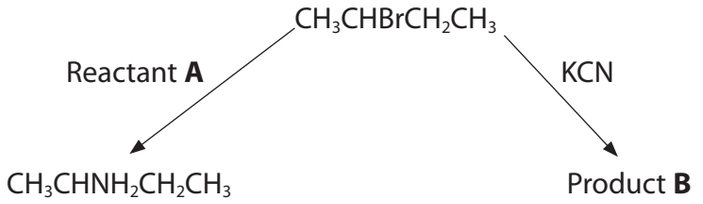
Answer ALL questions.

Write your answers in the spaces provided.

Some questions must be answered with a cross in a box ☒.
If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 This question is about halogenoalkanes.

(a) Some reactions of 2-bromobutane are:



(i) Give the **formula** for Reactant **A**.

(1)

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(ii) Give the **displayed** formula of the organic Product **B**.

(1)

(b) Which of these statements best explains why 2-chlorobutane reacts with potassium cyanide at a slower rate than 2-bromobutane?

(1)

☒ **A** the C-Cl bond has a higher bond enthalpy than the C-Br bond

☒ **B** the C-Cl bond has a lower bond enthalpy than the C-Br bond

☒ **C** the C-Cl bond is less polar than the C-Br bond

☒ **D** the C-Cl bond is more polar than the C-Br bond

(c) Halogenoalkanes are hydrolysed by hydroxide ions to form alcohols.

(i) Give reasons why these reactions are classified as nucleophilic substitution.

(2)

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(ii) Which of the following shows the relative rate of hydrolysis of 1-bromobutane, 2-bromobutane and 2-bromo-2-methylpropane?

(1)

		Fastest rate →		**Slowest rate**
☒	**A**	1-bromobutane	2-bromobutane	2-bromo-2-methylpropane
☒	**B**	1-bromobutane	2-bromo-2-methylpropane	2-bromobutane
☒	**C**	2-bromo-2-methylpropane	1-bromobutane	2-bromobutane
☒	**D**	2-bromo-2-methylpropane	2-bromobutane	1-bromobutane

(iii) The reaction between 2-bromo-2-methylpropane and hydroxide ions takes place in two steps.

$$(CH_3)_3CBr \rightarrow (CH_3)_3C^+ + Br^- \quad \text{slow}$$

$$(CH_3)_3C^+ + OH^- \rightarrow (CH_3)_3COH \quad \text{fast}$$

Give the rate equation for the reaction of 2-bromo-2-methylpropane with hydroxide ions. Justify your answer.

(2)

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(Total for Question 1 = 8 marks)

2 This question is about carboxylic acids and their derivatives.

(a) Which method can be used to produce a carboxylic acid using only the reactants shown?

(1)

☒ **A** hydrolysis of ethyl ethanoate with sodium hydroxide solution

☒ **B** hydrolysis of butanenitrile with dilute hydrochloric acid

☒ **C** reaction of butanoyl chloride with concentrated ammonia

☒ **D** reaction of but-2-ene with acidified potassium manganate(VII)

(b) Which of these reagents can be used to make the ester, propyl ethanoate, in a single step reaction?

(1)

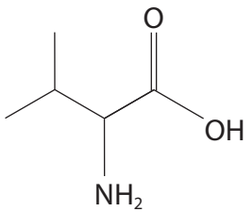
☒ **A** CH_3CH_2CHO and CH_3CH_2OH

☒ **B** CH_3CH_2COCl and CH_3CH_2OH

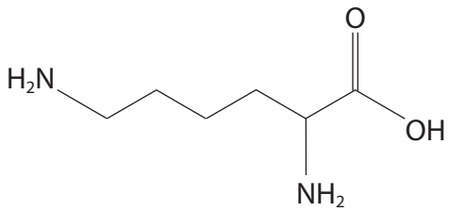
☒ **C** CH_3CHO and $CH_3CH_2CH_2OH$

☒ **D** CH_3COCl and $CH_3CH_2CH_2OH$

(c) The structures of two amino acids are shown.



valine



lysine

Give the **skeletal** formula for

(i) valine in a solution at pH 10

(1)

(ii) lysine in a solution at pH 2

(1)

(d) Gas chromatography is used in conjunction with mass spectrometry to analyse esters found in drinks.

State the purpose of each technique.

(i) Gas chromatography

(1)

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(ii) Mass spectrometry

(1)

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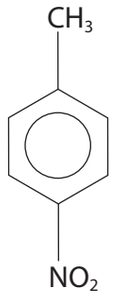
(Total for Question 2 = 6 marks)

3 This question is about arenes.

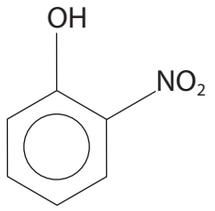
(a) Methylbenzene reacts with a mixture of concentrated nitric and sulfuric acids to form 1-methyl-4-nitrobenzene.



