Temasek Junior College
Integrated Programme

Year 4 Chemistry

Topic 10.4: Alcohol Notes

Name:

Class:

Date:

Learning objectives

At the end of this notes, you must be able to:

- ☐ **(a)** describe alcohols as a homologous series containing the –OH group
- ☐ **(b)** draw the structures of branched and unbranched alcohols C1–C4 and name the unbranched alcohols methanol to butanol
- ☐ **(c)** describe the reactions of alcohols in terms of combustion, acid-metal displacement and oxidation to carboxylic acids
- ☐ **(d)** describe the formation of ethanol by the catalysed addition of steam to ethene and by fermentation of glucose

Topic Outline

1 Introduction

1.1 Nomenclature

2 Physical Properties of Alcohols

2.1 Melting and Boiling points

3 Isomerism in Alcohols

4 Chemical Properties of Alcohols: Reaction of alcohols

4.1 Combustion

4.2 Acid-Metal displacement

4.3 Oxidation

4.4 Condensation

5 Manufacturing Ethanol from Ethene

5.1 Addition of Steam (Hydration)

5.2 Fermentation of Yeast

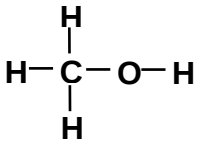
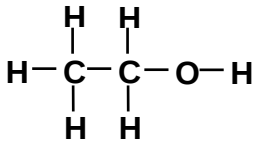
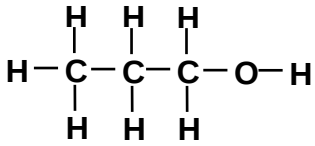
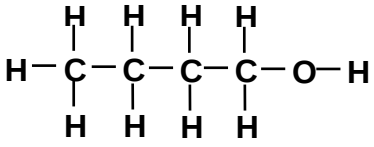
6 Use of Ethanol as a Biofuel

1 Introduction

- Alcohols are organic compounds made up of carbon, hydrogen and oxygen.
- General Formula : **$C_nH_{2n+1}OH$** *or* **ROH**
- Functional Group : **–OH** _____ **functional group**

1.1 Nomenclature

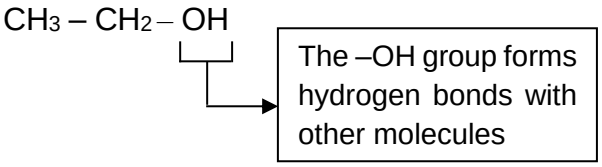
- Alcohol is named with a suffix '–**ol**' to indicate presence of the alcohol group.
- The following table shows the first four members of the alcohol homologous series.

Structural formula	Displayed / Full structural formula and Name	General formula of alcohols, in terms of n, where n is an integer starting with n = 1
CH_3OH	 methanol	
CH_3CH_2OH	 ethanol	
$CH_3CH_2CH_2OH$	 propan-1-ol	
$CH_3CH_2CH_2CH_2OH$	 butan-1-ol	

2 Physical Properties of Alcohols

- Alcohol molecules have an **alkyl group** as well as a **–OH group**.
- In addition to intermolecular forces of attraction**, hydrogen bonds** between the molecules are present as well.
- The **hydrogen bond between alcohol molecules refers to the electrostatic forces of attraction between a <u>hydrogen atom</u>** that is **covalently bonded to the oxygen <u>atom (an electronegative atom) and a lone pair of electrons on an oxygen atom from another alcohol molecule</u>**.

Example: Ethanol



2.1 Boiling Point and Melting Point

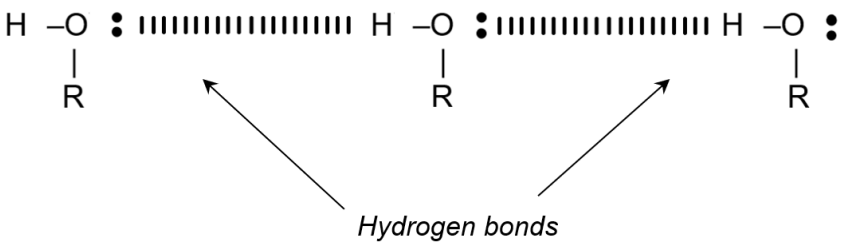
(i) Boiling points of alcohols are *higher* than hydrocarbons of similar M_r.

