PEARSON EDEXCEL IAL CHEMISTRY · YCH11

CHEMISTRY



EXAM QUESTION PACK

UNIT 2: MASS SPECTRA AND IR

SCORE	PERCENTAGE
/108	%

STEMUP

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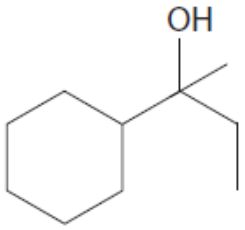
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Q1.

An alcohol **Y** has the structure shown.



(a) Describe a **chemical** test and its positive result for the alcohol functional group in **Y**.

(2)

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(b) **Y** reacts with concentrated phosphoric(V) acid, H_3PO_4, to form four isomers with the molecular formula $C_{10}H_{18}$.

(i) Draw the skeletal formulae of the **four** isomers formed in this reaction.

(4)

(ii) Describe, by referring to wavenumbers and bonds, how the infrared spectra of the isomers differ from the infrared spectrum of alcohol **Y**.

(2)

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(c) An isomer of **Y**, citronellol, has the systematic name 3,7-dimethyloct-6-en-1-ol.

Draw the structure of citronellol.

(2)

(Total for question = 10 marks)

Q2.

Answer the questions with a cross in the boxes you think are correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

A white solid, **X**, gives a red colour in the flame test and a cream precipitate forms when acidified silver nitrate solution is added to a solution of **X**.

(a) What is the white solid, **X**?

(1)

☒ **A** lithium chloride

☒ **B** calcium chloride

☒ **C** strontium bromide

☒ **D** barium bromide

(b) What causes the flame colour to be red?

(1)

☒ **A** electrons absorb blue and green light as they are promoted

☒ **B** electrons emit red light as they are promoted

☒ **C** blue and green light is absorbed as electrons return to lower energy levels

☒ **D** red light is emitted as electrons return to lower energy levels

Use this space for any rough working. Anything you write in this space will gain no credit.

(Total for question = 2 marks)

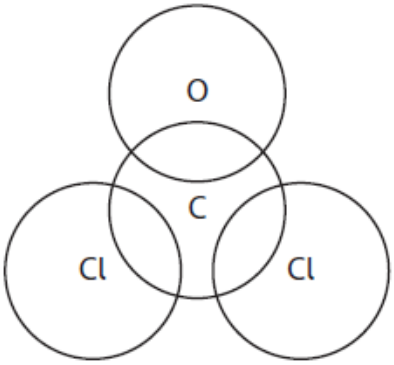
Q3.

Phosgene ($COCl_2$) is a colourless gas used in the pharmaceutical industry.

Phosgene has a boiling temperature of 8 °C and is extremely toxic.

(a) Complete the dot-and-cross diagram to show the bonding in phosgene.

(2)



(b) Phosgene can be formed from carbon monoxide and chlorine, using a catalyst of activated carbon.

$$CO(g) + Cl_2(g) \leftrightarrow COCl_2(g) \qquad \Delta_r H = -107.6 \text{ kJ mol}^{-1}$$

(i) State and explain how the reaction conditions could be changed to maximise the **equilibrium** yield of phosgene in this reaction.

(4)

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(ii) The standard enthalpy change of formation for phosgene is $\Delta_f H = -220.1$ kJ mol^{-1}.

Complete the Hess cycle and determine the standard enthalpy change of formation for carbon

monoxide. Use the data from (b)(i).

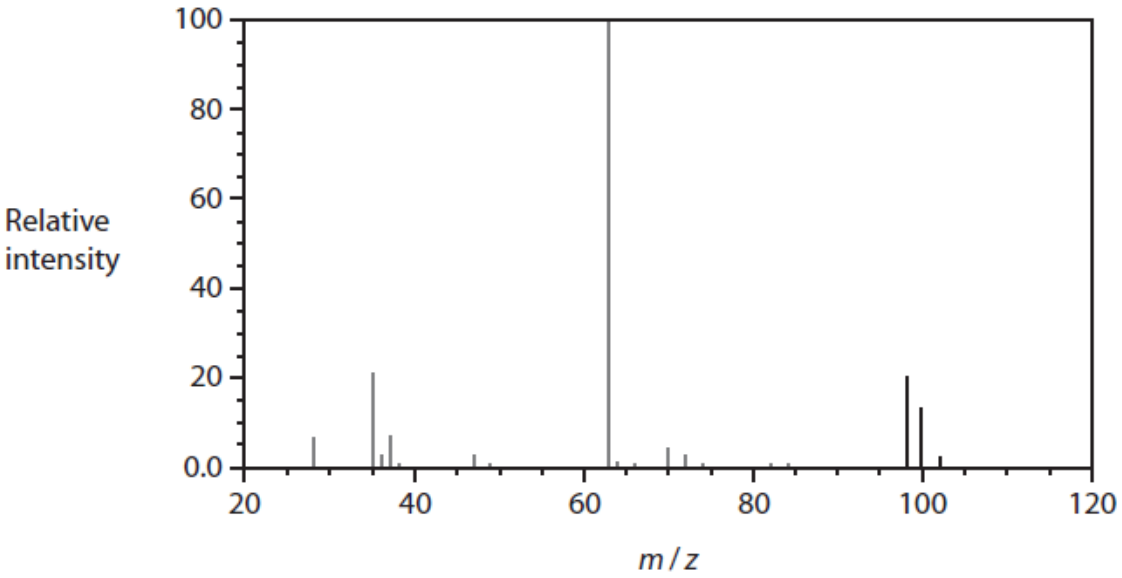
Include state symbols in your cycle.

(4)

$CO(g) \quad + \quad Cl_2(g) \quad \rightarrow \quad COCl_2(g)$

(c) The mass spectrum of a sample of phosgene is shown.

The peak at $m / z = 65$ has been omitted.



(i) Give the reason for the **ratio** of peak heights at m / z values of 102, 100 and 98.

(2)

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(ii) Suggest an identity for the peak at $m / z = 63$.

(1)

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(iii) The peak at $m / z = 65$ has been omitted.

Draw **on the mass spectrum** the peak at $m / z = 65$, showing its relative intensity.

(1)

(d) Use your Data Booklet to suggest the wavenumber of a strong absorbance you would expect to see in the infrared spectrum for phosgene. Justify your answer.

(2)

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(e) In UV light, trichloromethane ($CHCl_3$, boiling temperature 61°C) reacts with oxygen to form phosgene and hydrogen chloride.

(i) Write an equation for this reaction.
State symbols are not required.

(1)

(ii) In a closed bottle, the rate of this reaction decreases with time.

Give a reason for this.

(1)

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(iii) Suggest a precaution that should be taken when opening a bottle of trichloromethane.

(1)

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(iv) Trichloromethane can be used as an anaesthetic.

Suggest whether an old bottle of trichloromethane can still be used for medical treatment, giving a reason for your answer.

(1)

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(Total for question = 20 marks)

Q4.

(a) The concentration of atmospheric carbon dioxide is at its highest level for 800 000 years.

Carbon Capture and Utilisation (CCU) uses waste carbon dioxide from industrial processes to make green fuels,
methanol, plastics or pharmaceuticals. One method uses the reaction between carbon dioxide and hydrogen to make methanol.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \qquad \Delta_r H = -49.5\,kJ\,mol^{-1}$$

The conditions for this industrial reaction are a pressure of 50 atm, a temperature of 250 °C and a copper catalyst.

(i) Explain why high pressure is used.

(2)

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(ii) Discuss the factors leading to a choice of 250 °C in this process.

(3)

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(iii) Give a reason why using a catalyst to increase the rate makes the process more sustainable.

(1)

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(b) Methanol can be oxidised to produce methanoic acid.

(i) State the reagents and reaction conditions for this oxidation in the laboratory.

(2)

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(ii) Complete the equation to show the products of this oxidation.

State symbols are not required.

(1)

$$CH_3OH + \text{.....} [O] \rightarrow$$

(iii) Give a chemical test, and its positive result, that could be used to confirm the functional group in methanoic acid.

(2)

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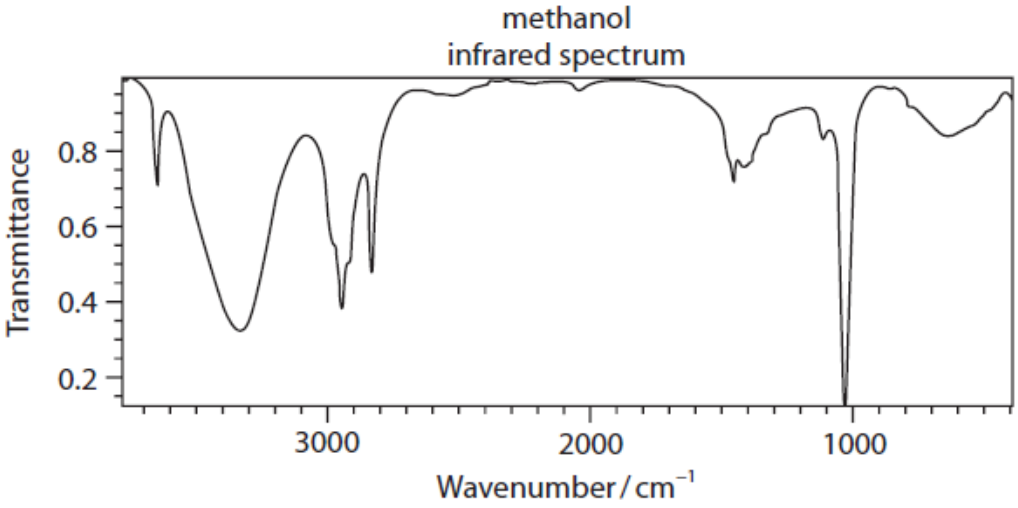
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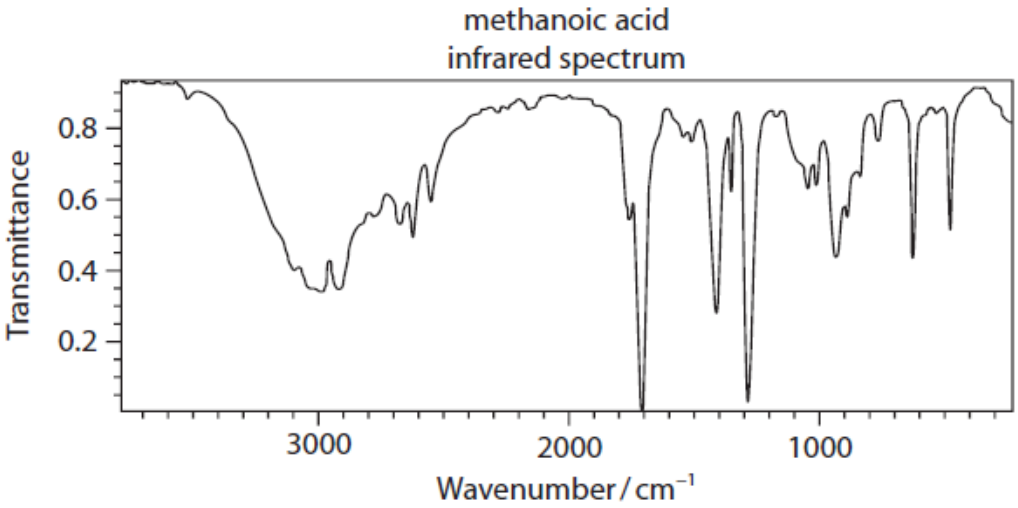
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(iv) The infrared spectra of methanol and methanoic acid are shown.

