Cambridge OL

Chemistry

CODE: (5070)

Chapter 13

Organic chemistry 02

13.1 Functional group

Chapter 12 explains that the functional group of an organic molecule determines its chemical properties, leading to the existence of numerous organic molecules.

▲ **Figure 13.1** This fruit juice contains plenty of vitamin C, or ascorbic acid, which contains the functional group –COOH

▼ **Table 13.1** The functional groups present in some homologous series of organic compounds

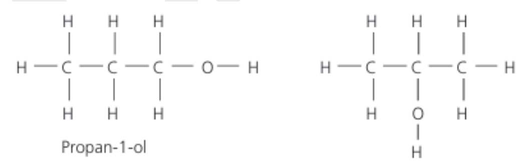
Class of compound	Functional group
Alcohols	R–OH
Carboxylic acids	R–COOH
Esters	R–COOR
Amines	$R{-}NH_2$
Amides	$R{-}CONH_2$

13.2 Alcohols [R-OH]

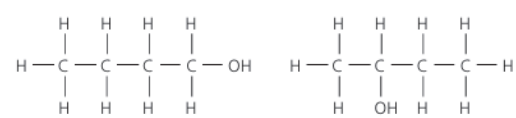
The alcohols form a homologous series with the general formula CnH2n+1OH, with an –OH as the functional group. They are named by reference to the corresponding alkane, with the hydrocarbon chain numbered from the end that gives the lowest number to the –OH group position. Propan-1-ol and propan-2-ol are two isomers of propanol and butanol, respectively, with their respective formulae shown in Figure 13.2.

▼ **Table 13.2** Some members of the alcohol family

Alcohol	Formula	Melting point/°C	Boiling point/°C
Methanol	CH_3OH	–94	64
Ethanol	CH_3CH_2OH	–117	78
Propanol	$CH_3CH_2CH_2OH$	–126	97
Butanol	$CH_3CH_2CH_2CH_2OH$	–89	117



a Propan-1-ol and propan-2-ol



b Butanol-1-ol and butan-2-ol

▲ **Figure 13.2** Displayed formulae of alcohols

Alcohols have high boiling points and relatively low volatility. Alcohol molecules are like water molecules (H–OH) in that they are polar.

Alcohol molecules are similar to water molecules with an alkyl group replaced by an H atom, making them miscible. Ethanol, the most important alcohol, is produced through fermentation or hydration of ethene. It is a neutral, colorless, and volatile liquid that is used extensively in everyday products like paints, glues, and aftershaves.

▲ **Figure 13.4** This aftershave contains alcohol

Combustion

The combustion of ethanol is an important property of ethanol. Ethanol burns quite readily with a clean, hot flame.

ethanol + oxygen → carbon dioxide + water + energy

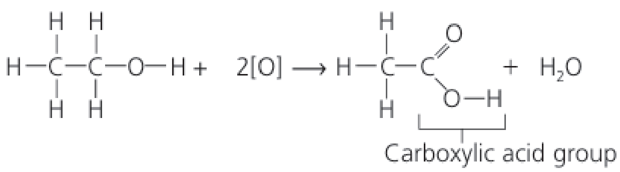
$$CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g) + \text{energy}$$

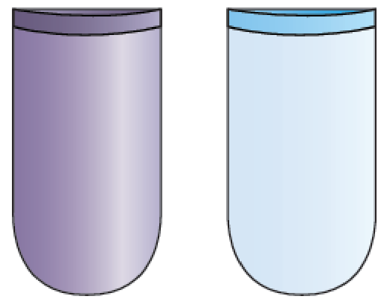
Oxidation

Ethanol oxidizes in the atmosphere, producing vinegar through the process of alcohol oxidation. Bacteria aid this process, and ethanol can also be oxidized to ethanoic acid by agents like potassium manganate (VII), removing its purple color.

ethanol + oxygen (from potassium manganate (VII)) $\xrightarrow{\text{heat}}$ ethanoic acid + water

$$CH_3CH_2OH(l) + 2[O] \longrightarrow CH_3COOH(aq) + H_2O(l)$$





▲ **Figure 13.5** Potassium manganate(VII) turns from purple to colourless

Manufacture of ethanol

Biotechnology uses microorganisms or enzymes to produce foods like yoghurt and bread, with fermentation being one of the oldest biotechnologies, catalyzed by yeast enzymes.

