

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

AS CHEMISTRY

Paper 2 Organic and Physical Chemistry

Time allowed: 1 hour 30 minutes

Materials

For this paper you must have:

- the Periodic Table/Data Sheet, provided as an insert (enclosed)
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do **not** write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- All working must be shown.
- Do **all** rough work in this book. Cross through any work you do not want to be marked.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 80.

Advice

You are advised to spend about 65 minutes on **Section A** and 25 minutes on **Section B**.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
Section B	
TOTAL	



J U N 2 2 7 4 0 4 2 0 1

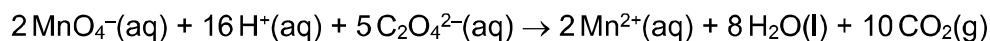
Section A

Answer **all** questions in this section.

0 1

This question is about rates of reaction.

Potassium manganate(VII), KMnO_4 , reacts with sodium ethanedioate, $\text{Na}_2\text{C}_2\text{O}_4$, in the presence of dilute sulfuric acid.



The reaction mixture is purple at the start and goes colourless when **all** the $\text{MnO}_4^-(\text{aq})$ ions have reacted.

The rate of reaction can be measured as $\frac{1000}{t}$ where t = the time taken for the mixture to go colourless.

A student investigated how long it takes for this reaction mixture to go colourless at different temperatures. The same concentrations and volumes of each reagent were used in an experiment at each temperature. **Table 1** shows the results.

Table 1

Temperature / °C	32	38	44	54	67
Time t / s	155	85	50	22	9
$\frac{1000}{t}$	6.45	11.8	20.0	45.5	///

0 1 . 1

Complete **Table 1**.

[1 mark]

0 1 . 2

State the independent variable in this investigation.

[1 mark]

Temperature

0 1 . 3

The student noticed that the temperature of each reaction mixture decreased during each experiment.

Suggest how the student calculated the temperature values in **Table 1**.

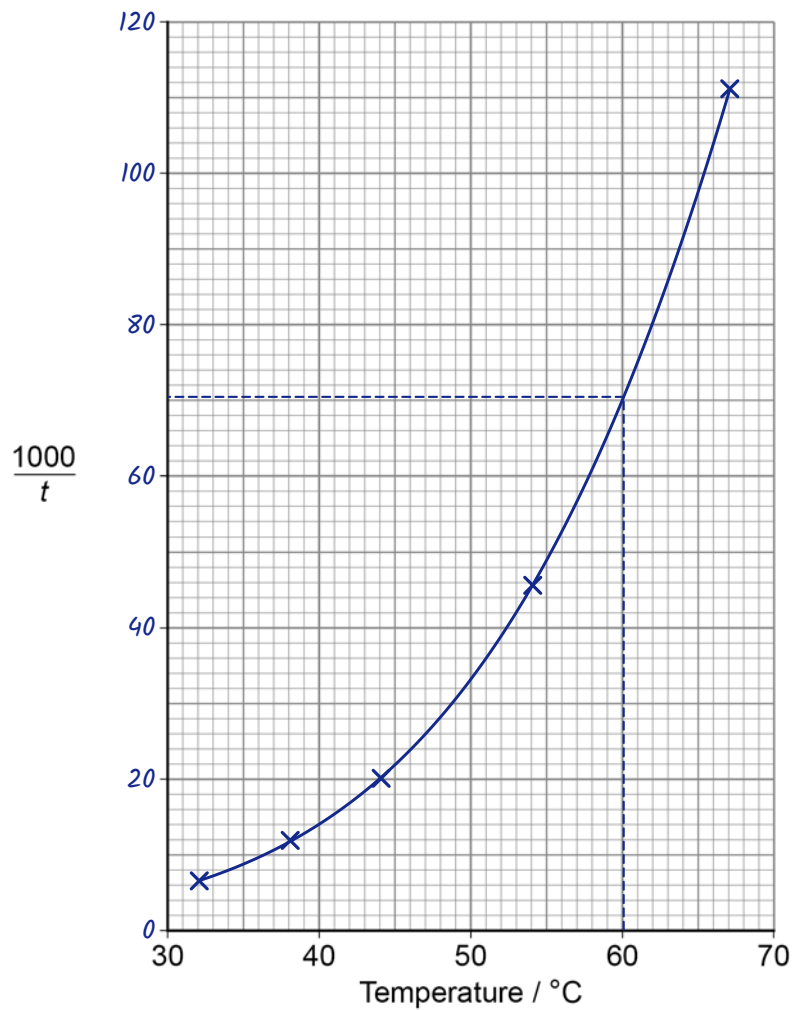
[1 mark]

Measure the temperature of the mixture at the start and at the end of the reaction and calculate the mean (average) of the two values.



