecules, generating more free radicals. These reactions are called **propagation steps**. They can be thought of as a chain reaction, which only stops when free radicals react with each other.

■■ Two free radicals reacting together will form a molecule, with no free radicals generated. Therefore this is called a **termination step.**

Heterolytic fission

The second type of bond breaking involves the 'uneven' breaking of a covalent bond. In heterolytic fission the more electronegative atom takes both the electrons in the covalent bond.

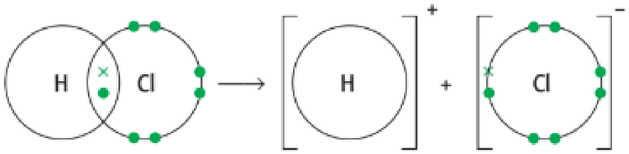
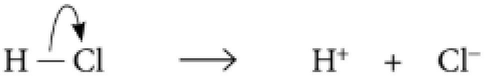


Figure 14.23 Heterolytic fission of a covalent bond.

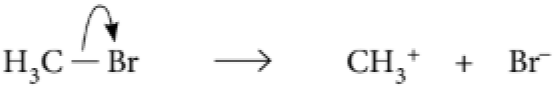
We can show this type of bond breaking in an equation.

A small curly arrow shows the movement of a pair of electrons:



$$H-Cl \longrightarrow H^+ + Cl^-$$

The heterolytic fission of a bond can involve a C X bond, where X is an atom more electronegative than carbon.

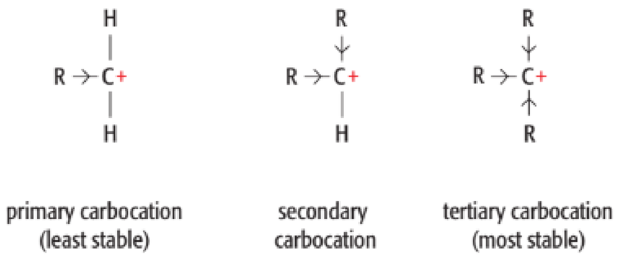


$$H_3C-Br \longrightarrow CH_3^+ + Br^-$$

This leaves the methyl group one electron short, resulting in the formation of a positively charged ion. This type of alkyl ion is called a **carbocation**.

We say that the electron-donating nature of alkyl groups has a positive inductive effect on adjacent groups. Therefore, in carbocations the more alkyl groups attached to the **positively charged carbon**, the less the charge density is on the carbon atom with the three covalent bonds.

So when carbocations are formed as intermediates in reactions, the tertiary carbocation is most likely to form as its positive charge is, in effect, 'smeared' over the C+ atom and the three carbon atoms it is bonded to. Carbocations are an example of a species called an **electrophile**.



Key: where R = an alkyl group

Figure 14.24 Note that the carbon atom with the positive charge only has three covalent bonds, not the usual four, making it electron deficient. Alkyl groups have the effect of spreading out the charge on the carbocation. The more alkyl groups adjacent to the positively charged carbon atom, the more stable the carbocation.

> An electrophile is an acceptor of a pair of electrons.

You will also meet **nucleophiles** when studying organic reactions. These are electron-rich species, i.e. they carry a negative, or partial negative, charge.

> A nucleophile is a donator of a pair of electrons.

Types of organic reaction

Addition reactions involve the formation of a single product from two reactant molecules.

$$C_2H_4 + Br_2 \longrightarrow C_2H_4Br_2$$

Elimination reactions result in the removal of a small molecule from a larger one. An example is the dehydration of an alcohol by concentrated sulfuric acid

$$C_2H_5OH \xrightarrow{\text{conc. } H_2SO_4} C_2H_4 + H_2O$$

Substitution reactions involve the replacement of one atom, or a group of atoms, by another.

$$CH_4 + Cl_2 \xrightarrow{\text{UV light}} CH_3Cl + HCl$$

Hydrolysis is the breakdown of a molecule by water. This type of reaction is often speeded up by acid or alkali.

$$C_2H_5Br + H_2O \longrightarrow C_2H_5OH + HBr$$

Hydrolysis with alkali is faster, and gives slightly different products:

$$C_2H_5Br + NaOH \longrightarrow C_2H_5OH + NaBr$$

Oxidation is defined as the loss of electrons from a species. However, in organic reactions it is often simpler to think of oxidation reactions in terms of the number of oxygen and/or hydrogen atoms before and after a reaction.