Fermentation

Anaerobic respiration is a process where yeast uses sugar solution for energy, breaking down sugar to produce carbon dioxide and ethanol. The optimal temperature for this process is 25-35°C.

glucose $\xrightarrow{\text{yeast}}$ ethanol + carbon dioxide

$$C_6H_{12}O_6(aq) \longrightarrow 2C_2H_5OH(l) + 2CO_2(g)$$

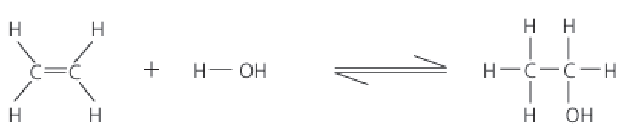
A batch process is an industrial method for fermenting glucose, where each batch undergoes a stage before moving on to the next. The primary product, ethanol, is separated from the mixture through fractional distillation, and the process is repeated with another batch of reagents.

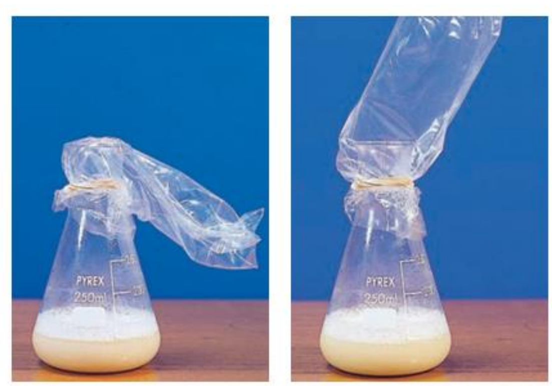
Hydration of ethene

The hydration of ethene in the production of ethanol, a solvent and fuel, is crucial for its production. This process involves adding water to the double bond in ethene, typically over an acid catalyst.

ethene + steam $\underset{\text{phosphoric(V) acid catalyst}}{\overset{300°C,\ 6000\ kPa}{\rightleftharpoons}}$ ethanol

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$





▲ **Figure 13.8** Fermenting glucose and yeast to produce ethanol. The bag is inflated during the experiment by CO_2

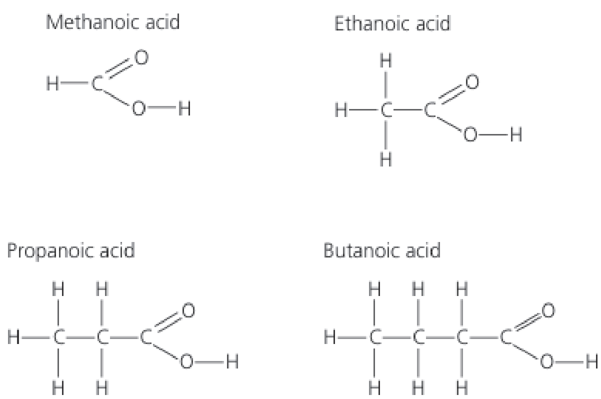
▼ **Table 13.3** Summary of the two methods that are used to make ethanol

	Fermentation	**Hydration**
Conditions employed	37°C and so less energy needed compared to the hydration method	300°C, 6000 kPa uses a catalyst of phosphoric acid
Processing	Manufactured in batches	Manufactured by a continuous process
Sustainability	Sustainable source – the glucose is renewable	Finite source – ethene is non-renewable
Purification	Fractional distillation	Becomes pure during production
Percentage yield	Low – about 15%	High – about 96%

▼ **Table 13.4** Advantages and disadvantages of preparation methods for ethanol

	Advantages	**Disadvantages**
Fermentation	• Low energy consumption • Uses readily available materials	• Slow process • Not a continuous process
Hydration of ethene	• Much faster process • Continuous process	• High energy consumption • Requires ethene which has to be obtained by cracking

Carboxylic acids, a homologous series with the general formula $C_nH_{2n+1}COOH$, possess –COOH as their functional group, with their melting and boiling points shown in Table 13.5 and Figure 13.9.