0 1 . 4 Use the data in **Table 1** to plot a graph of $\frac{1000}{t}$ against temperature.

[3 marks]



0 1 . 5 Use your graph in Question **01.4** to find the time taken for the mixture to go colourless at 60 °C
Show your working.

[1 mark]

From the graph at 60 °C, $1000/t = 70$

$$t = 1000 \div 70 = 14.3 \text{ s}$$

Time t 14.3 s

Turn over ►



0 1 . 6

The investigation shows that increasing the temperature causes the rate of reaction to increase.

Explain why a small increase in temperature causes a large increase in the rate of reaction.

[2 marks]

Most particles have less energy than the activation energy. A small increase in temperature means many more particles have energy greater than or equal to the activation energy (the Maxwell-Boltzmann distribution shifts to the right).

So there are many more successful collisions per unit time (a much greater frequency of successful collisions), so the rate increases a lot.

9



Turn over for the next question

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outside the
box*

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ANSWER IN THE SPACES PROVIDED**

Turn over ►



0 2

A student has samples of these four compounds but does not know which is which:

- butanoic acid
- 2-methylpropanal
- 2-methylpropanoic acid
- 2-methylpropan-1-ol

Step 1: Two of these compounds can be identified by simple chemical tests.

Step 2: The other two compounds, that contain the same functional group as each other, can then be distinguished using a spectroscopic technique.

Describe how these two steps could be used to identify which compound is which.

[6 marks]

Step 1: Add Tollens' reagent to a sample of each of the four compounds and warm gently in a water bath. Only 2-methylpropanal (the aldehyde) gives a silver mirror, so it is identified. The other three compounds show no change.

Then add acidified potassium dichromate(VI) to fresh samples of the remaining three compounds and warm. Only 2-methylpropan-1-ol (a primary alcohol) is oxidised, so the solution changes from orange to green. The two carboxylic acids do not react, so the solution stays orange.

The Tollens' test must be done first, because the aldehyde would also turn acidified potassium dichromate(VI) from orange to green, so it could not be told apart from the alcohol.

The two compounds left are butanoic acid and 2-methylpropanoic acid. Both give effervescence with sodium carbonate solution (carbon dioxide is produced), which confirms they both contain the carboxylic acid group.

Step 2: Distinguish the two acids using infrared spectroscopy. Both have the same functional groups, so both spectra show a broad O-H (acid) absorption at $2500-3000\text{ cm}^{-1}$ and a C=O absorption at $1680-1750\text{ cm}^{-1}$,



so these cannot be used.

Instead, use the fingerprint region (below 1500 cm^{-1}) of each spectrum. Compare the fingerprint region of each unknown acid with the spectra of known samples of butanoic acid and 2-methylpropanoic acid (e.g. from a database). The acid whose fingerprint region is an exact match with butanoic acid is butanoic acid, and the other is 2-methylpropanoic acid.



0 3

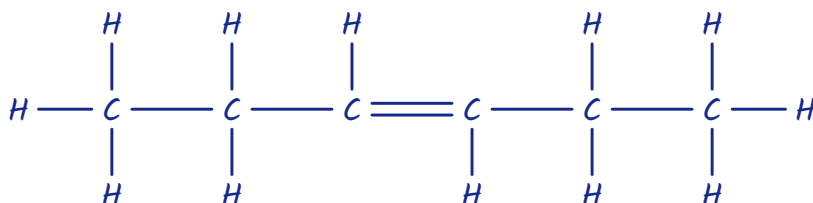
This question is about isomers.