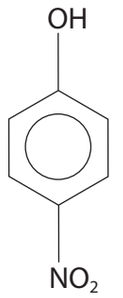
Give the mechanism for the reaction, including an equation for the formation of the electrophile.

(4)

(b) Phenol reacts with dilute nitric acid at room temperature to form a mixture of 2-nitrophenol and 4-nitrophenol.



2-nitrophenol



4-nitrophenol

(i) Explain why phenol reacts with nitric acid more readily than benzene.

(2)

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(ii) Suggest an explanation for 2-nitrophenol being less soluble in water than 4-nitrophenol.

(2)

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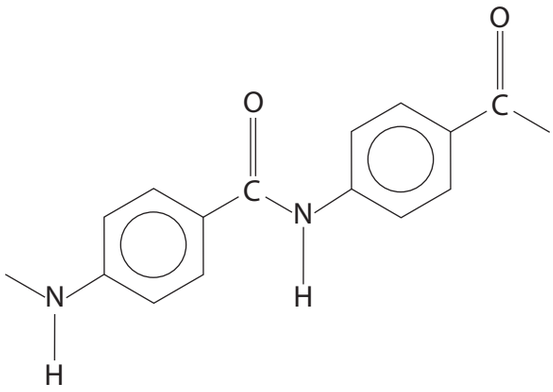
(c) Part of the structure of a polyamide is shown.



Draw the structure of a single monomer that could be used to form this polyamide.

(1)

(Total for Question 3 = 9 marks)

4 This question is about hydrocarbons.

(a) 0.28 g of a gaseous hydrocarbon, **J**, was burned in excess oxygen.
0.88 g of carbon dioxide and 0.36 g of water were formed.
The volume of 0.28 g of **J** at 1.01×10^5 Pa and 298 K is 123 cm^3.

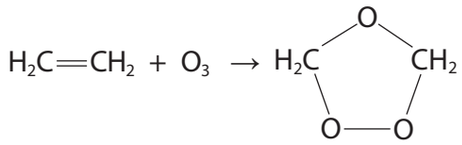
Use this information to show that the molecular formula of **J** is C_4H_8.

(4)

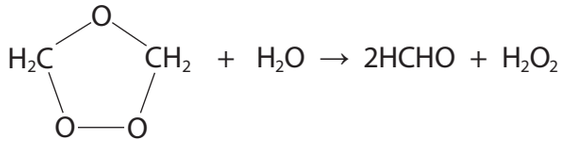
(b) Draw the **skeletal** formulae of the four isomers of alkenes with molecular formula C_4H_8.

(3)

(c) Ozone reacts with an alkene, such as ethene, dissolved in an organic solvent to form an ozonide.



When hydrolysed by warming with water and zinc dust, the ozonide splits up to form carbonyl compounds.



These reactions can be used to find the position of a double bond in an alkene.

The hydrocarbon **J** was treated with ozone and the product was hydrolysed by warming with water and zinc dust.
Two different carbonyl compounds, **K** and **L**, were formed and separated.

The mass spectrum of compound **K** showed a molecular ion peak at *m/z* 30.

The mass spectrum of compound **L** showed a molecular ion peak at *m/z* 58 and there were 2 peaks on the ^{13}C NMR spectrum.

Use this information to deduce the identities of the carbonyl compounds **K** and **L** and hence the hydrocarbon **J**. Justify your answers.

Write equations for the reaction between hydrocarbon **J** and ozone and for the hydrolysis of the product.

(5)

(d) 120cm^3 of a mixture of alkene **J** and butane were reacted with bromine at room temperature and pressure in the absence of sunlight. 0.32g of bromine reacted. Calculate the percentage by volume of alkene **J** in the mixture. **(3)**

(Total for Question 4 = 15 marks)

5 This question is about the decomposition of hydrogen iodide.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

The decomposition of hydrogen iodide is catalysed by the heterogeneous catalyst platinum.

(a) State the meaning of the term heterogeneous.

(1)

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(b) (i) Label the axes and draw a curve to show the Maxwell-Boltzmann distribution of molecular energies in a gas. Mark on your graph a suitable value for the activation energy, E_a, for the reaction.

(3)

(ii) Use the Maxwell-Boltzmann distribution to explain why a catalyst increases the rate of a reaction.

