SL Paper 2

This question is about ethene, C_2H_4, and ethyne, C_2H_2.

a.i. Ethyne, like ethene, undergoes hydrogenation to form ethane. State the conditions required. [2]

a.ii. Outline the formation of polyethene from ethene by drawing three repeating units of the polymer. [1]

b.i. Under certain conditions, ethyne can be converted to benzene. [2]

Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the reaction stated, using section 11 of the data booklet.

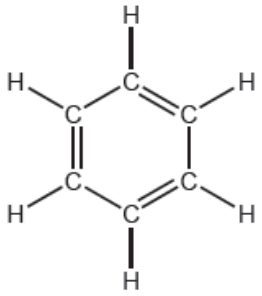
$$3C_2H_2(g) \rightarrow C_6H_6(g)$$

b.ii. Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the following similar reaction, using ΔH_f values in section 12 of the data booklet. [2]

$$3C_2H_2(g) \rightarrow C_6H_6(l)$$

b.iii. Explain, giving two reasons, the difference in the values for (b)(i) and (ii). If you did not obtain answers, use −475 kJ for (i) and −600 kJ for (ii). [2]

c. One possible Lewis structure for benzene is shown. [1]



State one piece of physical evidence that this structure is **incorrect**.

d. State the characteristic reaction mechanism of benzene. [1]

Halogenoalkanes can undergo substitution reactions with potassium hydroxide solution.

a.i. State an equation for the reaction of C_4H_9Cl with KOH. [1]

b.i. Draw four structural isomers of molecular formula $C_4H_{10}O$ which contain the –OH group. [4]

b.ii. On reaction with acidified potassium dichromate(VII), two of the isomers are oxidised in two steps to produce different products. Draw the structural formula of the **two** products formed from one of the isomers. [2]

b.iii. A third isomer is oxidized in one step. Draw the structural formula of the organic product formed. [1]

b.iv. State the colour change that takes place in these oxidation reactions. [1]

b.v. Identify the isomer which resists oxidation by acidified potassium dichromate(VI). [1]

Alkenes are an economically and chemically important family of organic compounds.

a.i. The reaction of alkenes with bromine water provides a test for unsaturation in the laboratory. Describe the colour change when bromine water is added to chloroethene. [1]

a.ii. Deduce the Lewis structure of chloroethene and identify the formula of the repeating unit of the polymer poly(chloroethene). [2]

c. (i) Deduce the structural formulas of the **two** alcohol isomers of molecular formula C_3H_8O. Name each isomer and identify each as either a primary or a secondary alcohol. [8]

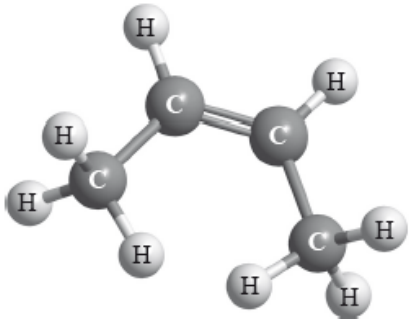
(ii) Oxidation of the alcohol isomers lead to the formation of different organic products. Determine the structures of the organic products formed from the oxidation of each alcohol isomer in (c) (i) above and list the conditions required to obtain the different products.

Alkenes, alcohols and esters are three families of organic compounds with many commercial uses.

Esters are often used in perfumes. Analysis of a compound containing the ester functional group only, gives a percentage composition by mass of C: 62.0% and H: 10.4%.

a.ii. State the meaning of the term *structural isomers*. [1]

a.iii. **X** is an isomer of C_4H_8 and has the structural formula shown below. [3]



Apply IUPAC rules to name this isomer. Deduce the structural formulas of **two** other isomers of C_4H_8.

a.iv. State the balanced chemical equation for the reaction of **X** with HBr to form **Y**. [1]

a.v. **Y** reacts with aqueous sodium hydroxide, NaOH(aq), to form an alcohol, **Z**. Identify whether **Z** is a primary, secondary or tertiary alcohol. [1]

a.vi. Explain **one** suitable mechanism for the reaction in (v) using curly arrows to represent the movement of electron pairs. [4]

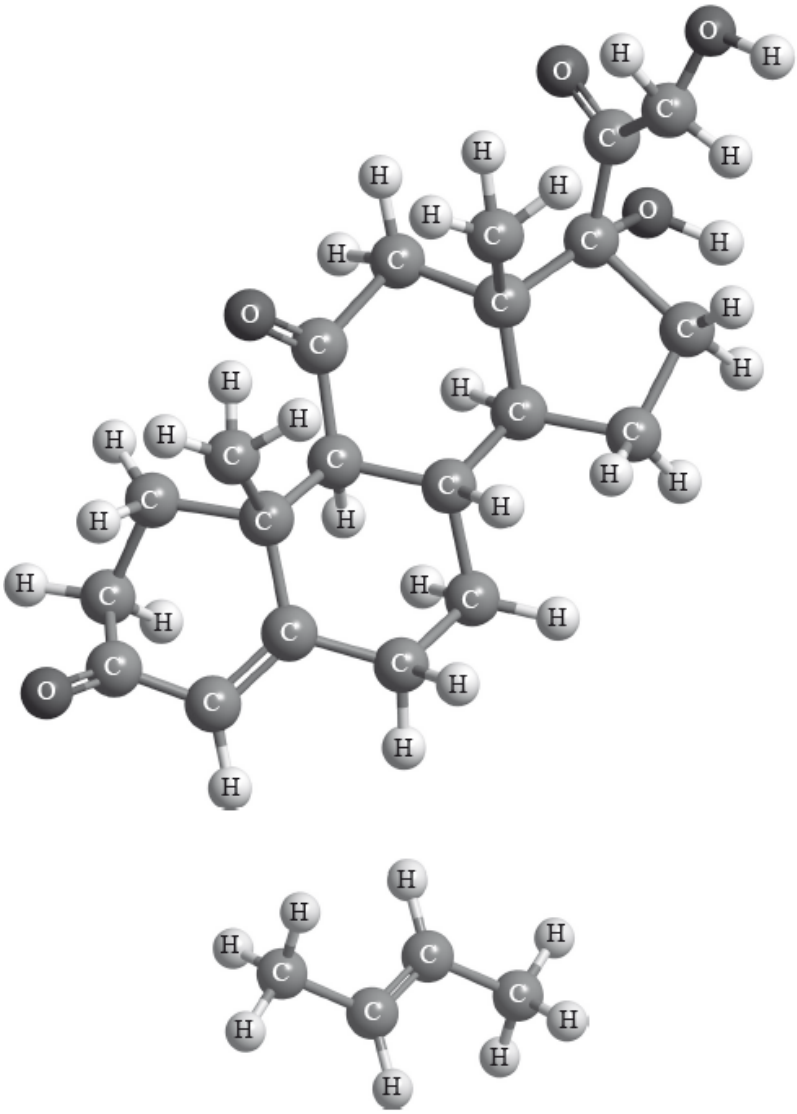
a.vii. Deduce the structural formula of the organic product formed when **Z** is oxidized by heating under reflux with acidified potassium dichromate(VI) **and** state the name of the functional group of this organic product. [2]

b.i. Draw the ester functional group. [1]

b.ii. Determine the empirical formula of the ester, showing your working. [4]

b.iii. The molar mass of the ester is $116.18\ \mathrm{g\,mol^{-1}}$. Determine its molecular formula. [1]

Cortisone is a therapeutic drug whose three-dimensional structure is represented below.



P

Menthol can be used in cough medicines. The compound contains 76.84% C, 12.92% H and 10.24% O by mass.

a.i. Identify the names of **two** functional groups present in cortisone. [2]

1.

2.

a.ii. Draw a circle around each of these **two** functional groups in the structure above and label them 1 and 2 as identified in (a) (i). [1]

b. Describe what is meant by the term *structural isomers*. [1]

c.i. Apply IUPAC rules to state the name of **P**. [1]

c.ii. **X** is a straight-chain structural isomer of **P**. Draw the structure of **X**. [1]

c.iii. [2]

$$CH_3CH{=}CHCH_3 \xrightarrow[(2)\ H_2O(l)]{(1)\ \text{concentrated } H_2SO_4(aq)} \mathbf{Q}$$

Q:

$$CH_3CH{=}CHCH_3 + H_2(g) \xrightarrow{\text{catalyst}} \mathbf{R}$$

R:

c.iv. Identify a suitable catalyst used in the reaction to form **R**. [1]

c.v. **P**, $CH_3CH{=}CHCH_3$, reacts with HBr to form $CH_3CHBrCH_2CH_3$. Suggest **one** suitable mechanism for the reaction of $CH_3CHBrCH_2CH_3$ with aqueous sodium hydroxide, using curly arrows to represent the movement of electron pairs. [4]

c.vi. State the structural formula of the organic product formed, **S**, when **Q** is heated under reflux with acidified potassium dichromate(VI). [1]

c.vii. Apply IUPAC rules to state the name of this product, **S**. [1]

c.viii. **P** can undergo a polymerization reaction. Draw **two** repeating units of the resulting polymer. [1]

d.i. Determine its empirical formula. [3]

d.ii. Determine its molecular formula given that its molar mass is $M = 156.30\ \text{g mol}^{-1}$. [1]

Benzene is an aromatic hydrocarbon.

a. Discuss the physical evidence for the structure of benzene. [2]

b. State the typical reactions that benzene and cyclohexene undergo with bromine. [1]

Benzene:

. . . . . .

Cyclohexene:

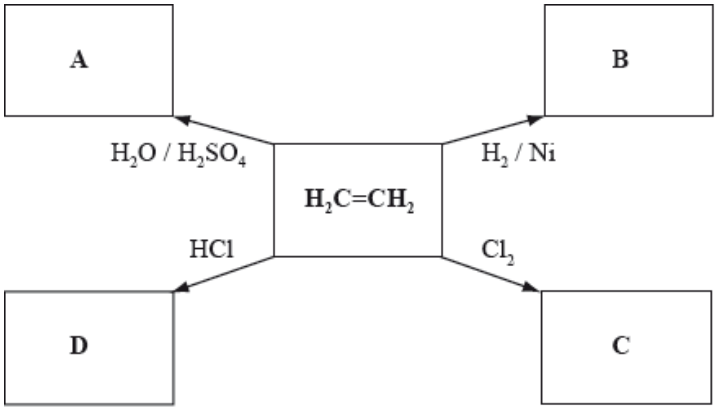
. . . . . .

Alkenes are important starting materials for a variety of products.

a. State and explain the trend of the boiling points of the first five members of the alkene homologous series. [3]

b. Describe **two** features of a homologous series. [2]

c. Below is a schematic diagram representing some reactions of ethene. The letters **A**–**D** represent the organic compounds formed from the reactants and catalysts shown. [[N/A



Deduce the structural formulas of compounds **A**, **B**, **C**, and **D** and state the IUPAC name of compound **C**.