▲ **Figure 13.9** The displayed formulae of the first four members of the carboxylic acids

▼ **Table 13.5** Some members of the carboxylic acid series

Carboxylic acid	**Structural formula**	**Melting point/ °C**	**Boiling point/ °C**
Methanoic acid	$HCOOH$	9	101
Ethanoic acid	CH_3COOH	17	118
Propanoic acid	CH_3CH_2COOH	−21	141
Butanoic acid	$CH_3CH_2CH_2COOH$	−6	164

Acids, including methanoic acid, found in stinging nettles and ant stings, and ethanolic acid, the main component of vinegar, are weak acids that react with metals like magnesium. Despite their weak nature, they can form salts like sodium methanoate (HCOONa).

$$\text{methanoic acid} + \text{sodium hydroxide} \rightarrow \text{sodium methanoate} + \text{water}$$

$$HCOOH(aq) + NaOH(aq) \rightarrow HCOONa(aq) + H_2O(l)$$

Ethanoic acid, a member of the homologous series, reacts with metals and carbonates, producing magnesium ethanoate and hydrogen from the metal salt.

$$\text{ethanoic acid} + \text{magnesium} \rightarrow \text{magnesium ethanoate} + \text{hydrogen}$$

$$2CH_3COOH(aq) + Mg(s) \rightarrow (CH_3COO)_2Mg(aq) + H_2(g)$$

Ethanoic acid reacts with carbonates such as sodium producing the salt sodium ethanoate (CH3COONa), carbon dioxide and water.

ethanoic acid + sodium carbonate → sodium ethanoate + carbon dioxide + water

$$2CH_3COOH(aq) + Na_2CO_3(s) \rightarrow 2CH_3COONa(aq) + CO_2 + H_2O(g)$$

13.4 Esters

Ethanoic acid will react with ethanol, in the presence of a few drops of concentrated sulfuric acid acting as a catalyst, to produce ethyl ethanoate – an **ester**.

$$\text{ethanoic acid} + \text{ethanol} \underset{H_2SO_4}{\overset{\text{conc}}{\rightleftharpoons}} \text{ethyl ethanoate} + \text{water}$$

$$CH_3COOH(l) + C_2H_5OH(l) \underset{H_2SO_4}{\overset{\text{conc}}{\rightleftharpoons}} CH_3COOC_2H_5(aq) + H_2O(l)$$

This reaction is called esterification.

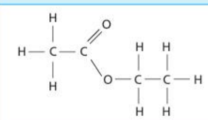
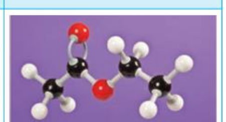
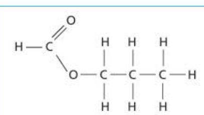
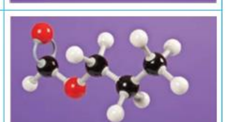
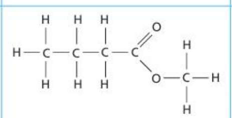
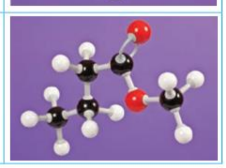
Esters are named after the acid and alcohol from which they are derived:

» Name – alcohol part first, acid part second,

» Formula – acid part first, alcohol part second,

Esters, found naturally in fruits and flowers, are used in food flavorings and perfumes. Fats and oils are energy storage compounds, possessing the same linkage as PET but with different units.

▼ **Table 13.6** The displayed formulae of some esters

Ester	Made from		Structure	3D model
	Alcohol	Carboxylic acid		
Ethyl ethanoate $CH_3COOC_2H_5$	Ethanol C_2H_5OH	Ethanoic acid CH_3COOH		
Propyl methanoate $HCOOC_3H_7$	Propan 1-ol C_3H_7OH	Methanoic acid HCOOH		
Methyl butanoate $C_3H_7COOCH_3$	Methanol CH_3OH	Butanoic acid C_3H_7COOH		

▲ **Figure 13.10** Perfumes contain esters

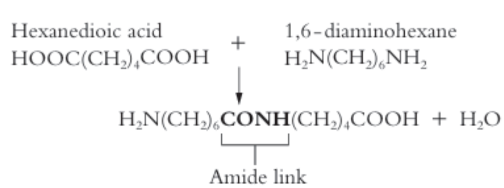
13.5 Condensation polymers

Poly(ethene), formed by addition polymerisation, can be represented by:

–A–A–A–A–A–A–A–A–A–A–

where A = monomer.

