WJEC Chemistry AS-level

1.1: Formulae and Equations

Practice Questions

England Specification

1. *(a)* A solution of calcium chloride was obtained by adding 0.40 g of calcium metal to 80 cm^3 of hydrochloric acid of concentration 0.20 mol dm^{-3}. The equation for the reaction is

$$Ca + 2HCl \longrightarrow CaCl_2 + H_2$$

(i) Use the information given to show that an excess of calcium metal was used.

[3]

(ii) State **one** observation made during the reaction apart from the mixture becoming warm.

_____ [1]

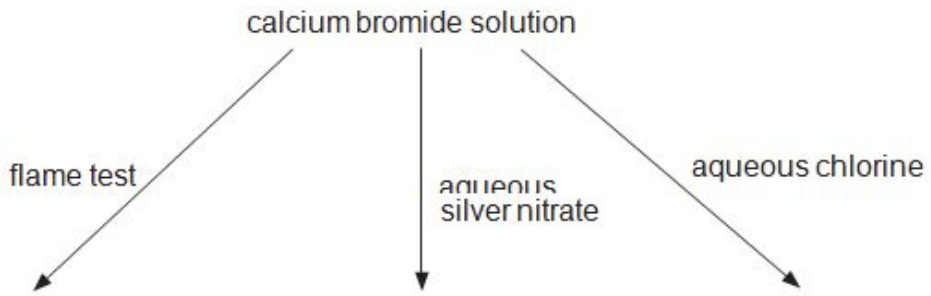
(b) A sample of a calcium compound **E** of mass 1.50 g was added to 200 cm^3 of cold water and the mixture heated until it all dissolved.

Use relevant information from the table to calculate the mass of compound **E** that crystallised when the solution was cooled to 0 °C. [2]

Solubility of compound **E** /g per 100 g of water	Temperature / °C
0.13	0
0.75	50
1.22	100

Mass that crystallised = ... g

(c) A student was given a solution of calcium bromide and asked to carry out the reactions shown in the diagram below.



(i) State the colour given in the flame test.

[1]

(ii) State what was seen when aqueous silver nitrate was added.

[1]]

(iii) Give the **ionic** equation for the reaction occurring in (ii).

[1]

(iv) State what was seen when aqueous chlorine was added to the solution of calcium bromide.

[1]

(v)Explain why chlorine reacted as described in (iv). Your answer should include:

- the type of bonding and the species present in calcium bromide
- why chlorine is able to react in this way
- the type of reaction occurring
- an appropriate equation

[5] QWC [1]

(Total 16 marks)

2. (a) This is a brief method written by a student to enable others to prepare ethyl ethanoate by esterification.

• Heat under reflux together 0.45 mol of ethanoic acid with an equimolar quantity of ethanol

• Add 5 cm3 of sulfuric acid

• Distil off everything boiling up to 82 °C

• Add the distillate to aqueous sodium hydrogencarbonate in a separating funnel

• Run off the ethyl ethanoate layer and dry it over anhydrous calcium chloride

• Distil off the dried ethyl ethanoate and collect the fraction boiling at 75-78 °C

(i) Give the equation for this reaction.

[1]

(ii) Calculate the mass of ethanoic acid needed for this experiment.

[1]

(iii) State an important detail that is missing from the first bullet point.

[1]

(iv) State why the sulfuric acid should have been added at the refluxing stage.

[1]

(v) State why sodium hydrogencarbonate needed to be added to the distillate.

[1]

(Total 20)

3. (a) Chlorine reacts with aqueous sodium hydroxide in one of two ways, depending on the temperature used.
(i)Write the equation for the reaction of chlorine with:

I. cold aqueous sodium hydroxide,

[1]

II. hot aqueous sodium hydroxide.

[1]

(ii) Classify this type of redox reaction.

[1]

(b) Chlorine reacts with many elements to form chlorides. Explain why phosphorus forms two chlorides, PCl_3 and PCl_5, but nitrogen only forms NCl_3. [2]

(c) Most ionic chlorides, e.g. sodium chloride, are soluble in water. However some, e.g. silver chloride, are insoluble.