Boiling points of alcohols are much higher than hydrocarbons of similar M_r.

Compound	M_r	Boiling Point / °C
CH_3CH_2OH	46.0	78
$CH_3CH_2CH_3$	44.0	–42

Reason: This is due to the **<u>–OH group</u>** <u>which allows for</u> **<u>hydrogen bonding</u>** <u>between alcohol molecules</u>.

Hydrogen bonding between alcohol molecules:



(ii) Boiling point increases with increasing total number of electrons present.

Alcohol	Boiling Point / °C
methanol	65
ethanol	78
propanol	97

Reason: As the size of the electron cloud increases, this leads to stronger intermolecular forces of attraction between molecules. Hence, greater amount of energy is required to overcome these forces leading to higher boiling points.

Straight–chain isomers have higher boiling points than their branched isomers.

Example: Butanol has a higher boiling point than 2–methylpropan–1–ol.

Isomer	Type of isomer	Boiling Point / °C
butanol	Straight chain isomer	118
2-methylpropan-1-ol	Branched chain isomer	108

Reason:

- Butanol has a **straight chain** while 2–methylpropan–1–ol has a **branched chain.**
- Extent of **surface area of contact : butanol > 2-methylpropan-1-ol**
- Extent of **intermolecular forces of attractions : butanol > 2-methylpropan-1-ol**
- **Energy requirement: butanol > 2-methylpropan-1-ol**

3 Isomerism

Alcohols exhibit **constitutional isomerism**.

Molecular formula of alcohol	Isomer of alcohol	Type of isomerism and reasoning
CH_4O	Not applicable. Only CH_3OH	
C_2H_6O	Not applicable. Only CH_3CH_2OH	
C_3H_8O	$CH_3CH_2CH_2OH$ propan–1–ol $CH_3CH(OH)CH_3$ propan–2–ol	propan-1-ol and propan-2-ol exhibit _____ isomerism due to _____
$C_4H_{10}O$	$CH_3CH_2CH_2CH_2OH$ butan–1–ol $CH_3CH_2CH(OH)CH_3$ butan–2–ol $(CH_3)_2CHCH_2OH$ 2–methylpropan–1–ol $(CH_3)_3COH$ 2–methylpropan–2–ol	1. ***Constitutional (Positional)*** *isomerism* Reason: 2. ***Constitutional (Chain)*** *isomerism* Reason:

4 Chemical Properties of Alcohols: Reaction of alcohols

4.1 Combustion (Self-directed learning)

Similar to hydrocarbon, alcohols can undergo combustion.

4.1.1 Complete Combustion

Complete combustion of alcohol will yield **CO_2 and H_2O** as products.

Example complete combustion of ethanol: $CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

4.1.2 Incomplete Combustion

Incomplete combustion of alcohol will yield **CO and H_2O** as products.

Example incomplete combustion of ethanol: $CH_3CH_2OH + 2O_2 \rightarrow 2CO + 3H_2O$

4.2 Acid−Metal displacement reaction

- Alcohols are <u>very weak</u> acids.
- Hence, alcohols can undergo **<u>acid-metal displacement reaction</u>** with reactive metals to form a **<u>salt and hydrogen gas</u>**.

General equation: $\mathbf{R}OH + Na \longrightarrow \mathbf{R}O^-Na^+ + \frac{1}{2} H_2$

Reagents and Conditions: ……

Type of reaction: ……

Observation: **Effervescence of H_2 observed that extinguishes a lighted splint with a pop sound**

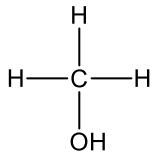
e.g. Reaction of ethanol with sodium

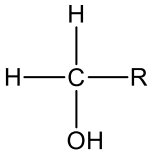
Note: Alcohols do not react with bases and carbonates.

4.3 Oxidation

- Primary alcohols are alcohols where the carbon atom bonded to the –OH group is bonded to two or three hydrogen atoms.

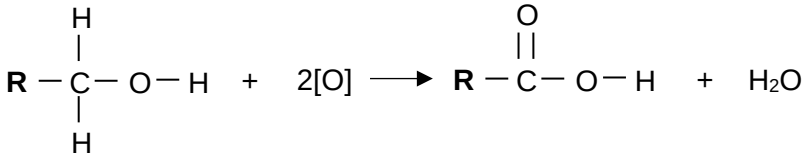
Examples of primary alcohol:





- **Primary alcohols** can undergo **oxidation** to form _____.