Hex-2-ene has the molecular formula C_6H_{12}

0 3 . 1

Draw the displayed formula of a **position** isomer of hex-2-ene that exists as *E* and *Z* isomers.

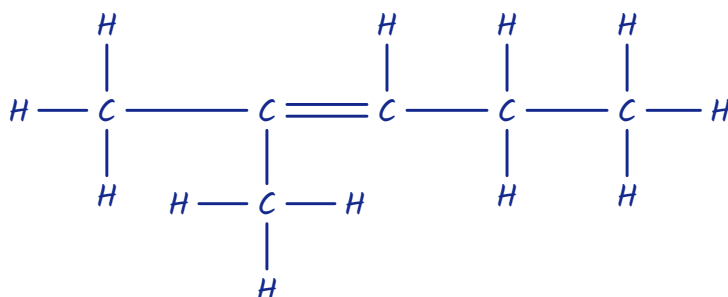
[1 mark]



0 3 . 2

Draw the displayed formula of a **chain** isomer of hex-2-ene that does **not** exist as *E* and *Z* isomers.

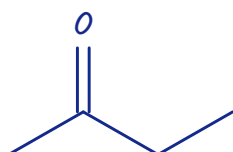
[1 mark]

Butanal has the molecular formula C_4H_8O

0 3 . 3

Draw the skeletal formula of a **functional group** isomer of butanal that has an absorption in the range $1680-1750\text{ cm}^{-1}$ in its infrared spectrum.

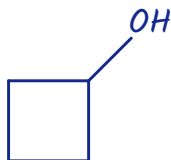
[1 mark]



0 3 . 4

Draw the skeletal formula of a structural isomer of butanal that has an absorption in the range $3230\text{--}3550\text{ cm}^{-1}$ in its infrared spectrum.

[1 mark]



0 3 . 5

Several saturated halogenoalkanes contain 17.8% carbon, 3.0% hydrogen and 79.2% bromine by mass.

Calculate the empirical formula of these compounds.

Give the IUPAC names of **two** saturated halogenoalkanes that have this empirical formula.

[4 marks]

$$C: 17.8 \div 12.0 = 1.48 \quad H: 3.0 \div 1.0 = 3.00 \quad Br: 79.2 \div 79.9 = 0.99$$

$$\div \text{smallest: } C = 1.48 \div 0.99 = 1.5 \quad H = 3.00 \div 0.99 = 3 \quad Br = 1$$

$$C : H : Br = 1.5 : 3 : 1 = 3 : 6 : 2$$

Empirical formula $C_3H_6Br_2$

Names of halogenoalkanes

1 1,2-dibromopropane

2 1,3-dibromopropane

Turn over ►

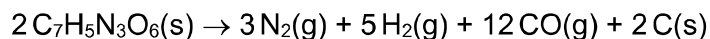


0 4

This question is about gas volumes.

0 4 . 1

TNT ($\text{C}_7\text{H}_5\text{N}_3\text{O}_6$) is an explosive because it can decompose very quickly and exothermically to form a large volume of gas. An equation for this decomposition is



Calculate the volume of gas, in m^3 , measured at 1250°C and $101\,000 \text{ Pa}$, produced by the decomposition of 1.00 kg of TNT ($M_r = 227.0$).

The gas constant, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$

[5 marks]

$$n(\text{TNT}) = 1000 \div 227.0 = 4.41 \text{ mol}$$

$$n(\text{gas}) = 4.41 \times (3 + 5 + 12) \div 2 = 4.41 \times 10 = 44.1 \text{ mol}$$

$$T = 1250 + 273 = 1523 \text{ K}$$

$$pV = nRT \text{ so } V = nRT \div p$$

$$V = (44.05 \times 8.31 \times 1523) \div 101000 = 5.52 \text{ m}^3$$

Volume of gas 5.52 m^3



0 4 . 2 Alkenes have the general formula C_nH_{2n}

When alkenes undergo complete combustion, 1.0 mol of C_nH_{2n} reacts with $\frac{3n}{2}$ mol of oxygen.

Calculate the volume of oxygen needed for the complete combustion of 200 cm³ of but-1-ene.

The volumes of all gases are measured at the same temperature and pressure.

