17 Alcohols and Carboxylic Acids

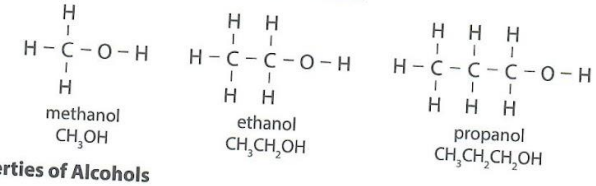
Study Station ▸▸

A What Are Alcohols?

Learning Outcomes

- Describe alcohols as a homologous series containing the –OH group.
- Draw the structures of alcohols with one to three carbon atoms and name the three alcohols.
- Describe the reactions of alcohols, namely combustion and oxidation to carboxylic acids.
- Describe the formation of ethanol by the fermentation of glucose.

1. **Alcohols** are organic compounds that contain the **hydroxyl** (**–OH**) functional group.
2. They have the general formula $\mathbf{C_nH_{2n+1}OH}$, where *n* is the number of carbon atoms.
3. The first three members of alcohols are shown below.



methanol CH_3OH | ethanol CH_3CH_2OH | propanol $CH_3CH_2CH_2OH$

Physical Properties of Alcohols

1. The physical properties of the first three alcohols are shown below.

Name of Alcohol	Molecular Formula	Boiling Point / °C	Physical State at 25 °C
methanol	CH_3OH	65	liquid
ethanol	C_2H_5OH	78	liquid
propanol	C_3H_7OH	97	liquid

2. The boiling points of alcohols increase down the homologous series. The intermolecular forces of attraction increase as the molecular size of the alcohols increases. Thus, more energy is required to overcome the intermolecular forces of attraction.
3. The solubility of alcohols decreases as their relative molecular mass increases.

Tip

Take note that alcohols are not alkalis although they have a hydroxyl (–OH) group. They do not ionise to produce hydroxide ions (OH^-) when dissolved in water.

Chemical Properties of Alcohols

1. Alcohols undergo complete combustion by burning in excess oxygen to form carbon dioxide and water.

   Example:

   $\underset{\text{ethanol}}{C_2H_5OH(l)} + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$

2. Alcohols burn with a clean blue flame without soot as the percentage by mass of carbon in them is lower compared to that in alkanes and alkenes.

3. Alcohols with the hydroxyl group bonded to the carbon atom at the end of their carbon chains are oxidised to carboxylic acids when they are heated with oxidising agents such as acidified potassium manganate(VII).

   Example:

   $\underset{\text{ethanol}}{CH_3CH_2OH(l)} + 2[O] \xrightarrow{\text{heat}} \underset{\text{ethanoic acid}}{CH_3COOH(aq)} + H_2O(l)$

   - The oxygen from the oxidising agent is represented by "[O]" in the chemical equation.
   - Acidified potassium manganate(VII) is reduced and changes from purple to colourless when it oxidises ethanol to ethanoic acid.

Formation of Ethanol

1. Ethanol can be produced by the fermentation of glucose in fruits, vegetables or grains.
2. During **fermentation**, yeast acts on glucose in the absence of oxygen to form ethanol and carbon dioxide.

   $\underset{\text{glucose}}{C_6H_{12}O_6(aq)} \xrightarrow{\text{yeast}} \underset{\text{ethanol}}{2C_2H_5OH(aq)} + 2CO_2(g)$

3. High temperatures cause the enzymes in yeast to be denatured and fermentation to stop.
4. Fermentation of glucose takes a long time, but it is a sustainable method of producing ethanol as its starting materials are obtained from a renewable resource such as sugarcane.

Worked Example 17.1

Which statement about ethanol is **true**?

A It does not react with acidified potassium manganate(VII).

B It is an unsaturated compound.

C It is formed by the oxidation of ethanoic acid.

D It undergoes combustion.

Solution

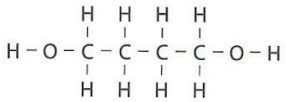
D

Explanation

Ethanol is oxidised by acidified potassium manganate(VII) to form ethanoic acid. Ethanol does not contain any carbon–carbon double bond. During combustion, ethanol burns in oxygen to produce carbon dioxide and water.