The enthalpy change of solution of an ionic compound and its solubility depend on the balance between two enthalpy changes. Name these enthalpy changes and state if they are endothermic or exothermic. Explain how the enthalpy change of solution of a compound and its solubility depend on the balance between them. [4] QWC [1]

(d) Some standard electrode potentials, $E^{\ominus}$, are given below.

System	$E^{\ominus}$/V
$\frac{1}{2}I_2(s) + e^- \rightleftharpoons I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$\frac{1}{2}Br_2(l) + e^- \rightleftharpoons Br^-(aq)$	+1.09
$\frac{1}{2}Cl_2(g) + e^- \rightleftharpoons Cl^-(aq)$	+1.36
$Ce^{4+}(aq) + e^- \rightleftharpoons Ce^{3+}(aq)$	+1.45

(i) Using the information from the table, state which of the **halides** will reduce Fe^{3+} to Fe^{2+}. Give a reason for your answer. [2]

(ii) Write the cell diagram of the cell formed by combining the $Fe^{3+}(aq)$, $Fe^{2+}(aq)$ and $Ce^{4+}(aq)$, $Ce^{3+}(aq)$ half cells and calculate the standard e.m.f. of this cell. [2]

(e) A flask containing an initial mixture of 0.100 mol of ethanoic acid and 0.083 mol of methanol was kept at 25 °C until the following equilibrium had been established.

$$CH_3COOH + CH_3OH \rightleftharpoons CH_3COOCH_3 + H_2O \qquad \Delta H = -3\,kJ\ mol^{-1}$$

The ethanoic acid present at equilibrium required 32.0 cm^3 of a 1.25 mol dm^{-3} solution of sodium hydroxide for complete reaction.

(i) Write an expression for the equilibrium constant, K_c, giving the units, if any. [2]

(ii) Calculate the number of moles of ethanoic acid present at equilibrium. [1]

(iii) Calculate the value of the equilibrium constant, K_c, for this reaction. [2]

(iv) State, giving a reason, what happens to the value of the equilibrium constant, K_c, if the temperature is increased. [1]

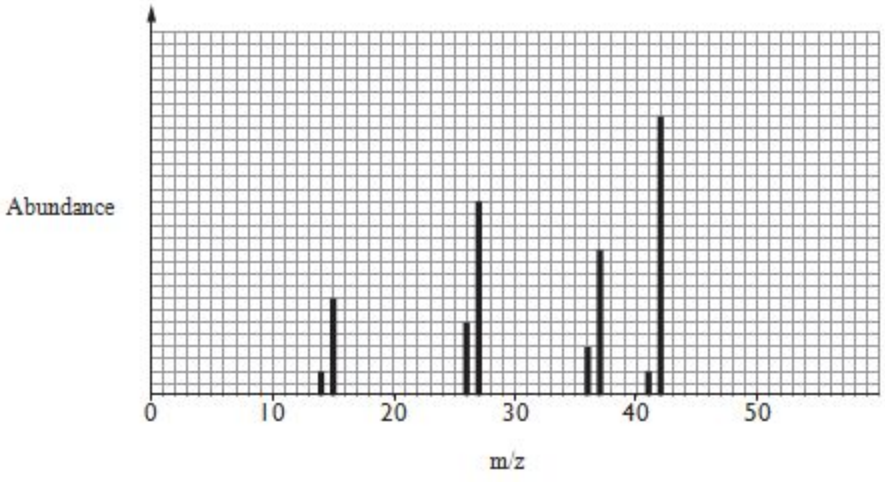
Total [20]

4. (a) Compound **X** is a straight-chain hydrocarbon that consists of 85.7 % carbon by mass.

(i) Find the **empirical** formula of compound **X**

[3]

(ii) Some peaks from the mass spectrum of **X** are shown below.



Use the empirical formula and the mass spectrum to find the molecular formula of **X**. Show your workings

[2]

(iii) Suggest what information the presence of the peak at m/z 15 gives about the structure of **X**.

[1]

(Total 6)

The Chemistry of Boron

Boron is an element at the top of Group 3. It forms a range of compounds whose behaviour is very different from the other elements in the same group. Boron shows the properties of a non-metal, however the remaining elements, including aluminium, gallium, indium and thallium all show metallic properties. This change is similar to that seen in other groups in the p-block with Group 4 having the non-metal carbon at the top and the metal lead at the bottom. In its compounds, boron exhibits the +3 oxidation state exclusively, forming materials such as BCl_3, BF_3 and B_2O_3. No compounds with a +1 oxidation state are known. Aluminium also exists only as the +3 oxidation state, however the +1 oxidation state becomes more common as the group is descended.