Oxidation is the addition of oxygen atoms to a molecule and/or the removal of hydrogen atoms from a molecule.

An example is the partial oxidation of ethanol to ethanal using acidified potassium dichromate(VI) solution,

$$C_2H_5OH + [O] \longrightarrow CH_3CHO + H_2O$$

■■ before the reaction ethanol contains one O atom and six H atoms

■■ after the reaction ethanal contains one O atom and four H atoms.

Ethanol loses two H atoms, indicating oxidation. The chemical equation for oxidation reactions is simplified using [O], but must be balanced. This is illustrated in the complete ethanol to ethanoic acid oxidation.

$$C_2H_5OH + 2[O] \longrightarrow CH_3COOH + H_2O$$

[O] represents an oxygen atom from the oxidising agent.

The 2 in front of the [O] is needed to balance the equation for oxygen atoms.
Reduction is the chemical opposite of oxidation.

$$CH_3COCH_3 + 2[H] \longrightarrow CH_3CHOHCH_3$$

Notice the use of [H] to simplify the chemical equation used to describe reduction reactions. [H] represents a hydrogen atom from the reducing agent. The 2 in front of the [H] is necessary to balance the equation for hydrogen atoms.

Revision questions

Q1 A mixture of the oxides of two elements of the third period is dissolved in water. The solution is approximately neutral.
What could be the constituents of the mixture?

A Al_2O_3 and MgO
B Na_2O and MgO
C Na_2O and P_4O_{10}
D SO_3 and P_4O_{10}

Q2 Aluminium chloride catalyses certain reactions by forming carbocations (carbonium ions) with chloroalkanes as shown.

$$RCl + AlCl_3 \rightarrow R^+ + AlCl_4^-$$

Which property makes this reaction possible?

A $AlCl_3$ is a covalent molecule.
B $AlCl_3$ exists as the dimer Al_2Cl_6 in the vapour.
C The aluminium atom in $AlCl_3$ has an incomplete octet of electrons.
D The chlorine atom in RC*l* has a vacant p orbital.

Q3 What are the products of the thermal decomposition of magnesium nitrate?

A magnesium nitride and oxygen
B magnesium oxide and nitrogen
C magnesium oxide, nitrogen and oxygen
D magnesium oxide, nitrogen dioxide and oxygen

Q4 Chlorine compounds show oxidation states ranging from –1 to +7.
What are the reagent(s) and conditions necessary for the oxidation of elemental chlorine into a compound containing chlorine in the +5 oxidation state?

A $AgNO_3$(aq) followed by NH_3(aq) at room temperature
B concentrated H_2SO_4 at room temperature
C cold dilute NaOH(aq)
D hot concentrated NaOH(aq)

Q5 Which gaseous hydride most readily decomposes into its elements on contact with a hot glass rod?

A ammonia
B hydrogen chloride
C hydrogen iodide
D steam

Q6 Which reagent, when mixed and heated with ammonium sulphate, liberates ammonia?

A aqueous bromine
B dilute hydrochloric acid
C limewater
D acidified potassium dichromate(VI)

Q7 Which pollutant is formed in the internal combustion engine and, if not removed by the catalytic converter, may become involved in the formation of acid rain?

A C **B** C_8H_{18} **C** CO **D** NO

Q9 Which ion is most polarising?
A Al^{3+}
B Ba^{2+}
C Mg^{2+}
D Na^{+}

Q10 Which element has the same oxidation number in all of its known compounds?
A beryllium
B chlorine
C nitrogen
D sulphur

Q11 Due to their similar ionic radii, the reactions of lithium and magnesium and their corresponding compounds are very similar.
Which statement concerning the reactions of lithium and its compounds is correct?
A Lithium carbonate decomposes on heating at a relatively low temperature, forming lithium oxide and carbon dioxide.
B Lithium nitrate decomposes on heating, forming lithium nitrite and oxygen.
C Lithium only burns slowly in oxygen.
D Lithium reacts violently with cold water, liberating hydrogen.