A:

B:

C:

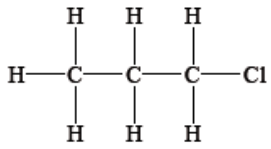
IUPAC name: . . . . . .

D:

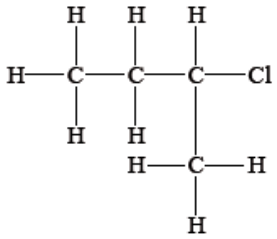
d. Describe a chemical test that could be used to distinguish between pent-1-ene and pentane. [2]

e. State and explain whether the following molecules are primary, secondary or tertiary halogenoalkanes. [4]

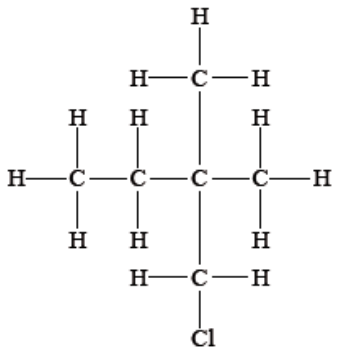
E:



F:



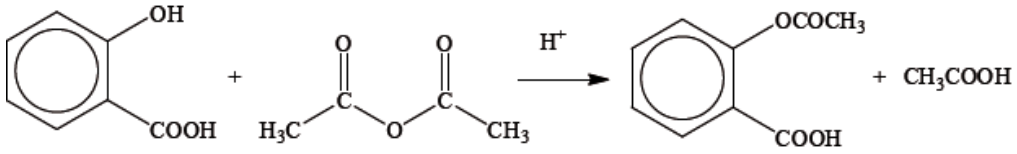
G:



f. Explain, using equations, the following steps in the free-radical mechanism of the reaction of methane with chlorine. [4]

- Initiation
- Propagation
- Termination

Aspirin, one of the most widely used drugs in the world, can be prepared according to the equation given below.



salicylic acid ethanoic anhydride *aspirin* ethanoic acid

A student reacted some salicylic acid with excess ethanoic anhydride. Impure solid aspirin was obtained by filtering the reaction mixture. Pure aspirin was obtained by recrystallization. The following table shows the data recorded by the student.

Mass of salicylic acid used	3.15 ± 0.02 g
Mass of pure aspirin obtained	2.50 ± 0.02 g

a. State the names of the **three** organic functional groups in aspirin. [3]

b.i. Determine the amount, in mol, of salicylic acid, $C_6H_4(OH)COOH$, used. [2]

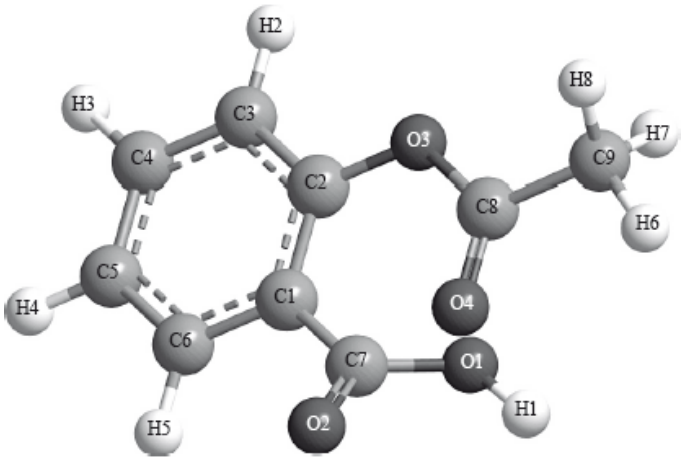
b.ii. Calculate the theoretical yield, in g, of aspirin, $C_6H_4(OCOCH_3)COOH$. [2]

b.iii Determine the percentage yield of pure aspirin. [1]

b.iv State the number of significant figures associated with the mass of pure aspirin obtained, and calculate the percentage uncertainty associated with this mass. [2]

b.v Another student repeated the experiment and obtained an experimental yield of 150%. The teacher checked the calculations and found no errors. Comment on the result. [1]

b.vi The following is a three-dimensional computer-generated representation of aspirin. [2]



A third student measured selected bond lengths in aspirin, using this computer program and reported the following data.

Bond	Bond length / $\times 10^{-10}$ m
C1–C2	1.4
C2–C3	1.4
C3–C4	1.4
C4–C5	1.4
C5–C6	1.4
C6–C1	1.4
C2–O3	1.4

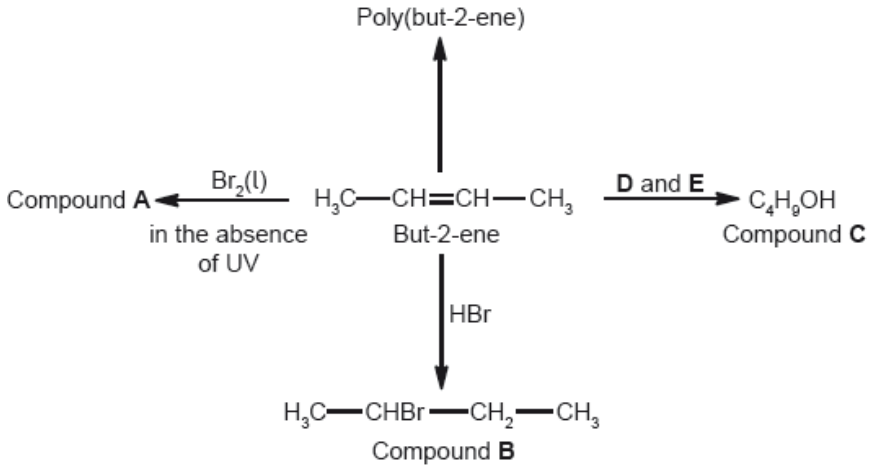
The following hypothesis was suggested by the student: "*Since all the measured carbon-carbon bond lengths are equal, all the carbon-oxygen bond lengths must also be equal in aspirin. Therefore, the C8–O4 bond length must be 1.4 $\times$ 10^{-10} m*". Comment on whether or not this is a valid hypothesis.

b.vii The other product of the reaction is ethanoic acid, CH_3COOH. Define an acid according to the Brønsted-Lowry theory and state the conjugate base of CH_3COOH. [2]

Brønsted-Lowry definition of an acid:

Conjugate base of CH_3COOH:

Some reactions of but-2-ene are given below.



a.i. Deduce the full structural formula of compound **A**. [1]

a.ii. Apply IUPAC rules to name compound **A**. [1]

a.iii. Describe the colour change observed when excess but-2-ene reacts with bromine to form compound **A**. [1]

b. State the names of the reagents **D** and **E**. [2]

c. (i) Outline **two** reasons why the polymerization of alkenes is of economic importance. [3]

(ii) Identify the structure of the repeating unit of poly(but-2-ene).

d. Compound **C**, C_4H_9OH, can also be formed directly from compound **B**, $CH_3CHBrCH_2CH_3$. [2]

(i) State the reagent and the conditions required for this reaction.

(ii) State the name of the type of reaction occurring in this conversion.

e. Compound **C** can be oxidized by acidified potassium dichromate(VI) to form compound **F**. [2]

(i) State the name of the functional group present in compound **F**.

(ii) Deduce the structural formula of an alcohol which is a structural isomer of compound **C** and **cannot** be oxidized by acidified potassium dichromate(VI).

f. Explain why but-2-ene is more volatile than compound **C**, C_4H_9OH. [2]

g.i. Define the term *average bond enthalpy*. [2]

g.ii. Deduce the equation for the complete combustion of compound **C**. [1]

g.iii. Determine the enthalpy change, ΔH, in $kJ\,mol^{-1}$, for the complete combustion of compound **C** when all reactants and products are in the gaseous state, using table 10 of the data booklet. [3]

An example of a homogeneous reversible reaction is the reaction between hydrogen and iodine.

$$\mathrm{H_2(g) + I_2(g) \rightleftharpoons 2HI(g)}$$

Propane can be formed by the hydrogenation of propene.

$$\mathrm{CH_3CH{=}CH_2(g) + H_2(g) \rightarrow CH_3CH_2CH_3(g)}$$

a.i. Outline the characteristics of a homogeneous chemical system that is in a state of equilibrium. [2]

a.ii. Deduce the expression for the equilibrium constant, K_c. [1]

a.iii. Predict what would happen to the position of equilibrium and the value of K_c if the pressure is increased from 1 atm to 2 atm. [2]

a.iv. The value of K_c at 500 K is 160 and the value of K_c at 700 K is 54. Deduce what this information tells us about the enthalpy change of the forward reaction. [1]

a.v. The reaction can be catalysed by adding platinum metal. State and explain what effect the addition of platinum would have on the value of the equilibrium constant. [2]

b.i. State the conditions necessary for the hydrogenation reaction to occur. [2]

b.ii. Enthalpy changes can be determined using average bond enthalpies. Define the term *average bond enthalpy*. [2]

b.iii. Determine a value for the hydrogenation of propene using information from Table 10 of the Data Booklet. [2]

b.iv. Explain why the enthalpy of hydrogenation of propene is an exothermic process. [1]

c.i. Describe a chemical test that could be used to distinguish between propane and propene. In **each** case state the result of the test. [2]

c.ii. Under certain conditions propene can polymerize to form poly(propene). State the type of polymerization taking place and draw a section of the polymer to represent the repeating unit. [2]

c.iii. Other than polymerization, state **one** reaction of alkenes which is of economic importance. [1]

2-methylbutan-2-ol, $\mathrm{(CH_3)_2C(OH)CH_2CH_3}$, is a liquid with a smell of camphor that was formerly used as a sedative. One way of producing it starts with 2-methylbut-2-ene.

2-chloro-2-methylbutane contains some molecules with a molar mass of approximately $106\ \mathrm{g\,mol^{-1}}$ and some with a molar mass of approximately $108\ \mathrm{g\,mol^{-1}}$.

a. Draw the structure of 2-methylbut-2-ene. [1]

b. State the other substances required to convert 2-methylbut-2-ene to 2-methylbutan-2-ol. [2]

c. Explain whether you would expect 2-methylbutan-2-ol to react with acidified potassium dichromate(VI). [2]

d. Explain why 2-methylbut-2-ene is less soluble in water than 2-methylbutan-2-ol. [2]

f.i. Outline why there are molecules with different molar masses. [1]

Chlorine occurs in Group 7, the halogens.

Two stable isotopes of chlorine are $^{35}\mathrm{Cl}$ and $^{37}\mathrm{Cl}$ with mass numbers 35 and 37 respectively.

Chlorine has an electronegativity value of 3.2 on the Pauling scale.