Explain how these could be used to show that **all** the methanol has been converted to methanoic acid,
quoting relevant bonds and wavenumbers.
Use your Data Booklet.

(3)





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(c) (i) Methanol produced from petrol by CCU may be mixed with petrol derived from fossil fuels.

A concentration of 5% by mass of methanol is used.

Explain how the use of this fuel would affect the increase in global temperatures.

(2)

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(ii) Calculate the mass of carbon dioxide released when 1 mol of octane (C_8H_{18}) is burned completely.

(1)

(iii) A motorist who uses 1200 kg of fuel each year in a car changes to a fuel with 5% of the mass of petrol replaced
by methanol produced by CCU.

Calculate the annual reduction, in kg, of carbon dioxide released by the car.

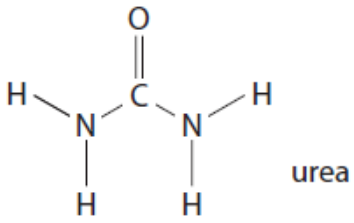
[Assume petrol has the same molecular formula as octane and the added methanol does not contribute any additional
carbon dioxide when burned.]

(2)

(Total for question = 19 marks)

Q5.

Some diesel cars contain an extra catalytic converter for the reduction of nitrogen oxides (NO_x) in exhaust gases.
A solution of urea is used for this process.



urea

(a) Urea has a melting temperature of 133 °C.

Explain why this value is higher than expected for a relatively small molecule.

(3)

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(b) A saturated solution of urea has a concentration of 9.07 mol dm^{-3} at 25°C.

Calculate the mass of urea in 150 cm^3 of a saturated solution.

(2)

(c) State why NO_x emissions are harmful to the environment.

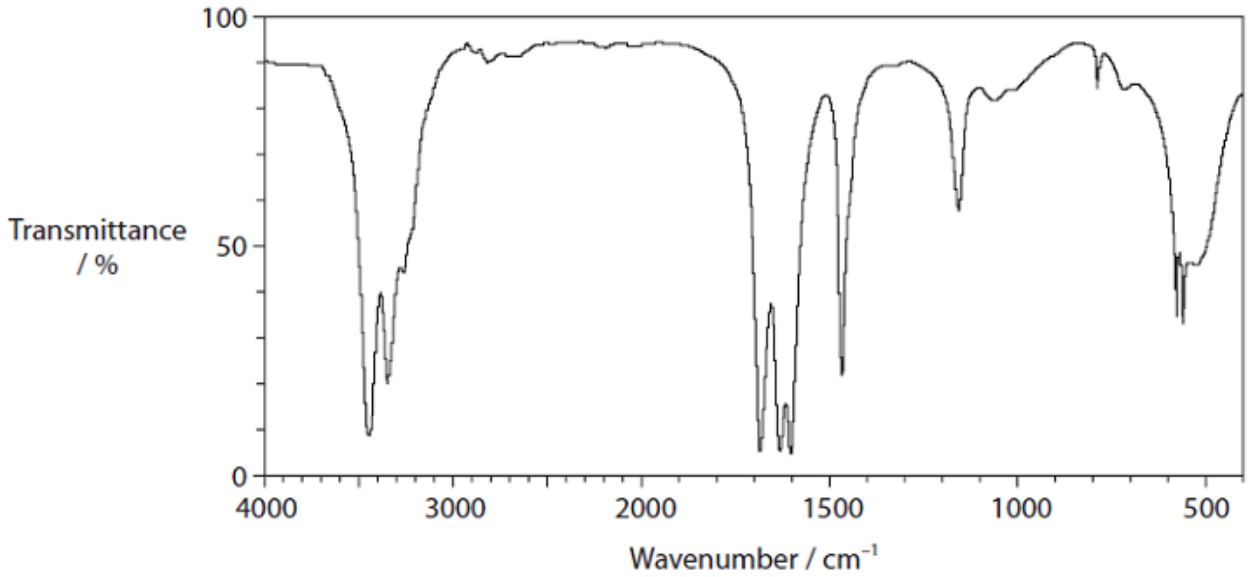
(1)

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(d) An infrared spectrum of urea is shown.

Refer to your Data Booklet.



(i) Draw a circle around an absorption in the spectrum that could be due to the stretching of the N—H bond.

(1)

(ii) Identify the bond responsible for the absorption at 1683 cm^{-1}.

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(1)

(e) In a diesel car exhaust system, the urea reacts with water to form ammonia and carbon dioxide. The enthalpy change for this reaction is +133 kJ mol^{-1}.

(i) Complete the equation for this **reversible** reaction.

State symbols are not required.

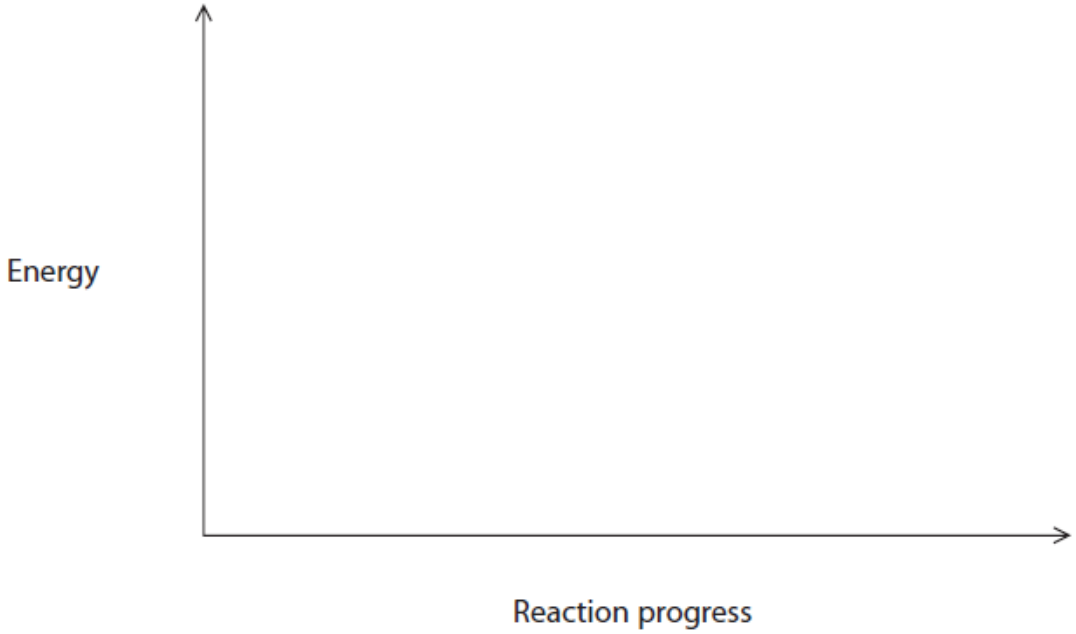
(1)

$(NH_2)_2CO + H_2O$

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(ii) Sketch the reaction profile for the forward reaction on the axes provided.

Include labels for ΔH and the activation energy (E_a).



(3)

(f) The catalytic converter contains metal oxides. When the exhaust gases pass through the catalytic converter, ammonia reacts with NO_x gases to form nitrogen and water.

(i) Explain why it is **not** correct to state that urea is acting as a catalyst in the reaction.

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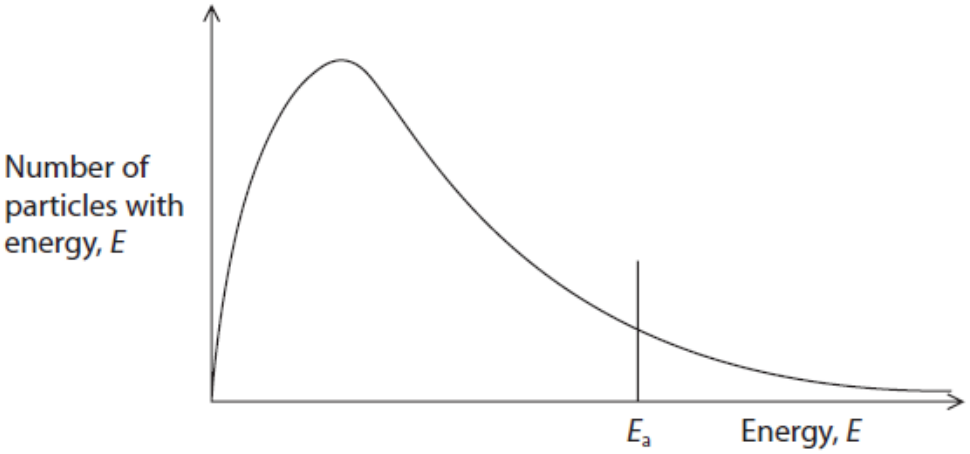
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(1)

(ii) Explain how a catalyst increases the rate of a chemical reaction.

Use the Maxwell-Boltzmann distribution shown and refer to the collision theory.

(3)



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(g) The catalytic converter works best at a temperature of around 350 °C.

(i) Suggest how the catalytic converter reaches this temperature.

(1)

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(ii) The chemical reactions in the exhaust system of a diesel car, using a catalytic converter, form 89.3 m^3 of nitrogen per hour.

Calculate the number of molecules of nitrogen formed per hour.

[Molar volume at 350 °C = 51.1 dm^3 mol^{-1}

Avogadro constant, $L = 6.02 \times 10^{23}$ mol^{-1}]

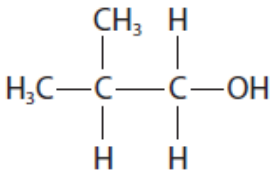
(3)

(Total for question = 20 marks)

Q6.

This question is about the four structural isomers with the formula $C_4H_{10}O$ which are alcohols.

One of the isomers, 2-methylpropan-1-ol, is shown.



(a) 2-methylpropan-1-ol is a primary alcohol.

Explain what is meant by the terms *alcohol* and *primary*.