[1 mark]

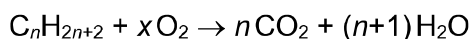
but-1-ene: $n = 4$, so $3n/2 = 6$ mol O_2 per mol

$$200 \times 6 = 1200$$

Volume of oxygen 1200 cm³

0 4 . 3 Alkanes have the general formula C_nH_{2n+2}

Alkanes undergo complete combustion in a plentiful supply of oxygen.



Determine x in terms of n

[1 mark]

O atoms on right = $2n + (n + 1) = 3n + 1$

$$x = (3n + 1) \div 2$$

x $(3n + 1)/2$

7

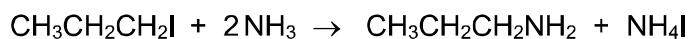
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0 5

This question is about the synthesis of propylamine ($\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$) by the reaction of 1-iodopropane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{I}$) with an excess of ammonia.



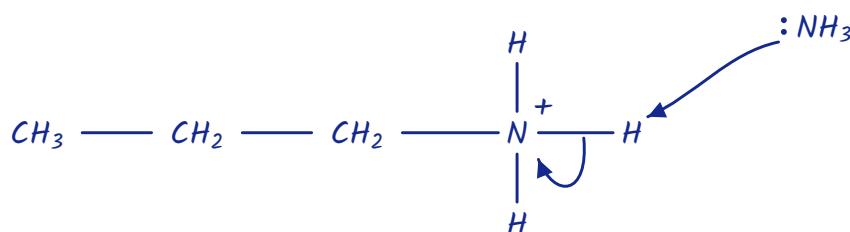
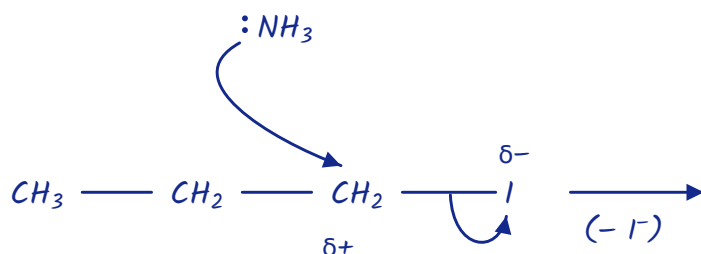
0 5 . 1

Name and outline the mechanism for this reaction.

[5 marks]

Name of mechanism Nucleophilic substitution

Outline of mechanism



0 5 . 2

1-iodopropane is a liquid at room temperature.

Calculate the number of molecules in 5.0 cm^3 of 1-iodopropane ($M_r = 169.9$).
Give your answer in standard form.

For 1-iodopropane, density = 1.75 g cm^{-3}

The Avogadro constant, $L = 6.022 \times 10^{23} \text{ mol}^{-1}$

[2 marks]

$$\text{mass} = 5.0 \times 1.75 = 8.75 \text{ g}$$

$$n = 8.75 \div 169.9 = 0.0515 \text{ mol}$$

$$\text{molecules} = 0.0515 \times 6.022 \times 10^{23} = 3.10 \times 10^{22}$$

Number of molecules 3.10×10^{22}

0 5 . 3

In an experiment, 10.3 g of 1-iodopropane ($M_r = 169.9$) are reacted with an excess of ammonia. 2.3 g of propylamine ($M_r = 59.0$) are produced.

Calculate the percentage yield in this experiment.

[2 marks]

$$n(\text{1-iodopropane}) = 10.3 \div 169.9 = 0.0606 \text{ mol}$$

$$n(\text{propylamine}) = 2.3 \div 59.0 = 0.0390 \text{ mol}$$

$$\% \text{ yield} = (0.0390 \div 0.0606) \times 100 = 64.3 \%$$

Percentage yield 64.3%

9

Turn over ►



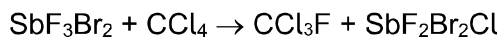
0 6

Trichlorofluoromethane (CCl_3F) was developed as a refrigerant. The production and use of CCl_3F is now restricted.

0 6

1

The equation for a process used to manufacture CCl_3F is



Calculate the percentage atom economy for the production of CCl_3F in this reaction. Give your answer to 3 significant figures.