Chloroethene, $H_2C{=}CHCl$, the monomer used in the polymerization reaction in the manufacture of the polymer poly(chloroethene), PVC, can be synthesized in the following two-stage reaction pathway.

$$\text{Stage 1:} \quad \mathrm{C_2H_4(g) + Cl_2(g) \rightarrow ClCH_2CH_2Cl(g)}$$
$$\text{Stage 2:} \quad \mathrm{ClCH_2CH_2Cl(g) + HC{=}CHCl(g) + HCl(g)}$$

a.i. Define the term *isotopes of an element*. [2]

a.ii. Calculate the number of protons, neutrons and electrons in the isotopes ^{35}Cl and ^{37}Cl. [2]

Isotope	Number of protons	Number of neutrons	Number of electrons
$^{35}\mathrm{Cl}$			
$^{37}\mathrm{Cl}$			

a.iii. Using the mass numbers of the two isotopes and the relative atomic mass of chlorine from Table 5 of the Data Booklet, determine the percentage abundance of each isotope. [2]

Percentage abundance ^{35}Cl:

Percentage abundance ^{37}Cl:

b.i. Define the term *electronegativity*. [1]

b.ii. Using Table 7 of the Data Booklet, explain the trends in electronegativity values of the Group 7 elements from F to I. [2]

b.iii. State the balanced chemical equation for the reaction of potassium bromide, KBr(aq), with chlorine, Cl_2(aq). [1]

b.iv. Describe the colour change likely to be observed in this reaction. [1]

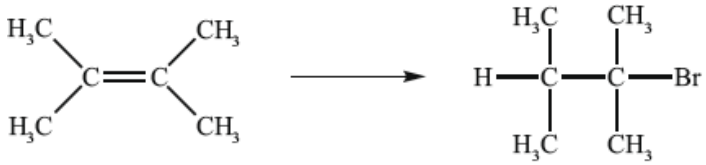
c.ii. Determine the enthalpy change, ΔH, in $\mathrm{kJ\,mol^{-1}}$, for stage 1 using average bond enthalpy data from Table 10 of the Data Booklet. [3]

c.iii. State whether the reaction given in stage 1 is exothermic or endothermic. [1]

c.iv. Draw the structure of poly(chloroethene) showing **two** repeating units. [1]

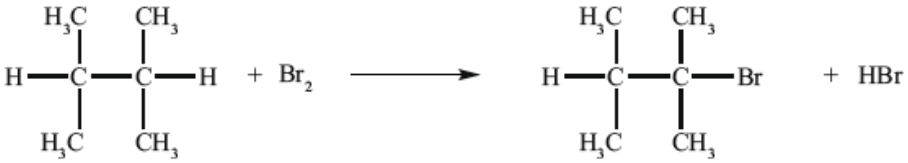
c.v. Suggest why monomers are often gases or volatile liquids whereas polymers are solids. [2]

Alkenes, such as **A** (shown below), are important intermediates in the petrochemical industry because they undergo addition reactions to produce a wide variety of products, such as the conversion shown below.

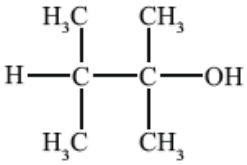


A **B**

Another way to make **B** is the reaction shown below.

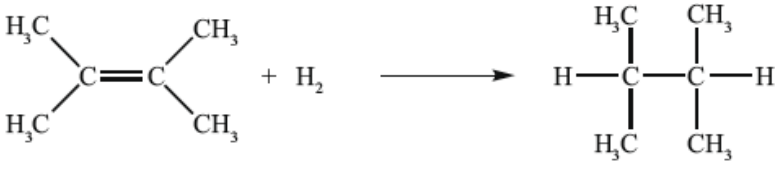


B can be converted into **C**.



C

In the gas phase, **A** reacts with hydrogen to form **D**.



A **D**

a. Applying IUPAC rules, state the name of **A**. [1]

b. State the reagent required to convert **A** into **B**. [1]

c. (i) State the conditions required for this reaction to occur. [2]

(ii) Outline why it would give a poor yield of the desired product.

d. (i) State the reagent required. [4]

(ii) Explain the mechanism of this reaction, using curly arrows to represent the movement of electron pairs.

e. **A** can also be converted into **C** without going via **B**. State the reagent and conditions required. [2]

f. (i) State why **C** is **not** readily oxidized by acidified potassium dichromate(VI). [2]

(ii) Deduce the structural formula of an isomer of **C** that could be oxidized to a carboxylic acid by this reagent.

g.i. State the conditions required for this reaction to occur. [1]

g.ii. State the homologous series to which **D** belongs. [1]

g.iii. Determine the enthalpy change, in $\mathrm{kJ\,mol^{-1}}$, for the reaction of **A** with hydrogen, using Table 10 of the Data Booklet, and state whether the reaction is exothermic or endothermic. [4]

g.iv. The standard enthalpy change of combustion of **A** is $-4000\ \mathrm{kJ\,mol^{-1}}$. Calculate the amount of **A**, in mol, that would have to be burned to raise the temperature of $1\ \mathrm{dm^3}$ of water from 20 °C to 100 °C. [2]

Bromomethane was used as a pesticide until it was found to be ozone-depleting.

a. State the equation for the reaction between methane and bromine to form bromomethane. [1]

b. Explain, using equations, the complete free-radical mechanism for the reaction of methane with bromine, including necessary reaction conditions. [4]

c. Bromine can be produced by the electrolysis of **molten** sodium bromide. Deduce the half-equation for the reaction at each electrode. [2]

Positive electrode (anode):

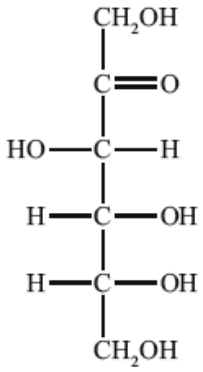
Negative electrode (cathode):

d. Bromine reacts with aqueous sodium iodide: [1]

$$\mathrm{Br_2(aq) + 2NaI(aq) \rightarrow I_2(aq) + 2NaBr(aq)}$$

Identify the oxidizing agent in this reaction.

The open-chain structure of D-fructose is shown below.



a. State the names of **two** functional groups in D-fructose. [1]

b. Deduce the empirical formula of D-fructose. [1]

c. Calculate the percentage composition by mass of D-fructose. [2]

d. State a balanced equation for the complete combustion of D-fructose. [2]

Three compounds with similar relative molecular masses are butane, propanal and propan-1-ol.

a.i. List the three compounds in order of increasing boiling point (lowest first) and explain the differences in their boiling points. [4]

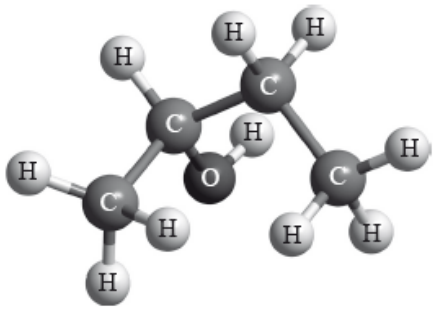
a.ii. Predict, with an explanation, which of the three compounds is **least** soluble or miscible in water. [2]

a.iii When propan-1-ol is oxidized using a warm acidified solution of potassium dichromate(VI) two different organic products can be obtained. Deduce the name and structural formula for each of these two products. [3]

a.iv Propan-2-ol is an isomer of propan-1-ol. Draw the structure of propan-2-ol. [1]

a.v. Identify the class of alcohols that propan-2-ol belongs to and state the name of the organic product formed when it is oxidized by an acidified solution of potassium dichromate(VI). [2]

The following diagram shows the three-dimensional structure of a molecule.



a. Apply IUPAC rules to state the name of this molecule. [1]

b. Deduce the structural formula of **two** isomers of the molecule above with the same functional group. [2]

c. Describe, using an equation, the oxidation by acidified potassium dichromate(VI) of the substance shown in the diagram. Use the symbol [O] to represent the oxidizing agent. [1]

Ethanol has many industrial uses.

a. (i) State an equation for the formation of ethanol from ethene and the necessary reaction conditions. [4]

Equation:

Conditions:

(ii) Deduce the volume of ethanol, in dm^3, produced from $1.5\ \mathrm{dm}^3$ of ethene, assuming both are gaseous and at the same temperature and pressure.

b.i. Define the term *average bond enthalpy*. [2]

b.ii. Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in $\mathrm{kJ\ mol}^{-1}$, using the values in table 10 of the data booklet, assuming all reactants and products are gaseous. [4]

b.iii. Suggest why the value of the enthalpy of combustion of ethanol quoted in table 12 of the data booklet is different to that calculated using bond enthalpies. [1]

b.iv. Explain why the reaction is exothermic in terms of the bonds involved. [1]

c. Identify the homologous series to which ethanol belongs and state **two** features of a homologous series. [3]

$25.0\ \mathrm{cm}^3$ of $0.200\ \mathrm{mol\,dm}^{-3}$ ethanoic acid were added to $30.0\ \mathrm{cm}^3$ of a $0.150\ \mathrm{mol\,dm}^{-3}$ sodium hydrogencarbonate solution, $\mathrm{NaHCO_3(aq)}$.

The molar mass of a volatile organic liquid, **X**, can be determined experimentally by allowing it to vaporize completely at a controlled temperature and pressure. 0.348 g of **X** was injected into a gas syringe maintained at a temperature of 90 °C and a pressure of $1.01 \times 10^5\ \mathrm{Pa}$. Once it had reached equilibrium, the gas volume was measured as $95.0\ \mathrm{cm}^3$.

Bromoethane, $\mathrm{CH_3CH_2Br}$, undergoes a substitution reaction to form ethanol, $\mathrm{CH_3CH_2OH}$.

a. Outline how electrical conductivity can be used to distinguish between a $0.200\ \text{mol}\,\text{dm}^{-3}$ solution of ethanoic acid, CH_3COOH, and a $0.200\ \text{mol}\,\text{dm}^{-3}$ solution of hydrochloric acid, HCl. [1]

b. (i) State an equation for the reaction of ethanoic acid with a solution of sodium hydrogencarbonate. [5]

(ii) Determine which is the limiting reagent. Show your working.

(iii) Calculate the mass, in g, of carbon dioxide produced.

c. (i) Determine the amount, in mol, of **X** in the gas syringe. [4]

(ii) Calculate the molar mass of **X**.

d. (i) Identify the reagent necessary for this reaction to occur. [4]

(ii) Deduce the mechanism for the reaction using equations and curly arrows to represent the movement of electron pairs.

e.ii. Determine the enthalpy change, in kJ mol^{-1}, for this reaction, using Table 10 of the Data Booklet. [3]

f. Bromoethene, CH_2CHBr, can undergo polymerization. Draw a section of this polymer that contains six carbon atoms. [1]

Chloroethene, C_2H_3Cl, is an important organic compound used to manufacture the polymer poly(chloroethene).

a.i. Draw the Lewis structure for chloroethene and predict the H–C–Cl bond angle. [2]

a.ii. Draw a section of poly(chloroethene) containing six carbon atoms. [1]

a.iii. Outline why the polymerization of alkenes is of economic importance and why the disposal of plastics is a problem. [2]

b.i. Chloroethene can be converted to ethanol in two steps. For each step deduce an overall equation for the reaction taking place. [2]

Step 1:

Step 2:

b.ii. State the reagents and conditions necessary to prepare ethanoic acid from ethanol in the laboratory. [2]

b.iii. State an equation, including state symbols, for the reaction of ethanoic acid with water. Identify a Brønsted-Lowry acid in the equation and its conjugate base. [3]

Factors that affect the rate of a chemical reaction include particle size, concentration of reactants and the temperature of the reaction.