The starting molecules for nylon are more complicated than those for poly(ethene) and are called 1,6-diaminohexane and hexanedioic acid.



This sort of reaction is called **condensation polymerisation**.

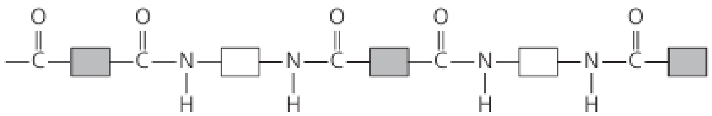
▲ **Figure 13.11** A nylon polymer chain is made up from the two molecules arranged alternately just like the two different coloured poppet beads in the photo

This differs from addition polymerisation, where there is only one product. Because an amide link is formed during the polymerisation, nylon is known as a **polyamide**.

This type of polymerisation, in which two kinds of monomer unit react, results in a chain of the type:

–A–B–A–B–A–B–A–B–A–B–

Generally, polyamides have the structure:



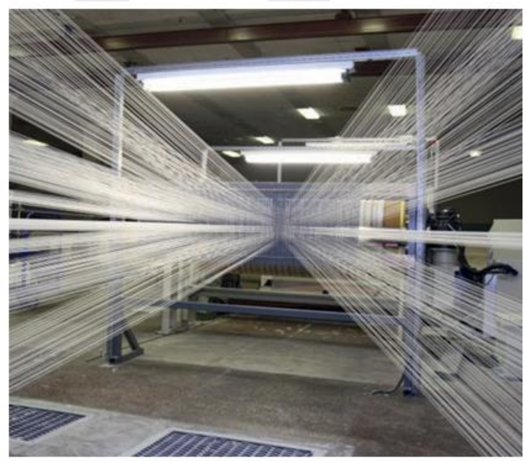
Polymerisation involves condensation reactions between monomer molecules, resulting in various polymers with varying properties, such as poly(ethyleneterephthalate) or PET, produced by reacting ethane-1,2-diol with benzene-1,4-dicarboxylic acid.

Ethane-1,2-diol $HO(CH_2)_2OH$ + Benzene-1,4-dicarboxylic acid $HOOC(C_6H_4)COOH$

↓

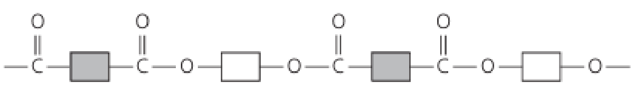
$HO(CH_2)_2$**OCO**$(C_6H_4)COOH + H_2O$

Ester link



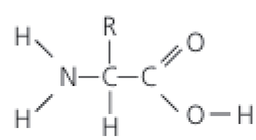
▲ **Figure 13.12** Nylon fibre is formed by forcing molten plastic through hundreds of tiny holes

This ester link is the same linkage as in fats.
Generally, polyesters have the structure:



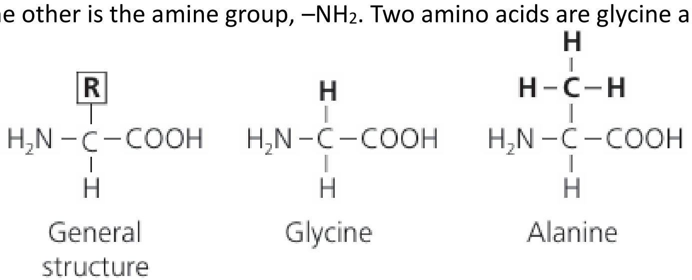
PET, like nylon, can be transformed into yarn for weaving, making it softer but harder wearing. Its polyester structure is formed by an ester link during polymerization.

