1 The chemical **X** is an ester with formula $CH_3COOC(CH_3)_3$ which occurs in raspberries and pears. It can be prepared in the laboratory by refluxing ethanoic acid with an alcohol in the presence of a catalyst.

(a) **Name** the alcohol and catalyst which would be used to make **X**.

(2)

Alcohol .....

Catalyst .....

(b) After refluxing, the resulting mixture is distilled to give an impure product containing **X**. The impure product is washed several times with sodium carbonate solution and then dried.

(i) Name the piece of equipment in which the impure product would be washed.

(1)

.....

(ii) What is the purpose of washing the impure product with sodium carbonate solution?

(1)

.....

(iii) Name a suitable drying agent.

(1)

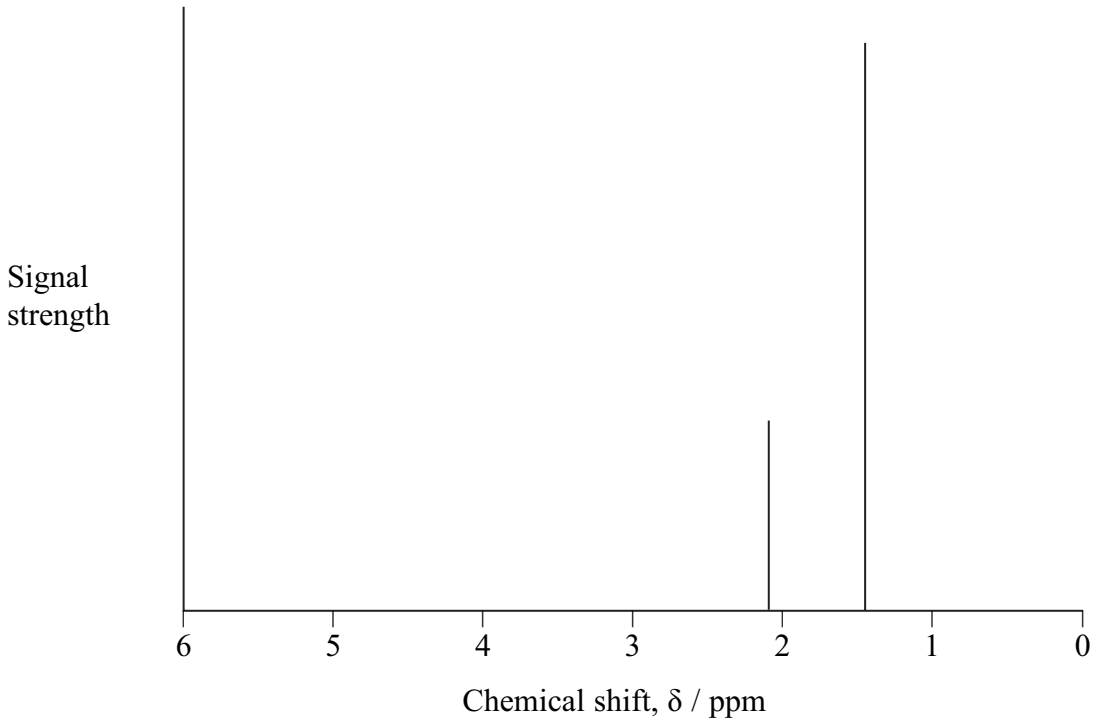
.....

(iv) The impure product is then redistilled and **X**, which has a boiling temperature of 97 °C, is collected. Draw a labelled diagram of the apparatus you would use.

(3)

*(c) **Spectrum 1** is the high resolution proton nmr spectrum of **X**, $CH_3COOC(CH_3)_3$.

Spectrum 1



Explain how **spectrum 1** is consistent with the structure of **X**. You should refer to the number and height of the peaks, the atoms which produce them and their splitting patterns.

(4)

(d) **X** has an isomer, **Y**. **Y** is an ester which can be made from ethanoic acid and 2-methylpropan-1-ol.