(3)

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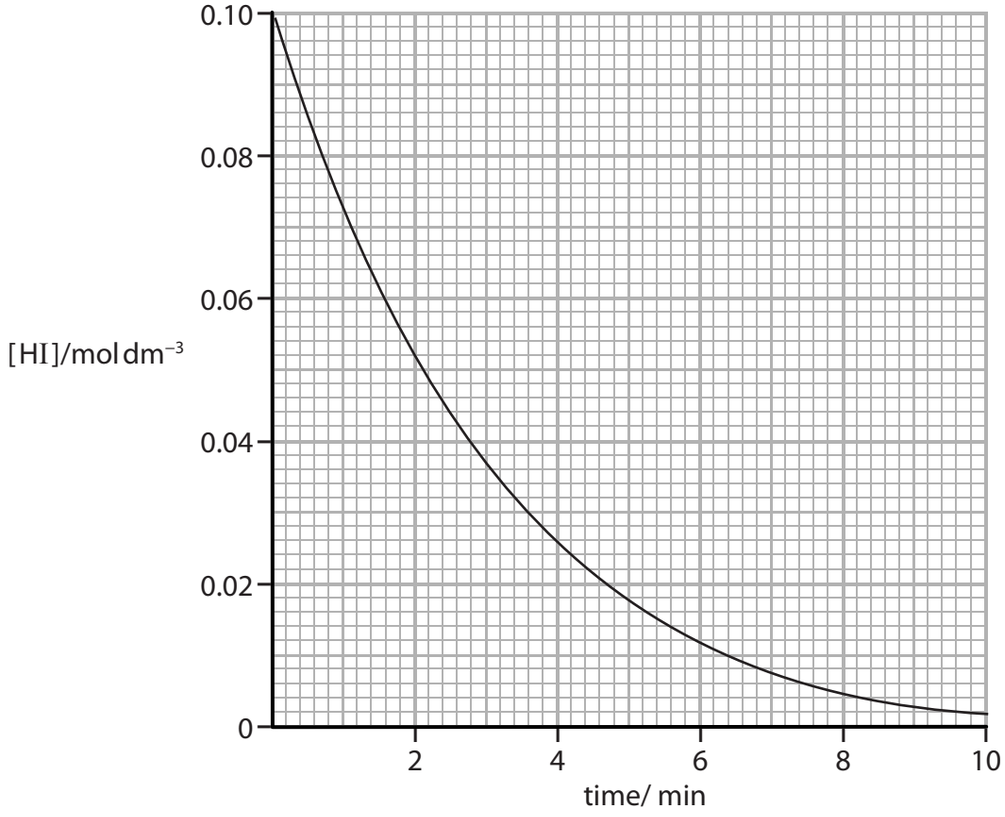
(c) The graph shows how the concentration of hydrogen iodide changes with time when a platinum catalyst is present.



Measure two successive half-lives from the graph, showing your working, and deduce the order of reaction with respect to hydrogen iodide. Justify your answer.

(2)

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(d) At 556 K, hydrogen iodide decomposes without a catalyst.

The following data were obtained.

Initial concentration of hydrogen iodide / mol dm^{-3}	**Initial rate of reaction / mol dm^{-3} s^{-1}**
0.100	7.040×10^{-9}
0.300	6.336×10^{-8}

(i) Deduce the order of reaction with respect to hydrogen iodide when there is no catalyst present. Justify your answer.

(2)

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(ii) Write the rate equation for the reaction without a catalyst and calculate the rate of reaction when the initial concentration of hydrogen iodide is 0.500 mol dm^{-3}.

(2)

(iii) The rate constant for this reaction was determined at various temperatures. The data from these experiments are shown in the table.

Temperature T / K	**Rate constant k / dm^3 mol^{-1}s^{-1}**	**ln k**	**1/T /K^{-1}**
556	7.04×10^{-7}	–14.17	0.00180
575	2.44×10^{-6}	–12.92	0.00174
629	6.04×10^{-5}	–9.71	0.00159
666	4.38×10^{-4}	–7.73	0.00150
700	2.32×10^{-3}	–6.07	0.00143

Use the data in the table to plot a graph and use it to calculate the activation energy, E_a, of the reaction, giving your answer to an appropriate number of significant figures and stating the units.

The rate constant of a reaction, k, is related to the temperature, **T**, by the expression

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{a constant}$$

(5)

Activation energy = ...

(Total for Question 5 = 18 marks)

6 This question is about hydrocarbons and chloroalkanes.

(a) (i) Which could be the molecular formula of a cycloalkane?

(1)

☒ **A** C_5H_{12}

☒ **B** C_6H_{14}

☒ **C** C_7H_{14}

☒ **D** C_7H_{16}

(ii) Which could be the molecular formula of an alkene with two double bonds?

(1)

☒ **A** C_6H_{12}

☒ **B** C_6H_{14}

☒ **C** C_7H_{12}

☒ **D** C_7H_{14}

(b) Draw a dot-and-cross diagram to show the bonding in a molecule of propene.

Only outer shell electrons should be shown.