13.6 Natural polyamides

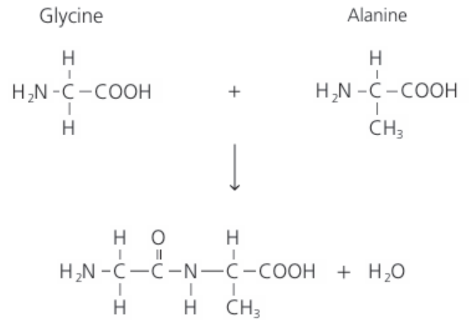


Proteins, natural polyamides, are condensation polymers derived from amino acid monomers, with various types of side chains representing different structures.

The other is the amine group, $–NH_2$. Two amino acids are glycine and alanine.

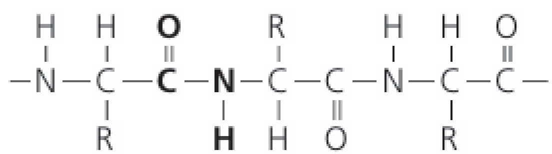


Proteins are formed by condensation polymerisation.



a **dipeptide**
(composed of two amino acids joined together)

Protein chains formed by the reaction of many amino acid molecules have the general structure shown below.



Proteins, comprising 15% of body weight, are formed through further reaction with amino acids at each end, with at least 100 amino acids involved, making them a key component of food.

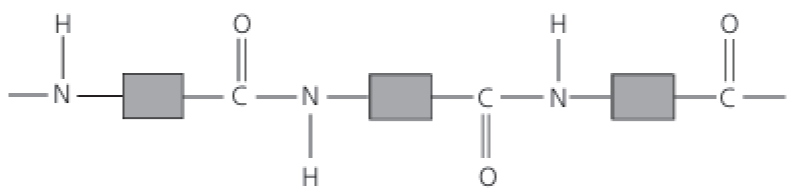


Figure 13.13 General structure of a protein

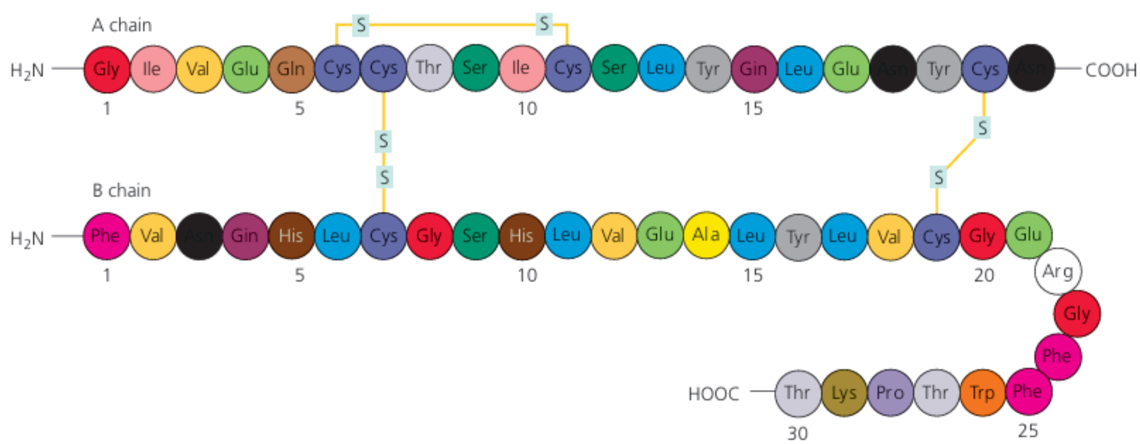
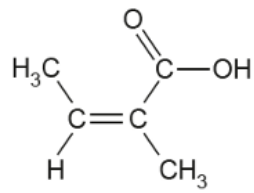


Figure 13.14 The structure of a protein – human insulin (the different coloured circles represent different amino acids in this protein)

Revision questions

13. Nov/2021/Paper_21/No.8

The structure of angelic acid is shown.



(a) Explain how this structure shows that angelic acid is an unsaturated compound.

.... [1]

(b) Deduce the molecular formula of angelic acid.

.... [1]

(c) Angelic acid is a weak acid.

(i) Define the term *acid*.

.... [1]

(ii) Explain the meaning of the term *weak* as applied to acids.

(d) Angelic acid can be polymerised.