[2 marks]

$$M_r \text{ CCl}_3\text{F} = 12.0 + 3(35.5) + 19.0 = 137.5$$

$$M_r \text{ SbF}_3\text{Br}_2 = 121.8 + 3(19.0) + 2(79.9) = 338.6$$

$$M_r \text{ CCl}_4 = 12.0 + 4(35.5) = 154.0$$

$$\% \text{ atom economy} = 137.5 \div (338.6 + 154.0) \times 100$$

$$= 137.5 \div 492.6 \times 100 = 27.9 \%$$

Percentage atom economy 27.9 %

An alternative synthesis of CCl_3F is the free-radical substitution reaction between fluoromethane (CH_3F) and chlorine.

0 6

2

An intermediate in this alternative synthesis is dichlorofluoromethane (CHCl_2F)

Give equations to represent the two propagation steps in the conversion of CHCl_2F into CCl_3F

[2 marks]

Propagation step 1



Propagation step 2



0 6 3

Analysis of the products of this reaction shows the formation of a compound with the empirical formula CCl_2F

Give an equation to represent a termination step forming this compound.
Show the structural formula of the product in the equation.

[1 mark]



5

Turn over for the next question

Turn over ►



0 7

In Europe, some of the glucose from crops is fermented to produce ethanol.

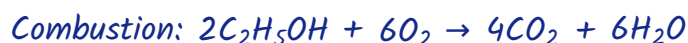
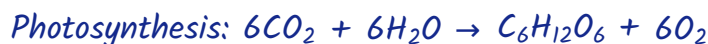
Use of a carbon-neutral fuel leads to no net emissions of carbon dioxide to the atmosphere.

0 7 . 1

The ethanol produced by fermentation of glucose may be regarded as a carbon-neutral fuel.

Justify this statement. Include the relevant chemical equations in your answer.

[4 marks]



The crops take in 6CO_2 from the atmosphere to make one $\text{C}_6\text{H}_{12}\text{O}_6$ by photosynthesis. Fermentation gives out 2CO_2 and burning the two ethanol molecules gives out 4CO_2 , so 6CO_2 are given out in total. The CO_2 taken in equals the CO_2 given out, so there are no net CO_2 emissions.

Coffee beans from South America are exported to Europe in an outer layer called silverskin.

The waste silverskin can be fermented to produce a solution containing propanone, ethanol and butan-1-ol.

0 7 . 2

Suggest why ethanol produced in Europe using silverskin from South America is less likely to be carbon-neutral than ethanol produced from crops grown in Europe.

[1 mark]

The silverskin must be transported from South America to Europe, which burns fuel and produces CO_2 (carbon emissions), so it has a larger carbon footprint.



0 7 3

Table 2 shows the enthalpies of combustion of the three fuels from the fermentation of silverskin.

Table 2

Fuel	Standard enthalpy of combustion / kJ mol^{-1}	Energy released per mole of CO_2 produced / kJ
ethanol, $\text{C}_2\text{H}_5\text{OH(l)}$	-1371	$1371 \div 2 = 685.5$
butan-1-ol, $\text{C}_4\text{H}_9\text{OH(l)}$	-2673	$2673 \div 4 = 668.3$
propanone, $\text{C}_3\text{H}_6\text{O(l)}$	-1786	$1786 \div 3 = 595.3$

One way to measure a fuel's environmental impact is to measure the amount of energy released per mole of CO_2 produced.

Complete **Table 2**.

Use your answers to deduce the fuel with the lowest environmental impact by this measure.

[2 marks]

Ethanol has the lowest environmental impact, because it releases the most energy per mole of CO_2 produced (685.5 kJ).

Question 7 continues on the next page

Turn over ►



0 7 . 4

A student investigated the combustion of propanone ($\text{C}_3\text{H}_6\text{O}$) using calorimetry.

A copper calorimeter containing water was heated by the complete combustion of some propanone. The student did not record the final temperature of the water.

Table 3 shows the student's results.

Table 3

Mass of propanone burned / g	1.18
Mass of water / g	260
Initial temperature of water / °C	22.3
Final temperature of water / °C	Not recorded

Use the results in **Table 3** to calculate a value for final temperature of the water in the experiment.