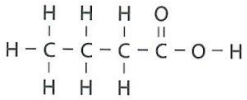
Worked Example 17.2

The structural formula of compound **Q** is shown below.

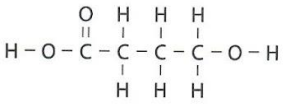


Which of the following shows the full structural formula of the product formed when compound **Q** is heated with acidified potassium manganate(VII)?

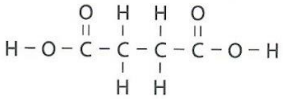
A



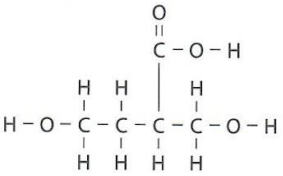
B



C



D



Solution

C

Explanation

Compound **Q** contains two hydroxyl groups, which are each joined to the carbon atom at each end of its carbon chain. The $-CH_2OH$ groups are oxidised to $-COOH$ groups.

Worked Example 17.3

Two reactions are shown below.

$$\text{Glucose} \xrightarrow{\text{A}} C_2H_5OH \xrightarrow{\text{B}} CH_3COOH$$

(a) Name reactions **A** and **B**.

(b) Describe how a colour change may occur in reaction **B**.

Strategy

(a) Deduce the relevant reactions that involve ethanol and ethanoic acid.

(b) Ethanol can be oxidised to ethanoic acid by an oxidising agent such as potassium manganate(VII). Consider the change in the colour of potassium manganate(VII).

Solution

(a) **A**: Fermentation
B: Oxidation

(b) Purple acidified potassium manganate(VII) turns colourless as it oxidises ethanol to ethanoic acid.

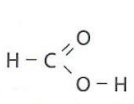
Link Discover Chemistry (3rd Edition) Textbook — Section 17.1

B What Are Carboxylic Acids?

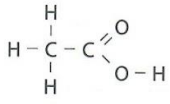
Learning Outcomes

- Describe carboxylic acids as a homologous series containing the –COOH group.
- Describe the formation of ethanoic acid through the oxidation of ethanol by atmospheric oxygen or acidified potassium manganate(VII).

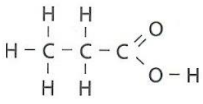
1. **Carboxylic acids** are organic compounds that contain the **carboxyl** (**–COOH**) functional group.
2. They have the general formula $\mathbf{C_nH_{2n+1}COOH}$, where *n* is the number of carbon atoms minus one.
3. The first three members of the carboxylic acids are shown below.



methanoic acid
$HCOOH$



ethanoic acid
CH_3COOH



propanoic acid
CH_3CH_2COOH

Tip

When naming a carboxylic acid, consider all the carbon atoms in the compound, including the carbon atom in the –COOH group.

Physical Properties of Carboxylic Acids

1. The boiling points of the first three carboxylic acids are shown below.

Name of Carboxylic Acid	Molecular Formula	Boiling Point / °C
methanoic acid	HCOOH	101
ethanoic acid	CH_3COOH	118
propanoic acid	C_2H_5COOH	141

2. The boiling points of carboxylic acids increase down the homologous series. The intermolecular forces of attraction increase as the molecular size of the carboxylic acids increases. Thus, more energy is required to overcome the intermolecular forces of attraction.
3. Carboxylic acids have higher boiling and melting points than alcohols and hydrocarbons with the same number of carbon atoms.
4. Carboxylic acids are soluble in water.

Formation of Ethanoic Acid

1. Ethanoic acid can be formed by heating a mixture of ethanol and acidified potassium manganate(VII). Acidified potassium manganate(VII) acts as the oxidising agent.

$$C_2H_5OH(aq) + 2[O] \longrightarrow CH_3COOH(aq) + H_2O(l)$$

2. Ethanoic acid can also be formed by reacting ethanol with oxygen. Ethanol is slowly oxidised to ethanoic acid by bacteria present in the air.

$$C_2H_5OH(aq) + O_2(g) \xrightarrow{\text{bacteria}} CH_3COOH(aq) + H_2O(l)$$

Common Error

✗ The oxidation of ethanol in air is represented by the chemical equation

$$C_2H_5OH + 2[O] \longrightarrow CH_3COOH + H_2O.$$

✓ The oxidation of ethanol in air is represented by the chemical equation

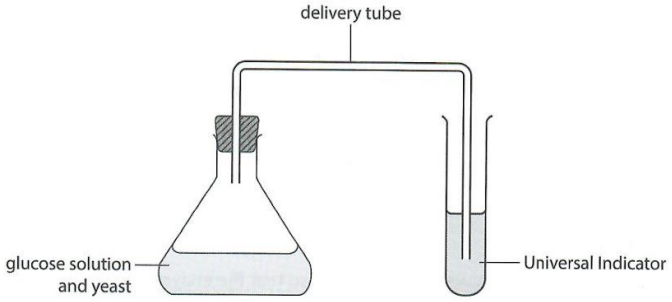
$$C_2H_5OH + O_2 \longrightarrow CH_3COOH + H_2O.$$

Explanation

Bacteria in the air acts as a catalyst in the reaction between ethanol and oxygen. Since ethanol reacts with oxygen and not with an oxidising agent, the symbol "[O]" should not be included in the chemical equation representing the reaction.

Worked Example 17.4

The experimental set-up below is used to form ethanol using glucose solution and yeast.



(a) Name the reaction in this experiment.

(b) Suggest why it is **not** advisable to increase the rate of reaction by increasing the temperature of the reaction mixture.

(c) After some time, the colour of Universal Indicator changes from pale green to orange. Explain why.

(d) Suggest why the delivery tube in the experimental set-up is immersed in the Universal Indicator.

(e) A compound is formed when the ethanol formed is exposed to air. Draw the structural formula of the compound.

Strategy

(a) Yeast acts on glucose in the absence of oxygen to form ethanol and carbon dioxide.

(b) Consider the effect of temperature on yeast.

(c) Acidic solutions cause Universal Indicator to turn orange.

(d) Consider what would happen if the delivery tube is not immersed in the Universal Indicator.

(e) Consider what is formed when ethanol is oxidised by atmospheric oxygen.

Solution

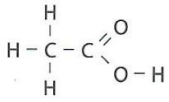
(a) Fermentation

(b) The yeast will denature at a high temperature. This will cause fermentation to stop.

(c) Carbon dioxide is bubbled into Universal Indicator and dissolves to form an acidic solution.

(d) This prevents oxygen from entering the experimental set-up and oxidising ethanol into ethanoic acid.

(e)



Worked Example 17.5

The fermentation of glucose becomes faster when yeast is added to glucose solution. The fermentation reaction is exothermic. It stops when the concentration of ethanol produced is about 15 %.

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

(a) Name **one** source of glucose for the fermentation reaction.

(b) The reaction mixture is cooled before ethanol is extracted from the mixture. Suggest why.

(c) Why does fermentation stop? Suggest **two** reasons.

(d) Name **one** way to separate the ethanol from the mixture.

Strategy

Fermentation of glucose occurs at around 37 °C so that the enzymes in the yeast are not denatured. An ethanol solution with a concentration higher than 15 % will kill the yeast and stop the fermentation reaction.

Solution

(a) Sugarcane / Rice / Barley (Any one)

(b) To prevent the enzymes in the yeast from being denatured

(c) All the glucose is used up. The high concentration of ethanol has killed the yeast in the mixture.

(d) Fractional distillation

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Checkpoint 17.1

1. **X** is the second member of the alcohol homologous series.

   (a) (i) State the name and chemical formula of **X**.

   (ii) Draw the full structural formula of **X**.

   (b) Write the chemical equation for the reaction between **X** and atmospheric oxygen.

   (c) A solution of **X** can be produced by the fermentation of glucose.

   Describe how this process is carried out in the laboratory using appropriate apparatus.

   (d) **X** is commonly used as a fuel for vehicles. Suggest **one** reason why it can be used for this purpose.

2. Linoleic acid is an unsaturated carboxylic acid that is used to make fats. Its structural formula is shown in FIgure 17.1.

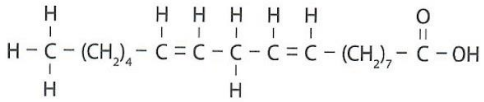


Figure 17.1

(a) Why is linoleic acid described as "unsaturated"?

(b) Predict the observation(s) that would be made if the following reagents are added separately to linoleic acid.

(i) Aqueous sodium carbonate

(ii) Aqueous bromine

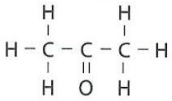
(c) Linoleic acid is able to react with ethanol. Ethanol can be obtained through the fermentation of sugar using yeast.

Write a chemical equation to show the fermentation of sugar to obtain ethanol.

Test Station ▸▸

1. Which of the following is the product of the oxidation of propanol?

A



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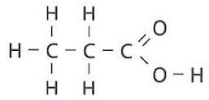

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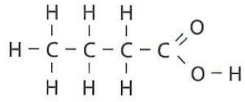

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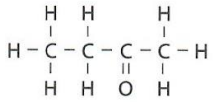

2. Figure 17.2 shows the structural formula of compound **Y**.

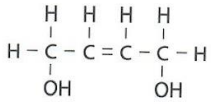

Figure 17.2

Which of the following statements about compound **Y** are **correct**?

1 It causes acidified potassium manganate(VII) to change from purple to colourless.

2 It causes aqueous bromine to be decolourised.

3 It turns blue litmus paper red.

A 1 and 2 only

B 1 and 3 only

C 2 and 3 only

D All of the above

3. The structural formula of an organic compound is shown in Figure 17.3.

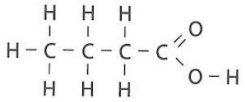

Figure 17.3

Which of the following statements about the organic compound is **true**?

A It has the same pH value as aqueous ammonia.

B It is formed by the oxidation of butanol.

C It turns red litmus paper blue.

D It undergoes an addition reaction with bromine.

4. Ethanol is used as an alternative source of energy. It can be produced by the fermentation of glucose.

Figure 17.4 shows how ethanol is produced from sugarcane.

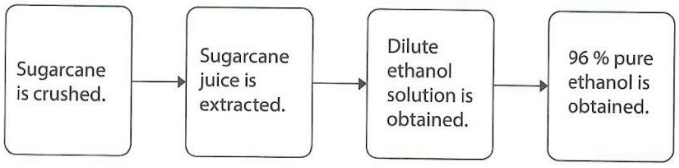

Figure 17.4

(a) Name the process that is used to obtain pure ethanol. [1]

(b) Explain why fermentation of glucose must be carried out in the absence of air. [1]

(c) Suggest why ethanol is used as an alternative source of energy. [1]

5. Figure 17.5 shows the amount of ethanol used as a fuel in a country, **Z**, from 2000 to 2015.

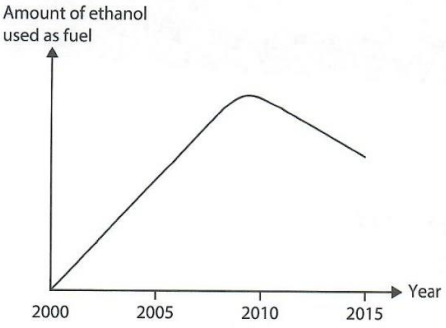

Figure 17.5

(a) Based on Figure 17.5, describe the trend in the amount of ethanol used as fuel over the years in country **Z**. [1]

(b) Ethanol burns in excess oxygen to produce carbon dioxide and water.

$$C_2H_5OH(aq) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$$

(i) Calculate the relative molecular mass of ethanol. [1]

(ii) Assuming that petrol contains 25 % of ethanol, calculate the volume of carbon dioxide gas produced by ethanol when 20 g of petrol is used as fuel. [3]

(c) Biobutanol is a fuel produced from the fermentation of biomass such as grains and leaves.

Suggest why it is important to develop fuels such as biobutanol as alternatives to petroleum. [1]