MEGA LECTURE · A LEVEL CHEMISTRY

Chapter 16: Alcohols

OCR A Level Chemistry A (H432) — Structured Practice Worksheet

SPECIFICATION	TOTAL MARKS	SUGGESTED TIME
3.2.3 Alcohols: classification, production, oxidation, dehydration, esterification	86	1 hour 44 minutes

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Instructions to candidates

- Answer **all** questions in the spaces provided. Show all working in calculations.
- Marks are shown in brackets [ ] at the end of each part.

Question 1 — Classification and naming of alcohols 3.2.3

a. Classify each of the following alcohols as primary, secondary or tertiary. **[3]**

Alcohol	Classification
$CH_3CH_2CH_2OH$	
$(CH_3)_2CHOH$	
$(CH_3)_3COH$	

b. State the structural feature that is used to decide whether an alcohol is primary, secondary or tertiary. **[2]**

c. Give the IUPAC name of each alcohol in part (a). **[3]**

Alcohol	IUPAC name
$CH_3CH_2CH_2OH$	
$(CH_3)_2CHOH$	
$(CH_3)_3COH$	

Question 1 total: 8 marks

Question 2 — Production of ethanol 3.2.3

Ethanol can be manufactured industrially either by fermentation of glucose (from plant sugars) or by catalytic hydration of ethene (from crude oil/natural gas).

a. Write a balanced equation for the fermentation of glucose to ethanol. **[2]**

b. State the conditions required for fermentation. **[2]**

c. Write a balanced equation, including state symbols, for the catalytic hydration of ethene. **[2]**

d. State the conditions used industrially for the catalytic hydration of ethene. **[2]**

e. Compare fermentation and the hydration of ethene as routes to ethanol, referring to the sustainability of the feedstock used and the atom economy of each process. **[4]**

Question 2 total: 12 marks

Question 3 — Combustion of alcohols 3.2.3

a. Write a balanced equation, including state symbols, for the complete combustion of ethanol. **[2]**

b. State why alcohols such as ethanol are increasingly used as fuels (biofuels) rather than, or blended with, petrol. **[2]**

c. Explain, in terms of the products formed, why incomplete combustion of an alcohol is undesirable. **[2]**

Question 3 total: 6 marks

Question 4 — Oxidation of primary alcohols 3.2.3

Propan-1-ol, $CH_3CH_2CH_2OH$, can be oxidised using acidified potassium dichromate(VI), $K_2Cr_2O_7/H_2SO_4$.

a. State the colour change observed during this oxidation and name the chromium species responsible for each colour. **[2]**

b. Describe the practical conditions used to oxidise propan-1-ol to propanal (the aldehyde) as the major product, and write an equation for this reaction using [O] to represent the oxidising agent. **[3]**

c. Describe how the practical conditions differ when propan-1-ol is instead oxidised fully to propanoic acid, and write an equation for this reaction using [O]. **[3]**

d. Write a full balanced equation, using $Cr_2O_7^{2-}/H^+$, for the oxidation of propan-1-ol all the way to propanoic acid. **[2]**

e. Suggest a simple chemical test that would confirm that propan-1-ol has been fully oxidised to propanoic acid rather than stopping at propanal. **[2]**

Question 4 total: 12 marks

Question 5 — Oxidation of secondary and tertiary alcohols 3.2.3

Propan-2-ol, $(CH_3)_2CHOH$, and 2-methylpropan-2-ol, $(CH_3)_3COH$, are each heated under reflux with acidified potassium dichromate(VI).

a. Write an equation, using [O], for the oxidation of propan-2-ol, and name the type of product formed. **[3]**

b. State what happens if the product from part (a) is heated for longer with excess oxidising agent. **[2]**

c. Explain why 2-methylpropan-2-ol does not react with acidified dichromate(VI) under these conditions. **[3]**

d. State the observation made when 2-methylpropan-2-ol is heated with acidified dichromate(VI). **[2]**

Question 5 total: 10 marks

Question 6 — Dehydration of alcohols

3.2.3

Butan-2-ol, $CH_3CH(OH)CH_2CH_3$, is heated with a concentrated acid catalyst to form an alkene by elimination.

a. State a suitable catalyst and the conditions for this dehydration, and name the type of reaction occurring. **[2]**

b. Draw the mechanism for the acid-catalysed dehydration of butan-2-ol to but-2-ene, showing relevant curly arrows, lone pairs, charges and the carbocation intermediate. **[4]**

Mechanism — show curly arrows, the carbocation intermediate, and all relevant charges

c. Explain why a mixture of alkene products (but-1-ene and but-2-ene) can form from this dehydration. **[2]**

d. State the type of isomerism shown between but-1-ene and but-2-ene. **[2]**

Question 6 total: 10 marks

Question 7 — Esterification 3.2.3

Ethanol reacts with ethanoic acid in the presence of a concentrated sulfuric acid catalyst.

a. Write a balanced equation for this reaction and name the organic product formed. **[2]**

b. State the role of the concentrated sulfuric acid in this reaction. **[2]**

c. State the practical conditions used to carry out this reaction. **[2]**

d. Explain why this reaction reaches a position of equilibrium, and suggest one way the yield of ester could be increased. **[2]**

e. State one everyday use of esters. **[2]**

Question 7 total: 10 marks

Question 8 — Reaction with sodium; sustainability of ethanol 3.2.3

a. Write a balanced equation for the reaction of ethanol with sodium metal. **[2]**

b. State the observations made when a small piece of sodium is added to ethanol. **[2]**

c. Describe a simple test to confirm the identity of the gas produced in this reaction. **[2]**

d. Explain why sodium reacts less vigorously with ethanol than it does with water. **[3]**

e. Discuss the sustainability of producing bioethanol by fermentation of plant sugars compared with producing ethanol from ethene derived from crude oil. **[3]**

Question 8 total: 12 marks

Question 9 — Extended response

Synoptic

Ethanol used as a biofuel is usually produced by fermentation, while ethanol used industrially as a solvent is more often produced by direct catalytic hydration of ethene. Evaluate the sustainability of these two routes to ethanol, and explain how the oxidation of ethanol using acidified potassium dichromate(VI) can be controlled, by choice of conditions, to give either ethanal or ethanoic acid as the major product. **[6]**

This question is marked using a level of response.

Question 9 total: 6 marks

PAPER TOTAL: 86 MARKS

MARK SCHEME — Chapter 16: Alcohols

Award marks independently unless stated. ECF applies to calculations.

Q1 (a) [3]

- $CH_3CH_2CH_2OH$ — primary. (1)
- $(CH_3)_2CHOH$ — secondary. (1)
- $(CH_3)_3COH$ — tertiary. (1)

Q1 (b) [2]

- Classification depends on the number of carbon atoms (alkyl groups) directly attached to the carbon atom bearing the −OH group. (1)
- Primary = one carbon attached; secondary = two carbons attached; tertiary = three carbons attached (any correct comparison). (1)

Q1 (c) [3]

- $CH_3CH_2CH_2OH$ = propan-1-ol. (1)
- $(CH_3)_2CHOH$ = propan-2-ol. (1)
- $(CH_3)_3COH$ = 2-methylpropan-2-ol. (1)

Q2 (a) [2]

- $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (1 species, 1 balancing). (2)

Q2 (b) [2]

- Yeast (containing the enzyme zymase) is added to an aqueous solution of glucose. (1)
- Carried out at a warm temperature (around 30–40 °C) in the absence of air/oxygen (anaerobic). (1)

Q2 (c) [2]

- $C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$ (1 equation with reversible arrow, 1 state symbols). (2)

Q2 (d) [2]

- Steam and ethene passed over a phosphoric acid (H_3PO_4) catalyst. (1)
- Temperature of about 300 °C and pressure of about 60–70 atm. (1)

Q2 (e) [4]

- Fermentation uses a renewable feedstock (glucose/sugar from plants), whereas ethene is obtained from crude oil, a finite/non-renewable resource. (1)
- Fermentation is therefore considered more sustainable in terms of raw materials, although it requires land/water use that could otherwise grow food. (1)
- Hydration of ethene has a higher atom economy (100%, as ethanol is the only product) than fermentation (glucose is only partly converted to ethanol, with CO_2 also formed as a by-product, lowering the atom economy). (1)
- Hydration is a continuous process with a fast rate, while fermentation is a slow, batch process; the ethanol formed by fermentation is also dilute and must be concentrated by distillation, using more energy. (1)

Q3 (a) [2]

- $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$ (1 balancing, 1 state symbols). (2)

Q3 (b) [2]

- Alcohols can be produced renewably (e.g. bioethanol by fermentation of plant material), unlike petrol which comes from finite crude oil. (1)
- Burning bioethanol can be considered closer to carbon-neutral, as CO_2 released on combustion was recently absorbed by the growing plant via photosynthesis. (1)

Q3 (c) [2]

- Incomplete combustion occurs when there is a limited/insufficient supply of oxygen. (1)
- It produces carbon monoxide and/or carbon (soot) instead of only carbon dioxide; carbon monoxide is toxic, as it binds to haemoglobin in place of oxygen. (1)

Q4 (a) [2]

- The orange dichromate(VI) solution turns green. (1)
- Orange colour is due to $Cr_2O_7^{2-}$ ions; green colour is due to Cr^{3+} ions formed as the dichromate(VI) is reduced. (1)

Q4 (b) [3]

- The alcohol is added slowly/gently heated with a limited amount of oxidising agent. (1)
- The aldehyde product is distilled off as it forms, before it can be oxidised further. (1)
- $CH_3CH_2CH_2OH + [O] \rightarrow CH_3CH_2CHO + H_2O$. (1)

Q4 (c) [3]

- The alcohol is heated under reflux with an excess of the oxidising agent. (1)
- Reflux prevents loss of volatile reactants/products, allowing full/prolonged oxidation to occur. (1)
- $CH_3CH_2CH_2OH + 2[O] \rightarrow CH_3CH_2COOH + H_2O$. (1)

Q4 (d) [2]

- $3CH_3CH_2CH_2OH + 2Cr_2O_7^{2-} + 16H^+ \rightarrow 3CH_3CH_2COOH + 4Cr^{3+} + 11H_2O$ (1 species correct, 1 fully balanced). (2)

Accept the simplified [O] equation with full credit if balancing marks are awarded consistently.

Q4 (e) [2]

- Add (a small amount of) solid/aqueous sodium carbonate (or another carbonate) to the product. (1)
- Effervescence (CO_2 gas released) confirms an acidic carboxylic acid is present; an aldehyde would give no reaction. (1)

Accept testing with universal indicator/pH paper: carboxylic acid gives a distinctly acidic pH, aldehyde is approximately neutral.

Q5 (a) [3]

- $(CH_3)_2CHOH + [O] \rightarrow (CH_3)_2CO + H_2O$ (1 formula, 1 balancing). (2)
- The product, propanone, is a ketone. (1)

Q5 (b) [2]

- The ketone is not oxidised further, even with excess oxidising agent and prolonged reflux. (1)
- This is because there is no hydrogen atom on the carbon of the C=O group left to remove (further oxidation would require breaking a C−C bond). (1)

Q5 (c) [3]

- 2-Methylpropan-2-ol is a tertiary alcohol, so the carbon atom bearing the −OH group is attached to three other carbon (alkyl) groups. (1)
- This carbon therefore has no hydrogen atom attached to it. (1)
- Oxidation by acidified dichromate(VI) requires removal of a hydrogen atom from the carbon bearing the −OH group, so this cannot occur. (1)

Q5 (d) [2]

- No colour change is observed. (1)
- The dichromate(VI) solution remains orange, showing that no reaction/oxidation occurs. (1)

Q6 (a) [2]

- Concentrated sulfuric acid (H_2SO_4) or concentrated phosphoric acid (H_3PO_4) catalyst, with heating. (1)
- This is an elimination reaction. (1)

Q6 (b) [4]

- Lone pair on the −OH oxygen shown attacking/accepting a proton (H^+) from the acid catalyst, forming a protonated alcohol ($-OH_2^+$). (1)
- Curly arrow from the C−O bond showing heterolytic fission, with water leaving as the departing group. (1)
- Correct carbocation intermediate shown with a positive charge on the carbon that bore the −OH group. (1)
- Curly arrow from a C−H bond on an adjacent (β) carbon to form the C=C double bond, with loss of H^+ regenerating the acid catalyst. (1)

Q6 (c) [2]

- A hydrogen atom can be removed from either of the two carbon atoms adjacent to the carbon that bore the −OH group. (1)
- Loss of a hydrogen from one side gives but-1-ene, and loss from the other side gives but-2-ene, so a mixture of both alkenes forms. (1)

Q6 (d) [2]

- Positional (chain/structural) isomerism — the double bond is in a different position within the same carbon skeleton. (2)

Q7 (a) [2]

- $CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$ (1 equation). (1)
- Product named ethyl ethanoate. (1)

Q7 (b) [2]

- Acts as a catalyst, increasing the rate at which equilibrium is reached. (1)
- Also helps to shift the equilibrium towards the ester by absorbing/removing water formed in the reaction. (1)

Q7 (c) [2]

- The mixture is heated under reflux. (1)
- With a few drops of concentrated sulfuric acid added as catalyst. (1)

Q7 (d) [2]

- The reaction does not go to completion because the ester can also be hydrolysed back to the acid and alcohol, so a position of equilibrium is reached (forward and reverse reactions both occur). (1)
- The yield of ester can be increased by using an excess of one reactant (e.g. the alcohol or acid) or by removing the ester/water as it forms. (1)

Q7 (e) [2]

- Any one appropriate use, e.g. as a solvent, flavouring, perfume/fragrance. (2)

Q8 (a) [2]

- $2Na(s) + 2C_2H_5OH(l) \rightarrow 2C_2H_5ONa(l) + H_2(g)$ (1 species, 1 balancing). (2)

Q8 (b) [2]

- The sodium reacts, disappearing gradually, with effervescence (bubbles of gas). (1)
- The reaction is less vigorous than the reaction of sodium with water (no flame/no dangerous spitting typically observed). (1)

Q8 (c) [2]

- Collect the gas and test it with a lit splint. (1)
- A squeaky pop confirms the gas is hydrogen. (1)

Q8 (d) [3]

- The O−H bond in water is more polarised than the O−H bond in ethanol. (1)
- This is because the ethyl group in ethanol is electron-donating (positive inductive effect), pushing electron density towards the oxygen and reducing the polarity of the O−H bond. (1)
- The less polarised (less reactive) O−H bond in ethanol makes it react less readily/vigorously with sodium than the more polar O−H bond in water. (1)

Q8 (e) [3]

- Bioethanol is produced from a renewable feedstock (plant sugars/biomass), whereas ethanol from ethene relies on crude oil, a finite resource. (1)
- Growing crops for fermentation absorbs CO_2 during growth, which can offset (some of) the CO_2 released when the ethanol is later burned, giving a smaller net carbon footprint. (1)
- However, growing crops for bioethanol can compete with food production for land and water, and fermentation/distillation still requires energy input, so bioethanol is not necessarily fully carbon-neutral or without environmental impact. (1)

Q9 [6] — Level of response

- **Level 3 (5–6):** Gives a clear, well-organised evaluation of the sustainability of both routes to ethanol (feedstock, atom economy/by-products) and a fully correct explanation of how conditions control oxidation to ethanal versus ethanoic acid, with appropriate reference to distillation/reflux.
- **Level 2 (3–4):** Covers most of the required content for both parts of the question but with some omissions or a less complete/organised explanation of one of the two areas.
- **Level 1 (1–2):** Makes some relevant, valid points about sustainability and/or oxidation conditions, but the answer is limited, largely one-sided, or lacks clear scientific reasoning.

Indicative content: *Fermentation uses a renewable feedstock (glucose from plants) and is often regarded as more sustainable, though it is slow, produces dilute ethanol requiring energy-intensive distillation, and can compete with food production for land; hydration of ethene uses a finite fossil-fuel feedstock but is fast, continuous, and has 100% atom economy since ethanol is the only product. To obtain ethanal, the primary alcohol is oxidised with a limited amount of acidified potassium dichromate(VI) and the aldehyde is distilled off as it forms, before it can be oxidised further; to obtain ethanoic acid, an excess of oxidising agent is used and the mixture is heated under reflux to ensure complete oxidation of the alcohol (via the aldehyde) to the carboxylic acid.*

END OF MARK SCHEME · 86 marks