Boranes

There are very many compounds formed between boron and hydrogen and these are called boranes. These boranes are grouped into series and two examples of these are:

- *Nido*-boranes with a general formula of B_nH_{n+4}. This series includes pentaborane(9), B_5H_9, and decaborane(14), $B_{10}H_{14}$.
- *Arachno*-boranes with a general formula of B_nH_{n+6}. The first member of this series is tetraborane(10), B_4H_{10}.

All of these boranes are electron deficient, which leads them to be very reactive. The majority react explosively on contact with air, which led to their proposed use as a rocket fuel. To destroy the stockpile of B_5H_9 when it was no longer needed, the US government treated it with steam to form a solution of boric acid (H_3BO_3) and hydrogen gas.

Boron nitride

Boron nitride has a giant covalent structure that has the same number of electrons as graphite and diamond. They are said to be isoelectronic. Boron nitride exists in two forms:

- Hexagonal boron nitride has a structure similar to graphite, and is sometimes called 'white graphite' because of its excellent lubricating properties. Unlike graphite, hexagonal boron nitride is an insulator and has applications which depend upon this property.
- Cubic boron nitride has a diamond structure, and is the second hardest natural material known. It has high thermal conductivity and is chemically inert.

Uses of boron compounds

Nearly all boron ore extracted from the Earth is destined for refinement into boric acid and sodium tetraborate. Most boric acid is used in the production of shock-resistant glass, whilst sodium tetraborate is used as an additive to detergents. Boron is also used in nuclear reactors, where boron shielding is used as a control, taking advantage of its high cross-section for neutron capture.

5. (a) Explain why boron forms compounds with the +3 oxidation state alone, but thallium compounds are more stable with the +1 oxidation state *(lines 6-9)*. [2]

(b) Boranes are compounds made up of boron and hydrogen only *(lines 11-16)*. A sample of a gaseous borane was found to contain 78.14 % boron and 21.86 % hydrogen by mass. A sample of this borane of mass 1.232 g occupied a volume of 1 dm3 at 273 K and 1 atm pressure.

[The molar volume of a gas at 273 K and 1 atm pressure is 22.4 dm^3.]

(i) What is the empirical formula of this borane?

[2]

Empirical formula .....

(ii) What is the molecular formula of this borane?

[3]

Molecular formula .....

(c) Explain the term *electron deficient (line 17)*.

[1]

(d) Balance the equation for the reaction of pentaborane(9), B_5H_9, with steam *(lines 18-20)*. [1]

..... B_5H_9 + ... H_2O ⟶ ..... H_3BO_3 + ... H_2

(e) The standard enthalpy change of formation of pentaborane(9) is +42.8 kJ mol^{-1}. State what information this value gives about the stability of this compound. [1]

(f) Hexagonal boron nitride and graphite have similar structures *(lines 24-26)*. Describe the differences between these two isoelectronic materials in terms of their bonding and structure.

[3] QWC [1]

(g) Boron-10 absorbs a neutron *(line 33)* to form an intermediate, which then decays by emission of an alpha particle.

Give the mass number and atomic number of the final product.

[1]

Mass number.....

Atomic number.....

(Total 15)

6.

Read the passage below and then answer the questions in the spaces provided.

Some chemistry of the alkynes

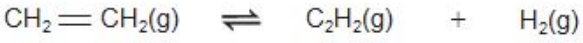
The alkynes are a homologous series of hydrocarbons, which have the general formula C_nH_{2n-2}.

The simplest member of the series is ethyne (acetylene). All alkynes contain a carbon to carbon triple bond (C≡C).

ethyne

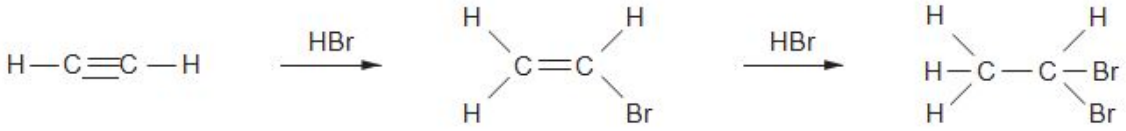
Until 50 years ago ethyne was the main starting material for the preparation of aliphatic compounds. It was made by the reaction of calcium carbide with water.