Q12 Which statement is most likely to be true for astatine, which is below iodine in Group VII of the Periodic Table?
A Astatine and aqueous potassium chloride react to form aqueous potassium astatide and chlorine.
B Potassium astatide and hot dilute sulphuric acid react to form white fumes of only hydrogen astatide.
C Silver astatide reacts with dilute aqueous ammonia in excess to form a solution of a soluble complex.
D Sodium astatide and hot concentrated sulphuric acid react to form astatine.

Q13 Nitrogen dioxide and sulphur dioxide have some properties in common.
Which property is shown by one of these compounds, but not by the other?
A forms ‘acid-rain’
B is a reducing agent
C is insoluble in water
D is used as a food-preservative

Q14 The following species contain the same number of electrons.
In which order do their radii increase?

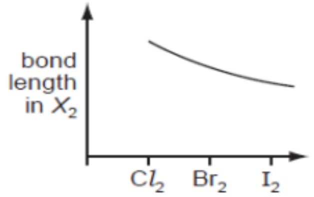
	smallest radius	→	largest radius
A	Ar	K^+	Ca^{2+}
B	Ca^{2+}	Ar	K^+
C	Ca^{2+}	K^+	Ar
D	K^+	Ar	Ca^{2+}

Q16 Use of the Data Booklet is relevant to this question.
Which is true for calcium or its compounds compared with the corresponding statements for magnesium?
A Calcium has a smaller atomic radius.
B Calcium oxide reacts less vigorously with water.
C Calcium reacts more vigorously with water.
D The sum of the first two ionisation energies of calcium is greater.

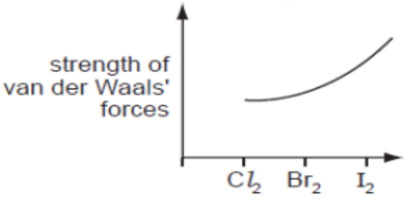
Q17 Concentrated sulphuric acid is added to separate solid samples of sodium chloride, sodium bromide or sodium iodide.
With which sample(s) does sulphuric acid act as an oxidising agent?
A sodium chloride only
B sodium chloride and sodium bromide
C sodium bromide and sodium iodide
D sodium iodide only

Q18 Which graph correctly describes a trend found in the halogen group?

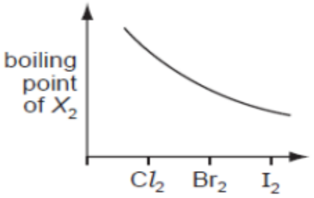
A



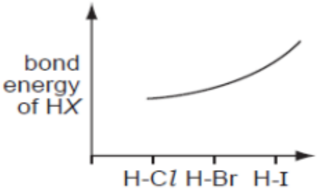
B



C



D



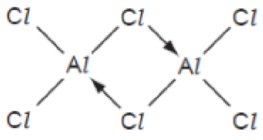
Q19 Limestone, $CaCO_3$, has been used as a building material for thousands of years, and was used on the Pyramids in Egypt. In the past hundred years many limestone buildings have begun to suffer damage.
What is the cause of this damage?
A hydrocarbon emissions from motor vehicles
B increased temperature due to global warming
C increased ultraviolet radiation as the ozone layer is destroyed
D sulphur dioxide from fossil fuels forming ‘acid rain’

Q21 In which pair is the radius of the second atom greater than that of the first atom?
A Na, Mg B Sr, Ca C P, N D Cl, Br

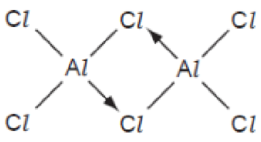
Q22 The oxide and chloride of an element X are separately mixed with water. The two resulting solutions have the same effect on litmus.
What is element X?
A sodium
B magnesium
C aluminium
D phosphorus

Q23 Aluminium chloride sublimes at 178 °C.
Which structure best represents the species in the vapour at this temperature?