Assume that no heat was lost in the experiment and that the heat capacity of the calorimeter is negligible.

For propanone, enthalpy of combustion = $-1786 \text{ kJ mol}^{-1}$

For water, specific heat capacity = $4.18 \text{ J g}^{-1} \text{ K}^{-1}$

[4 marks]

$$n(\text{propanone}) = 1.18 \div 58.0 = 0.0203 \text{ mol}$$

$$q = 0.0203 \times 1786 = 36.3 \text{ kJ} = 36300 \text{ J}$$

$$q = mc\Delta T \text{ so } \Delta T = q \div mc = 36300 \div (260 \times 4.18) = 33.4 \text{ }^{\circ}\text{C}$$

$$\text{Final temperature} = 22.3 + 33.4 = 55.7 \text{ }^{\circ}\text{C}$$

Final temperature of water 55.7 °C



0 7 5 Butan-1-ol can be added to petrol for cars.

An equation for the complete combustion of gaseous butan-1-ol is shown.

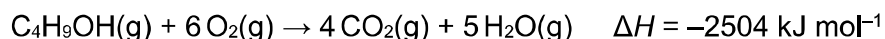


Table 4 shows some mean bond enthalpy data.

Table 4

Bond	C=O	C-H	C-O	O-H	O=O
Mean bond enthalpy / kJ mol^{-1}	805	412	360	463	496

Use these data to calculate a value for the mean C-C bond enthalpy in gaseous butan-1-ol.

[3 marks]

$$\text{Bonds broken: } 3(\text{C}-\text{C}) + 9(\text{C}-\text{H}) + (\text{C}-\text{O}) + (\text{O}-\text{H}) + 6(\text{O}=\text{O})$$

$$= 3(\text{C}-\text{C}) + 9(412) + 360 + 463 + 6(496) = 3(\text{C}-\text{C}) + 7507$$

$$\text{Bonds made: } 8(\text{C}=\text{O}) + 10(\text{O}-\text{H}) = 8(805) + 10(463) = 11070$$

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

$$-2504 = 3(\text{C}-\text{C}) + 7507 - 11070$$

$$3(\text{C}-\text{C}) = 1059$$

$$\text{C}-\text{C} = 1059 \div 3 = 353 \text{ kJ mol}^{-1}$$

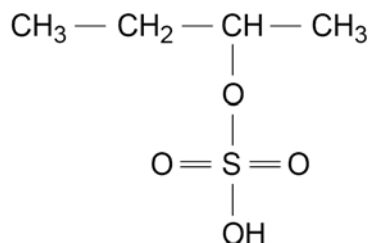
C-C bond enthalpy 353 kJ mol^{-1}

Question 7 continues on the next page

Turn over ►



In the first part of this process, but-1-ene reacts with concentrated sulfuric acid to form compounds **W** and **X**.



Compound **X**

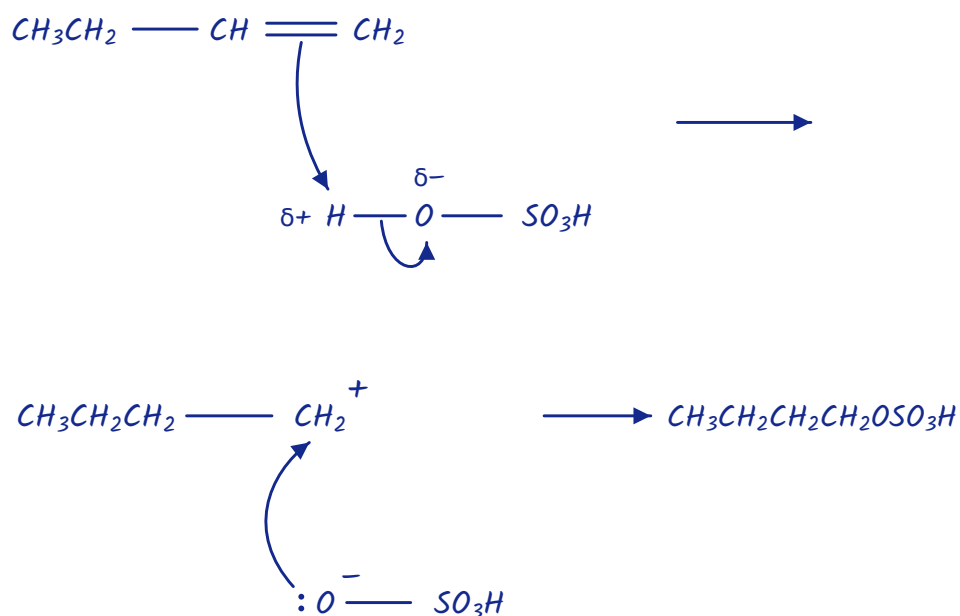
Butan-1-ol is then made from compound **W**.