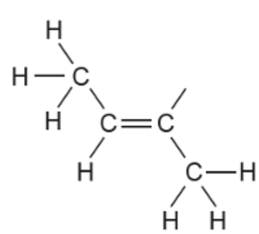
(i) State the name of the type of polymerisation that occurs.

.... [1]

(ii) Draw the partial structure of the polymer of angelic acid. Show two repeat units.

(e) Angelic acid reacts with methanol, CH_3OH, to form an ester.

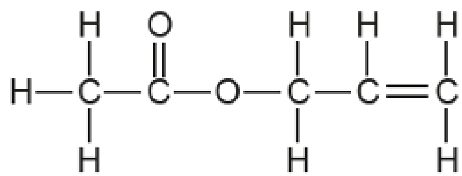
Complete the structure of this ester to show all the atoms and all the bonds.



(f) Construct the equation for the complete combustion of methanol.

32. Jun/2021/Paper_21/No.9

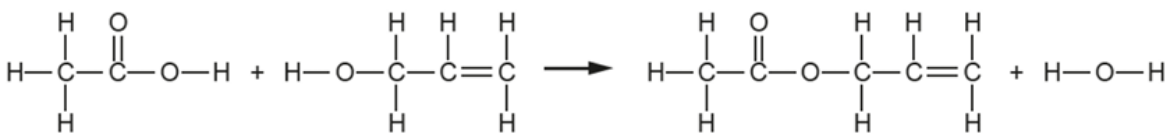
The structure of propenyl ethanoate is shown.



(a) Use the structure to explain why propenyl ethanoate is unsaturated.

(b) Describe a chemical test to show that propenyl ethanoate is unsaturated.

(c) Propenyl ethanoate is prepared by the reaction between a carboxylic acid and an alcohol, as shown.



(i) Name the carboxylic acid used.

.... [1]

(ii) The reaction uses concentrated sulfuric acid as a catalyst.

Describe how a catalyst speeds up a chemical reaction.

(d) In an experiment 11.6 g of the alcohol is reacted with an excess of the carboxylic acid. The experimental yield of propenyl ethanoate is 6.72 g.

[The relative formula mass of propenyl ethanoate is 100.]

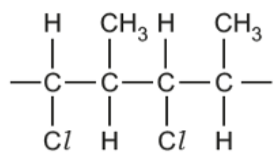
(i) Show that the maximum possible yield of propenyl ethanoate is 20.0 g.

(ii) Calculate the percentage yield of propenyl ethanoate in this experiment.

34. Jun/2021/Paper_22/No.3

There is concern about the disposal of plastics made from non-biodegradable polymers.

(a) The partial structure of a non-biodegradable polymer is shown.



(i) Name the type of polymer shown.

.... [1]

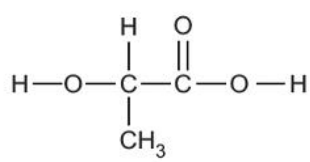
(ii) Draw the structure of the monomer used to make this polymer.

(iii) This polymer is often disposed of by combustion.

Suggest one problem associated with this method of disposal.

(b) Lactic acid is used to make poly(lactic acid), a biodegradable polymer.

The structure of lactic acid is shown.



(i) Suggest what is meant by the term *biodegradable*.

(ii) Draw the partial structure of poly(lactic acid).

Show at least two repeat units.

(iii) A factory uses 500 tonnes of lactic acid to make poly(lactic acid).

The percentage yield is 100% but the mass of poly(lactic acid) made is less than 500 tonnes.

Explain why the mass of poly(lactic acid) made is less than 500 tonnes.

(iv) Aqueous lactic acid reacts with acidified potassium manganate(VII).

There is a colour change from purple to colourless.

Suggest what happens to the lactic acid in this reaction.

.... [1]

(v) Aqueous lactic acid is neutralised by aqueous sodium hydroxide.

Write the ionic equation for this neutralisation.

.... [1]

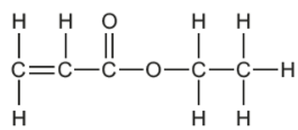
(vi) Aqueous lactic acid reacts with magnesium.

Name the gas made in this reaction.