Since then the main source of organic compounds has been crude oil (petroleum).
A modern method for producing a good yield of ethyne is by heating ethene above 1150 °C.

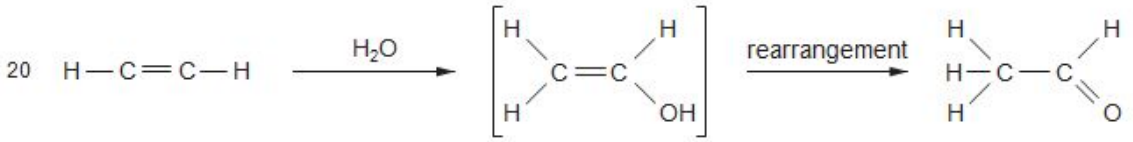


One laboratory method for making ethyne is by reacting 1,2-dibromoethane with an excess of alcoholic potassium hydroxide solution. Potassium bromide and water are the other products of this reaction.

Alkynes are unsaturated compounds and react similarly to alkenes when treated with a hydrogen halide.

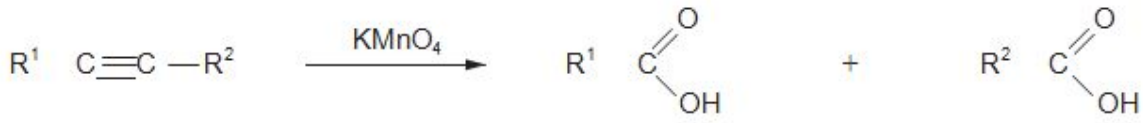


When ethyne is passed into aqueous sulfuric acid, containing mercury(II) ions as a catalyst, ethanal is produced.

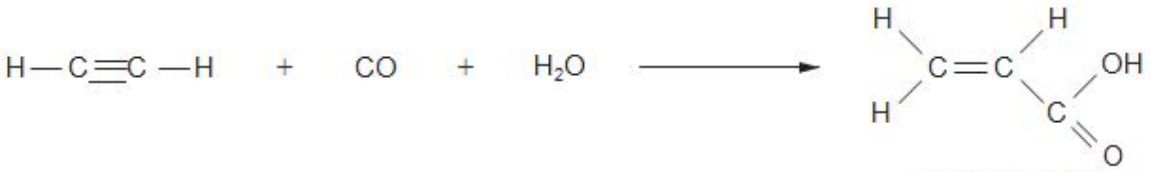


ethenol

The oxidation of ethyne to carbon dioxide and water is the chemical basis of oxy-acetylene welding. If an alkyne is less strongly oxidised by using potassium manganate(VII) solution under suitable conditions the C ≡C bond is broken to give carboxylic acids.



25 Complete carbon to carbon bond fission of the alkyne does not occur if the alkyne is reacted with carbon monoxide and water in the presence of a catalyst.



- End of passage -

(a) Write the **displayed** formula of pent-2-yne.

[1]

(b) Chemical suppliers used to sell calcium carbide in tins containing 500 g. Calculate the volume of ethyne that will be obtained at room temperature and pressure from 500 g of calcium carbide (M_r 64.1) *(line 8)*.

[1 mol of ethyne has a volume of 24.0 dm^3 at room temperature and pressure] [2]

Volume = ... dm^3

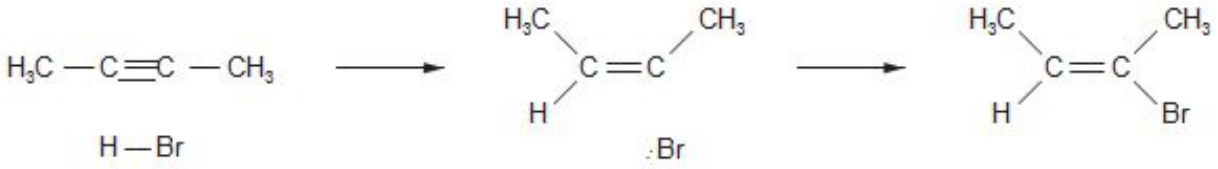
(c)The article describes the preparation of ethyne from ethene *(lines 10-11)*.State how the information given indicates that this is an endothermic process.