Name and outline a mechanism to show the conversion of but-1-ene into compound **W** in the first part of this process.

[5 marks]

Name of mechanism *Electrophilic addition*

Outline of mechanism



07.7

There is a very low yield of butan-1-ol from but-1-ene in this manufacturing process.

Explain why.

[2 marks]

*Butan-1-ol is made from W, which is formed via a primary carbocation,
and a primary carbocation is less stable than a secondary carbocation.
So most of the but-1-ene reacts via the more stable secondary
carbocation to form X, and very little W forms.*

21

Turn over for Section B

Turn over ►



Section B

Answer **all** questions in this section.Only **one** answer per question is allowed.

For each answer completely fill in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



If you want to change your answer you must cross out your original answer as shown.

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

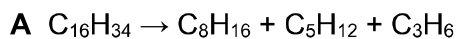
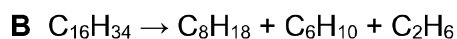
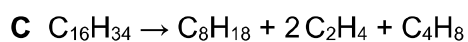
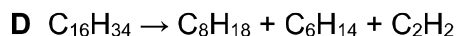
You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 8

When hexadecane ($C_{16}H_{34}$) is heated to a high temperature, one molecule of hexadecane decomposes to form an alkane containing eight carbon atoms and two different unsaturated compounds.

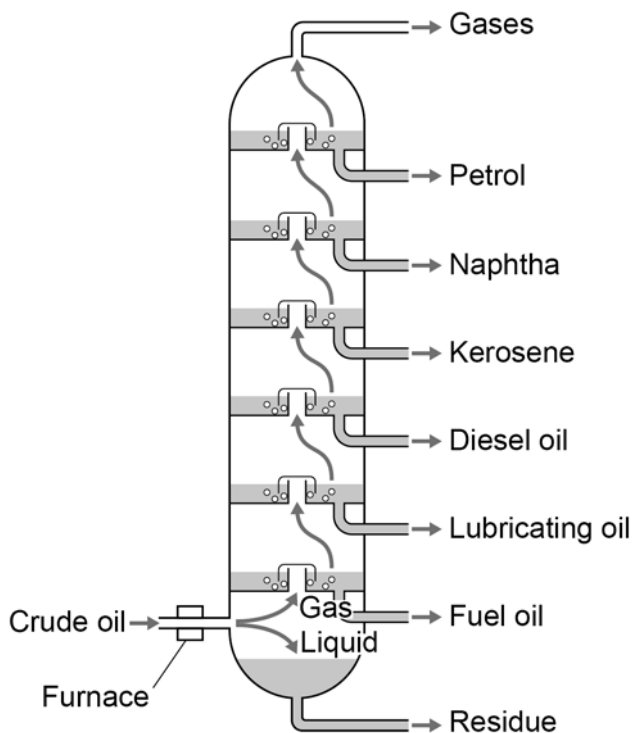
Which equation could represent this reaction?

[1 mark]

☐☐☒☐

0 9

The diagram shows a fractionating column used in the industrial fractional distillation of crude oil.



Which statement is correct?

[1 mark]

- A** The most viscous product is fuel oil.
- B** The boiling point of naphtha is higher than diesel oil.
- C** Molecules in diesel oil are held together by hydrogen bonds.
- D** Kerosene is a mixture of compounds.

☐
☐
☐
☒

1 0

Which statement about poly(ethene) is correct?