(2)

(c) Predict the shape and bond angles in a CH_3^- ion. Justify your answer.

(4)

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(d) The first step in the reaction between chlorine and propane involves the formation of chlorine radicals.

(i) What type of bond breaking produces radicals?

(1)

☒ **A** heterolytic fission

☒ **B** heterolytic fusion

☒ **C** homolytic fission

☒ **D** homolytic fusion

(ii) Write equations for the propagating steps in the mechanism to form 2-chloropropane.

(2)

(iii) Explain why it is difficult to produce a pure sample of 2-chloropropane when chlorine reacts with propane.

(2)

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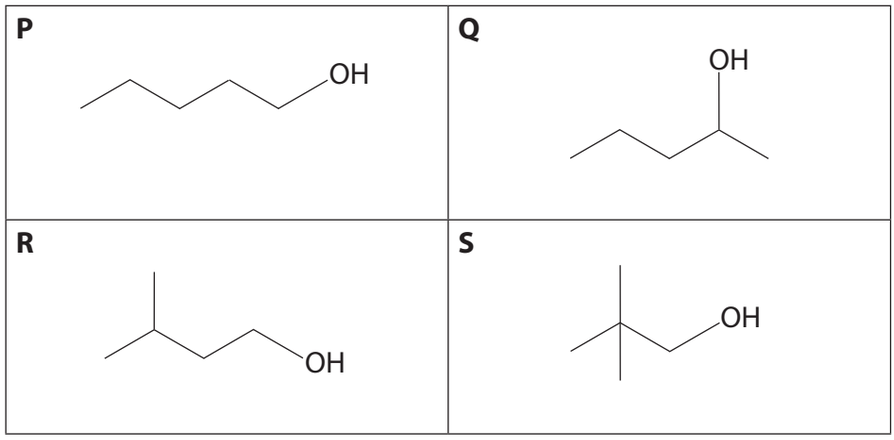
(Total for Question 6 = 13 marks)

7 This question is about alcohols.

(a) The skeletal formulae of four alcohols with molecular formula $C_5H_{12}O$ are shown.



(i) Which of the alcohols has a chiral centre?

(1)

☒ **A** alcohol **P**

☒ **B** alcohol **Q**

☒ **C** alcohol **R**

☒ **D** alcohol **S**

(ii) Which of the alcohols are classified as primary?

(1)

☒ **A** alcohol **P** only

☒ **B** alcohols **P** and **R** only

☒ **C** alcohols **P**, **R** and **S** only

☒ **D** alcohols **P**, **Q**, **R** and **S**

(iii) Which of the alcohols can be oxidised to form 3-methylbutanoic acid?

(1)

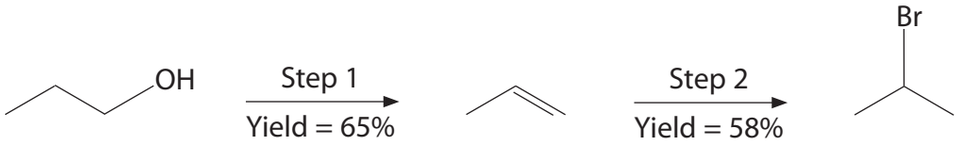
☒ **A** alcohol **P**

☒ **B** alcohol **Q**

☒ **C** alcohol **R**

☒ **D** alcohol **S**

(b) 2-bromopropane can be produced from propan-1-ol as shown in the sequence.



Calculate the mass of 2-bromopropane produced from 3.0 g of propan-1-ol in this sequence.

(3)

*(c) Devise a synthesis of butan-2-ol using ethanol as the only organic starting material and involving the formation of a Grignard reagent. Include the essential reagents and conditions for the reactions and give the structures of the intermediates.

(6)

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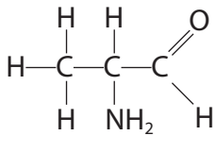
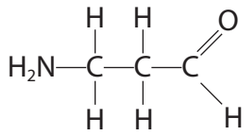
(Total for Question 7 = 12 marks)

8 This question is about 2-aminopropanal and 3-aminopropanal.



2-aminopropanal



3-aminopropanal

(a) Explain whether each of the following methods could be used to distinguish between these substances.

Method A Using very accurate mass spectroscopy to measure the relative molecular mass to four decimal places.

Method B Measuring the rotation of the plane of plane-polarised monochromatic light.

Method C Reacting the substances with Fehling's solution.

(3)

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*(b) Describe the high resolution proton NMR spectra of 2-aminopropanal and 3-aminopropanal. Explain how the spectra can be used to distinguish between these substances.

Use of the Data booklet to determine chemical shifts is not required.

(6)

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(Total for Question 8 = 9 marks)

TOTAL FOR PAPER = 90 MARKS