[1]

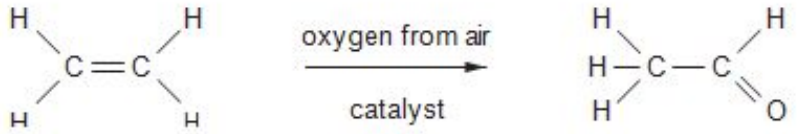
(d) Give the equation for the preparation of ethyne from 1,2-dibromoethane and potassium hydroxide solution *(lines 12-13)*

[1]

(e) Alkynes react with hydrogen bromide by electrophilic addition to give brominated alkenes. By analogy with the reaction of propene with hydrogen bromide, complete the mechanism of the reaction of but-2-yne with hydrogen bromide to give 2-bromobut-2-ene. [3]



(f) The article describes the preparation of ethanal from ethyne *(line 20)*. Another method uses ethene as the starting material.



Suggest **two** factors that should be considered when recommending which of these two processes should be used to produce ethanal. [2]

Factor 1 .....

.....

Factor 2 .....

.....

(g) Potassium manganate(VII) is used to break the —C≡C— triple bond to produce carboxylic acids. Give the displayed formula and hence the empirical formula of the alkyne that reacts in this way to give benzenecarboxylic acid and propanoic acid *(line 24)*. [2]

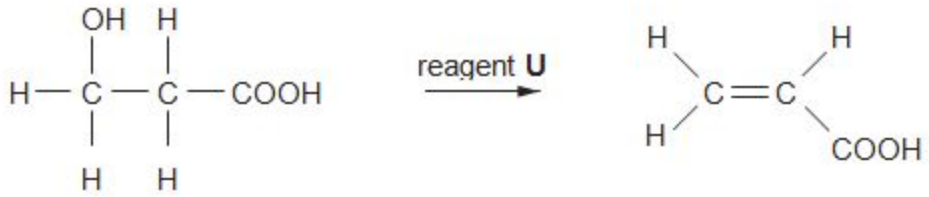
Displayed formula *Empirical formula* .....

(h)Ethyne reacts with carbon monoxide in the presence of water to produce propenoic acid *(line 27)*.

(i) Give the structure of the repeating unit obtained when propenoic acid is polymerised to give poly(propenoic acid).

[1]

(ii) A new method to obtain propenoic acid is by the fermentation of a suitable sugar. This method gives 3-hydroxypropanoic acid, which can then be converted to propenoic acid.



3-hydroxypropanoic acid

I. Suggest the name of reagent **U**. . . . . [1]

II. Use the data sheet to give a difference between the infrared spectrum of 3-hydroxypropanoic acid and propenoic acid

[1]

III. State why 3-hydroxypropanoic acid will **not** undergo the triiodomethane (iodoform) reaction.

[1]

(Total 16)

7. (a) Petroleum is one of the most important resources in the world. It is estimated that we consume about 88 million barrels each day. Describe the general chemical composition of petroleum.

[1]

(b) Butane is a useful fuel obtained from petroleum. Write an equation for the complete combustion of butane.

[1]

(c) Another fuel is methane. Give the H—$\hat{C}$—H bond angle in a methane molecule. [1]

(d) Explain why the H—$\hat{O}$—H bond angle in water is less than the H—$\hat{C}$—H bond angle in methane. [3]

QWC [1]

(e) Covalent compounds like methane and butane are gases at room temperature, however metals are generally solids with high melting temperatures.

(i) State, giving a reason, whether you would expect butane to have a higher or lower boiling temperature than methane.

[1]

(ii) Describe briefly the nature of metallic bonding and use this to explain why metals are malleable (can be hammered into shape) and conduct electricity.

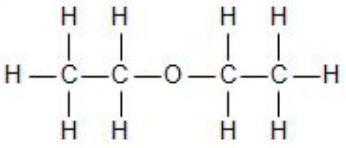
[4] QWC [1]

(Total 13)

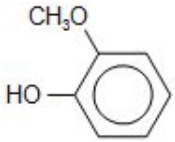
8.