General equation: **R**CH_2OH + 2[O] → **R**$COOH$ + H_2O



primary alcohol *carboxylic acid*

Reagents & Conditions:	**$KMnO_4$(aq), dilute H_2SO_4, heat under reflux**	*OR*
	$K_2Cr_2O_7$(aq), dilute H_2SO_4, heat under reflux	
Type of Reaction:	**Oxidation**	
Observation:	**Purple $KMnO_4$ solution is decolourised**	*OR*
	Orange $K_2Cr_2O_7$ solution turns green	

Example: Oxidation of ethanol by heating under reflux with $KMnO_4$ or $K_2Cr_2O_7$ acidified with H_2SO_4

Chemical equation: CH_3CH_2OH + 2[O] → CH_3COOH + H_2O

ethanol ethanoic acid

Quick-check:

1. Write balanced chemical equation for the oxidation of propan–1–ol when heated under reflux with acidified potassium dichromate(VI).

   Chemical equation: .....

2. Write balanced chemical equation for the oxidation of butan–1–ol when heated under reflux with acidified potassium dichromate(VI). State the observation expected.

   Chemical equation: .....

   Observation: .....

4.4 Condensation

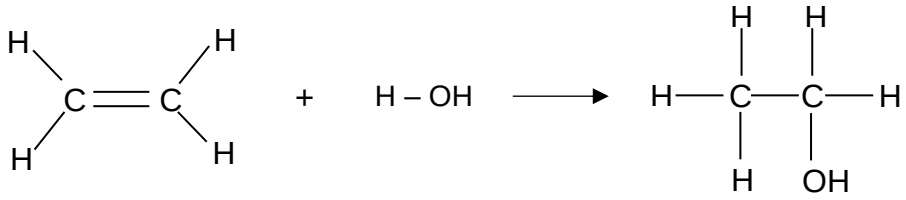
Alcohols can react with carboxylic acids to form esters through condensation reactions, and it is named **esterification**. Details of this will be covered in Carboxylic acids notes.

5 Manufacturing Ethanol from Ethene

Ethanol can be manufactured through two methods: **addition** and **fermentation**.

5.1 Addition of Steam (Hydration)

Ethanol is synthesised through the addition of steam to ethene.



ethene *ethanol*

Reagent:	**Steam or H_2O (g)**
Condition:	**Concentrated H_3PO_4 as catalyst, high temperature and pressure**
Type of reaction:	**Addition**

5.2 Fermentation of Yeast

Fermentation is the chemical process in which microorganisms such as **yeast** act on carbohydrates to produce ethanol and carbon dioxide. Examples of carbohydrates include sugars and starch. The optimal temperature for fermentation is **37 °C**.

Example: Using $C_6H_{12}O_6(aq)$ to represent an aqueous solution of glucose

Chemical equation: $\mathbf{C_6H_{12}O_6(aq) \xrightarrow{37\ °C} 2CH_3CH_2OH(aq) + 2CO_2(g)}$

Reagent:	**Glucose**, $C_6H_{12}O_6$ or any carbohydrate in aqueous solution
Condition:	**37 °C, yeast, absence of oxygen**
Type of reaction:	**Fermentation**

THINK: *What is the disadvantage of using fermentation method to synthesise ethanol?*
(Students to research on this and prepare answer before lesson)

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6 Science and environment (Self-directed learning)

Seed the Future

Planting roots for a sustainable tomorrow

Sustainability Considerations in Alcohol Production and Consumption

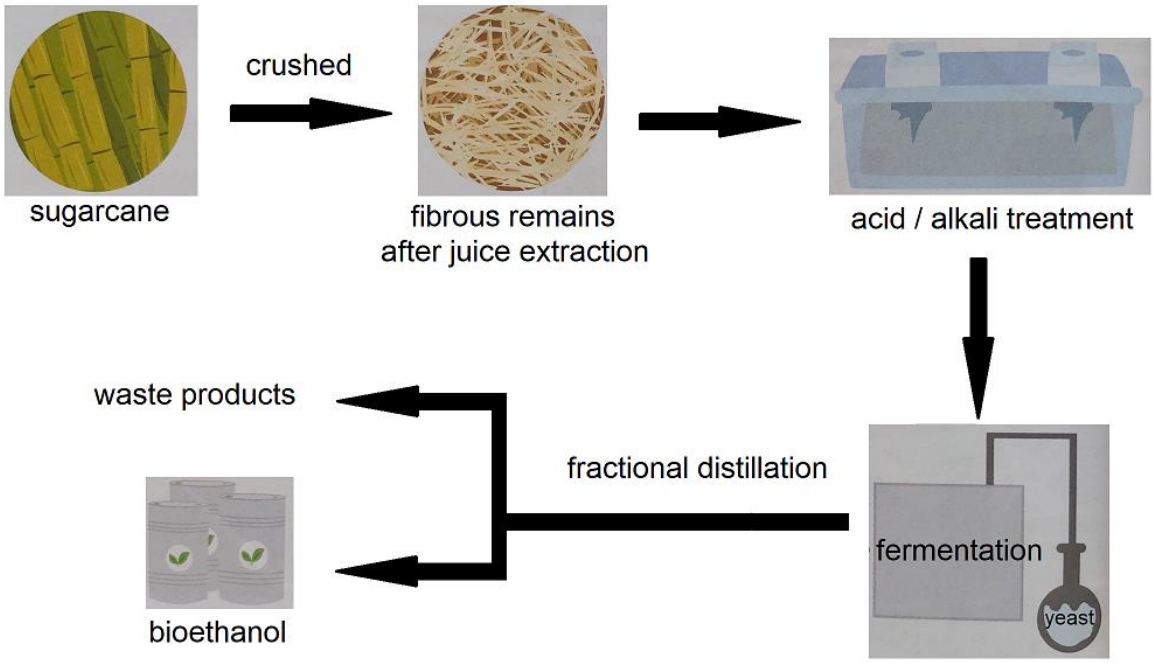
The sustainability of alcohol, particularly ethanol and other alcoholic beverages, involves both environmental and social considerations. While alcohol production can support renewable energy sources—such as bioethanol derived from crops like corn and sugarcane, which can be used as a fuel—its overall sustainability is complex. The cultivation of these crops often requires significant land, water, and energy resources, contributing to deforestation, water scarcity, and greenhouse gas emissions. Additionally, the fermentation and distillation processes involved in alcohol production can be energy-intensive. However, some alcohol producers are adopting more sustainable practices, such as using renewable energy, reducing water usage, and recycling waste materials. In the beverage sector, efforts are being made to reduce packaging waste, use organic farming methods, and promote environmentally conscious production processes. Despite these efforts, the broader sustainability of alcohol production still requires balancing agricultural impacts, energy consumption, and waste management.

6.1 Use of ethanol as a biofuel

The amount of crude oil and natural gas present today is limited in supply. Furthermore, components of crude oil could be used to make other useful chemicals if they are not used as fuel. In addition, carbon dioxide is one of the main products of burning crude oil and natural gas. Carbon dioxide is a greenhouse gas and contributes to global warming. Other pollutants such as sulfur dioxide are also produced.

Getting energy from the combustion of crude oil and natural gas is still considered the most economical and convenient method. However, it is very important for us to search for alternatives at the same time.

Biofuels are alternative **renewable** energy sources to crude oil and natural gas. Biofuels come from plants or animals, and can be replaced relatively quickly after use. For example, ethanol can be obtained from the fermentation of the sugar in sugarcane plants. As sugarcane plants can be regrown and replaced within a short period of time, the ethanol generated from sugarcane is considered a renewable source. Ethanol produced from plants such as sugarcane or corn is also known as **bioethanol** when used as an alternative to fossil fuels.



process of converting sugarcane into bioethanol

The burning of bioethanol is considered more **environmentally sustainable** compared to the use of fossil fuels. As sugarcane grows, it absorbs carbon dioxide during photosynthesis, which offsets the carbon dioxide produced when the bioethanol is burnt.

Burning of ethanol in excess oxygen:

$$CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

However, to produce enough bioethanol for use, a lot of sugarcane plants need to be planted and transported for treatment. These processes may require the use of fossil fuels or other valuable resources. More carbon dioxide may also be produced in these processes. Hence, more research must be done to produce biofuels at a low cost with less impact on the environment.