.... [1]

36. Jun/2021/Paper_22/No.9

The structure of ethyl propenoate is shown.

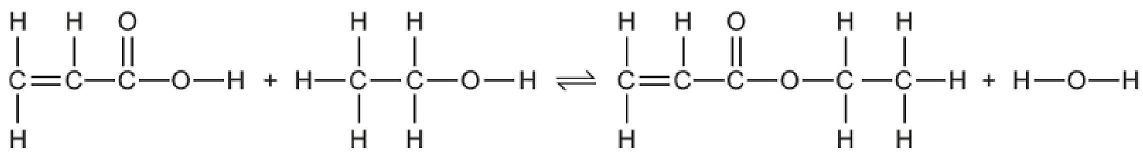


(a) Circle the atoms in the structure that show that ethyl propenoate is an ester. [1]

(b) Aqueous bromine is shaken with a sample of ethyl propenoate.

Explain, in terms of the structure of ethyl propenoate, why the aqueous bromine turns colourless.

(c) Ethyl propenoate is prepared by the reversible reaction between a carboxylic acid and an alcohol, as shown.



A mixture of the carboxylic acid and the alcohol is allowed to reach equilibrium.

(i) Name the alcohol used in the reaction.

.... [1]

(ii) The reaction uses an acid catalyst.

State the effect of this catalyst on the position of equilibrium.

.... [1]

(iii) The concentration of the alcohol is increased.

Describe and explain what happens to the position of equilibrium.

(d) In an experiment 10.8 g of the carboxylic acid is reacted with an excess of the alcohol. The experimental yield of ethyl propenoate is 9.45 g.

[The relative formula mass of the carboxylic acid is 72.]

(i) Show that the maximum possible yield of ethyl propenoate is 15.0 g.

(ii) Calculate the percentage yield of ethyl propenoate in this experiment.

17. Nov/2021/Paper_21/No.6

(a) The table shows some properties of five alcohols.

alcohol	formula	density in g/cm^3	boiling point in °C
methanol	CH_3OH	0.791	65
ethanol	C_2H_5OH	0.789	79
propanol	C_3H_7OH	0.803	97
butanol	C_4H_9OH	0.810	117
pentanol	$C_5H_{11}OH$	0.814	138

(i) What is the general trend in the density of the alcohols as the number of carbon atoms in a molecule increases?

(ii) Describe and explain the change in the boiling point of the alcohols as the number of carbon atoms in a molecule increases.

(b) Ethanol, C_2H_5OH, reacts with butanoic acid, $C_3H_7CO_2H$, to produce an ester.

A few drops of a strong acid are added to catalyse the reaction.

(i) What does the term *strong* mean, when applied to acids?

(ii) Name and draw the structure of the ester produced when ethanol reacts with butanoic acid, showing all of the atoms and all of the bonds.

(c) Ethanol can be oxidised to ethanoic acid in the laboratory.

State the reagents and conditions used in this reaction.

(d) Concentrated ethanoic acid, CH_3CO_2H, reacts with calcium.

The products are calcium ethanoate and hydrogen.

(i) Construct the equation for this reaction.

.... [1]

(ii) State and explain how the rate of this reaction changes when the experiment is repeated using dilute ethanoic acid.

All other conditions stay the same.

Include in your answer ideas about collisions between particles.

37. Jun/2020/Paper_21/No.4

The table shows some properties of five esters.

name	structure	relative molecular mass	melting point /°C	boiling point /°C
methyl ethanoate	CH_3COOCH_3	74	–98	57
ethyl ethanoate	$CH_3COOCH_2CH_3$	88	–84	77
propyl ethanoate	$CH_3COOCH_2CH_2CH_3$	102	–95	102
butyl ethanoate	$CH_3COOCH_2CH_2CH_2CH_3$	116	–78	126
pentyl ethanoate	$CH_3COOCH_2CH_2CH_2CH_2CH_3$	130	–71	148

(a) These esters are part of a homologous series.

State **two** characteristics of a homologous series.

(b) The next member of the homologous series is hexyl ethanoate.

Explain why it is more difficult to predict the melting point than the boiling point of hexyl ethanoate.