[1 mark]

- A** It has a lower relative molecular mass than ethene.
- B** It has a lower density than ethene at standard temperature and pressure.
- C** It has a higher melting point than ethene.
- D** It decolourises bromine water.

☐
☐
☒
☐

Turn over ►



1 1

A polymer is formed from the monomer $\text{CH}_2=\text{CHCN}$

Which statement is **not** correct?

[1 mark]

A The monomer is propanenitrile.

☒

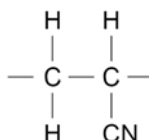
B The monomer is unsaturated.

☐

C The polymer is an addition polymer.

☐

D The polymer has the repeating unit


☐

1 2

Which alcohol when dehydrated forms a mixture of alkenes?

[1 mark]

A propan-1-ol

☐

B propan-2-ol

☐

C pentan-1-ol

☐

D pentan-2-ol

☒

1 3

Which compound has the highest boiling point?

[1 mark]

A $\text{CH}_3\text{COCH}_2\text{CH}_3$

☐

B $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$

☒

C $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$

☐

D $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$

☐


1 4

Which statement about molecules in a gas is correct?

[1 mark]

- A At a fixed temperature they **all** move at the same speed. ☐
- B At a fixed temperature their average kinetic energy is constant. ☒
- C As temperature increases, there are more molecules with the most probable energy. ☐
- D As temperature decreases, there are fewer molecules with the mean energy. ☐

1 5

Which compound produces $(\text{CH}_3)_2\text{CHCOCH}_3$ when oxidised?

[1 mark]

- A 2-methylpropan-1-ol ☐
- B 2,2-dimethylpropanol ☐
- C 2-methylbutan-2-ol ☐
- D 3-methylbutan-2-ol ☒

1 6

Which reaction does **not** result in a change in the shape around a carbon atom?

[1 mark]

- A chloromethane with aqueous sodium hydroxide ☒
- B ethene with bromine ☐
- C propane with excess oxygen ☐
- D propan-1-ol with acidified potassium dichromate(VI) ☐

Turn over ►



1 7

Which compound has the same empirical formula and molecular formula?

[1 mark]

A butane

☐

B but-1-ene

☐

C propane

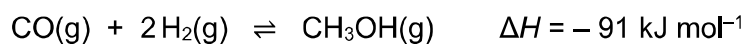
☒

D propene

☐

Questions 18, 19 and 20

Methanol is made in this equilibrium reaction, using a catalyst.



1 8

The reaction reaches equilibrium in a container of fixed volume.

Which is the expression for K_c for this equilibrium?

[1 mark]

$$\text{A } K_c = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}] + [\text{H}_2]^2}$$

☐

$$\text{B } K_c = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}] [\text{H}_2]^2}$$

☒

$$\text{C } K_c = \frac{[\text{CO}] + [\text{H}_2]^2}{[\text{CH}_3\text{OH}]}$$

☐

$$\text{D } K_c = \frac{[\text{CO}] [\text{H}_2]^2}{[\text{CH}_3\text{OH}]}$$

☐

1 9

2.0 mol of carbon monoxide is mixed with 3.0 mol of hydrogen and allowed to reach equilibrium.

The equilibrium mixture contains 0.6 mol of methanol.

What is the total amount, in mol, of gas at equilibrium?

[1 mark]**A** 3.2☐**B** 3.8☒**C** 4.4☐**D** 5.0☐**2 0**

Which change in condition will decrease the equilibrium yield of methanol?

[1 mark]**A** Increase the amount of CO in the equilibrium mixture.☐**B** Increase the pressure.☐**C** Increase the surface area of the catalyst.☐**D** Increase the temperature.☒

Turn over for the next question

Turn over ►

Questions 21 and 22

When 2-bromobutane is warmed with potassium hydroxide solution, substitution and elimination reactions both occur.

2 1

Which of these compounds is **not** produced?

[1 mark]

A butan-1-ol

☒

B butan-2-ol

☐

C but-1-ene

☐D *E*-but-2-ene☐

2 2

What is the role of the hydroxide ions in the elimination reaction?

[1 mark]

A base

☒

B catalyst

☐

C electrophile

☐

D nucleophile

☐

15

END OF QUESTIONS



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