Propan-1-ol and propan-2-ol are two structural isomers of $\mathrm{C_3H_8O}$.

a.i. Define the term *rate of a chemical reaction*. [1]

a.ii. List the **three** characteristic properties of reactant particles which affect the rate of reaction as described by the collision theory. [3]

a.iii. On the axes below sketch **two** Maxwell-Boltzmann energy distribution curves for the same sample of gas, one at a temperature T and another at a higher temperature T'. Label both axes. Explain why raising the temperature increases the rate of a chemical reaction. [5]

a.iv. Explain why coal dust burns much faster than a large piece of coal with the same mass. [1]

b.i. State the equation for the complete combustion of $\mathrm{C_3H_8O}$. [2]

b.ii. Both propan-1-ol and propan-2-ol can be oxidized in aqueous solution by potassium dichromate(VI). State any necessary conditions for the oxidation to occur and describe the colour change during the oxidation process. [3]

b.iii. State the name(s) and structure(s) of the organic product(s) that can be formed when each of the alcohols is oxidized and suggest why one of the alcohols gives two organic products and the other only gives one organic product. [5]

Intermolecular forces are attractive forces between molecules.

Consider the compounds $\mathrm{(CH_3)_2NH}$ and $\mathrm{CH_4}$.

a. Identify the intermolecular forces present in hydrogen iodide in the liquid state, HI(l). [1]

b.i. Deduce the full structural formula for both compounds, showing **all** the bonds present. [2]

$(CH_3)_2NH$ CH_4

b.ii. State and explain which compound can form hydrogen bonds **with water**. [2]

b.iii. Draw a diagram showing the resulting hydrogen bonds between water and the compound chosen in (ii). [1]

Halogenoalkanes can be classified as primary, secondary or tertiary.

Alkanes undergo few reactions other than combustion and halogenation.

Under certain conditions but-2-ene can react with water to form butan-2-ol.

a. (i) State the meaning of the term *isomers*. [5]

(ii) Deduce the structural formulas of 2-bromobutane and 1-bromo-2-methylpropane, and identify each molecule as primary, secondary or tertiary.

b. (i) Explain why alkanes have low reactivity. [10]

(ii) Outline the meaning of the term *homolytic fission*.

(iii) Describe the meaning of the symbol $Br\bullet$.

(iv) State an equation for the reaction of ethane with bromine.

(v) Explain the reaction of ethane with bromine using equations for the initiation step, two propagation steps and one termination step.

c. (i) Identify a suitable catalyst for this reaction. [5]

(ii) But-2-ene can be converted to 2-bromobutane and then to butan-2-ol as follows:

$$CH_3CH{=}CHCH_3 \overset{I}{\rightarrow} CH_3CH(Br)CH_2CH_3 \overset{II}{\longrightarrow} CH_3CH(OH)CH_2CH_3$$

Identify the reagent(s) and conditions necessary for each of the steps **I** and **II**.

Step **I**:

Step **II**:

Two students were asked to use information from the Data Booklet to calculate a value for the enthalpy of hydrogenation of ethene to form ethane.

$$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$$

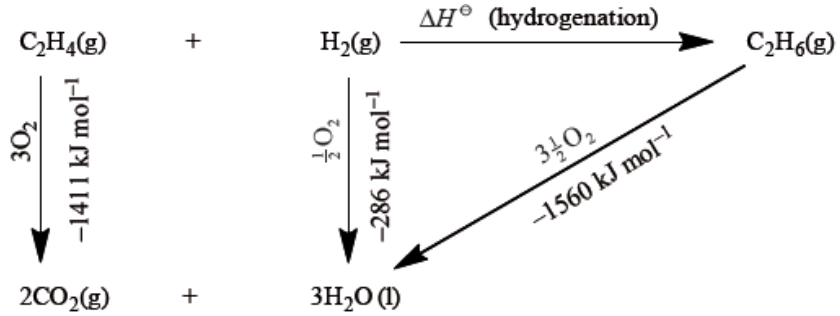
John used the average bond enthalpies from Table 10. Marit used the values of enthalpies of combustion from Table 12.

John then decided to determine the enthalpy of hydrogenation of cyclohexene to produce cyclohexane.

$$C_6H_{10}(l) + H_2(g) \rightarrow C_6H_{12}(l)$$

a. Calculate the value for the enthalpy of hydrogenation of ethene obtained using the average bond enthalpies given in Table 10. [2]

b. Marit arranged the values she found in Table 12 into an energy cycle. [1]



Calculate the value for the enthalpy of hydrogenation of ethene from the energy cycle.

c. Suggest **one** reason why John's answer is slightly less accurate than Marit's answer. [1]

d.i. Use the average bond enthalpies to deduce a value for the enthalpy of hydrogenation of cyclohexene. [1]

d.ii. The percentage difference between these two methods (average bond enthalpies and enthalpies of combustion) is greater for cyclohexene than it was for ethene. John's hypothesis was that it would be the same. Determine why the use of average bond enthalpies is less accurate for the cyclohexene equation shown above, than it was for ethene. Deduce what extra information is needed to provide a more accurate answer. [2]

---

a. State **two** features of a homologous series. [2]

b. Ethane, a member of the homologous series of alkanes, can react with bromine. [4]

Explain the free-radical mechanism of this reaction, including any necessary reaction conditions.

Ethene belongs to the homologous series of the alkenes.

A bromoalkane, C_4H_9Br, reacts with a warm, aqueous sodium hydroxide solution, NaOH.

The time taken to produce a certain amount of product using different initial concentrations of C_4H_9Br and NaOH is measured. The results are shown in the following table.

Reaction	$[C_4H_9Br]$ / 10^{-2} mol dm^{-3}	[NaOH] / 10^{-3} mol dm^{-3}	t / s
A	1.0	2.0	46
B	2.0	2.0	23
C	2.0	4.0	23

a.i. Outline **three** features of a homologous series. [3]

a.ii. Describe a test to distinguish ethene from ethane, including what is observed in **each** case. [2]

a.iii. Bromoethane can be produced either from ethene or from ethane. State an equation for **each** reaction. [2]

b.i. State the equation for the reaction of $\mathrm{C_4H_9Br}$ with NaOH. [1]

b.ii. Suggest what would happen to the pH of the solution as the reaction proceeds. [1]

c.i. Deduce the effect of the concentration of $\mathrm{C_4H_9Br}$ and NaOH on the rate of reaction. [2]

C_4H_9Br:

NaOH:

c.ii. Suggest why **warm** sodium hydroxide solution is used. [1]

c.iii. Deduce whether C_4H_9Br is a primary or tertiary halogenoalkane. [2]

c.iv. Determine the structural formula of C_4H_9Br. [1]

c.v. Describe, using an equation, how $\mathrm{C_4H_9Br}$ can be converted into $\mathrm{C_4H_8Br_2}$. [1]

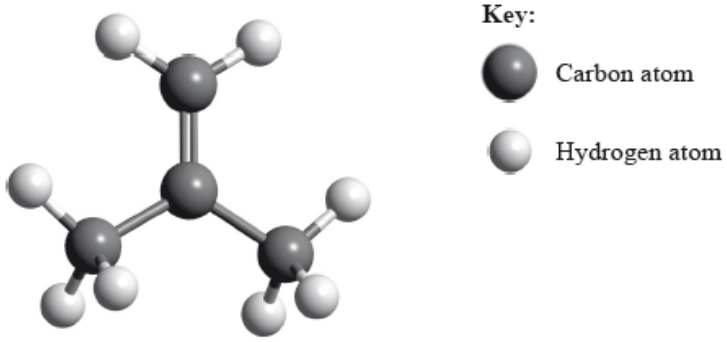
d. Explain the mechanism for the reaction in (c) of $\mathrm{C_4H_9Br}$ with NaOH, using curly arrows to represent the movement of electron pairs. [4]

The alkenes are an example of a homologous series.

Bromine water, $Br_2(aq)$, can be used to distinguish between the alkanes and the alkenes.

The polymerization of the alkenes is one of the most significant reactions of the twentieth century.

a. State the name of the alkene shown. [1]



b. Bromine water, $Br_2(aq)$, can be used to distinguish between the alkanes and the alkenes. [3]

(i) Describe the colour change observed when the alkene shown in part (a) is added to bromine water.

(ii) Draw the structural formula and state the name of the product formed.

c. (i) Outline **two** reasons why the polymers of the alkenes are of economic importance. [6]

(ii) State the type of polymerization reaction shown by the alkene in part (a).

(iii) Deduce the structure of the resulting polymer showing **three** repeating units.

(iv) Explain why monomers are often gases or volatile liquids, but polymers are solids.

In an experiment to measure the enthalpy change of combustion of ethanol, a student heated a copper calorimeter containing 100 cm^3 of water with a spirit lamp and collected the following data.