(2)

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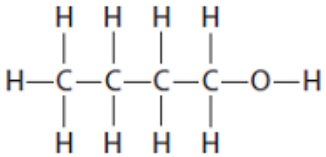
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(b) Complete the table for the other three structural isomers of $C_4H_{10}O$ which are alcohols.

(5)

Name		butan-2-ol	
Displayed formula			
Classification of alcohol			tertiary

(c) 2-methylpropan-1-ol can be oxidised to 2-methylpropanoic acid, in a two-step process.

$$(CH_3)_2CHCH_2OH \xrightarrow{\text{Step 1}} (CH_3)_2CHCHO \xrightarrow{\text{Step 2}} (CH_3)_2CHCOOH$$

(i) Identify by name or formula the reagents needed to prepare the oxidising mixture.

(2)

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(ii) Write the equation for Step **1** using [O] to represent the oxygen from the oxidising agent.

(1)

(iii) Infrared spectroscopy provides information on functional groups.

In an experiment, a sample of 2-methylpropan-1-ol was treated with an oxidising agent.

Show that infrared spectroscopy can be used to show that both the alcohol and the aldehyde are present in the resulting mixture.
In your answer refer to any relevant wavenumber ranges and bonds responsible for the infrared spectrum.
Refer to page 7 of the Data Booklet.

(2)

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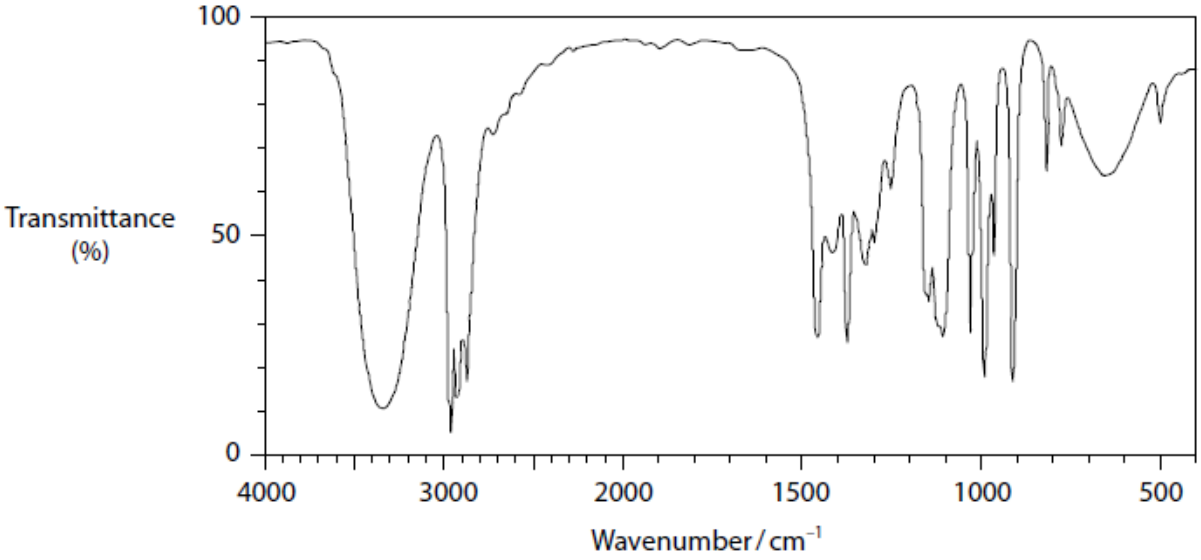
(Total for question = 12 marks)

Q7.

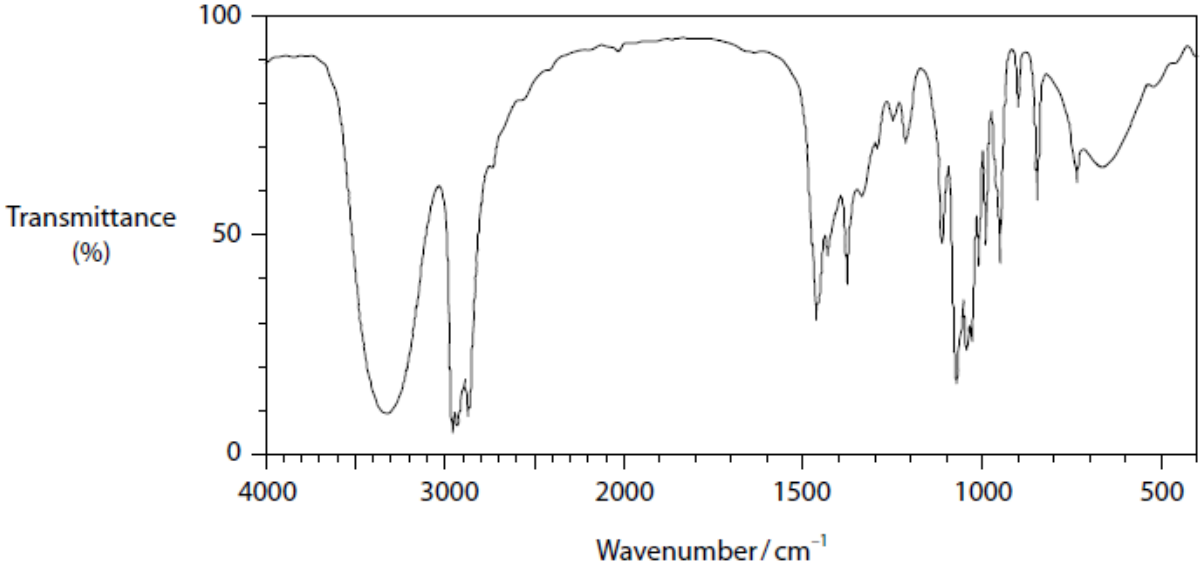
Three compounds, A, B and C, each have the same molecular formula $C_4H_{10}O$ and are known to be alcohols.

(a) The infrared spectra of compounds A, B and C are shown.

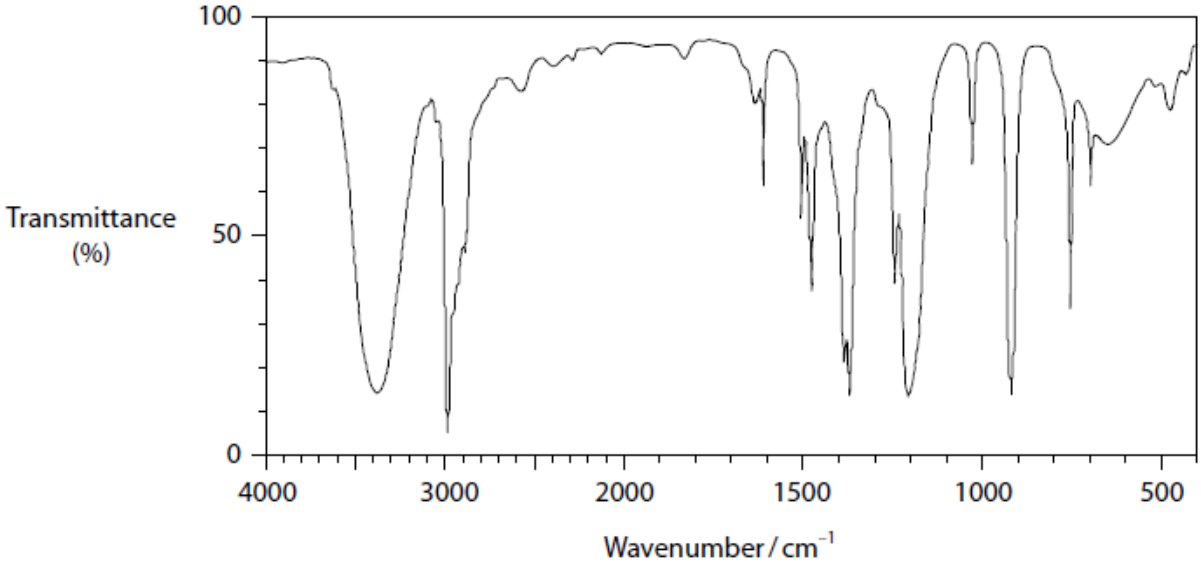
Compound A



Compound B



Compound C



(i) Identify one feature, common to all three infrared spectra, which shows that A, B and C are all alcohols.

(1)

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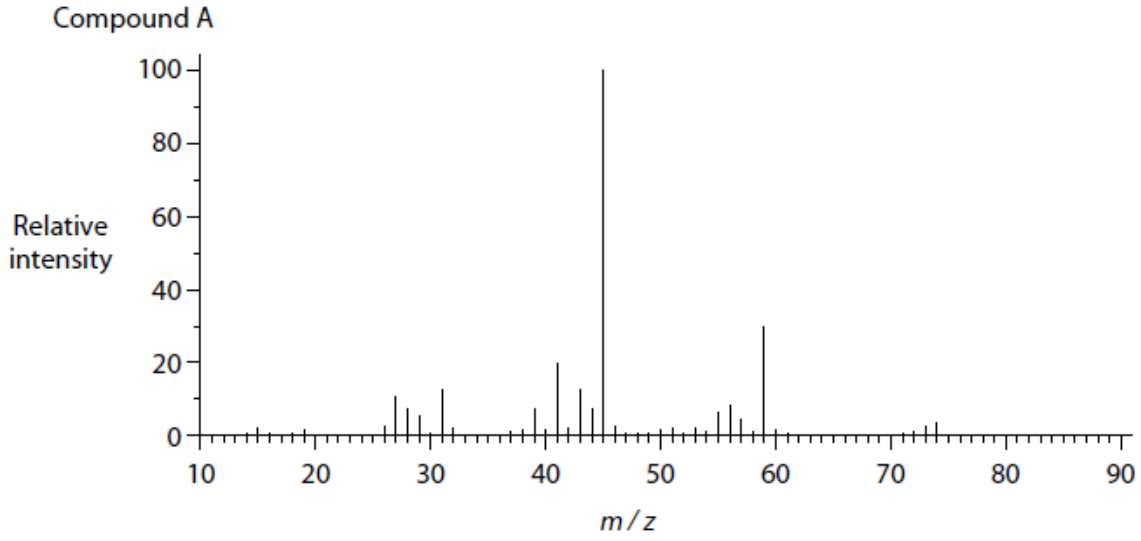
(ii) State, giving a reason for your answer, if it is possible to identify each of these three alcohols on the basis of the infrared spectra alone.