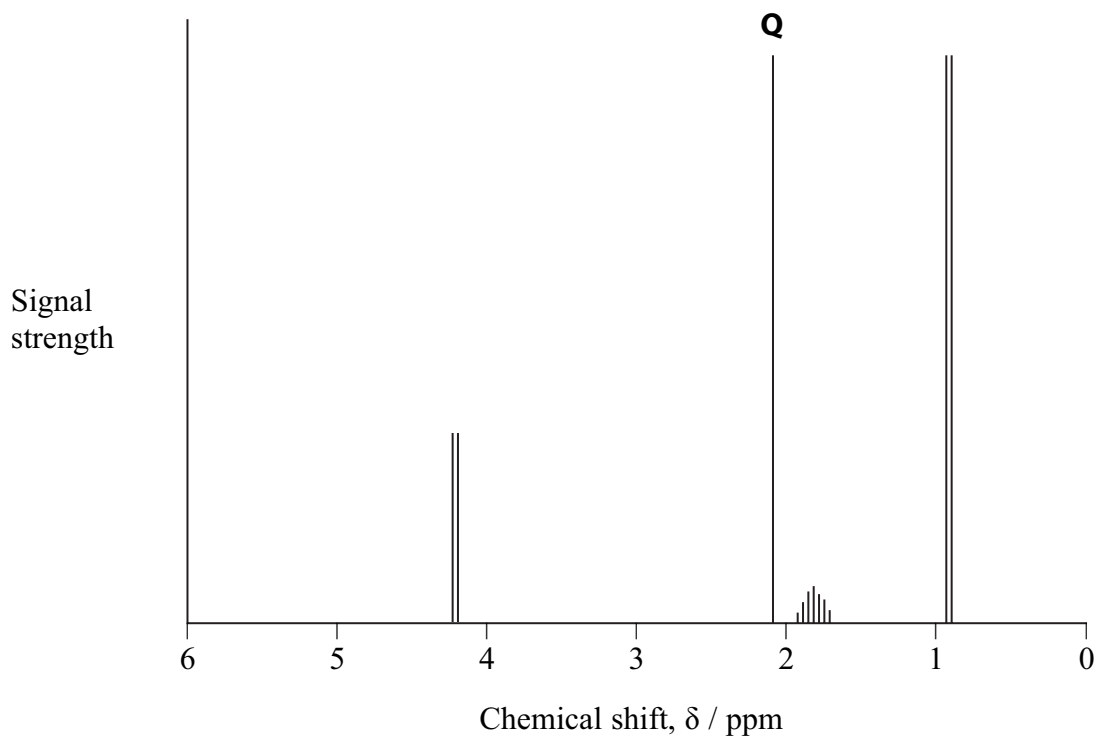
(i) Draw the structural formula of **Y**.

(1)

(ii) **Spectrum 2** is the high resolution proton nmr spectrum of **Y**. On your structural formula in (i), circle the atom or atoms causing the peak labelled **Q** on **spectrum 2**.

(1)

Spectrum 2



(e) **X** has several other structural isomers which have a broad peak at approximately 2960 cm ^{1} in their infrared spectra. Some of the isomers have a chiral carbon atom and all have a higher boiling temperature than **X**. None of them reacts with 2,4-dinitrophenylhydrazine.

*(i) Draw the structure of **one** of the isomers which is optically active, explaining how you use **all** the information in the question.

(5)

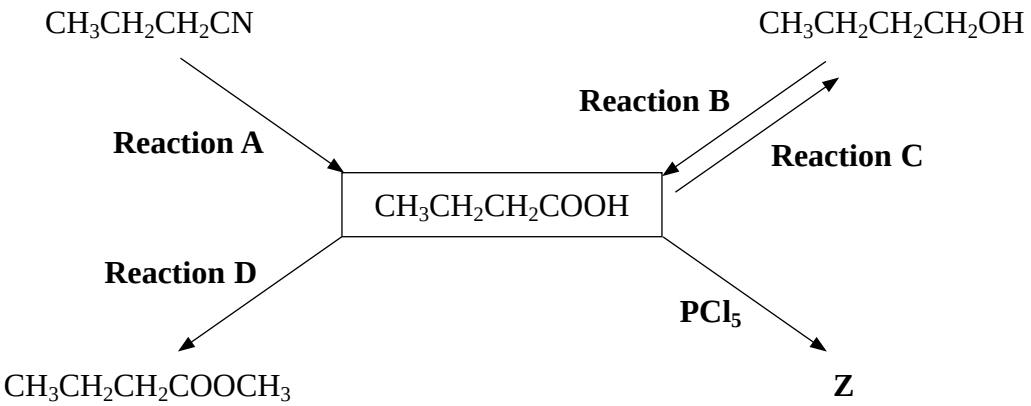
(ii) Could the compound you have drawn in (e)(i) be distinguished by infrared spectroscopy from its other isomers with the properties listed above? Explain your answer.