The chemistry of some compounds containing the ether (R–O–R) linkage

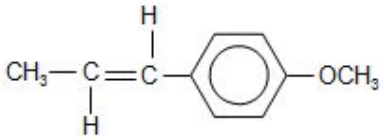
Organic compounds containing the R–O–R linkage, where R is alkyl or aryl are very common. This is due in part to the stability of the C–O bond. Some examples are shown below.



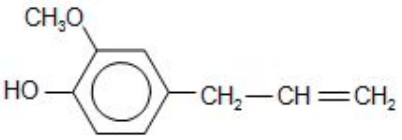
ethoxyethane



guaiacol

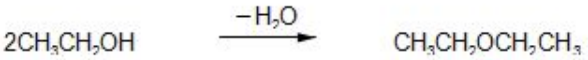


anethole



eugenol

Ethoxyethane (diethyl ether) is one of the most familiar compounds containing the ether linkage. It can be made by heating ethanol with an excess of concentrated sulfuric acid, which acts as a dehydrating agent.



Another method is by reacting bromoethane with sodium ethoxide (a source of the ethoxide ion).

ethoxide ion

Ethoxyethane has a boiling temperature of 35 °C whereas ethanol, a smaller molecule, boils at 78 °C. The solubility of these two compounds in water also varies. Ethanol is completely miscible with water but ethoxyethane has a much reduced solubility.

The strong C–O bond means that compounds such as ethoxyethane and methoxybenzene have relatively few reactions. However, carbon–oxygen bond fission occurs when they are heated with concentrated hydrobromic (HBr) or hydriodic acid (HI).

methoxybenzene

20 Naturally occurring compounds that contain the ether linkage often owe their reactions to other functional groups present in the molecule. Both eugenol (found in cloves) and guaiacol (from wood) have medicinal uses. Anethole (occurring in aniseed) has a promising use as an insecticide and is also effective against some bacteria and fungi.

- End of passage -

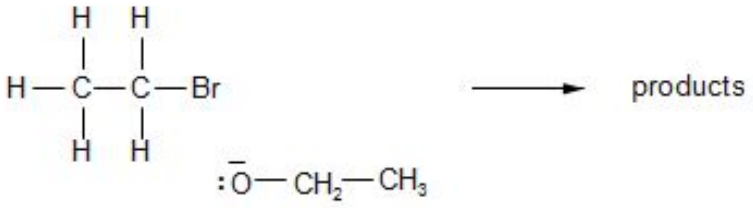
(a) (i) Bethan prepared some ethoxyethane *(line 6)* by reacting ethanol with concentrated sulfuric acid. She used 69 g of ethanol ($M_r = 46$) and obtained a 45 % yield of ethoxyethane ($M_r = 74$). Calculate the mass of ethoxyethane obtained. [3]

Mass = ... g

(ii) One of the reasons for only obtaining a 45 % yield of ethoxyethane was that sulfuric acid reacted with ethanol in a different reaction. State the organic product of this side reaction

_____ [1]

(iii) Bethan would have obtained a higher percentage yield of ethoxyethane if she had reacted bromoethane with sodium ethoxide *(line 10)*. This reaction is an example of nucleophilic substitution. Complete the mechanism below by inserting curly arrows and appropriate partial charges (δ+, δ-). [2]



(iv) Ethoxyethane has a much lower boiling temperature than ethanol because its molecules are unable to hydrogen bond with each other. State the feature of a molecule that needs to be present for hydrogen bonding to occur.

[1]

(b) Guaiacol *(line 4)* reacts with (aqueous) bromine.

(i) By analogy with the reaction of phenol with (aqueous) bromine, suggest a displayed formula for the organic product of the reaction between guaiacol and (aqueous) bromine.

[1]

(ii) Describe what is seen during this reaction.

[1]

(c) The article shows the formulae of anethole and eugenol *(line 5)*. State a reagent that will react with eugenol but not with anethole, giving the observation.

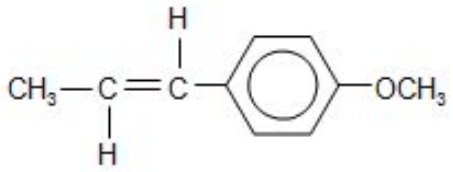
[2]

Reagent . . . . . .