A



B



C $Al^{\bullet} + 3Cl^{\bullet}$

D $Al^{3+}(Cl^{-})_3$

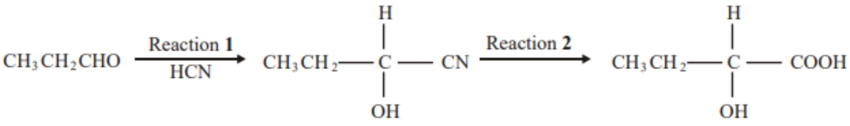
Q24 Use of the Data Booklet is relevant to this question.
What mass of solid residue can be obtained from the thermal decomposition of 4.10 g of anhydrous calcium nitrate?
A 0.70 g B 1.00 g C 1.40 g D 2.25 g

Q25 What happens when chlorine is bubbled through aqueous potassium iodide?
A Chlorine is oxidised to chloride ions.
B Hydrochloric acid is formed.
C Iodide ions are oxidised to iodine.
D Potassium iodide is reduced to iodine.

Q26 The emissions from a power station contain about 14 tonnes of SO_2 per hour from the oxidation of FeS_2 contained in the coal.
What is the most practical way of preventing the SO_2 from being released into the atmosphere?
A Cool the gases and the SO_2 will liquefy and can be removed.
B Dissolve the ionic FeS_2 in hexane.
C Pass the emissions through a bed of calcium oxide.
D Pass the gases through concentrated sulphuric acid to dissolve the SO_2.

Q27 he gaseous oxides of nitrogen have positive enthalpy changes of formation.
Which factor is likely to make the most significant contribution to these enthalpy changes?
A the high bond energy of the nitrogen molecule, N_2
B the high electron affinity of nitrogen atoms
C the high electron affinity of oxygen atoms
D the similarity of the electronegativities of oxygen and nitrogen

1. Consider the sequence of reactions below.



$$CH_3CH_2CHO \xrightarrow[\text{HCN}]{\text{Reaction } \mathbf{1}} CH_3CH_2-\overset{H}{\underset{OH}{C}}-CN \xrightarrow{\text{Reaction } \mathbf{2}} CH_3CH_2-\overset{H}{\underset{OH}{C}}-COOH$$

P **Q** **R**

(a) Name and outline a mechanism for Reaction **1**.

Name of mechanism ....

Mechanism

(5)

(b) (i) Name compound **Q**

....

(ii) The molecular formula of **Q** is C_4H_7NO. Draw the structure of the isomer of **Q** which shows geometrical isomerism and is formed by the reaction of ammonia with an acyl chloride.

(3)

(c) Draw the structure of the main organic product formed in each case when **R** reacts separately with the following substances:

(i) methanol in the presence of a few drops of concentrated sulphuric acid;

(ii) acidified potassium dichromate(VI);

(iii) concentrated sulphuric acid in an elimination reaction.

(3)
(Total 11 marks)

2. Alcohol **X** has the structure $(CH_3)_2C(OH)CH(CH_3)_2$

(a) (i) Name alcohol **X.**

....

(ii) Name and outline the mechanism for the reaction occurring when alcohol **X** is converted into 2,3-dimethylbut-2-ene in the presence of a strong acid.

Name of mechanism..

Mechanism

(iii) Give the structure of, and name an isomer of 2,3-dimethylbut-2-ene which is also formed in the reaction. Explain why two products are obtained.

Structure

Name of isomer..

Explanation ....

....

....

(10)

(b) (i) Write an equation for the reaction between alcohol **X** and ethanoyl chloride. Name and outline a mechanism for this reaction, using ROH to represent the alcohol in the mechanism.

Equation

Name of mechanism..

Mechanism

(ii) Give an alternative method for obtaining the organic reaction product in part (b) (i), starting from alcohol **X**, other than using ethanoic anhydride.

State the type of reaction, the reagent(s) used and the reaction conditions.

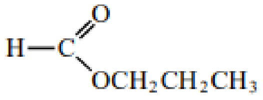
Type of reaction. ....

Reagent(s)...

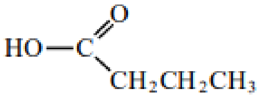
Conditions...

(9)
(Total 19 marks)

3. (a) Consider the following pair of isomers.



C



D

(i) Name compound **C**.

....

(ii) Identify a reagent which could be used in a test-tube reaction to distinguish between **C** and **D**. In each case, state what you would observe.