Initial temperature of water:	$20.0\ ^\circ C$
Final temperature of water:	$55.0\ ^\circ C$
Mass of ethanol burned:	$1.78\ g$
Density of water:	$1.00\ g\ cm^{-3}$

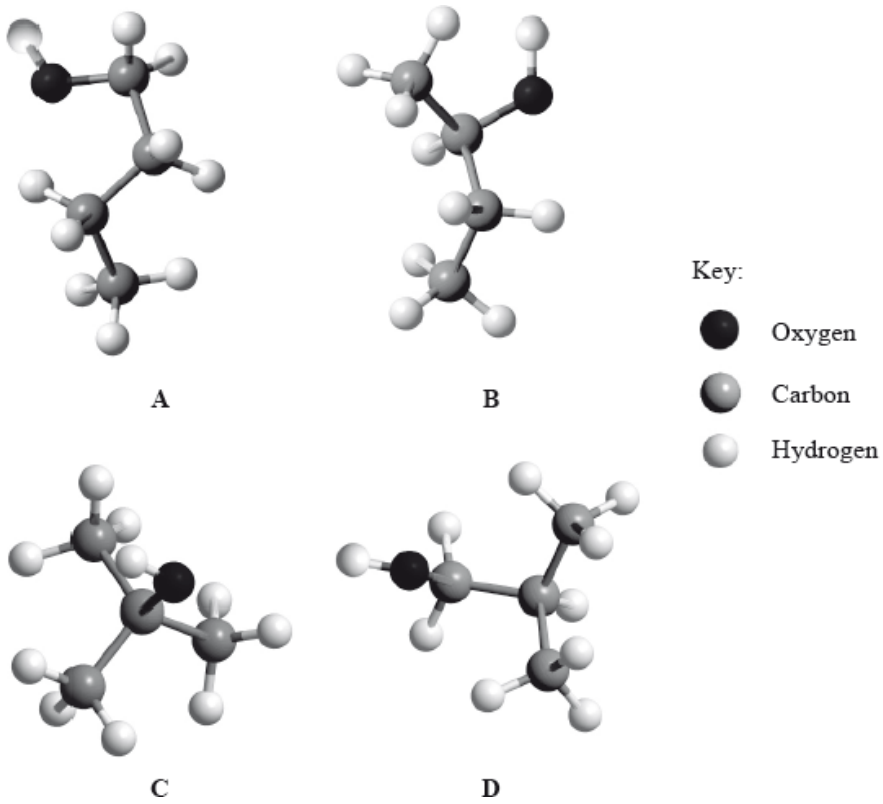
a. (i) Use the data to calculate the heat evolved when the ethanol was combusted. [6]

(ii) Calculate the enthalpy change of combustion per mole of ethanol.

(iii) Suggest two reasons why the result is not the same as the value in the Data Booklet.

b. Ethanol is part of the homologous series of alcohols. Describe **two** features of a homologous series. [2]

c. (i) Below are **four structural** isomers of alcohols with molecular formula $C_4H_{10}O$. State the name of each of the isomers **a**, **b**, **c** and **D**. [8]



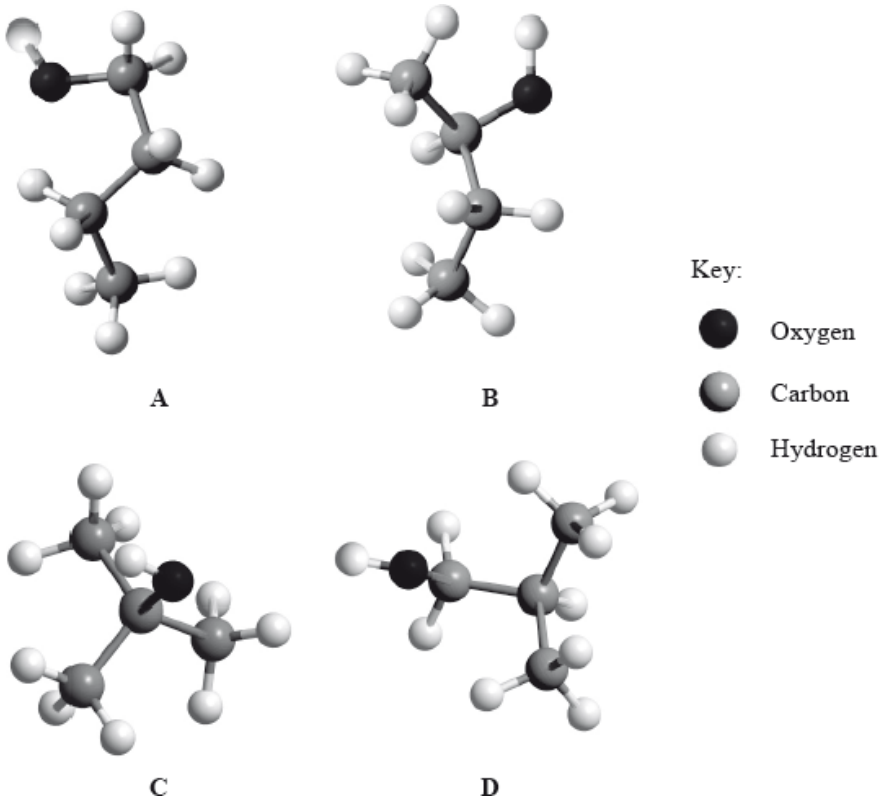
(ii) Determine the isomer that cannot be oxidized by acidifi ed potassium dichromate(VI), $K_2Cr_2O_7$.

(iii) Determine the isomer which can be oxidized to butanal.

(iv) Determine the isomer which can be oxidized to butanone.

(v) Suggest the structural formula of another isomer of $C_4H_{10}O$.

d. [4]



(i) Isomer **a** is formed by reacting 1-bromobutane with aqueous sodium hydroxide. State whether the reaction would proceed via an S_N1 or S_N2 mechanism.

(ii) Explain the mechanism named in part (d) (i) using curly arrows to represent the movement of electron pairs.

An organic compound, **X**, with a molar mass of approximately $88\ \mathrm{g\,mol^{-1}}$ contains 54.5% carbon, 36.3% oxygen and 9.2% hydrogen by mass.

a. (i) Distinguish between the terms *empirical formula* and *molecular formula*. [9]

Empirical formula:

Molecular formula:

(ii) Determine the empirical formula of **X**.

(iii) Determine the molecular formula of **X**.

(iv) **X** is a straight-chain carboxylic acid. Draw its structural formula.

(v) Draw the structural formula of an isomer of **X** which is an ester.

(vi) The carboxylic acid contains two different carbon-oxygen bonds. Identify which bond is stronger and which bond is longer.

Stronger bond:

Longer bond:

b. (i) State and explain which of propan-1-ol, $\mathrm{CH_3CH_2CH_2OH}$, and methoxyethane, $\mathrm{CH_3OCH_2CH_3}$, is more volatile. [5]

(ii) Propan-1-ol, $\mathrm{CH_3CH_2CH_2OH}$, and hexan-l-ol, $\mathrm{CH_3(CH_2)_4CH_2OH}$, are both alcohols. State and explain which compound is more soluble in water.

c. Graphite is used as a lubricant and is an electrical conductor. Diamond is hard and does not conduct electricity. Explain these statements in terms of the structure and bonding of these allotropes of carbon. [6]

Graphite:

Diamond:

In some countries, ethanol is mixed with gasoline (petrol) to produce a fuel for cars called gasohol.

a.i. Define the term *average bond enthalpy*. [2]

a.ii. Use the information from Table 10 of the Data Booklet to determine the standard enthalpy change for the complete combustion of ethanol. [3]

$$\mathrm{CH_3CH_2OH(g) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)}$$

a.iii. The standard enthalpy change for the complete combustion of octane, $\mathrm{C_8H_{18}}$, is $-5471\ \mathrm{kJ\,mol^{-1}}$. Calculate the amount of energy produced in kJ when 1 g of ethanol and 1 g of octane is burned completely in air. [2]

a.iv. Ethanol can be oxidized using acidified potassium dichromate, $\mathrm{K_2Cr_2O_7}$, to form two different organic products. [4]

$$\mathrm{CH_3CH_2OH \xrightarrow[H^+]{Cr_2O_7^{2-}} \textbf{A} \xrightarrow[H^+]{Cr_2O_7^{2-}} \textbf{B}}$$

State the structural formulas of the organic products **A** and **B** and describe the conditions required to obtain a high yield of each of them.

a.v. Deduce and explain whether ethanol or **A** has the higher boiling point. [2]

a.vi. Ethene can be converted into ethanol by direct hydration in the presence of a catalyst according to the following equation. [2]

$$\mathrm{C_2H_4(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)}$$

For this reaction identify the catalyst used and state **one** use of the ethanol formed other than as a fuel.

b.i. State the name of **one** structural isomer of pentane. [1]

---

a. Define the term *average bond enthalpy*. [2]

b. Deduce the balanced chemical equation for the complete combustion of butan-1-ol. [1]

c. Determine the standard enthalpy change, in $\mathrm{kJ\,mol^{-1}}$, for the complete combustion of butan-1-ol, using the information from Table 10 of the Data Booklet. [3]

d. Based on the types of intermolecular force present, explain why butan-1-ol has a higher boiling point than butanal. [2]

Acids play a key role in processes in everyday life.

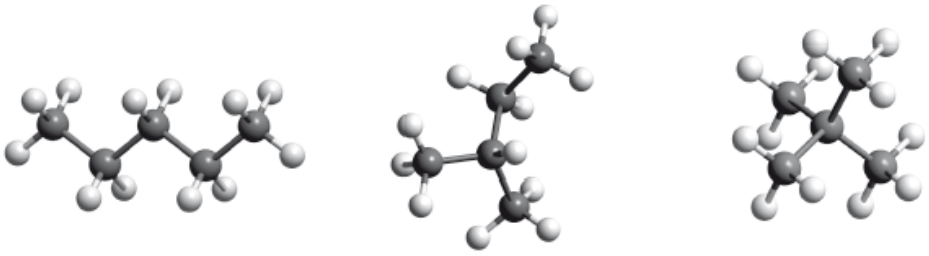
The wine industry is important to the economy of many countries. Wine contains ethanol. In a laboratory in Chile, chemists tested the pH of a bottle of wine when opened and found it to have a pH of 3.8. After a few days, the pH had decreased to 2.8.

a.i. Deduce the change in hydrogen ion concentration, $[H^+]$. [1]

a.ii. State the name of the compound formed that is responsible for this decreased pH value. [1]

b. Sulfuric acid present in acid rain can damage buildings made of limestone. Predict the balanced chemical equation for the reaction between limestone and sulfuric acid including state symbols. [2]

The boiling points of the isomers of pentane, C_5H_{12}, shown are 10, 28 and 36 °C, but not necessarily in that order.



A B C

a.i. Identify the boiling points for each of the isomers **A**, **B** and **C** and state a reason for your answer. [3]

Isomer	A	B	C
Boiling point			

a.ii. State the IUPAC names of isomers **B** and **C**. [[N/A

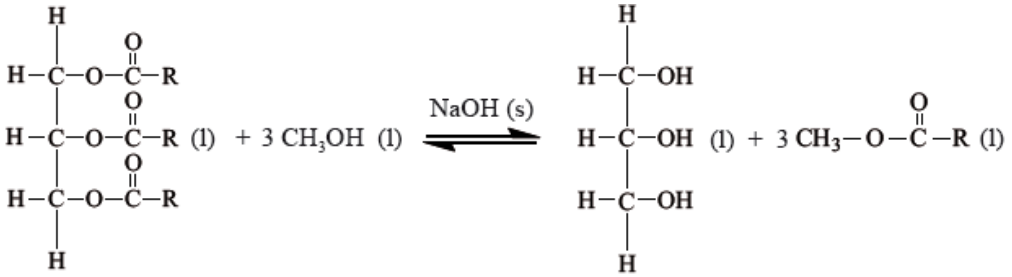
B:

C:

b. Both C_5H_{12} and $C_5H_{11}OH$ can be used as fuels. Predict which compound would release a greater amount of heat per gram when it undergoes complete combustion. Suggest **two** reasons to support your prediction. [3]

c. In many cities around the world, public transport vehicles use diesel, a liquid hydrocarbon fuel, which often contains sulfur impurities and undergoes incomplete combustion. All public transport vehicles in New Delhi, India, have been converted to use compressed natural gas (CNG) as fuel. Suggest **two** ways in which this improves air quality, giving a reason for your answer. [3]

Biodiesel makes use of plants' ability to fix atmospheric carbon by photosynthesis. Many companies and individuals are now using biodiesel as a fuel in order to reduce their carbon footprint. Biodiesel can be synthesized from vegetable oil according to the following reaction.