(1)

(Total for Question 20 marks)

2 This question is about butanoic acid, $CH_3CH_2CH_2COOH$.

(a) Some reactions involving butanoic acid are shown below.



(i) What type of reaction is **Reaction A**?

(1)

(ii) Identify, by name or formula, the reagent which is used with sulfuric acid to carry out **Reaction B**.

(1)

(iii) What reagent is used in **Reaction C**?

(1)

(iv) Name the organic product of **Reaction D** and write a balanced equation for its formation.

(2)

Name

Equation

(v) Write the **displayed** formula for **Z**, the organic product of the reaction of butanoic acid with phosphorus(V) chloride, PCl_5.

(1)

(b) Butanoic acid and propane-1,2,3-triol are formed when fats in milk are hydrolysed. The presence of milk fat in low fat spreads is detected by hydrolysing the spread, and then analysing the products using gas chromatography (also called gas-liquid chromatography, GLC).

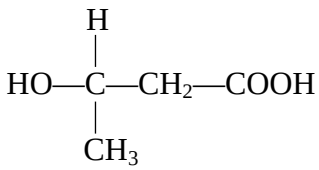
(i) Explain why nitrogen, rather than oxygen, is used as the carrier gas in GLC.

(1)

(ii) What property determines whether butanoic acid or propane-1,2,3-triol would move faster through the chromatography column?

(1)

(c) The formula of 3-hydroxybutanoic acid is shown below.



(i) 3-hydroxybutanoic acid can form a polymer which is used to make "green" packaging as it is biodegradable.

Draw a section of this polymer, showing TWO monomer units. Clearly show any double bonds.

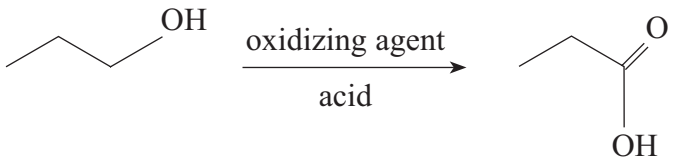
(2)

(ii) The polymer cannot be used in acidic conditions. What reaction would occur when the polymer is in prolonged contact with an acid?

(1)

(Total for Question = 11 marks)

3 The carboxylic acid, propanoic acid, can be prepared by oxidation of the alcohol, propan-1-ol.



propan-1-ol propanoic acid

(a) (i) Identify a suitable oxidizing agent you could use in this reaction.

(1)

.....

(ii) If you carried out this preparation in the laboratory, describe **two** measures you would take to ensure the maximum possible yield of propanoic acid is obtained.

(2)

.....

.....

.....

.....

(iii) Propanoic acid can be made by the hydrolysis of a nitrile. Give the structural formula of the nitrile and write an equation for this reaction.

(3)

Structural formula .....

Equation

*(b) Propanoic acid reacts with methanol, CH_3OH, to form the ester, methyl propanoate.

$$CH_3CH_2COOH + CH_3OH \rightleftharpoons CH_3CH_2COOCH_3 + H_2O$$

Even with the use of a catalyst, this reaction is quite slow and incomplete. Suggest a reagent, to replace the propanoic acid, which would form the ester at a faster rate. Suggest **two** reasons why your chosen reagent reacts faster.

(3)

(c) The structure of methyl propanoate can be investigated by using high resolution ^1H nuclear magnetic resonance (nmr) spectroscopy.

(i) What type of radiation interacts with ^1H nuclei in nmr spectroscopy?

(1)

(ii) Describe what happens to ^1H nuclei when they absorb this radiation.

(2)

(iii) Complete the table to show values for the chemical shift of the different ^1H nuclei in methyl propanoate and their splitting pattern. Page 7 of the data booklet gives information about chemical shifts.

(2)

^1H environment	Chemical shift, δ / ppm	Splitting pattern
CH_3O	3.7	Singlet
CH_2	2.3	
CH_3		Triplet

(Total for Question 14 marks)