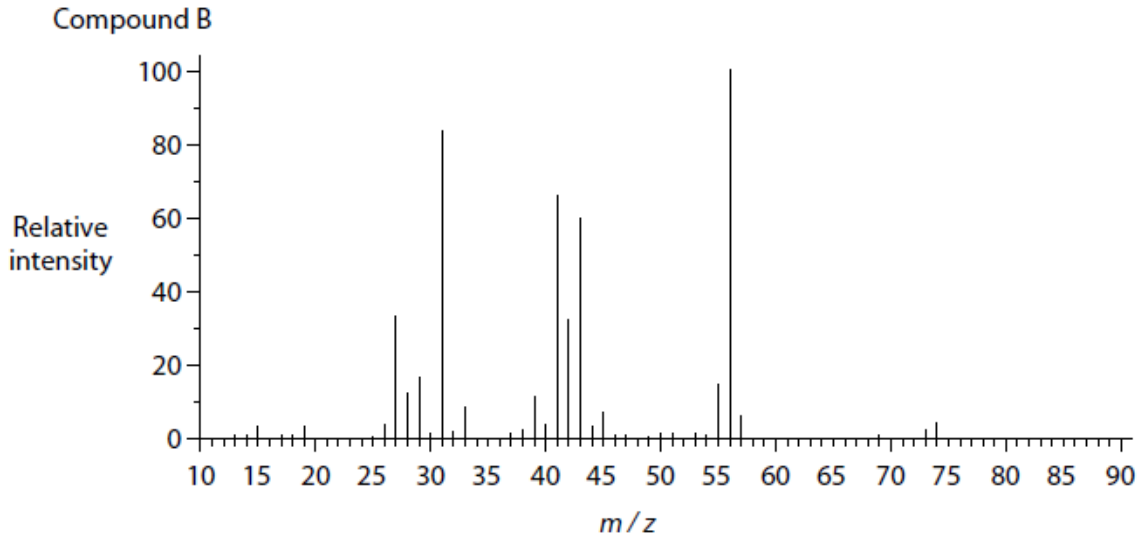
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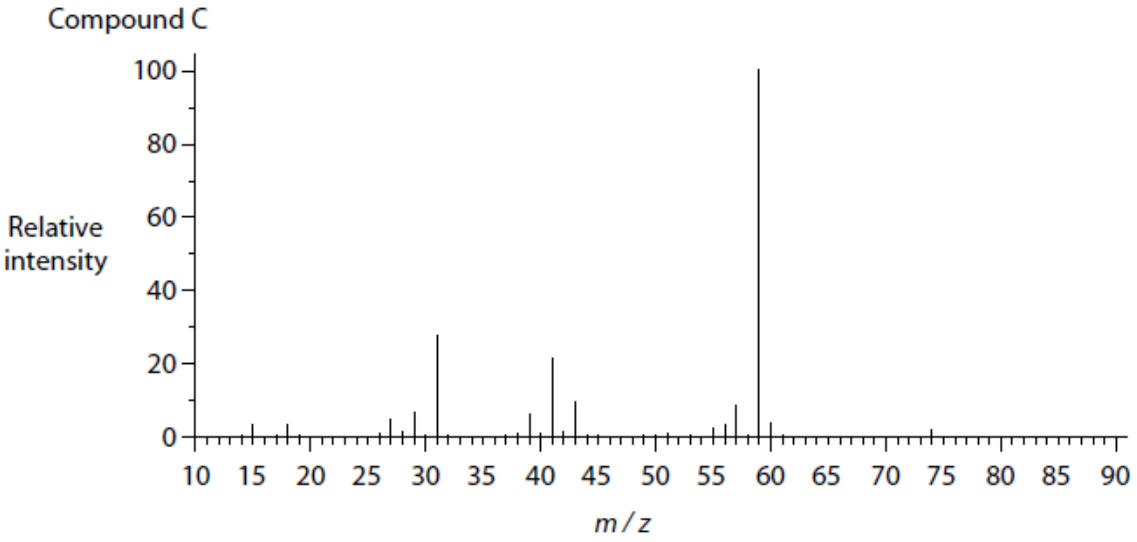
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(b) The mass spectra of the compounds A, B and C are shown.







(i) Identify one feature common to the mass spectra of compounds A, B and C which shows that the molecular formula is $C_4H_{10}O$.

(1)

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(ii) Using the fragmentation patterns, a student proposed that:

compound A is butan-2-ol
compound B is butan-1-ol
compound C is 2-methylpropan-2-ol

State how the appearance in the spectra of the following peaks supports the student's conclusion.

(3)

the fragment causing the peak at $m/z = 45$ for compound A

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the fragment causing the peak at $m/z = 31$ for compound B

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the fragment causing the peak at $m/z = 59$ for compound C

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(c) To help with the identification of compounds A and B, the student decided to mix each of them with potassium dichromate(VI) and dilute sulfuric acid solutions, and then distil the mixture immediately.

(i) Identify, by name and structural formula, the organic compound present at the conclusion of each of these two oxidation reactions.

(3)

Organic compound used	Name of oxidation product	Structural formula of oxidation product
A, butan-2-ol		
B, butan-1-ol		

(ii) To identify A and B, the student decided that one further chemical test should be used on their oxidation products.

Give a suitable reagent and expected observations that could be used to distinguish between the oxidation products of A and B.

(3)

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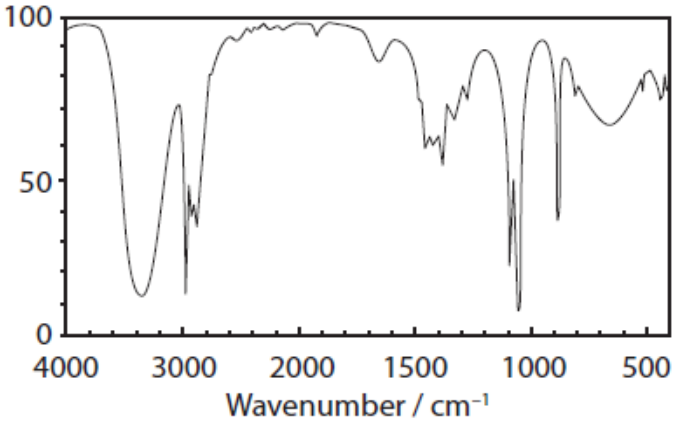
(Total for question = 12 marks)

Q8.

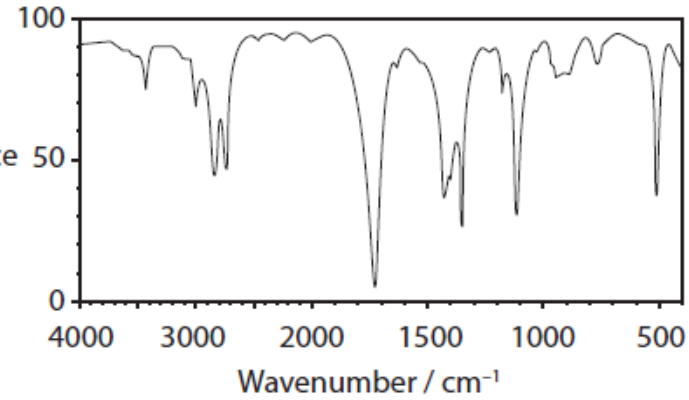
Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Which could be the infrared spectrum of $CH_2=CHCH_2OH$?

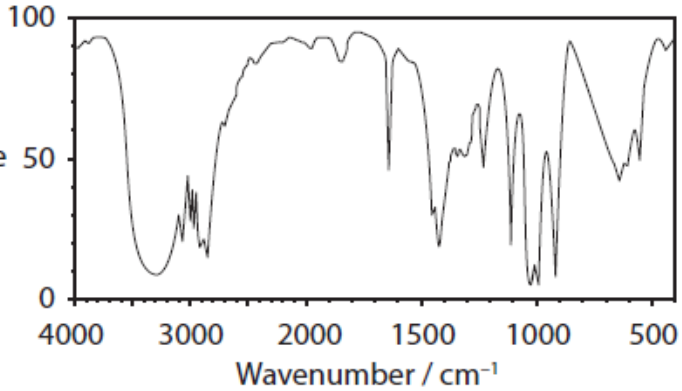
☒ **A**



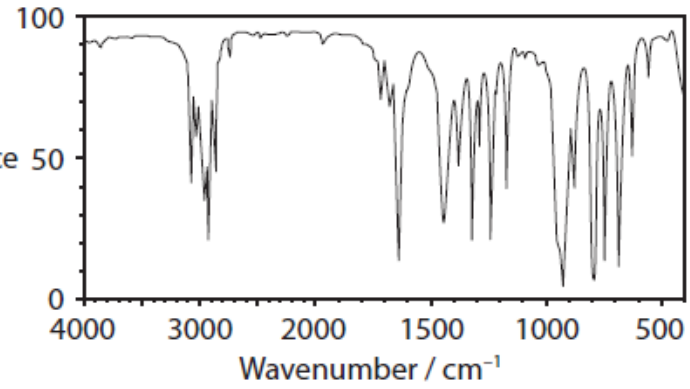
☒ **B**



☒ **C**



☒ **D**

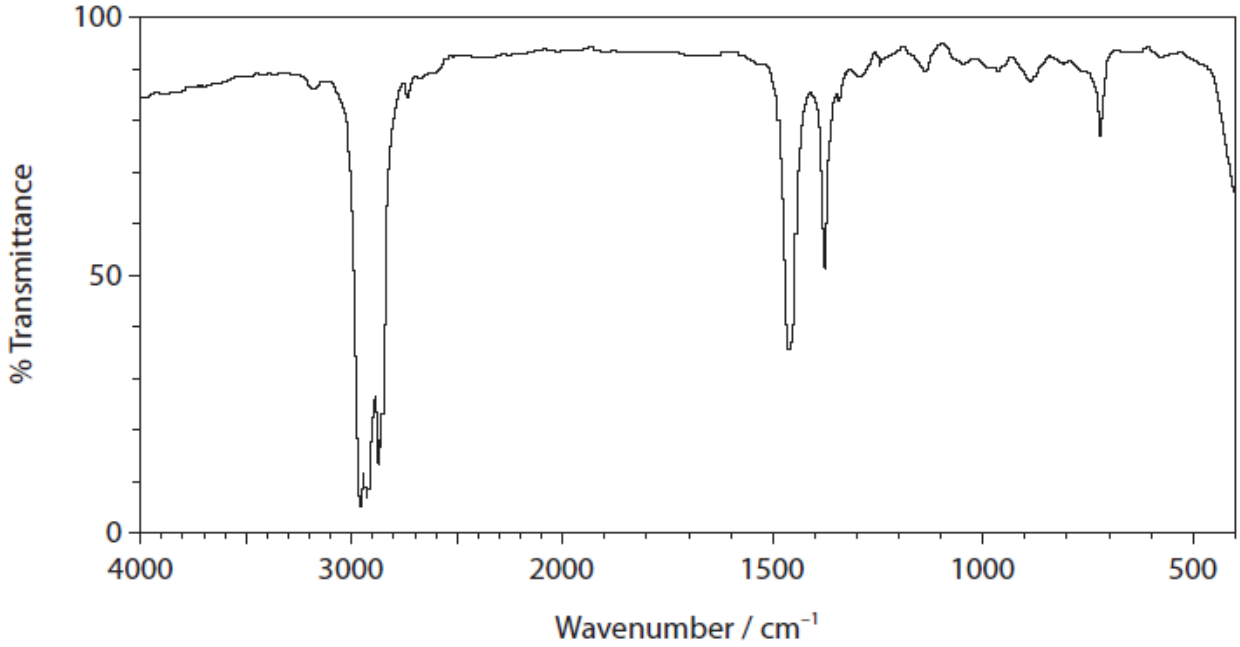


(Total for question = 1 mark)

Q9.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The infrared spectrum of an organic compound is shown.