The reversible arrows in the equation indicate that the production of biodiesel is an equilibrium process.

a. Identify the organic functional group present in both vegetable oil and biodiesel. [1]

b. For part of her extended essay investigation into the efficiency of the process, a student reacted a pure sample of a vegetable oil (where $\mathrm{R} = \mathrm{C_{17}H_{33}}$) with methanol. The raw data recorded for the reaction is below. [3]

$$\begin{aligned} &\text{Mass of oil} &&= 1013.0\ \text{g} \\ &\text{Mass of methanol} &&= 200.0\ \text{g} \\ &\text{Mass of sodium hydroxide} &&= 3.5\ \text{g} \\ &\text{Mass of biodiesel produced} &&= 811.0\ \text{g} \end{aligned}$$

The relative molecular mass of the oil used by the student is 885.6. Calculate the amount (in moles) of the oil and the methanol used, and hence the amount (in moles) of excess methanol.

c.i. State what is meant by the term *dynamic equilibrium*. [1]

c.ii. Using the abbreviations [vegetable oil], [methanol], [glycerol] and [biodiesel] deduce the equilibrium constant expression (K_c) for this reaction. [1]

c.iii Suggest a reason why excess methanol is used in this process. [1]

c.iv State and explain the effect that the addition of the sodium hydroxide catalyst will have on the position of equilibrium. [2]

d. The reactants had to be stirred vigorously because they formed two distinct layers in the reaction vessel. Explain why they form two distinct layers and why stirring increases the rate of reaction. [2]

e. Calculate the percentage yield of biodiesel obtained in this process. [2]

Ethane reacts with chlorine in the presence of sunlight.

a. Complete the overall equation for this reaction by stating the products. [1]

$\mathrm{C_2H_6 + Cl_2 \rightarrow}$

b. State the type of mechanism by which this reaction occurs. [1]

c. Traces of butane, $\mathrm{C_4H_{10}}$, are also found amongst the products of this reaction. Explain how this product arises. [2]

Hydrocarbons, such as nonane, $\mathrm{C_9H_{20}}$, are essential as fuels and as raw materials.

Propene, which can be obtained from nonane, can be polymerized.

a. State a balanced equation for the complete combustion of nonane. [2]

b. Combustion also often forms carbon and carbon monoxide. Outline what **reaction conditions** result in these being produced. [1]

c. (i) State the type of polymerization that occurs. [2]

(ii) Draw the structure of a segment of the polymer containing six carbon atoms.

Consider the following sequence of reactions.

$$\mathrm{RCH_3} \xrightarrow{reaction1} \mathrm{RCH_2Br} \xrightarrow{reaction2} \mathrm{RCH_2OH} \xrightarrow{reaction3} \mathrm{RCOOH}$$

$\mathrm{RCH_3}$ is an unknown alkane in which R represents an alkyl group.

The mechanism in *reaction 2* is described as S_N2.

Propan-1-ol has two structural isomers.

a. The alkane contains 81.7% by mass of carbon. Determine its empirical formula, showing your working. [3]

b. Equal volumes of carbon dioxide and the unknown alkane are found to have the same mass, measured to an accuracy of two significant figures, at the same temperature and pressure. Deduce the molecular formula of the alkane. [1]

c. (i) State the reagent and conditions needed for *reaction 1*. [2]

(ii) State the reagent(s) and conditions needed for *reaction 3*.

d. *Reaction 1* involves a free-radical mechanism. Describe the stepwise mechanism, by giving equations to represent the initiation, propagation and termination steps. [4]

e. (i) State the meaning of each of the symbols in S_N2. [4]

(ii) Explain the mechanism of this reaction using curly arrows to show the movement of electron pairs, and draw the structure of the transition state.

f. (i) Deduce the structural formula of each isomer. [4]

(ii) Identify the isomer from part (f) (i) which has the higher boiling point and explain your choice. Refer to both isomers in your explanation.

a. A hydrocarbon has the empirical formula $\mathrm{C_3H_7}$. When 1.17 g of the compound is heated to 85 °C at a pressure of 101 kPa it occupies a volume of $400\ \mathrm{cm^3}$. [4]

(i) Calculate the molar mass of the compound, showing your working.

(ii) Deduce the molecular formula of the compound.

b. $\mathrm{C_5H_{12}}$ exists as three isomers. Identify the structure of the isomer with the **lowest** boiling point and explain your choice. [2]

c.i. Ethanol is a primary alcohol that can be oxidized by acidified potassium dichromate(VI). Distinguish between the reaction conditions needed to produce ethanal and ethanoic acid. [2]

Ethanal:

Ethanoic acid:

c.ii. Determine the oxidation number of carbon in ethanol and ethanal. [2]

Ethanol:

Ethanal:

c.iii. Deduce the half-equation for the oxidation of ethanol to ethanal. [1]

c.iv. Deduce the overall redox equation for the reaction of ethanol to ethanal with acidified potassium dichromate(VI) by combining your answer to part (c) (iii) with the following half-equation: [2]

$$\mathrm{Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)}$$

d.i. Describe **two** characteristics of a reaction at equilibrium. [2]

d.ii. Describe how a catalyst increases the rate of a reaction. [2]

d.iii. State and explain the effect of a catalyst on the position of equilibrium. [2]

e. Ethanoic acid reacts with ethanol to form the ester ethyl ethanoate. [1]

$$\mathrm{CH_3COOH(l) + CH_3CH_2OH(l) ????? CH_3COOCH_2CH_3(l) + H_2O(l)}$$

The esterification reaction is exothermic. State the effect of increasing temperature on the value of the equilibrium constant (K_c) for this reaction.

Ethene, C_2H_4, and hydrazine, N_2H_4, are hydrides of adjacent elements in the periodic table.

The polarity of a molecule can be explained in terms of electronegativity.

The reaction between N_2H_4(aq) and HCl (aq) can be represented by the following equation.

$$\mathrm{N_2H_4(aq) + 2HCl(aq) \rightarrow N_2H_6^{2+}(aq) + 2Cl^-(aq)}$$

a. (i) Draw Lewis (electron dot) structures for $\mathrm{C_2H_4}$ and $\mathrm{N_2H_4}$ showing all valence electrons. [7]

(ii) State and explain the H–C–H bond angle in ethene and the H–N–H bond angle in hydrazine.

b. (i) Define the term *electronegativity*. [4]

(ii) Compare the relative polarities of the C–H bond in ethene and the N–H bond in hydrazine.

(iii) Hydrazine is a polar molecule and ethene is non-polar. Explain why ethene is non-polar.

c. The boiling point of hydrazine is much higher than that of ethene. Explain this difference in terms of the intermolecular forces in each compound. [2]

d. Hydrazine is a valuable rocket fuel. [3]

The equation for the reaction between hydrazine and oxygen is given below.

$$\mathrm{N_2H_4(g) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)}$$

Use the bond enthalpy values from Table 10 of the Data Booklet to determine the enthalpy change for this reaction.

e. State the name of the product and identify the type of reaction which occurs between ethene and hydrogen chloride. [2]

f. (i) Identify the type of reaction that occurs. [2]

(ii) Predict the value of the H–N–H bond angle in $\mathrm{N_2H_6^{2+}}$.

Ethane-1,2-diol, $HOCH_2CH_2OH$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

a. Ethane-1,2-diol can be formed according to the following reaction. [7]

$$\mathrm{2CO\ (g) + 3H_2\ (g) \rightleftharpoons HOCH_2CH_2OH\ (g)}$$

(i) Deduce the equilibrium constant expression, K_c, for this reaction.

(ii) State how increasing the pressure of the reaction mixture at constant temperature will affect the position of equilibrium and the value of K_c.

Position of equilibrium:

K_c:

(iii) Calculate the enthalpy change, ΔH^θ, in kJ, for this reaction using section 11 of the data booklet. The bond enthalpy of the carbon–oxygen bond in CO (g) is 1077kJmol^{-1}.

(iv) The enthalpy change, ΔH^θ, for the following similar reaction is –233.8 kJ.

$$2CO(g) + 3H_2(g) \rightleftharpoons HOCH_2CH_2OH\ (l)$$

Deduce why this value differs from your answer to (a)(iii).

b. Determine the average oxidation state of carbon in ethene and in ethane-1,2-diol. [2]

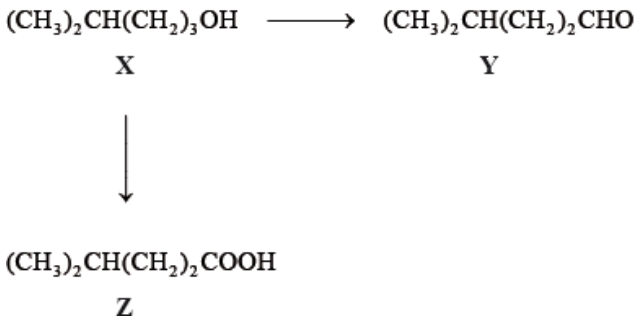
Ethene:

Ethane-1,2-diol:

c. Explain why the boiling point of ethane-1,2-diol is significantly greater than that of ethene. [2]

d. Ethane-1,2-diol can be oxidized first to ethanedioic acid, $(COOH)_2$, and then to carbon dioxide and water. Suggest the reagents to oxidize ethane-1,2-diol. [1]

Consider the following reactions.



An important environmental consideration is the appropriate disposal of cleaning solvents. An environmental waste treatment company analysed a cleaning solvent, **J**, and found it to contain the elements carbon, hydrogen and chlorine only. The chemical composition of **J** was determined using different analytical chemistry techniques.

Combustion Reaction:

Combustion of 1.30 g of **J** gave 0.872 g $\mathrm{CO_2}$ and 0.089 g $\mathrm{H_2O}$.