Observation. . . . . .

(d) (i) State the molecular formula of anethole *(line 5)*. [1]

(ii) The article describes C–O bond fission of an ether linkage by hydrobromic acid *(lines 17-18)*. Suggest a displayed formula for the aromatic compound formed when **anethole** reacts with hydrobromic acid. [1]

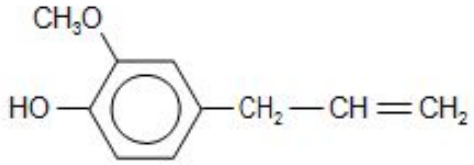


anethole

displayed formula of product

(e) An isomer of eugenol *(line 5)*, compound **Y**, reacts with sodium carbonate giving carbon dioxide. Suggest a displayed formula for compound **Y** and state the name of the functional group present in the organic compound that produces carbon dioxide in this reaction.

[2]



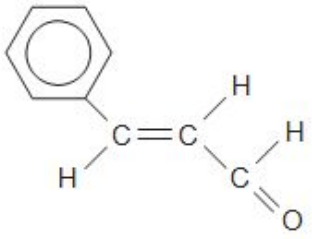
eugenol

displayed formula for compound **Y**

Functional group .....

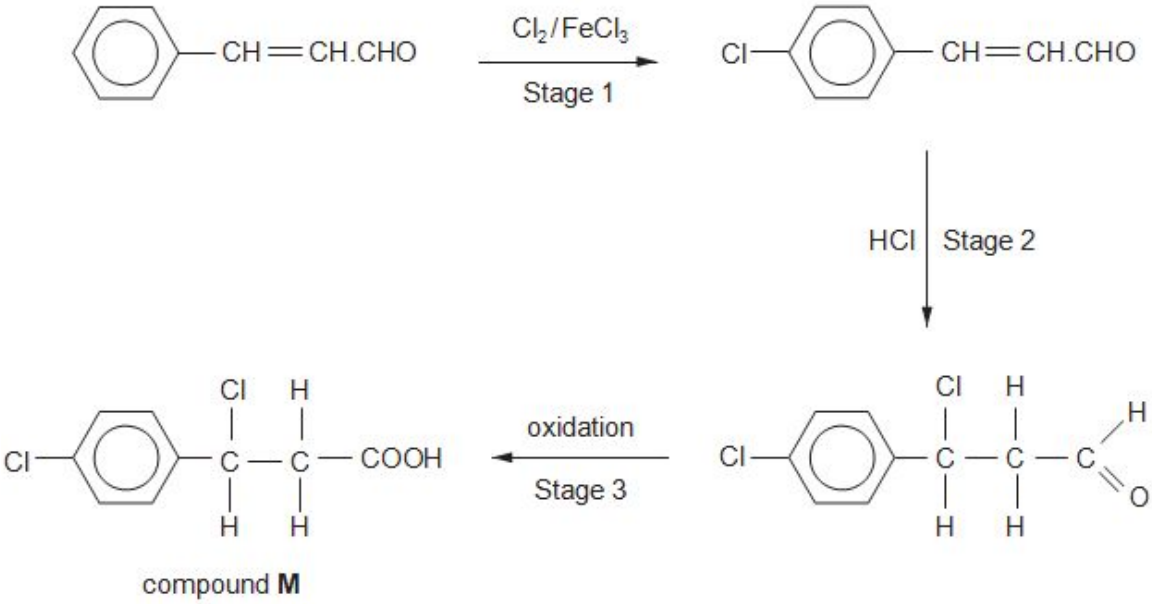
Total [15]

(a) Cinnamaldehyde (3-phenylprop-2-enal) is a pale yellow liquid that occurs in the oil obtained from the bark of cinnamon trees.



cinnamaldehyde

An organic chemist suggested the following method for producing compound **M** from cinnamaldehyde.



compound **M**

9. (a)(i) Suggest **two** reasons why the reaction of cinnamaldehyde with chlorine is **unlikely** to give only the compound shown and give the displayed formula of another possible product.

[3]

(ii) Give the displayed formula of another product that may be formed when hydrogen chloride is added across the double bond in the second stage, explaining why this can occur.

[2]

(iii) State the name of a suitable oxidising agent for stage 3.

[1]

(iv) Explain why compound **M**, made in this way from cinnamaldehyde, has no effect on the plane of polarised light.

[2] QWC [1]

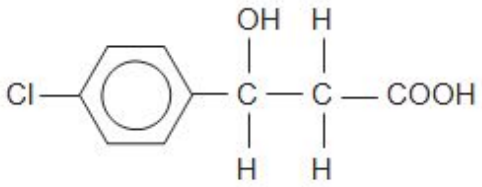
(v) Bethan attempted to reverse stage 3 by using a reducing agent. Suggest a suitable reducing agent that she should use and give the displayed formula of a different product that could be an impurity in her product.

[2]

(b) You are given a pure sample of compound **M** and asked to carry out some reactions with it.

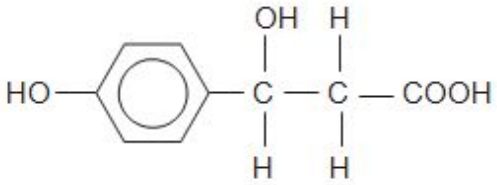
(i) A sample is added to aqueous sodium hydrogencarbonate. State what is seen during this reaction and name the functional group that has been confirmed. [2]

(ii) Compound **M** is heated under reflux with aqueous sodium hydroxide, followed by acidification. The organic product of this reaction is compound **N**.



compound **N**

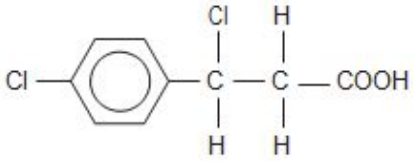
Explain why compound **N** is formed in preference to compound **P**.



compound **P**

[2]

(c) Compound **R** is an isomer of compound **M** (whose formula is shown below).

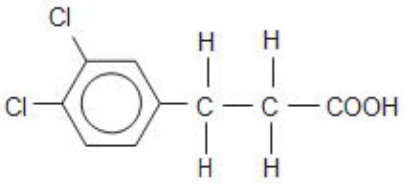


compound **M**

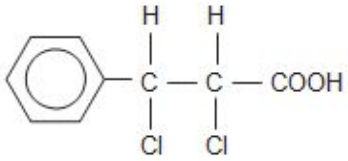
Tests on compound **R** show that it:

- does not contain a chiral centre;
- has an aromatic-containing fragment at m/z 77 in its mass spectrum;
- is not quickly hydrolysed by the addition of water.

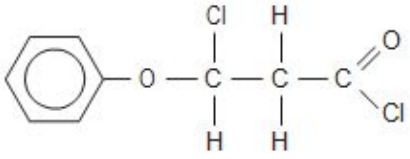
Three compounds that do **not** fit this information are shown below.



compound **1**



compound **2**



compound **3**

Discuss why **each** of these structures is **not** the formula for compound **R**, giving **one** reason for **each** compound. Give the displayed formula of a compound of your choice that **does fit** the information given for compound **R**. [4]

QWC [1]

Total [20]

10. (a) Petroleum (crude oil) is separated into useful parts by fractional distillation.

(i) Briefly describe how *fractional distillation* can be carried out.

[2]

(ii) A fraction is treated further to give a **branched-chain** alkane. The mass spectrum of this alkane shows a molecular ion, M^+, at m/z 72.

Use this information to give the molecular formula and then suggest a displayed formula for this alkane. [2]

(b)Cracking is a process that is used in the petroleum industry to obtain smaller alkanes and alkenes from larger alkanes.

(i) State why this process of making smaller molecules is carried out.

[1]

(ii) Methane is one of the products when nonane, C_9H_{20}, is cracked. The other products are butane and butadiene, C_4H_6.
Give an equation that represents this reaction. [1]

(c) Methane reacts with chlorine in a substitution reaction.

(i) The first stage of the reaction is as follows.

$$Cl_2 \longrightarrow 2Cl\bullet$$

State an essential condition for this stage. [1]

(ii) State what is meant by the term *propagation stage*. [1]

(iii) Write an equation that represents a propagation stage of this reaction. [1]

(Total 9)