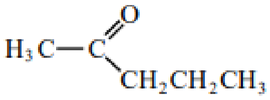
Reagent ....

Observation with ***C*** ....

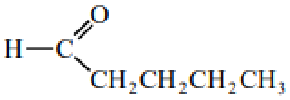
Observation with ***D***...

(4)

(b) Consider the following pair of isomers.



E



F

(i) Name compound **E**.

....

(ii) Identify a reagent which could be used in a test-tube reaction to distinguish between **E** and **F**. In each case, state what you would observe.

Reagent ....

Observation with ***E*** ....

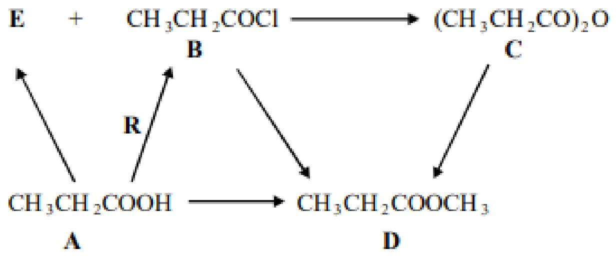
Observation with ***F***...

(4)

(c) Draw the structure of the chain isomer of **F** which shows optical isomerism.

(1)
(Total 9 marks)

4. This question is about compounds **A, B, C, D** and **E** and their interconversions. Some of these are shown in the diagram below.



(a) (i) Give the names of compounds **B** and **C.**

Name of compound **B** ....

Name of compound **C** ....

(2)

(ii) Describe one observation that would be made when compound **B** reacts with water.

....

....

(1)

(iii) Draw the graphical formula of the organic product formed when compound **B** reacts with ammonia.

(1)

(iv) When compound **C** is heated in water, it is hydrolysed to a carboxylic acid. Write the equation for the reaction that occurs

....

(1)

(b) Compounds **A, B** and **C** will each react with the same alcohol to form compound **D.**

(i) Give the name of the alcohol and the name of compound **D.**

Name of alcohol ....

Name of compound **D** ....

(2)

(ii) State the appropriate reaction conditions for the formation of compound **D** from each of the compounds **A, B** and **C.**

Condition(s) for **A** ....

Condition(s)for **B** ....

Condition(s) for **C** ....

(4)
(Total 11 marks)

5. (a) (i) Write an equation for the reaction of butan-2-ol with ethanoic acid, showing clearly the structure of the organic product.

(ii) Name the type of organic compound formed in part (a)(i) and suggest a use for this compound.

Type of compound..

Use...

(iii) Give a homogeneous catalyst for the reaction in part (a)(i) and state the meaning of the term *homogeneous.*

Catalyst...

Meaning of homogeneous..

....

(6)

(b) Write an equation for the complete combustion of butan-2-ol in an excess of oxygen.

....

(1)

(c) But-1-ene and other products can be made by the dehydration of butan-2-ol.

(i) Outline a mechanism for the dehydration of butan-2-ol into but-l-ene.

(ii) Explain why but-1-ene does not show geometrical isomerism.

....

....

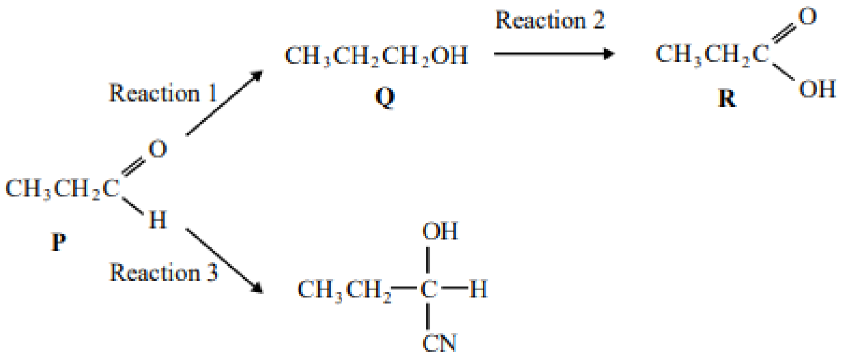
(iii) An alternative dehydration of butan-2-ol produces geometrical isomers.
Draw the structure of one of these geometrical isomers and give its full name.

Structure of geometrical isomer

Name...

(7)
(Total 14 marks)

6. Consider the following reaction scheme.



(a) Give the reagent(s) for Reaction 1 and name the type of reaction involved.

Reagent(s)..

Type of reaction..

(2)

(b) (i) Give the reagent(s) and conditions for Reaction 2.

Reagent(s)..

Conditions..

(ii) Write an equation for this reaction using the symbol [O] to represent the oxidising agent.

(4)

(c) Give the reagent(s) and name the mechanism involved in Reaction 3.

Reagent(s)..

Name of mechanism..

(2)

(d) Reaction 3 produces a mixture of two stereoisomers.

(i) What is the relationship between these two isomers?

....

....

(ii) How can separate samples of these isomers be distinguished?

....

....

(3)

(e) (i) Draw the structure and state the name of the organic product formed when **Q** reacts with **R.**

Structure

Name ....

(ii) Draw the structure of an isomer of **R** which forms ethanol on hydrolysis.

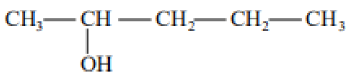
(3)

(f) Write an equation for the complete combustion of **P.**

....

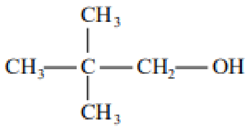
(2)
(Total 16 marks)

7. (a) The structures of two alcohols of formula $C_5H_{11}OH$ are shown below.



$CH_3-\underset{\underset{OH}{|}}{CH}-CH_2-CH_2-CH_3$

pentan–2–ol



$CH_3-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-CH_2-OH$

2.2–dimethylopropan–1–ol

(i) A third alcohol of formula $C_5H_{11}OH$ is tertiary. Draw the graphical formula and give the name of this alcohol.

Graphical formula

Name..

(2)

(ii) Draw the graphical formulae of **two** alkenes formed when pentan-2-ol is heated with concentrated sulphuric acid.

(2)

(2)

(iii) State the type of reaction taking place in (a)(ii).

....

(1)

(iv) Explain why the type of reaction taking place in (a)(ii) does not occur when 2,2-dimethylpropan-1-ol is heated with concentrated sulphuric acid.

....

....

(1)

(b) Compound **X** is converted into compound **Y** by the reactions outlined below.

$$\underset{\mathbf{X}}{CH_3CN} \xrightarrow{\text{Step 1}} CH_3COOH \xrightarrow{\text{Step 2}} CH_3COCl \xrightarrow{\text{Step 3}} \underset{\mathbf{Y}}{CH_3CONHCH_3}$$

(i) Give the name of compound **X.**

....

(1)

(ii) State the type of reaction taking place in Step 1.

....

(1)

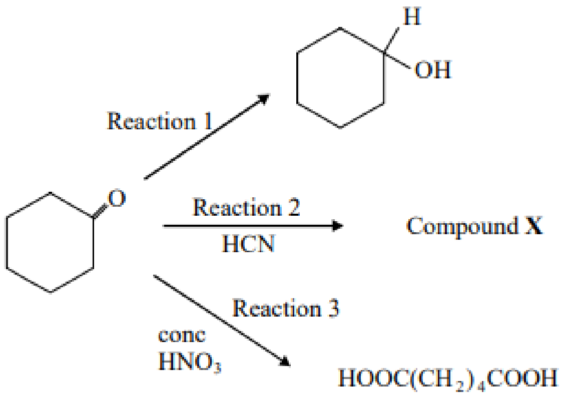
(iii) Write an equation for the reaction taking place in Step 3.

....

(2)

(Total 10 marks)

8. Consider the following three reactions of cyclohexanone, $C_6H_{10}O$.



(a) Give a suitable reagent for Reaction 1.

....

(1)

(b) Name the type of reaction and outline a mechanism for Reaction 2.

Type of reaction ....

Mechanism

(5)

(c) (i) Name the organic product of Reaction 3.

....

(ii) Calculate the maximum mass of this organic product that could be formed if 2.40 g of cyclohexanone were allowed to react in Reaction 3.

....

....

....

....

(4)

(Total 10 marks)