Precipitation Reaction with $AgNO_3(aq)$:

0.535 g of **J** gave 1.75 g AgCl precipitate.

a. One example of a homologous series is the alcohols. Describe **two** features of a homologous series. [2]

b.i. The IUPAC name of **X** is 4-methylpentan-1-ol. State the IUPAC names of **Y** and **Z**. [2]

Y:

Z:

b.ii. State the reagents and reaction conditions used to convert **X** to **Y** and **X** to **Z**. [2]

X to **Y**:

X to **Z**:

b.iii. **Z** is an example of a weak acid. State what is meant by the term *weak acid*. [1]

b.iv. Discuss the volatility of **Y** compared to **Z**. [2]

d.i. Determine the percentage by mass of carbon and hydrogen in **J**, using the combustion data. [3]

d.ii. Determine the percentage by mass of chlorine in **J**, using the precipitation data. [1]

d.iii. The molar mass was determined to be $131.38\ \text{g mol}^{-1}$. Deduce the molecular formula of **J**. [3]

The photochemical chlorination of methane can occur at low temperature.

a. Using relevant equations, show the initiation and the propagation steps for this reaction. [3]

Initiation:

. . . . . .

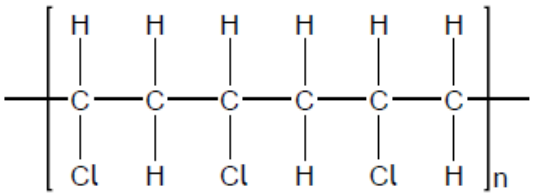
Propagation:

. . . . . .

. . . . . .

b. Bromine was added to hexane, hex-1-ene and benzene. Identify the compound(s) which will react with bromine in a well-lit laboratory. [1]

c. Polyvinyl chloride (PVC) is a polymer with the following structure. [1]



State the structural formula for the monomer of PVC.

Consider the following list of organic compounds.

Compound 1: $\text{CH}_3\text{CH}_2\text{CH(OH)CH}_3$

Compound 2: $\text{CH}_3\text{CH}_2\text{COCH}_3$

Compound 3: $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$

Compound 4: $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$

Hydrochloric acid neutralizes sodium hydroxide, forming sodium chloride and water.

$$\text{NaOH(aq)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)} \quad \Delta H^{\ominus} = -57.9\ \text{kJ mol}^{-1}$$

a. Apply IUPAC rules to state the name of compound 1. [1]

b. (i) Define the term *structural isomers*. [2]

(ii) Identify the two compounds in the list that are structural isomers of each other.

c. Determine the organic product formed when each of the compounds is heated under reflux with excess acidified potassium dichromate(VI). If no reaction occurs write NO REACTION in the table. [4]

Compound	Organic product
$CH_3CH_2CH(OH)CH_3$	
$CH_3CH_2COCH_3$	
$CH_3CH_2CH_2OH$	
$CH_3CH_2CH_2CHO$	

d. Explain the mechanism for the substitution reaction of bromoethane with sodium hydroxide. Use curly arrows to represent the movement of electron pairs. [4]

e. (i) Define the term *standard enthalpy change of reaction*, ΔH^{Θ}. [9]

(ii) Determine the amount of energy released, in kJ, when $50.0\ \text{cm}^3$ of $1.00\ \text{mol dm}^{-3}$ sodium hydroxide solution reacts with $50.0\ \text{cm}^3$ of $1.00\ \text{mol dm}^{-3}$ hydrochloric acid solution.

(iii) In an experiment, 2.50 g of solid sodium hydroxide was dissolved in $50.0\ \text{cm}^3$ of water. The temperature rose by 13.3 °C. Calculate the standard enthalpy change, in kJ mol^{-1}, for dissolving one mole of solid sodium hydroxide in water.

$$\text{NaOH(s)} \rightarrow \text{NaOH(aq)}$$

(iv) Using relevant data from previous question parts, determine ΔH^{Θ}, in kJ mol^{-1}, for the reaction of solid sodium hydroxide with hydrochloric acid.

$$\text{NaOH(s)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$$

Oxidation and reduction can be defined in terms of electron transfer or oxidation numbers.

Alcohols with the molecular formula $\text{C}_4\text{H}_9\text{OH}$ occur as four structural isomers. Three of the isomers can be oxidized with acidified potassium dichromate solution to form compounds with the molecular formula $\text{C}_4\text{H}_8\text{O}$. The half-equation for the dichromate ion is:

$$\text{Cr}_2\text{O}_7^{2-}\text{(aq)} + 14\text{H}^+\text{(aq)} + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+}\text{(aq)} + 7\text{H}_2\text{O(l)}$$

Electrolysis has made it possible to obtain reactive metals from their ores.

A reactivity series can be experimentally determined by adding the metals W, X, Y and Z to solutions of these metal ions. The following reactions were observed:

$$\mathrm{W^{2+}(aq) + X(s) \rightarrow W(s) + X^{2+}(aq)}$$
$$\mathrm{Y(s) + W^{2+}(aq) \rightarrow Y^{2+}(aq) + W(s)}$$
$$\mathrm{Z^{2+}(aq) + W(s) \rightarrow Z(s) + W^{2+}(aq)}$$
$$\mathrm{Y(s) + X^{2+}(aq) \rightarrow Y^{2+}(aq) + X(s)}$$

a. Define *oxidation* in terms of electron transfer. [1]

b. (i) Deduce the oxidation number of chromium in $\mathrm{Cr_2O_7^{2-}}$. [10]

(ii) Deduce the half-equation for the oxidation of the alcohol $\mathrm{C_4H_9OH}$.

(iii) Deduce the overall equation for the redox reaction.

(iv) Two of the isomers with the molecular formula $\mathrm{C_4H_9OH}$ can be oxidized further to form compounds with the molecular formula $\mathrm{C_4H_8O_2}$. Deduce the structural formulas of these two isomers.

(v) One isomer cannot be oxidized by acidified potassium dichromate solution.

Deduce its structural formula, state its name and identify it as a primary, secondary or tertiary alcohol.

Name:

Alcohol:

(vi) All isomers of the alcohol $\mathrm{C_4H_9OH}$ undergo complete combustion. State an equation for the complete combustion of $\mathrm{C_4H_9OH}$.

c. (i) Draw a labelled electrolytic cell for the electrolysis of molten potassium bromide, KBr. Include the direction of electron flow, the positive electrode (anode) and the negative electrode (cathode), the location of oxidation and reduction, and the electrolyte. [7]

(ii) Deduce a half-equation for the reaction that occurs at each electrode.

Positive electrode (anode):

Negative electrode (cathode):

(iii) Describe how current is conducted in a molten electrolyte.

d. (i) Deduce the order of reactivity of these four metals, from the least to the most reactive. [2]

(ii) A voltaic cell is made by connecting a half-cell of X in $\mathrm{XCl_2(aq)}$ to a half-cell of Z in $\mathrm{ZCl_2(aq)}$. Deduce the overall equation for the reaction taking place when the cell is operating.

Propane and propene are members of different homologous series.

a. Draw the full structural formulas of propane and propene. [1]

Propane:

Propene:

b. Both propane and propene react with bromine. [4]

(i) State an equation and the condition required for the reaction of 1 mol of propane with 1 mol of bromine.

(ii) State an equation for the reaction of 1 mol of propene with 1 mol of bromine.

(iii) State the type of each reaction with bromine.

Propane:

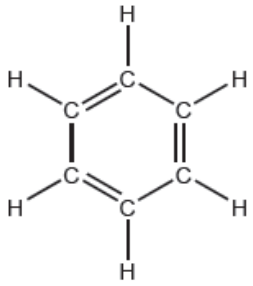
Propene:

The structure of an organic molecule can help predict the type of reaction it can undergo.

Improvements in instrumentation have made identification of organic compounds routine.

The empirical formula of an unknown compound containing a phenyl group was found to be C_4H_4O. The molecular ion peak in its mass spectrum appears at m/z = 136.

a. The Kekulé structure of benzene suggests it should readily undergo addition reactions. [2]



Discuss two pieces of evidence, **one** physical and **one** chemical, which suggest this is not the structure of benzene.

Physical evidence:

. . . . . .

. . . . . .

Chemical evidence:

. . . . . .

. . . . . .

b.i. Formulate the ionic equation for the oxidation of propan-1-ol to the corresponding aldehyde by acidified dichromate(VI) ions. Use section 24 of the data booklet. [2]

b.ii. The aldehyde can be further oxidized to a carboxylic acid. [2]

Outline how the experimental procedures differ for the synthesis of the aldehyde and the carboxylic acid.

Aldehyde:

. . . . . .

. . . . . .

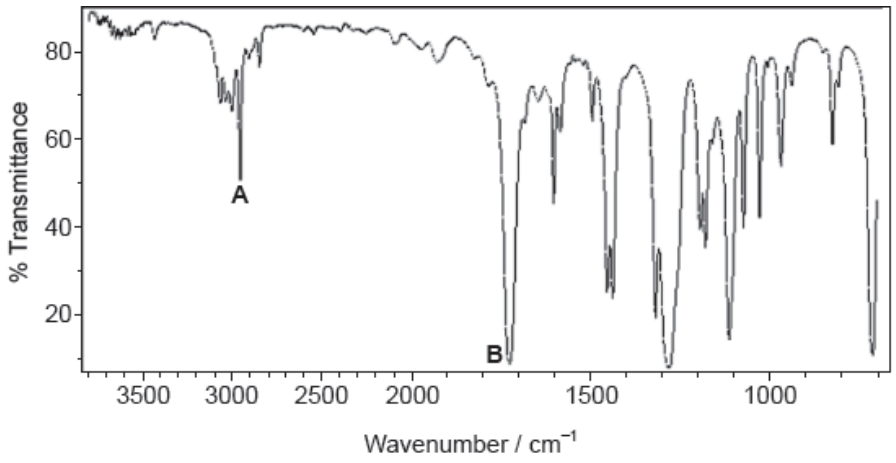
Carboxylic acid:

. . . . . .

. . . . . .

c.i. Deduce the molecular formula of the compound. [1]

c.ii. Identify the bonds causing peaks **A** and **B** in the IR spectrum of the unknown compound using section 26 of the data booklet. [1]



[Source: Food and Agriculture Organization of the United Nations, http://www.fao.org/fileadmin/user_upload/jecfa/img/851.gif. Reproduced with permission]

A:

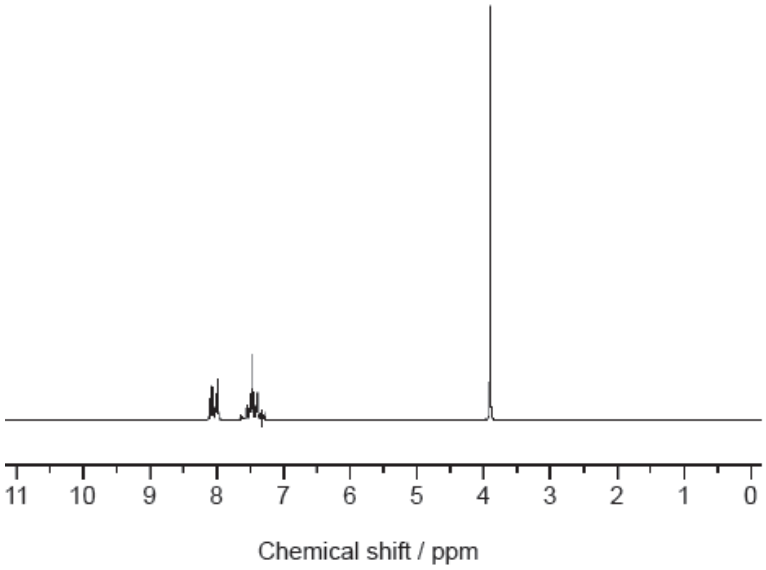
. . . . . .