Which of these compounds would give this infrared spectrum?

(1)

☒ **A** hexanal

☒ **B** hexane

☒ **C** hexanoic acid

☒ **D** hexan-1-ol

(Total for question = 1 mark)

Q10.

This question is about two isomeric alcohols and two isomeric carbonyl compounds.

propan-1-ol, $CH_3CH_2CH_2OH$ and propan-2-ol, $CH_3CH(OH)CH_3$

propanal, CH_3CH_2CHO and propanone, CH_3COCH_3

(a) Which reaction is possible?

(1)

☒ **A** reducing propan-1-ol to propanal

☒ **B** oxidising propan-1-ol to propanal

☒ **C** reducing propanal to propanone

☒ **D** oxidising propan-1-ol to propanone

(b) Which compound would be expected to give a significant peak at $m / z = 31$ in its mass spectrum?

(1)

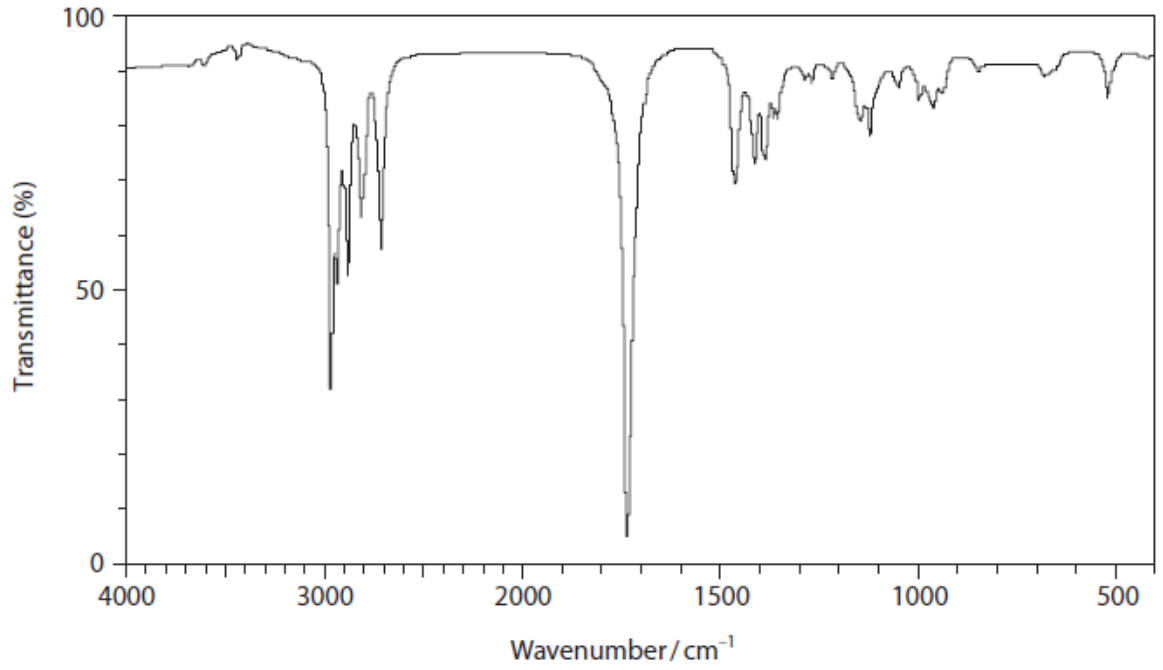
☒ **A** propan-1-ol

☒ **B** propan-2-ol

☒ **C** propanal

☒ **D** propanone

(c) The infrared spectrum of one of the four compounds is shown.



Identify the compound, using the infrared absorptions from the Data Booklet.

(1)

☒ **A** propan-1-ol

☒ **B** propan-2-ol

☒ **C** propanal

☒

D propanone

(Total for question = 3 marks)

Q11.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Which of these carboxylic acids would be expected to have a major peak at $m / z = 57$ in its mass spectrum?

☐ **A** $CH_3CH_2CH_2COOH$

☐ **B** CH_3COOH

☐ **C** $(CH_3)_2CHCOOH$

☐ **D** CH_3CH_2COOH

(Total for question = 1 mark)

Q12.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

In a mass spectrum, the molecular ion is the ion which always has the

☐ **A** greatest abundance

☐ **B** greatest stability

☐ **C** highest charge

☐ **D** highest mass/charge ratio

(Total for question = 1 mark)

Q13.

Butan-1-ol and butan-2-ol are isomers.

Which *m*/*z* value would be expected to have a significant peak in the mass spectrum of butan-1-ol but **not** that of butan-2-ol?

☒ **A** 15

☒ **B** 29

☒ **C** 43

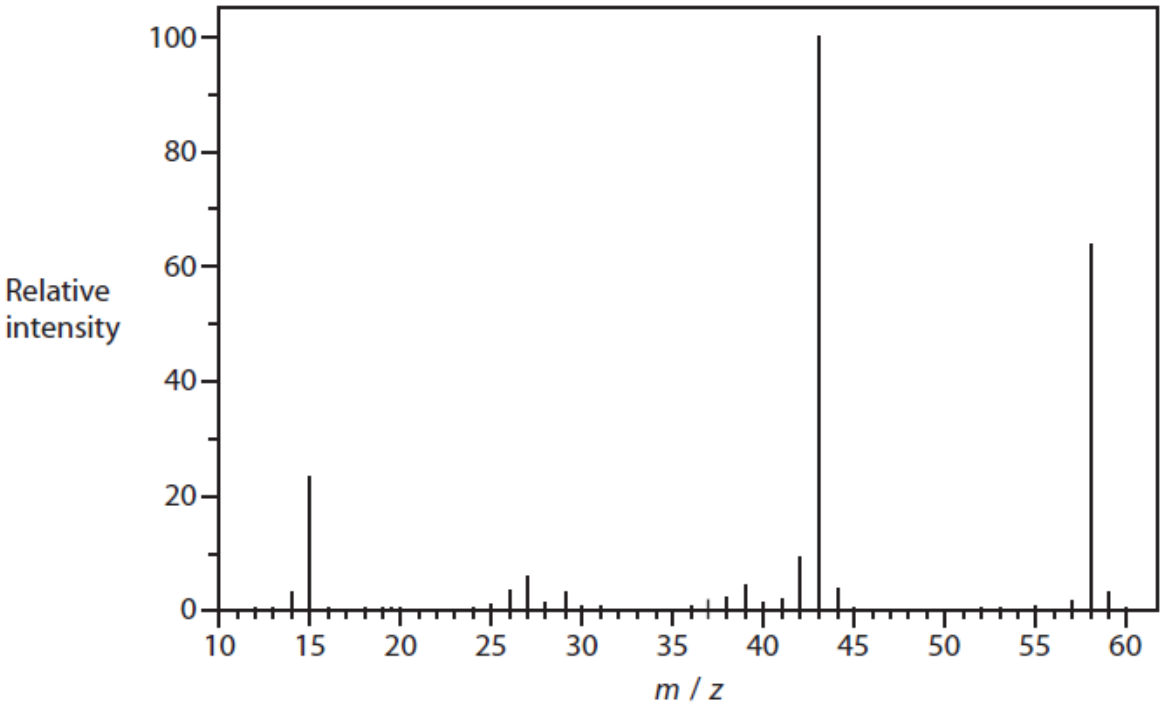
☒ **D** 57

(Total for question = 1 mark)

Q14.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The mass spectrum of propanone is shown.



Which fragment is most likely to produce the peak at $m / z = 43$?

- ☒ **A** $CH_3CH_2CH_2^+$
- ☒ **B** CH_3CO^+
- ☒ **C** CH_2CHO^+
- ☒ **D** $CHCH_2O^+$

(Total for question = 1 mark)

Q15.

A sample of 1,2-dichloroethane, CH_2ClCH_2Cl, contains only the isotopes ^{1}H, ^{12}C, ^{35}Cl and ^{37}Cl.

How many molecular ion peaks are there in its mass spectrum?

(1)

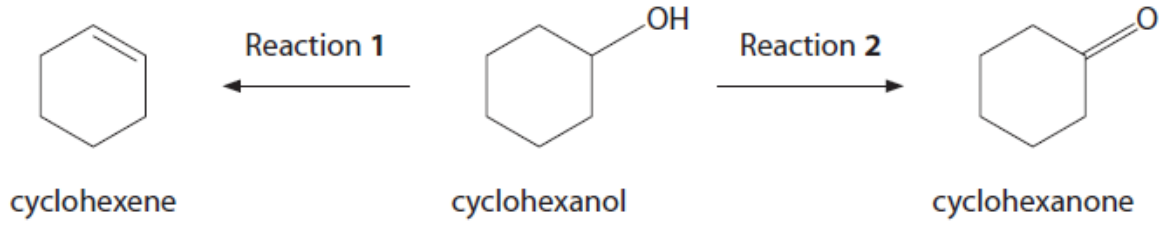
- ☒ **A** 1
- ☒ **B** 2
- ☒ **C** 3
- ☒ **D** 4

(Total for question = 1 mark)

Q16.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Two reactions of cyclohexanol are shown.



(a) What is the reagent for Reaction 1?

(1)

☒ **A** acidified potassium manganate(VII)

☒ **B** aqueous bromine

☒ **C** concentrated phosphoric(V) acid

☒ **D** phosphorus(V) chloride

(b) The reagent for Reaction 2 is acidified potassium dichromate(VI).

Which equation best represents this reaction?

(1)

☒ **A** $C_6H_{11}OH \rightarrow C_6H_{10}O + H_2$

☒ **B** $C_6H_{11}OH \rightarrow C_6H_{10}O + 2[H]$

☒ **C** $C_6H_{11}OH + [O] \rightarrow C_6H_{10}O + H_2O$

☒ **D** $C_6H_{11}OH + {}^{1}\!/_{2}O_2 \rightarrow C_6H_{10}O + H_2O$

(c) Cyclohexanol and cyclohexene each has a peak in their infrared spectrum which is **not** present for the other compound.

Which are these peaks?

(1)

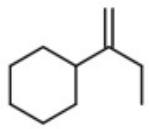
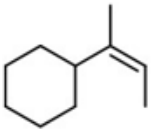
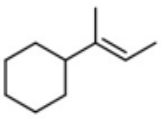
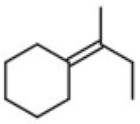
		Peak only in cyclohexanol / cm^{-1}	Peak only in cyclohexene / cm^{-1}
☒	**A**	2962-2853	1669-1645
☒	**B**	2962-2953	1720-1700
☒	**C**	3750-3200	1669-1645
☒	**D**	3750-3200	1720-1700

(Total for question = 3 marks)

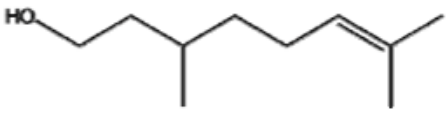
Mark Scheme

Q1.

Question Number	Answer	Additional guidance	Mark
(a)	answer that makes reference to the following points: • add PCl_5 / phosphorus(V) chloride /phosphorus pentachloride **(1)** • misty fumes evolved (that turn damp blue litmus red / form white smoke with ammonia) **(1)** OR • Add sodium / Na **(1)** • Effervescence / bubbles seen / fizzing **(1)** OR • Add Lucas' Reagent **(1)** • Solution turns cloudy immediately / quickly **(1)**	M2 dependent on correct reagent seen in M1. Allow PCl_3 Allow steamy fumes / white fumes Do not award white smoke **unless** in conjunction with exposure of fumes to ammonia Ignore gas given off / hydrogen given off Do not award heat with acidified dichromate(VI) ions	**(2)**

Question Number	Answer	Additional guidance	Mark
(b)(i)	 **(1)**  **(1)**  **(1)**  **(1)**	Allow any unambiguous type of structure	**(4)**

Question Number	Answer	Additional guidance	Mark
(b)(ii)	A description that makes reference to any two from the four following points: • Peak at 3750 – 3200 (cm^{-1}) due to O-H bond present in reactant / absent in product **(1)** • Peak at 1000-1300 (cm^{-1}) due to C-O bond present in reactant / absent in product **(1)** • Peak at 1669 – 1645 (cm^{-1}) due to C=C bond present in product / absent in reactant **(1)** • Peak at 3095 – 3010 (cm^{-1}) due to **C-H bond** present in **alkene** in product / absent in reactant **(1)**	Allow two peaks quoted or two bonds for one mark Allow any wavenumber or range of wavenumbers within the allowable range.	**(2)**

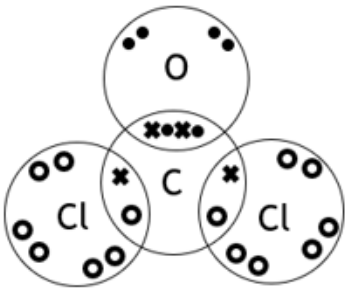
Question Number	Answer	Additional guidance	Mark
(c)	• Longest chain has eight carbon atoms, with terminal OH group **(1)** • rest of structure correct **(1)**	 Accept structural , skeletal or displayed formulae Ignore connectivity except O-H-C Allow 1 mark for correct displayed formulae with missing hydrocarbon hydrogens Allow 1 mark for correct structure of 2,6dimethylhept-5-en-1-ol	**(2)**

Q2.

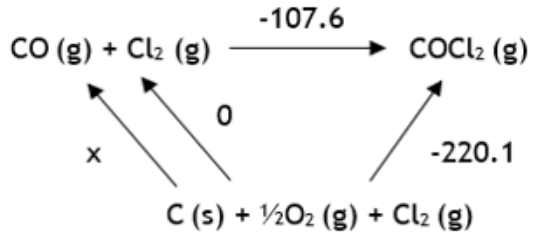
Question number	Answer	Mark
(a)	**The only correct answer is C** (strontium bromide) ***A** is not correct because the chloride will give a white precipitate* ***B** is not correct because the chloride will give a white precipitate* ***D** is not correct because the barium will give a green flame*	**(1)**

Question number	Answer	Mark
(b)	**The only correct answer is *D*** (red light is emitted as electrons return to lower energy levels) ***A** is not correct because the electrons absorb heat as they are promoted* ***B** is not correct because the electrons emit light when they return to ground state* ***C** is not correct because light energy is emitted when the electrons return to the ground state*	**(1)**

Q3.

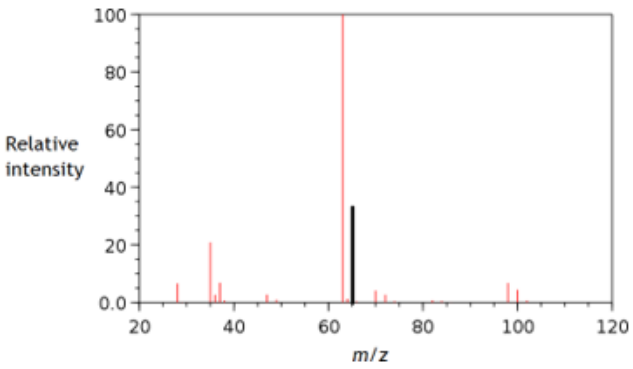
Q	Answer	Additional Guidance	Mark
(a)	An answer that makes reference to the following points: A diagram that includes: • carbon singly covalently bonded to two chlorine atoms and three lone pairs on each chlorine **(1)** • carbon doubly bonded to an oxygen atom and two lone pairs on the oxygen **(1)**	 Penalise lack of lone pairs once only Allow any representation of electrons Allow individual electrons spread out, rather than in pairs Allow horizontal shared pairs of electrons Ignore lines representing covalent bonds	**2**

Q	Answer	Additional Guidance	Mark
(b)(i)	An explanation that makes reference to the following points: Any two pairs from the three: • decrease the temperature **(1)** • as the (forward) reaction is exothermic **(1)** • increase the pressure **(1)** • as there a fewer moles of (gas) on the product side **(1)** **EITHER** • remove the phosgene (as it is formed) **(1)** • to reduce the concentration of product (so equilibrium moves to the right) **(1)** **OR** • add more CO / Cl_2 **(1)** • to increase the concentration of the reactants (so equilibrium moves to the right) **(1)**	Ignore references to rate of reaction Allow T↓ Allow "favours the exothermic reaction" Allow P↑ if numbers are quoted, they must be 2:1 Allow "favours the side with fewer moles"	**4**

Q	Answer	Additional Guidance	Mark
(b)(ii)	An answer that makes reference to the following points: • correct species **(1)** • correct state symbols **(1)** • correct arrows **(1)** • calculation of value **(1)**	Example of an answer:  ΔH_f CO = −220.1 – (−107.6) = −112.5 (kJ mol^{-1}) Accept state symbol for C(s, graphite) Ignore absence of arrow and value to chlorine Numbers are not required on the cycle	**4**

Q	Answer	Additional Guidance	Mark
(c)(i)	An explanation that makes reference to the following points: • chlorine isotopes (35 and 37) are in the ratio of 3:1 **(1)** • (as there are) two chlorine atoms give the ratio of 9:6:1 **(1)**	Accept ^{37}Cl 75% : ^{35}Cl 25% Allow this shown in workings e.g. $CO^{37}Cl^{37}Cl^{(+)}$ = 102, $CO^{35}Cl^{37}Cl^{(+)}$ = 100, $CO^{35}Cl^{35}Cl^{(+)}$ = 98 Do not award ^{36}Cl Mark independently Reference to isotopes of carbon should be penalised once	**2**

Q	Answer	Additional Guidance	Mark
(c)(ii)	An answer that makes reference to the following point • $CO^{35}Cl^{+}$	Allow the + on any of the atoms Ignore brackets	**1**

Q	Answer	Additional Guidance	Mark
(c)(iii)	An answer that makes reference to the following point • peak drawn at 65 with relative intensity of 33.3	Example of completed graph:  Allow a peak height between 30-35	**1**

Q	Answer	Additional Guidance	Mark
(d)	An answer that makes reference to the following points: • 1795 (cm^{-1}) **(1)** • (from the) C=O (stretching vibrations) **(1)**	Allow a number or range within 1630-1850 (cm^{-1}) M2 is dependent on M1 Allow a number or range within 550-850 (cm^{-1}) **and** C-Cl (stretching vibrations) for 2 marks Ignore acyl chloride Do not award M2 for aldehydes/ketones	**1**

Q	Answer	Additional Guidance	Mark
(e)(i)	An answer that makes reference to the following point: • balanced equation	$2CHCl_3 + O_2 \rightarrow 2COCl_2 + 2HCl$ Accept multiples of the equation Ignore state symbols even if incorrect	**1**

Q	Answer	Additional Guidance	Mark
(e)(ii)	An answer that makes reference to the following point: • oxygen concentration will decrease	Allow oxygen used up Allow [O_2] decreases Allow volume of oxygen decreases Do not award "air is used up" "Reactants are used up" is insufficient as doesn't apply information from the question Comments about trichloromethane decreasing negate the oxygen mark	**1**

Q	Answer	Additional Guidance	Mark
(e)(iii)	An answer that makes reference to the following point • use a fume cupboard (due to toxic and irritant gases)	Allow open in a well-ventilated laboratory / open outside / wear a **gas** mask Ignore eye protection / laboratory coats / gloves Ignore just "mask" and "do not inhale" Do not award face shield	**1**

Q	Answer	Additional Guidance	Mark
(e)(iv)	An answer that makes reference to the following points: • no, because some of the HCl/$COCl_2$ may have dissolved into the chloroform / be trapped as bubbles in the liquid	Allow may have reacted (with oxygen) to give (toxic) phosgene / $COCl_2$	**1**
		(Total for Question = 20 marks)	

Q4.

Question Number	Answer	Additional Guidance	Mark
(a)(i)	An explanation that makes reference to the following points: EQUILIBRIUM • there are more (gaseous) moles/molecules on LHS / less (gaseous) moles on RHS **(1)** • (so high pressure) moves equilibrium to RHS / increases yield of methanol **(1)** OR KINETIC • an increase in pressure increases the number/rate of collisions (of molecules) **(1)** • (So) increases the rate of reaction **(1)**	NOTE If two marks are scored they must be derived from either the kinetic or equilibrium explanations. If both explanations are used any incorrect statement negates one mark. Any reference to atoms scores 0 for M1 If numbers of moles given, they must be correct M2 depends on M1 for both explanations	**(2)**

Question Number	Answer	Additional Guidance	Mark
(a)(ii)	An explanation that makes reference to the following points: • the (forward) reaction is exothermic **(1)** • a lower temperature would increase the yield /move equilibrium to RHS or reverse argument **(1)** • a (compromise) temperature is used to ensure the rate is fast enough (without the equilibrium position moving too far to the LHS) ALLOW (increased/high/stated) temperature increases the rate of reaction **(1)**	Note: if (forward) reaction is identified as endothermic then neither M1 nor M2 can be scored Ignore references to cost/economics/ environmental	**(3)**

Question Number	Answer	Additional Guidance	Mark
(a)(iii)	An explanation that makes reference to one of the following points: (a catalyst) allows a lower temperature to be used / less energ is needed (1) (a copper catalyst is specific for methanol) so there is less waste/fewer other products/improves atom economy (1) (a catalyst) is not used up/can be used again (1)	Ignore just increases rate/ lowers activation energy	(1)

Question Number	Answer	Additional Guidance	Mark
(b)(i)	Reagents • sodium / potassium dichromate ((VI)) / $Na_2Cr_2O_7$/$K_2Cr_2O_7$/ $Cr_2O_7^{2-}$ **and** acidified / H+ / sulfuric acid (1) Reaction conditions • (Heat under) **reflux** (1)	Do not award potassium manganate(VII) M2 dependent on M1 or near miss	(2)

Question Number	Answer	Additional Guidance	Mark
(b)(ii)	$CH_3OH + 2[O] \longrightarrow HCOOH + H_2O$ (1)	Allow; CH_2O_2,CHOOH,HCO_2H	(1)

Question Number	Answer	Additional Guidance	Mark
(b)(iii)	Functional group test add any carbonate /hydrogencarbonate OR add magnesium (powder/ribbon) (1) OR addition of any alcohol (and strong acid to form an ester) Positive result (1) effervescence / bubbles / gas given off (turns lime water cloudy OR burns with a "pop") OR Fruity smell	Do not award the addition of Na or PCl_5 Ignore reference to indicator M2 depends on M1 or near miss	(2)

Question Number	Answer	Additional Guidance	Mark
(b)(iv)	• infra red absorption at 3750 - 3200 cm^{-1} /3300 cm^{-1} due to O-H of alcohol/methanol **(1)** • infra red absorption at 1725 - 1700 cm^{-1} /1700 cm^{-1} due to C=O group (of carboxylic acid/methanoic acid) **(1)** • peaks due to methanol/alcohol would disappear/be absent **(1)**	Allow the peak at 1020 for methanol in the fingerprint region Accept infra red absorption at 3300 - 2500 cm^{-1} /2500 cm^{-1} showing O-H group of COOH Allow the fingerprint region would change Penalise use of OH^-/-OH once only. In M1 and M2 penalise absence of bonds once only	**(3)**

Question Number	Answer	Additional Guidance	Mark
(c)(i)	An explanation that makes reference to two of the following points: • burning (petrol/methanol/fuel) produces CO_2 /greenhouse gases/contributes to global warming **(1)** • the methanol is made from captured CO_2 / is made from CO_2 that would have been released anyway **(1)** • the increase in global temperatures will be reduced **(1)**	IGNORE references to ozone depletion Do not award : methane is produced	**(2)**

Question Number	Answer	Additional Guidance	Mark
(c)(ii)	• 352g carbon dioxide (released per mole octane) **(1)**	Example calculation: 8 x 44 = 352 (g)	**(1)**

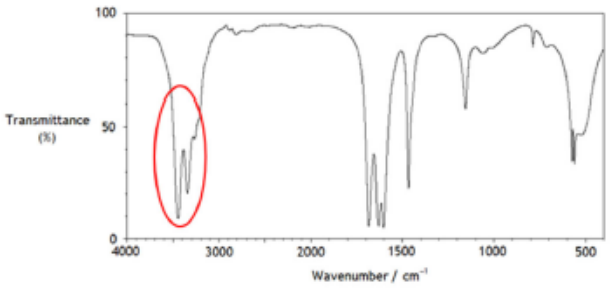
Question Number	Answer	Additional Guidance	Mark
(c)(iii)	• Mass petrol reduction per year **(1)** • Mass CO_2 reduction **(1)** OR • Moles of petrol used per year **(1)** • 5% reduction in CO_2 **(1)** OR • 5% reduction in moles of petrol used per year **(1)** • Mass CO_2 produced **(1)**	Example of calculation: 1200 x 0.05 = 60 (kg) 60 ÷ 114 x 352 = 185.26 kg (1200 x 1000) ÷ 114 = 10526 (moles) 352 x 10526 x 5 ÷ 100 = 185260 g = 185.26 kg 1200 x 1000 x 0.05 ÷ 114 = 526.3 (moles) 526.3 x 352 ÷ 1000 = 185.26 kg IGNORE SF except 1 SF correct answer with no working scores 2	**(2)**

Q5.

Question Number	Answer	Additional Guidance	Mark
(a)	An answer that makes reference to the following points: • urea forms hydrogen bonds **(1)** • urea forms (permanent) dipole-dipole forces **(1)** • these forces are stronger than London forces **(1)**	Ignore references to number of hydrogen bonds Allow a correct diagram Allow hydrogen bonds are the strong**est** intermolecular forces Allow dispersion forces/van der Waals for London forces Do not award M3 if breaking covalent bonds is referenced	**(3)**

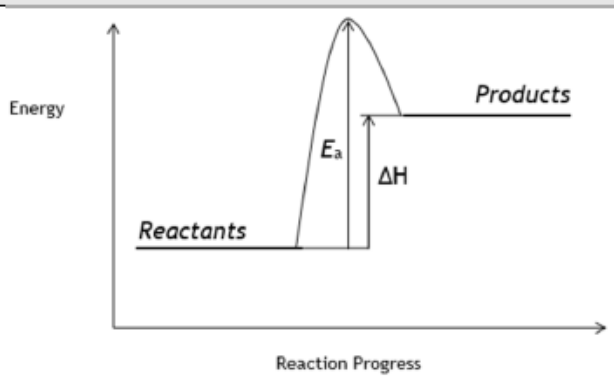
Question Number	Answer	Additional Guidance	Mark
(b)	An answer that makes reference to the following points: • M_r of urea **(1)** OR moles of urea • mass of urea required **(1)**	M_r = 60 (9.07 ÷ 1000) × 150 = 1.36(05) (9.07 ÷ 1000) × 150 × 60 = 81.63 (g) / 81.6 (g) Ignore SF except 1 SF Correct answer scores (2) No M2 if units other than grams are used	**(2)**

Question Number	Answer	Additional Guidance	Mark
(c)	An answer that makes reference to the following point: • (oxides of nitrogen lead to the formation of) acid rain	Allow formation of photochemical smog Allow "NO can react with ozone" Allow descriptions of acid rain formation e.g. forms HNO_3 Do not award greenhouse effect / global warming Do not award depletes the ozone layer without reference to nitrogen(II) oxide/NO	**(1)**

Question Number	Answer	Additional Guidance	Mark
(d)(i)	An answer that makes reference to the following point • correct peak circled	Example of completed spectra:  Allow any number of the three peaks in the region to be circled individually Extra circles negate the mark	**(1)**

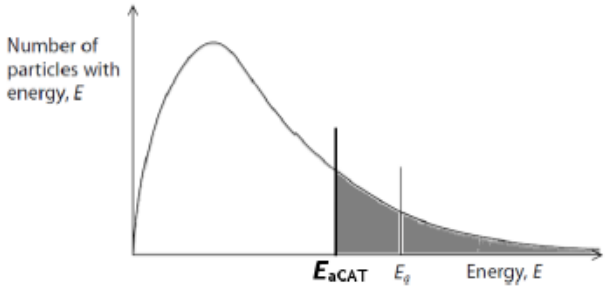
Question Number	Answer	Additional Guidance	Mark
(d)(ii)	An answer that makes reference to the following point • C=O		**(1)**

Question Number	Answer	Additional Guidance	Mark
(e)(i)	An answer that makes reference to the following points • products **and** reversible arrow	Example of balanced equation: $\rightleftharpoons 2NH_3 + CO_2$ Accept products in any order Allow multiples if equation is balanced Allow 2 full headed arrows, one in either direction	**(1)**

Question Number	Answer	Additional Guidance	Mark
(e)(ii)	An answer that makes reference to the following points: • line labelled products higher than line labelled reactants and to the right **(1)** • ΔH labelled correctly **(1)** • E_a labelled correctly **(1)**	 Accept actual reactants and products labelled on diagram (even if slightly incorrect names or formulae are used) Ignore state symbols even if incorrect Allow ΔH given as +133 Double-headed arrows penalised once only Arrows in wrong direction or missing heads penalised each time M2 and M3 can be given as a TE on exothermic reaction if arrows are consistent	**(3)**

Question Number	Answer	Additional Guidance	Mark
(f)(i)	An explanation that makes reference to the following points: • the urea is a reactant and forms a new product (that leaves the catalytic converter)	Allow "catalysts are not used up in the reaction" Allow "urea is used up in the reaction" Allow "the amount/mass of urea changed" Allow "urea is not reformed" Allow "the catalyst is a metal oxide" Ignore references to activation energy / rate / reusable Do not award "catalysts do not react"	**(1)**

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Question Number	Answer	Additional Guidance	Mark
(f)(ii)	An explanation that makes reference to the following points: • catalyst decreases the activation energy required **(1)** • more particles have the energy required for the reaction to take place **(1)** • increases the number of successful collisions per unit time / frequency of successful collisions **(1)**	Example of a completed diagram  Accept M1 shown on the diagram Allow "Ea moves to the left" Allow area under the curve above Ea increases for M2 NOTE: Shading is not required, but incorrect shading would negate M2	**(3)**

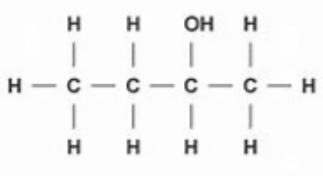
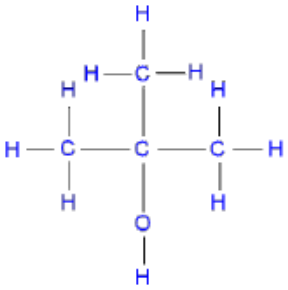
Question Number	Answer	Additional Guidance	Mark
(g)(i)	• hot gases from the engine warm up the catalytic converter	Allow uses the (heat) energy from the engine Allow energy from combustion of fuel Allow the reactions that occur in the catalytic converter are exothermic	**(1)**

Question Number	Answer	Additional Guidance	Mark
(g)(ii)	• conversion of m^3 to dm^3 **(1)** • moles of nitrogen **(1)** • number of molecules of nitrogen **(1)**	<u>An example of a calculation:</u> $89.3 \times 1000 = 89300\ dm^3$ $89300 \div 51.1 = 1747.6 / 1748$ mol $1748 \times 6.02 \times 10^{23} = 1.052 \times 10^{27} / 1.05 \times 10^{27} / 1.1 \times 10^{27}$ Allow TE throughout Ignore SF except 1SF Ignore units even if incorrect $1.052 \times 10^{24} / 1.05 \times 10^{24} / 1.1 \times 10^{24}$ scores 2 $1.052 \times 10^{21} / 1.05 \times 10^{21} / 1.1 \times 10^{21}$ scores 2 $2.747 \times 10^{30} / 2.75 \times 10^{30} / 2.8 \times 10^{30}$ scores 2 Correct answer with some working scores (3)	**(3)**

Q6.

Question Number	Answer	Additional Guidance	Mark
(a)	An explanation that makes reference to the following points: • contains the OH group/OH is the alcohol group **(1)** • primary means the C bonded to the OH (group) is attached to 1 (or 0) alkyl group / carbon atom/ R group **(1)**	Accept a hydrocarbon in which one H atom has been replaced by an OH group Allow contains O-H bond Allow contains a C-OH bond Ignore hydroxyl Do not award hydroxide/ OH^- Allow the OH group is attached to a carbon atom bonded to 2 (or 3) H atoms Do not award the OH is attached to a single R/alkyl/carbon group	**2**

Question Number	Answer	Additional Guidance	Mark
(b)			5

Name	**butan-1-ol**		**(2-)methylpropan-2-ol**	(2)	One mark for each name
Displayed formula				(2)	One mark for each correct displayed formula
Nature of alcohol	**primary**	**secondary**		(1)	One mark for both alcohol types One mark for both alcohol types Allow CH_3 and OH undisplayed Penalise missing Hs only once.

Question Number	Answer		Additional Guidance	Mark
(c)(i)	An answer that makes reference to the following points:			2
	• potassium dichromate((VI)) / $K_2Cr_2O_7$	(1)	Allow sodium dichromate((VI)) / $Na_2Cr_2O_7$ If oxidation state is given it must be correct Do not award potassium manganate(VII) / potassium permanganate	
	• sulfuric acid / H_2SO_4	(1)	Do not award hydrochloric acid Ignore just 'acidified' Ignore concentration of sulfuric acid Ignore heat	
	Note M2 depends on M1 or a near miss such as potassium permanganate or potassium dichromate with the wrong oxidation number		If no other mark is scored acidified dichromate / H^+ and $Cr_2O_7^{2-}$ score (1)	

Question Number	Answer	Additional Guidance	Mark
(c)(ii)	• $(CH_3)_2CHCH_2OH + [O] \rightarrow (CH_3)_2CHCHO + H_2O$	Allow $C_4H_{10}O + [O] \rightarrow C_4H_8O + H_2O$ The [O] may be above the arrow Allow displayed/molecular/skeletal	1

Question Number	Answer	Additional Guidance	Mark
(c)(iii)	An answer that makes reference to two of the following points: • (resulting mixture) would give a peak due to O–H bond in alcohols at 3750-3200 (cm^{-1}) (1) • would give a peak due to C=O bond in aldehydes at 1740-1720 (cm^{-1}) or would give a peak due to C–H bond in CHO at 2900-2820 and/ or 2775-2700 (cm^{-1}) (1)	Ignore any reference to the size/width of the peaks due to stretching etc Allow (resulting mixture) would give a peak due to OH (in alcohols) at 3750-3200 (cm^{-1}) Do not award -OH Do not award 1720-1700 (cm^{-1}) for C=O in ketones Allow any range within the range. Do not award single numbers but penalise once only If no other marks have been scored a correct wave number range for both the O-H and C=O score (1) 3750-3200 (cm^{-1}) 1740-1720 (cm^{-1})	

Q7.

Question number	Answer	Additional guidance	Mark
(a)(i)	• peak in the range 3750 - 3200 cm^{-1} and O-H (stretching) bond in alcohols	Must identify the bond and give the wavenumber range Allow peak at ~3375 cm^{-1}	1

Question number	Answer	Additional guidance	Mark
(a)(ii)	• not possible - All three contain the same bonds or possible - the fingerprint regions differ/by comparing the spectra to reference spectra	No mark for unjustified answer	1

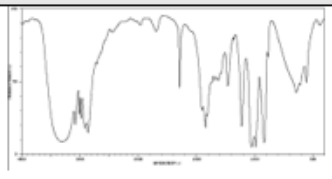
Question number	Answer	Additional guidance	Mark
(b)(i)	• (all show) parent/molecular ion peak at 74	Allow peak furthest to the right/highest m/z peak at 74 Do not award just 'peak at 74'	1

Question number	Answer		Additional guidance	Mark
(b)(ii)	• fragment $^{+}CH_3CHOH = 45$	(1)		3
	• fragment $^{+}CH_2OH = 31$	(1)		
	• fragment $^{+}(CH_3)_2COH = 59$	(1)	Ignore missing charge on fragments	

Question number	Answer				Additional guidance	Mark
(c)(i)					Allow displayed or skeletal formulae 1 mark for 2 correct names and 1 mark for each correct formula	3
	Organic compound used	Name of oxidation product	Structural formula of oxidation product			
	A	Butanone **and**	$CH_3CH_2COCH_3$	(1)		
	B	Butanal (1)	$CH_3CH_2CH_2CHO$	(1)		

Question number	Answer		Additional guidance	Mark
(c)(ii)	An answer that makes reference to the following points:			3
	• reagent: Benedict's/Fehling's	(1)	Allow Tollens' or iodine + alkali	
	• (oxidation product of) compound A: no change	(1)		
	• (oxidation product of) compound B: (Benedict's/Fehlings test) red precipitate.	(1)	(Tollens' reagent) silver mirror with (oxidation product of) B. No reaction with (oxidation product of) A (iodine + alkali) yellow precipitate (iodoform) with (oxidation product of) A. No reaction with oxidation product of B If (butanoic) acid in (c)(i), allow reagent: sodium carbonate/sodium hydrogencarbonate (solution) Observations: (oxidation product of) compound B: bubbles/fizzes	

Q8.

Q	Answer	Mark
	The only correct answer is C () ***A*** *is incorrect because this shows no absorbance for the C=C stretch* ***B*** *is incorrect because this shows no absorbance for the O-H stretch or C=C stretch* ***D*** *is incorrect because this shows no absorbance for the O-H stretch*	**1**

Q9.

Question Number	Answer	Mark
	The only correct answer is B (hexane) ***A*** *is not correct because the spectrum does not have a peak for the C=O* *C is not correct because the spectrum does not have a peak for the C=O and O-H* ***D*** *is not correct because the spectrum does not have a peak for the O-H*	(1)

Q10.

Question Number	Answer	Mark
(a)	**The only correct answer is B** (oxidising propan-1-ol to propanal) *A is incorrect because reducing an alcohol would produce an alkane* *C is incorrect because reducing propanal would produce propan-1-ol* *D is incorrect because oxidising propan-1-ol would produce propanal or propanoic acid*	**(1)**

Question Number	Answer	Mark
(b)	**The only correct answer is A** (propan-1-ol) *B is incorrect because propan-2-ol would not be expected to form a $^{+}CH_2OH$ fragment* *C is incorrect because propanal would not be expected to form a $^{+}CH_2OH$ fragment* *D is incorrect because propanone would not be expected to form a $^{+}CH_2OH$ fragment*	**(1)**

Question Number	Answer	Mark
(c)	**The only correct answer is C** (propanal) *A is incorrect because propan-1-ol would have a broad absorption at 3750-3200 cm^{-1} due to –OH* *B is incorrect because propan-2-ol would have a broad absorption at 3750-3200 cm^{-1} due to –OH* *D is incorrect because the absorption due to C=O in propanone would be at 1720-1700 cm^{-1} and C-H stretching vibrations at 2775-2700 cm^{-1} would be absent*	**(1)**

Q11.

Question number	Answer	Mark
	The only correct answer is D (CH_3CH_2COOH) *A is not correct because it will not have a major peak at m/z = 57* *B is not correct because it will not have a major peak at m/z = 57* *C is not correct because it will not have a major peak at m/z = 57*	**(1)**

Q12.

Question Number	Answer	Mark
	The only correct answer is D (highest mass/charge ratio) *A is not correct because the molecular ion does not always have the greatest abundance* *B is not correct because the molecular ion does not always have the greatest stability* *C is not correct because the molecular ion cannot have a higher charge than the other ions*	**(1)**

Q13.

Question Number	Answer	Mark
	The only correct answer is C (43) *A is not correct because both would be expected to have this peak due to* CH_3^+ *B is not correct because both would be expected to have this peak due to* $C_2H_5^+$ *D is not correct because both would be expected to have this peak due to* $C_4H_9^+$	**(1)**

Q14.

Q	Answer	Mark
	The only correct answer is B (CH_3CO^+) ***A*** *is incorrect because the fragment is not present in propanone* ***C*** *is incorrect because the fragment is not present in propanone* ***D*** *is incorrect because the fragment is not present in propanone*	**1**

Q15.

Question Number	Answer	Mark
	The only correct answer is C (3) *A is incorrect because different isotopes of chlorine have been ignored* *B is incorrect because different isotope combinations of chlorine have not been considered* *D is incorrect because 35Cl/37Cl and 37Cl/35Cl give the same peak*	**(1)**

Q16.

Question number	Answer	Mark
(a)	**The only correct answer is C** (concentrated phosphoric(V) acid) ***A*** *is incorrect because acidified potassium manganate(VII) converts an alkene into a diol* ***B*** *is incorrect because aqueous bromine reacts with an alkene to form a bromoalcohol* ***D*** *is incorrect because phosphorus(V) chloride reacts with an alcohol to form a chloroalkane*	**(1)**

Question number	Answer	Mark
(b)	**The only correct answer is C** ($C_6H_{11}OH + [O] \rightarrow C_6H_{10}O + H_2O$) ***A*** *is incorrect because [O] is needed from the oxidising agent and hydrogen gas would not be produced* ***B*** *is incorrect because [O] is needed from the oxidising agent and hydrogen atoms would not be produced* ***D*** *is incorrect because the oxidising agent is not oxygen gas*	**(1)**

Question number	Answer	Mark
(c)	**The only correct answer is C** (3750-3200, 1669-1645) ***A*** *is incorrect because there is a C-H bond in both compounds* ***B*** *is incorrect because there is a C-H bond in both compounds and there is no C=O in cyclohexene* ***D*** *is incorrect because there is no C=O in cyclohexene*	**(1)**