(c) At 25 °C ethyl ethanoate is a liquid.

Explain how the data in the table shows this.

(d) State one use for an ester.

(e) Propyl ethanoate is prepared by the reaction between ethanoic acid and propanol.

$$CH_3CO_2H + CH_3CH_2CH_2OH \rightleftharpoons CH_3COOCH_2CH_2CH_3 + H_2O$$

(i) Calculate the maximum mass of propyl ethanoate that can be made from 7.20 g of ethanoic acid and excess propanol.

Give your answer to **three** significant figures.

(ii) The concentration of ethanoic acid is increased.

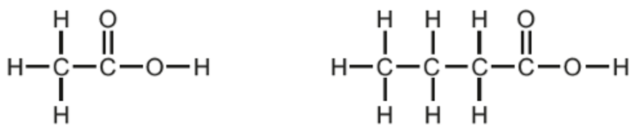
State and explain, in terms of particles, what happens to the rate of the forward reaction.

(iii) The water formed in the reaction is removed.

State and explain what happens to the position of the equilibrium.

38. Jun/2020/Paper_21/No.6

The structures of two carboxylic acids are shown.



ethanoic acid carboxylic acid **B**

(a) An isomer of carboxylic acid **B** has the name methylpropanoic acid.

(i) What is the name of carboxylic acid **B**?

(ii) What is the meaning of the term *isomer*?

(b) Vinegar contains ethanoic acid.

Describe the formation of vinegar from ethanol.

(c) Ethanoic acid reacts with calcium carbonate.

(i) Give the formula of the calcium salt formed in this reaction.

.... [1]

(ii) Name the other **two** products formed in this reaction.

.... and .... [1]

40. Jun/2020/Paper_22/No.3

The table shows some properties of five esters.

name	structure	relative molecular mass	melting point /°C	boiling point / °C
methyl methanoate	$HCOOCH_3$	60	−100	32
methyl ethanoate	CH_3COOCH_3	74	−98	57
methyl propanoate	$CH_3CH_2COOCH_3$	88	−88	80
methyl butanoate	$CH_3CH_2CH_2COOCH_3$	102	−95	102
methyl pentanoate	$CH_3CH_2CH_2CH_2COOCH_3$			

(a) These esters are part of a homologous series.

(i) State the relative molecular mass of methyl pentanoate.

(ii) Predict the boiling point of methyl pentanoate

.... °C [1]

(iii) Explain why it is **not** possible to predict the melting point of methyl pentanoate.

(b) At 35 °C methyl methanoate is a gas.

Explain how the data in the table shows this.

(c) Methyl pentanoate is used to flavour food.

Suggest one **other** use for esters.

(d) Methyl propanoate is prepared by the reaction between propanoic acid and methanol.

$$CH_3CH_2CO_2H + CH_3OH \rightleftharpoons CH_3CH_2COOCH_3 + H_2O$$

The forward reaction is exothermic.

(i) Calculate the maximum mass of methyl propanoate that can be made from 11.0 g of propanoic acid and excess methanol.

Give the answer to **three** significant figures.

(ii) The temperature of the reaction mixture is increased.

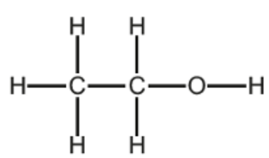
State and explain, in terms of particles, what happens to the rate of the forward reaction.

(iii) The temperature of the reaction mixture is increased.

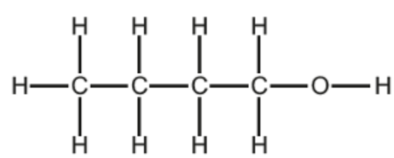
State and explain what happens to the position of the equilibrium.

41. Jun/2020/Paper_22/No.6

The structures of two alcohols are shown.



ethanol



alcohol **B**

(a) What is the name of alcohol **B**?

....

(b) Draw the structure of one other alcohol which is an isomer of **B**.

Show all of the atoms and all of the bonds.

(c) Ethanoic acid is produced by the oxidation of ethanol.

State the reagent for this reaction.

....

(d) Ethanol is a simple molecular compound.

Explain why liquid ethanol does **not** conduct electricity.