B:

. . . . . .

c.iii Deduce full structural formulas of **two** possible isomers of the unknown compound, both of which are esters. [2]

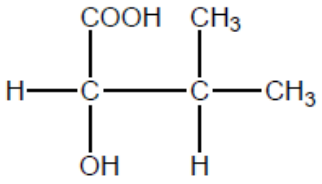
c.iv Deduce the formula of the unknown compound based on its ^{1}H NMR spectrum using section 27 of the data booklet. [1]



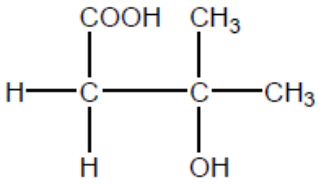
[Source: SDBS, National Institute of Advanced Industrial Science and Technology.]

The reactivity of organic compounds depends on the nature and positions of their functional groups.

The structural formulas of two organic compounds are shown below.



A



B

a.i. Deduce the type of chemical reaction and the reagents used to distinguish between these compounds. [1]

a.ii. State the observation expected for each reaction giving your reasons. [2]

Compound **A**:

. . . . . .

. . . . . .

. . . . . .

Compound **B**:

. . . . . .

. . . . . .

. . . . . .

a.iii Deduce the number of signals and the ratio of areas under the signals in the ^{1}H NMR spectra of the two compounds. [4]

Compound	Number of signals	Ratio of areas
A	. . . . .	. . . . .
B	. . . . .	. . . . .

b. Explain, with the help of equations, the mechanism of the free-radical substitution reaction of ethane with bromine in presence of sunlight. [4]

This question is about carbon and chlorine compounds.

a. Ethane, C_2H_6, reacts with chlorine in sunlight. State the type of this reaction and the name of the mechanism by which it occurs. [1]

Type of reaction:

. . . . . .

Mechanism:

. . . . . .

b. Formulate equations for the two propagation steps and one termination step in the formation of chloroethane from ethane. [3]

Two propagation steps:

. . . . . .

. . . . . .

. . . . . .

. . . . . .

One termination step:

. . . . . .

. . . . . .

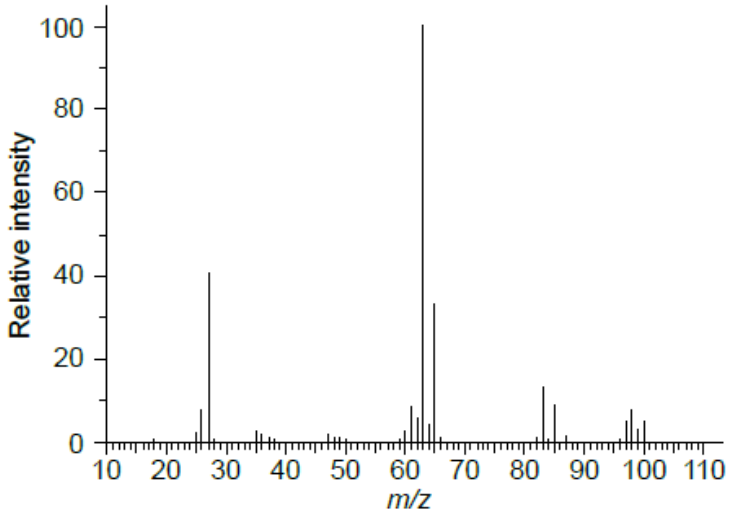
c.i. One possible product, **X**, of the reaction of ethane with chlorine has the following composition by mass: [2]

carbon: 24.27%, hydrogen: 4.08%, chlorine: 71.65%

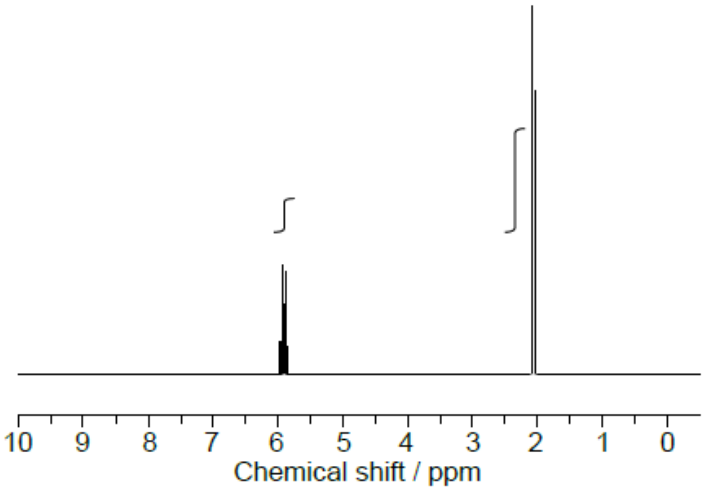
Determine the empirical formula of the product.

c.ii. The mass and ^{1}H NMR spectra of product **X** are shown below. Deduce, giving your reasons, its structural formula and hence the name of the compound. [3]

Mass spectrum:



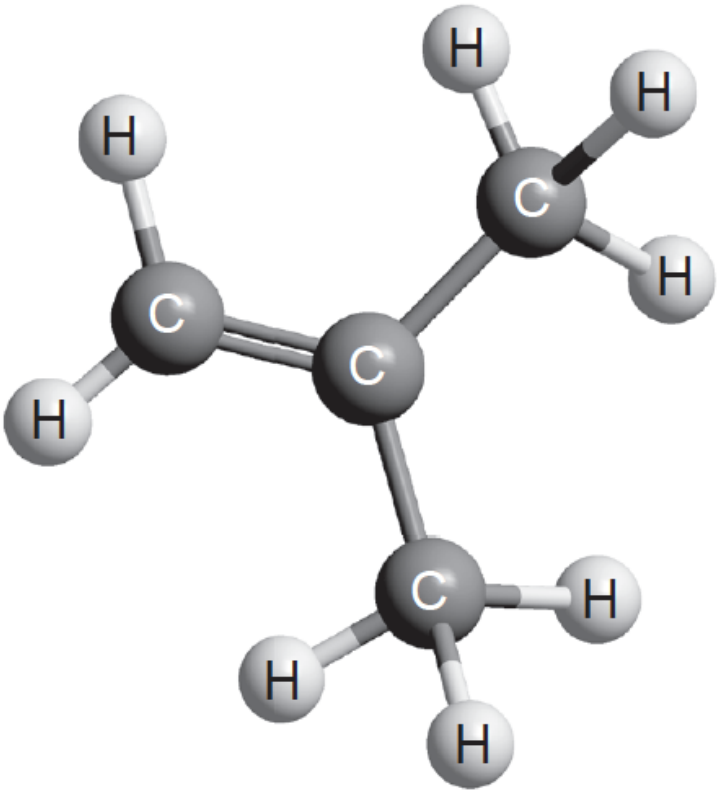
^{1}H NMR spectrum:



[Source: http://sdbs.db.aist.go.jp]

d. Chloroethene, C_2H_3Cl, can undergo polymerization. Draw a section of the polymer with three repeating units. [1]

Alkenes are widely used in the production of polymers. The compound **A**, shown below, is used in the manufacture of synthetic rubber.



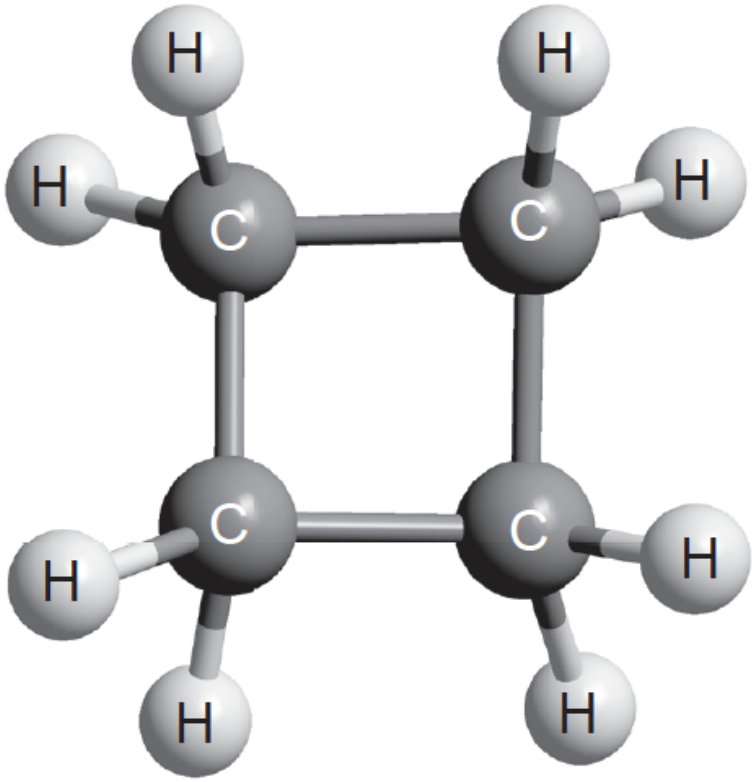
A

a. (i) State the name, applying IUPAC rules, of compound **A**. [3]

(ii) Draw a section, showing three repeating units, of the polymer that can be formed from compound **A**.

(iii) Compound **A** is flammable. Formulate the equation for its complete combustion.

b. Compound **B** is related to compound **A**. [5]



B

(i) State the term that is used to describe molecules that are related to each other in the same way as compound **A** and compound **B**.

(ii) Suggest a chemical test to distinguish between compound **A** and compound **B**, giving the observation you would expect for each.

Test:

Observation with **A**:

Observation with **B**:

(iii) Spectroscopic methods could also be used to distinguish between compounds **A** and **B**.

Predict one difference in the IR spectra **and** one difference in the ^{1}H NMR spectra of these compounds, using sections 26 and 27 of the data booklet.

IR spectra:

^{1}H NMR spectra:

c. A sample of compound **A** was prepared in which the ^{12}C in the CH_2 group was replaced by ^{13}C. [3]

(i) State the main difference between the mass spectrum of this sample and that of normal compound **A**.

(ii) State the structure of the nucleus and the orbital diagram of ^{13}C in its ground state.

No. protons . . . . . No. neutrons . . . . . .

Orbital diagram

d. Draw a 1s atomic orbital and a 2p atomic orbital. [1]

1s: 2p: