

AQA A-LEVEL CHEMISTRY • 7405

CHEMISTRY



EXAM QUESTION PACK

3.3.7 OPTICAL ISOMERISM

SCORE

/160

PERCENTAGE

%

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Q1.

Which pair of compounds does **not** form a racemic mixture when the compounds react?

- A  + HCl ☐
- B  + HCN ☐
- C  + HCl ☐
- D  + HCN ☐

(Total 1 mark)

Q2.

Which compound does **not** show stereoisomerism?

- A 1,2-dichloropropene ☐
- B 1,2-dichloropropane ☐
- C 1,3-dichloropropene ☐
- D 1,3-dichloropropane ☐

(Total 1 mark)

Q3.

Which compound forms optically active compounds on reduction?

- A $\text{CH}_3\text{CH}_2\text{C}(\text{CH}_3)=\text{CHCH}_3$ ☐
- B $\text{CH}_3\text{CH}_2\text{C}(\text{CH}_3)=\text{CH}_2$ ☐
- C CH_3COCH_3 ☐
- D $\text{CH}_3\text{CH}_2\text{COCH}_3$ ☐

(Total 1 mark)

Q4.

The aldehyde $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CHO}$ reacts with KCN followed by dilute acid to form a racemic mixture of the two stereoisomers of $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}(\text{OH})\text{CN}$

- (a) Give the IUPAC name of $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}(\text{OH})\text{CN}$

(1)

- (b) Describe how you would distinguish between separate samples of the two stereoisomers of $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}(\text{OH})\text{CN}$

(2)

- (c) Explain why the reaction produces a racemic mixture.

(3)

- (d) An isomer of $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CHO}$ reacts with KCN followed by dilute acid to form a compound that does not show stereoisomerism.

Draw the structure of the compound formed and justify why it does not show stereoisomerism.

Structure

Justification

(2)

(Total 8 marks)

Q5.

This question is about isomerism.

- (a) How many isomers are represented by the formula C_5H_{12} ?

Tick (✓) **one** box.

2 ☐

3 ☐

4 ☐

5 ☐

- (b) Name the type of structural isomerism shown by the isomers of C_5H_{12}

_____ (1)

- (c) 2-Hydroxypropanenitrile displays optical isomerism.

Draw three-dimensional representations of the two enantiomers of 2-hydroxypropanenitrile, showing how the two structures are related to each other.

(2)

- (d) Describe how separate samples of each of these enantiomers could be distinguished.

(2)

- (e) Butan-2-ol reacts with concentrated sulfuric acid to produce three isomeric alkenes.

Name and outline a mechanism to show how any **one** of the alkenes is formed.

Explain how this reaction can lead to the formation of each of these **three** alkenes.

Name of mechanism _____

Mechanism

Explanation _____

(8)

(Total 13 marks)

Q6.

Butanone is reduced in a two-step reaction using NaBH_4 followed by dilute hydrochloric acid.

- (a) Write an overall equation for the reduction of butanone using $[\text{H}]$ to represent the reductant.

(1)

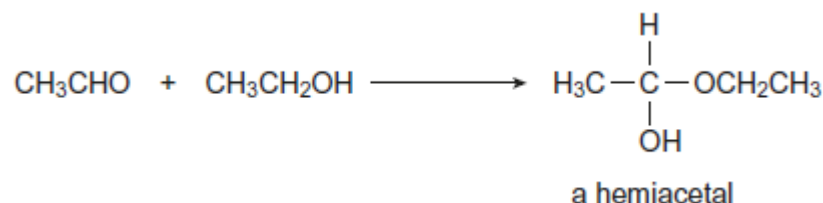
- (b) By considering the mechanism of the reaction, explain why the product has **no** effect on plane polarised light.

(6)

(Total 7 marks)

Q7.

Hemiacetals and acetals are compounds formed by the reaction of aldehydes with alcohols, such as the reaction of ethanal with ethanol.



- (a) (i) Use your knowledge of carbonyl mechanisms to suggest the name of the mechanism of this reaction.

(1)

- (ii) Outline how an ethanol molecule reacts with an ethanal molecule in the first step of this mechanism. Include two curly arrows to show the movement of electron pairs.

(2)

- (b) The reaction produces a racemic mixture of chiral molecules.

- (i) Explain the meaning of the term racemic mixture.

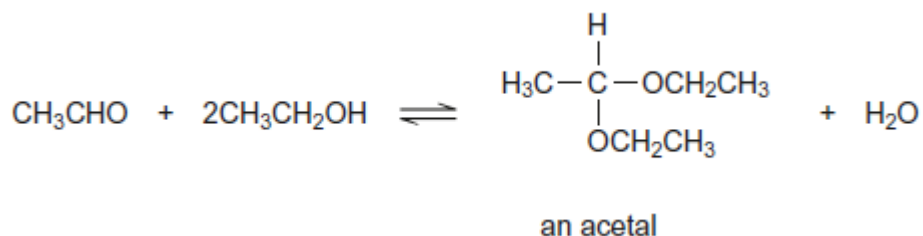
(1)

- (ii) State the relationship between two chiral molecules with the same structural formula.

(1)

- (c) In the presence of an acid catalyst such as dry hydrogen chloride, ethanal reacts with an excess of ethanol to form an acetal.

The overall reaction of ethanal with an excess of ethanol forms an equilibrium mixture as shown. All reactants and products are liquids.



A mixture of 0.75 mol of ethanal and 5.00 mol of ethanol was left to reach equilibrium in the presence of dry hydrogen chloride at a given temperature. The equilibrium mixture contained 0.42 mol of the acetal.

- (i) Calculate the amount, in moles, of ethanal and of ethanol in this equilibrium mixture.

Amount of ethanal _____ mol

Amount of ethanol _____ mol

Space for working _____

(2)

- (ii) In a different experiment using the same reaction as in part (c), an equilibrium mixture was established at a given temperature. This mixture contained 0.58 mol of ethanal, 3.76 mol of ethanol, 0.37 mol of the acetal and 0.65 mol of water in a total volume of 310 cm³.

Write an expression for the equilibrium constant K_c for this reaction.

Calculate a value for K_c at this temperature. Give units with your answer.

K_c _____

Calculation _____

(4)

- (d) Draw the structure of the acetal (C₄H₈O₂) formed by the reaction of ethanal with ethane-1,2-diol.

(1)
(Total 12 marks)

Q8.

The carbonyl compound $\text{CH}_3\text{CH}_2\text{CHO}$ reacts very slowly with HCN

- (a) Name and outline a mechanism for the reaction of $\text{CH}_3\text{CH}_2\text{CHO}$ with HCN

Name of mechanism _____

Mechanism

(5)

- (b) The reaction in part (a) produces a pair of enantiomers.

- (i) Draw the structure of each enantiomer to show how they are related to each other.

(2)

- (ii) State and explain how you could distinguish between the two enantiomers.

(2)

- (c) Give the IUPAC name of the product of the reaction in part (a).

(1)

- (d) In practice, KCN rather than HCN is added to the carbonyl compound.

Given that K_a for HCN = $4.0 \times 10^{-10} \text{ mol dm}^{-3}$, suggest why the reaction with HCN is very slow.

(2)

- (e) Acrylic fibres are used as a substitute for wool. Acrylics are copolymers of acrylonitrile with other compounds.

Acrylonitrile is the common name for the following compound.



- (i) Acrylonitrile can be formed from propene.

Write an equation for the reaction of propene with ammonia and oxygen to form acrylonitrile and one other product.

(1)

- (ii) The term copolymer is used to describe the product obtained when two or more different monomers form a polymer.

Draw the repeating unit of the acrylic copolymer that contains 75% acrylonitrile monomer and 25% chloroethene monomer.

(1)

- (iii) Name the type of polymerisation involved in part (ii)

(1)

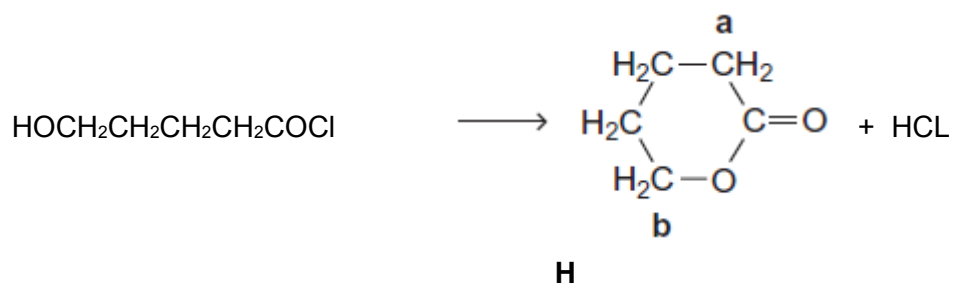
(Total 15 marks)

Q9.

This question is about some isomers of $\text{C}_5\text{H}_8\text{O}_2$

- (a) Compound **H** is a cyclic ester that can be prepared as shown.

On the structure of **H**, two of the carbon atoms are labelled.



- (i) Name and outline a mechanism for this reaction.

Use **Table C** on the Data Sheet to give the ^{13}C n.m.r. δ value for the carbon atom labelled **a** and the δ value for the carbon atom labelled **b**.

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(7)

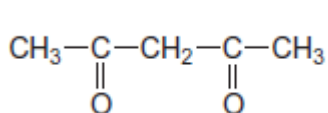
- (ii) $\text{HOCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COCl}$ can also react to form a polyester in a mechanism similar to that in part (i).

Draw the repeating unit of the polyester and name the type of polymerisation involved.

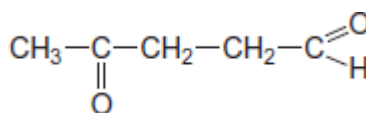
(2)

- (b) State how you could distinguish between compounds **J** and **K** by a simple test-tube reaction.

State how you could distinguish between **J** and **K** by giving the number of peaks in the ^1H n.m.r. spectrum of each compound.



J



K

(5)

- (c) Draw the structure of each of the following isomers of $\text{C}_5\text{H}_8\text{O}_2$.
Label each structure you draw with the correct letter **L**, **M**, **N**, **P** or **Q**.

L is methyl 2-methylpropenoate.

M is an ester that shows E-Z stereoisomerism.

N is a carboxylic acid with a branched carbon chain and does **not** show stereoisomerism.

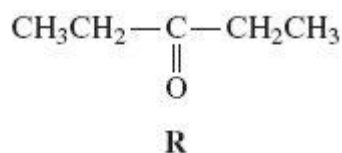
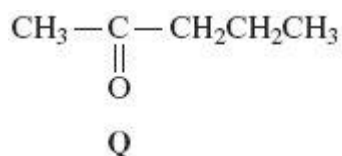
P is an optically active carboxylic acid.

Q is a cyclic compound that contains a ketone group and has only two peaks in its ^1H n.m.r. spectrum.

(5)
(Total 19 marks)

Q10.

Two isomeric ketones are shown below.



- (a) Name and outline a mechanism for the reaction of compound **Q** with HCN and name the product formed.

Name of mechanism _____

Mechanism

Name of product _____

(6)

- (b) Some students were asked to suggest methods to distinguish between isomers **Q** and **R**.

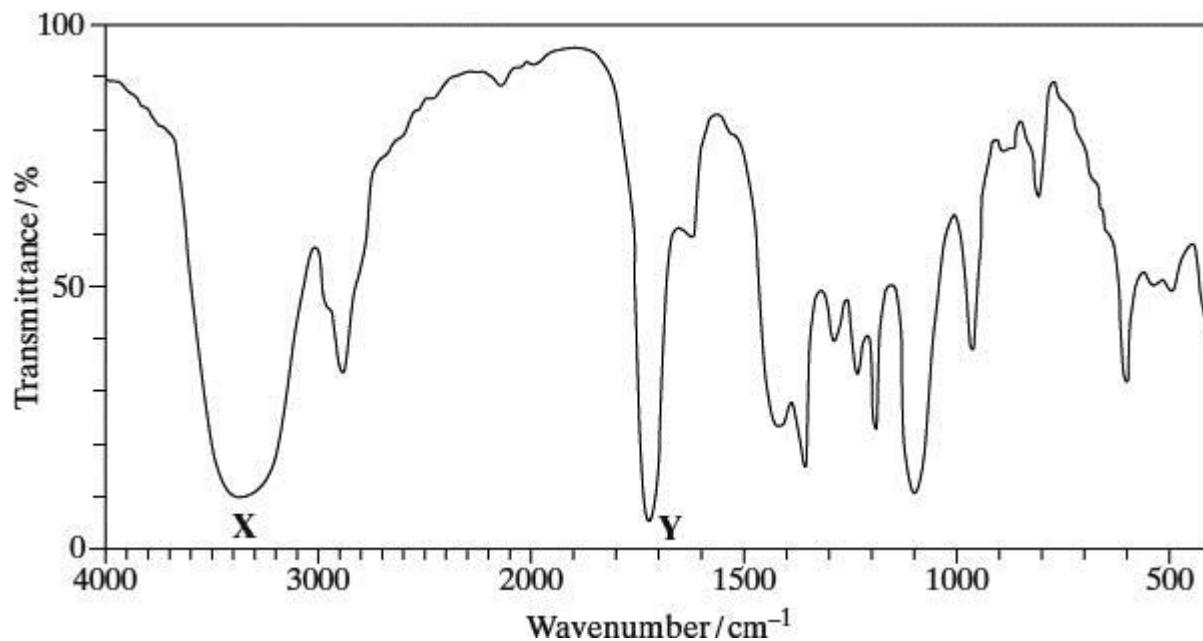
One student suggested testing the optical activity of the products formed when **Q** and **R** were reacted separately with HCN.

By considering the optical activity of these products formed from **Q** and **R**, explain why this method would **not** distinguish between **Q** and **R**.

(3)
(Total 9 marks)

Q11.

- (a) The infra-red spectrum of compound **A**, $C_3H_6O_2$, is shown below.



Identify the functional groups which cause the absorptions labelled **X** and **Y**.

Using this information draw the structures of the three possible structural isomers for **A**.

Label as **A** the structure which represents a pair of optical isomers.

(6)

- (b) Draw the structures of the three **branched-chain** alkenes with molecular formula C_5H_{10}

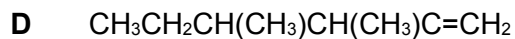
One of these dibromoalkanes has only three peaks in its proton n.m.r. spectrum. Deduce the integration ratio and the splitting patterns of these three peaks.

[illegible]

(Total 16 marks)

Which one of the following can exhibit both geometrical and optical isomerism?

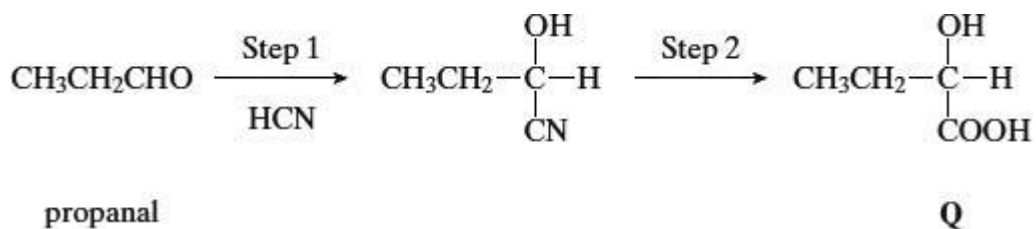
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(Total 1 mark)

Q13.

Consider the reaction sequence shown below.



- (a) Name and outline a mechanism for the reaction in Step 1.

Name of mechanism _____

Mechanism

(5)

- (b) (i) Name compound **Q** formed in Step 2.

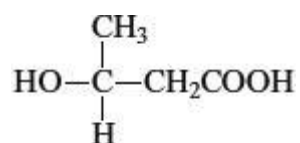
- (ii) Two stereoisomers are formed by the dehydration of **Q**. Give the structures of these two isomers and name the type of stereoisomerism shown.

Structures of isomers

Type of stereoisomerism _____

(4)

- (c) An isomer of **Q** which has the structure shown below is polymerised to form the biodegradable polymer known as PHB.

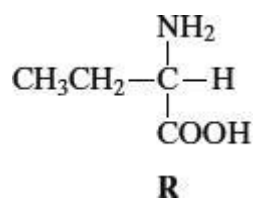


- (i) Draw the repeating unit of the polymer PHB.

- (ii) Suggest a reason why the polymer is biodegradable.

(2)

- (d) The amino acid **R** is shown below.



- (i) Draw the structure of the zwitterion formed by **R**.

- (ii) Draw the structure of the major organic product formed when an excess of **R** is reacted with bromomethane.

- (iii) Name the mechanism of the reaction which results in the formation of the product given in part (ii).

(3)

(Total 14 marks)

Q14.

Which one of the following reactions will produce an organic compound that has optical isomers?

- A** dehydration of butan-2-ol by heating with concentrated sulphuric acid
- B** reduction of pentan-3-one by warming with NaBH_4
- C** addition of Br_2 to 3-bromopropene
- D** reduction of 2,3-dimethylpent-2-ene with H_2 in the presence of a nickel catalyst

(Total 1 mark)

Q15.

Each of the parts (a) to (e) below concerns a different pair of isomers.

Draw one possible structure for each of the species **A** to **J**, using Table 2 on the Data Sheet where appropriate.

- (a) Compounds **A** and **B** have the molecular formula C_5H_{10}
A decolourises bromine water but **B** does not.

A

B

(2)

- (b) Compounds **C** and **D** have the molecular formula $C_2H_4O_2$

Each has an absorption in its infra-red spectrum at about 1700 cm^{-1} but only **D** has a broad absorption at 3350 cm^{-1}

C

D

(2)

- (c) Compounds **E** and **F** are esters with the molecular formula $C_5H_{10}O_2$

The proton n.m.r. spectrum of **E** consists of two singlets only whereas that of **F** consists of two quartets and two triplets.

E

F

(2)

- (d) Compounds **G** and **H** have the molecular formula $C_3H_6Cl_2$ **G** shows optical activity but **H** does not.

G

H

(2)

- (e) Compounds **I** and **J** have the molecular formula C_6H_{12}

Each has an absorption in its infra-red spectrum at about 1650 cm^{-1} and neither shows geometrical isomerism. The proton n.m.r. spectrum of **I** consists of a singlet only whereas that of **J** consists of a singlet, a triplet and a quartet.

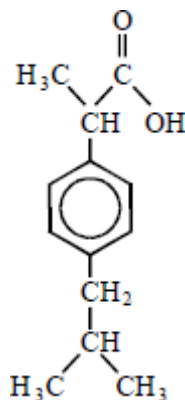
I

J

(2)
(Total 10 marks)

Q16.

Ibuprofen is a drug used as an alternative to aspirin for the relief of pain, fever and inflammation. The structure of ibuprofen is shown below.



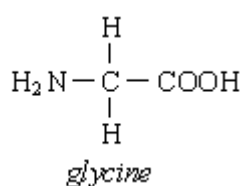
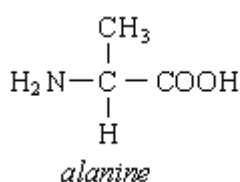
Which one of the following statements is **not** correct?

- A It has optical isomers.
- B It liberates carbon dioxide with sodium carbonate solution.
- C It undergoes esterification with ethanol.
- D It undergoes oxidation with acidified potassium dichromate(VI).

(Total 1 mark)

Q17.

The structures of the amino acids *alanine* and *glycine* are shown below.



- (a) Give the systematic name for *alanine*.

(1)

- (b) *Alanine* exists as a pair of stereoisomers.

- (i) Explain the meaning of the term *stereoisomers*.

(ii) State how you could distinguish between the stereoisomers.

(4)

(c) Give the structural formula of the species formed by *glycine* at pH 14.

(1)

(d) When two amino acids react together, a dipeptide is formed. Give the structural formulae of the **two** dipeptides which are formed when *alanine* and *glycine* react together.

Dipeptide 1

Dipeptide 2

(2)

- (e) Give the structural formula of the organic compound formed when *glycine* reacts with methanol in the presence of a small amount of concentrated sulphuric acid.

(1)

(Total 9 marks)

Q18.

Which one of the following statements about but-2-enal, $\text{CH}_3\text{CH}=\text{CHCHO}$, is **not** true?

- A** It has stereoisomers.
- B** It shows a strong absorption in the infra-red at about 1700 cm^{-1} .
- C** It will turn an acidified solution of potassium dichromate(VI) green.
- D** It can be dehydrated by concentrated sulphuric acid.

(Total 1 mark)

Q19.

- (a) **P**, **Q** and **R** have the molecular formula C_6H_{12}

All three are branched-chain molecules and none is cyclic.

P can represent a pair of optical isomers.

Q can represent a pair of geometrical isomers.

R can represent another pair of geometrical isomers different from **Q**.

Draw one possible structure for one of the isomers of each of **P**, **Q** and **R**.

Structure of P

Structure of Q

Structure of R

(3)

- (b) Butanone reacts with reagent **S** to form compound **T** which exists as a racemic mixture. Dehydration of **T** forms **U**, C₅H₇N, which can represent a pair of geometrical isomers.

- (i) State the meaning of the term *racemic mixture* and suggest why such a mixture is formed in this reaction.

Racemic mixture _____

Explanation _____

- (ii) Identify reagent **S**, and draw a structural formula for each of **T** and **U**.

Reagent S _____

Compound T

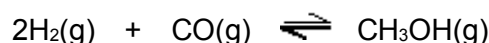
Compound U

(6)

(Total 9 marks)

Q20.

Hydrogen and carbon monoxide were mixed in a 2:1 mole ratio. The mixture was allowed to reach equilibrium according to the following equation at a fixed temperature and a total pressure of 1.75×10^4 kPa.



- (a) The equilibrium mixture contained 0.430 mol of carbon monoxide and 0.0850 mol of methanol.
- (i) Calculate the number of moles of hydrogen present in the equilibrium mixture.
- _____
- (ii) Hence calculate the mole fraction of hydrogen in the equilibrium mixture.

- (iii) Calculate the partial pressure of hydrogen in the equilibrium mixture.

(5)

- (b) In a different mixture of the three gases at equilibrium, the partial pressure of carbon monoxide was 7550 kPa, the partial pressure of hydrogen was 12300 kPa and the partial pressure of methanol was 2710 kPa.

- (i) Write an expression for the equilibrium constant, K_p , for this reaction.

- (ii) Calculate the value of the equilibrium constant, K_p , for the reaction under these conditions and state its units.

K_p _____

Units _____

(3)

- (c) Two isomeric esters **E** and **F** formed from methanol have the molecular formula $C_6H_{12}O_2$

Isomer **E** has only 2 singlet peaks in its proton n.m.r. spectrum.

Isomer **F** is optically active.

Draw the structures of these two isomers.

Isomer E

Isomer F

(2)
(Total 10 marks)

Q21.

On reduction, a racemate can be formed by

- A** $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CHO}$
- B** $\text{CH}_3\text{CH}_2\text{CH}_2\text{COCH}_3$
- C** $\text{CH}_3\text{CH}_2\text{COCH}_2\text{CH}_3$
- D** $\text{CH}_3\text{CH}=\text{CHCH}_2\text{CHO}$

(Total 1 mark)

Q22.

Which one of the following reaction mixtures would give a product capable of exhibiting optical isomerism?

- A** $\text{CH}_3\text{CH}=\text{CH}_2$ + HBr
- B** $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ + NaOH
- C** $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ + H_2SO_4
- D** $\text{CH}_3\text{CH}_2\text{CHO}$ + HCN

(Total 1 mark)

Mark schemes

Q1.

D

[1]

Q2.

D

[1]

Q3.

D

[1]

Q4.

(a) 2-hydroxyhexanenitrile

1

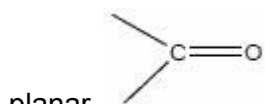
(b) (Plane) polarised light

1

Enantiomers would rotate light in opposite directions
not different alone

1

(c) planar carbonyl group or



*Not planar molecule,
not planar bond, not planar C=O*

1

Attack from either side

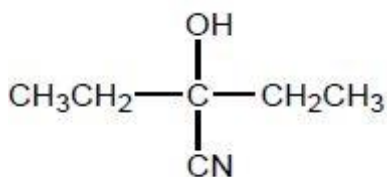
1

With equal probability

OR produces equal amounts (of the two isomers/enantiomers)

1

(d)



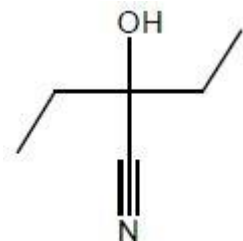
Does not contain a chiral centre

OR does not contain C attached to 4 different groups

OR contains two identical/ethyl groups

OR symmetrical (product)

Allow C₂H₅ or skeletal



M2 dependent on correct M1 (No structure = 0)

If pentan-3-one drawn then allow symmetrical ketone for M2

[8]

Q5.

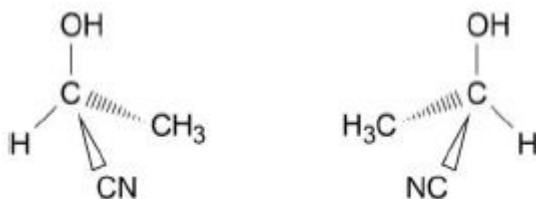
(a) 3

1

(b) Chain.

1

(c)



One 3D enantiomer.

1

Second enantiomer correctly drawn as 3D mirror image of first.

1

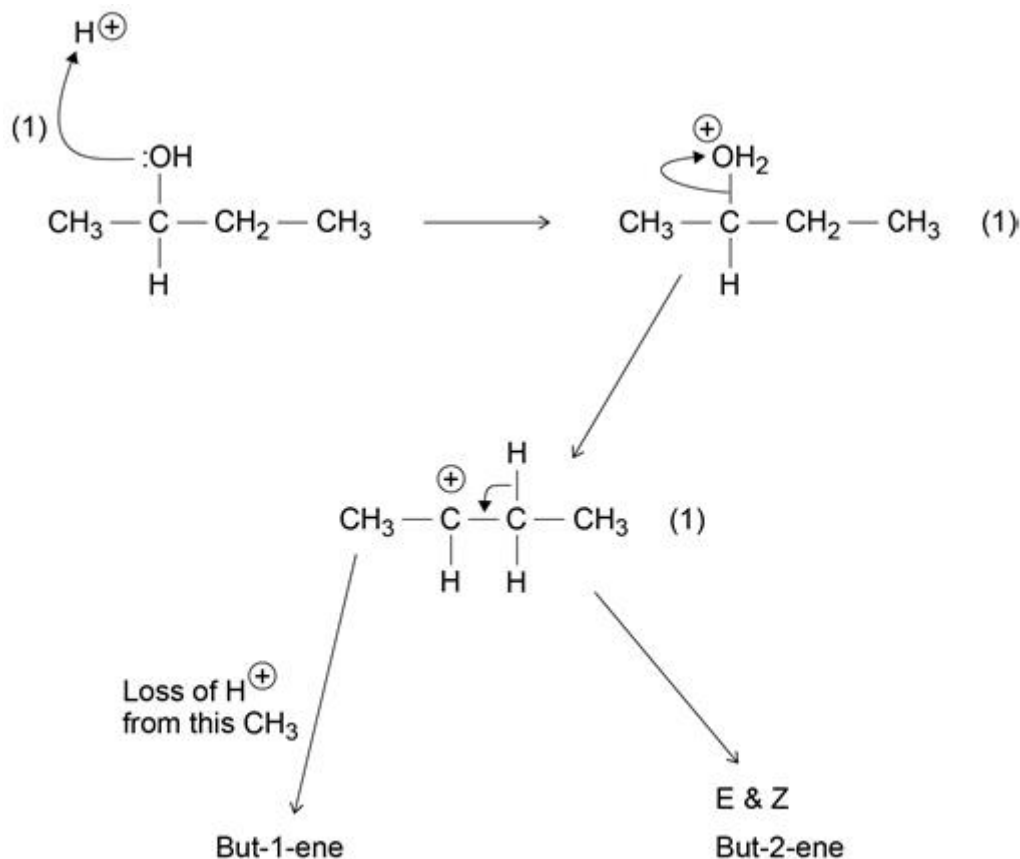
(d) Plane-polarised light.

1

Rotated in opposite directions.

1

(e) Elimination



Extended response question

M1

Mechanism (3 marks)

M2 arrow from lone pair on O to H^+

M3 1st intermediate **and** arrow from $\text{C}-\text{O}^+\text{H}_2$ bond to O (with loss of H_2O)

M4 2nd intermediate (carbocation) **and** arrow from $\text{C}-\text{H}$ bond to $\text{C}-\text{C}$ (with loss of H^+) to form $\text{C}=\text{C}$

M3 and M4 can be scored in one step (see alternative mechanism below).

If carbocation incorrect then answer cannot score maximum marks.

Explanation of formation of 3 alkenes

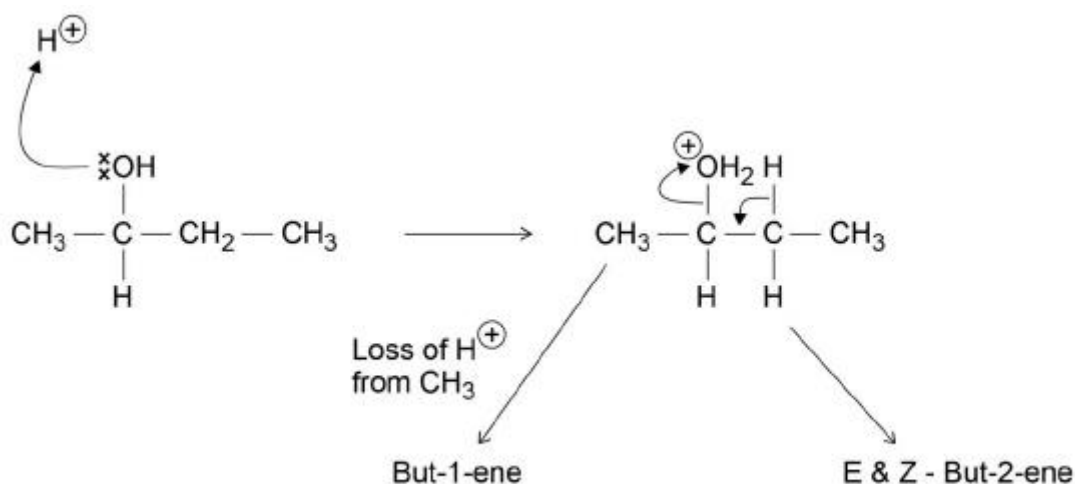
M5 loss of H^+ from C (in carbocation) adjacent to ^+C (to which $-\text{OH}$ was attached)

M6 From $^1\text{C}-^2\text{C}^+-^3\text{C}-^4\text{C}$ leads to but-1-ene

M7 From $^1\text{C}-^2\text{C}^+-^3\text{C}-^4\text{C}$ leads to but-2-ene

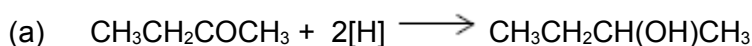
M8 But-2-ene formed as mixture of *E-Z* isomers

Alternative mechanism



[14]

Q6.



1

- (b) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 then stage 3.

Level 3
5 – 6 marks

All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.

Answer is mainly coherent and shows progression from stage 1 to stage 3.

Level 2
3 – 4 marks

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete.

Answer includes isolated statements but these are not presented in a logical order or show confused reasoning.

Level 1
1 – 2 marks

Insufficient correct chemistry to gain a mark.

Level 0
0 marks

Indicative Chemistry content

Stage 1: Formation of product

- Nucleophilic attack
- Planar carbonyl group
- H^- attacks from either side (stated or drawn)

Stage 2: Nature of product

- Product of step 1 shown
- This exists in two chiral forms (stated or drawn)
- Equal amounts of each enantiomer / racemic mixture formed

Stage 3: Optical activity

- Optical isomers / enantiomers rotate the plane of polarised light equally in
- With a racemic / equal mixture the effects cancel

6

[7]

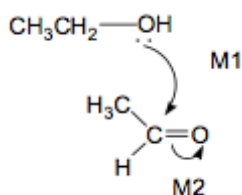
Q7.

- (a) (i) Nucleophilic addition

Any extra loses the mark

Allow minor spelling errors e.g. nucleophyllic

1



- (ii)

M1 for arrow from lone pair on oxygen in ethanol to C of $\text{C}=\text{O}$ (or to space half way between O and C)

M2 for arrow from $\text{C}=\text{O}$ bond to oxygen in ethanal

Do not allow M2 as first step without nucleophilic attack, but can allow M1 for attack on C^+ produced

+ rather than δ^+ on $\text{C}=\text{O}$ loses M2

Ignore any further steps

Mark independently

1

1

- (b) (i) Equal mixture of enantiomers/optical isomers OWTTE

1

- (ii) (Non-superimposable) mirror images

Ignore rotates light in opposite directions

Ignore stereoisomers

1

- (c) (i) Ethanal 0.33

1

Ethanol 4.16

Allow 4.2 for ethanol

$$K_c = \frac{[\text{acetal}][H_2O]}{[CH_3CHO][CH_3CH_2OH]^2} \text{ or with names}$$

$$(ii) \quad \frac{(0.37/0.31)(0.65/0.31)}{(0.58/0.31)(3.76/0.31)^2} \quad \text{OR} \quad \frac{(0.37)(0.65)}{(0.58)(3.76)^2} \times 0.31$$

Ignore slips in acetal structure or formula $C_6H_{14}O_2$

If K_c wrong, allow M4 only for units conseq to their K_c

If volume omitted (gives 2.93×10^{-2}) may only score M1 and M4

If volume used = 310 cm^3 allow M2 then award M3 for $9.08 - 9.23$ only and M4 for $\text{mol}^{-1} \text{ cm}^3$ only

Treat error in converting 310 cm^3 to dm^3 as AE

M1
M2

$$9.1 \times 10^{-3}$$

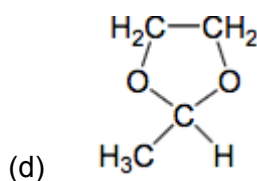
Allow range $9.08 \times 10^{-3} - 9.23 \times 10^{-3}$

M3

$$\text{mol}^{-1}\text{dm}^3$$

Not $\text{moles}^{-1}\text{dm}^3$

M4



1

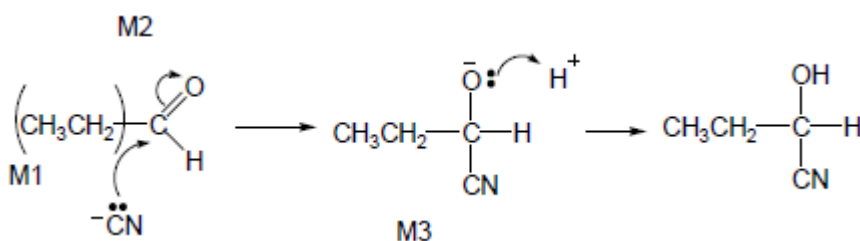
[12]

Q8.

(a) Nucleophilic addition

1

M4 for lp, arrow and H^+

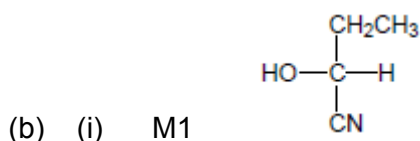


Allow $C_2H_5^-$ for $CH_3CH_2^-$

- M1 and M4 include lone pair and curly arrow.
- Allow: CN^- but arrow must start at lone pair on C.
- M2 not allowed independent of M1, but allow M1 for correct attack on C^+ .
- + rather than δ^+ on $C=O$ loses M2.

- Penalise incorrect partial charges.
- M3 is for correct structure including minus sign but lone pair is part of M4.
- Penalise extra curly arrows in M4.

4



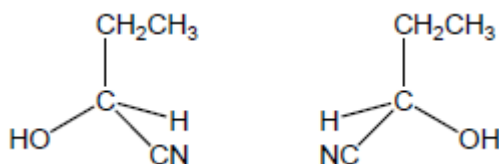
M1 for correct structure of product of part (a).

Allow C_2H_5- for CH_3CH_2- .

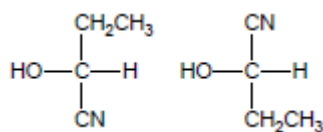
Penalise wrongly bonded, OH or CN or CH_2CH_3 once only in clip.

1

M2

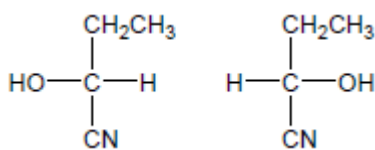


M2 cannot be gained by simply swapping two or more groups with no attempt to show a mirror image., e.g. do not allow M2 for



because these do not show the enantiomers as mirror images.

Students must show an attempt at mirror images, eg allow

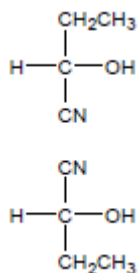


ie vertical groups same and horizontal swapped as if there was a mirror between them

No mirror need be shown

Do not penalize wedge bond when wedge comes into contact with both C & N

However these two could score M2 if placed as below as if with a "mirror" horizontally between them.



1

- (ii) M1 (Plane) polarized light
M2 only scores following correct M1

1

M2 Rotated in opposite directions (equally) (only allow if M1 correct or close)

Not just in different directions but allow one rotates light to the left and one to the right.

Not molecules rotate.

1

- (c) 2-hydroxybutane(-1-)nitrile

1

- (d) Weak acid / (acid) only slightly / partially dissociated / ionised
Ignore rate of dissociation.

1

[CN⁻] very low

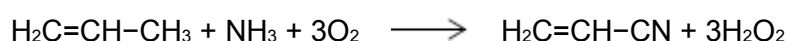
Allow (very) few cyanide ions.

Mark independently.

1

- (e) (i) $\text{H}_2\text{C}=\text{CH}-\text{CH}_3 + \text{NH}_3 + \frac{3}{2}\text{O}_2 \longrightarrow \text{H}_2\text{C}=\text{CH}-\text{CN} + 3\text{H}_2\text{O}$

OR

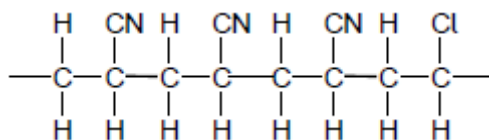


OR doubled.

Allow C₃H₆ and CH₂CHCN or C₃H₃N on this occasion only.

1

- (ii)

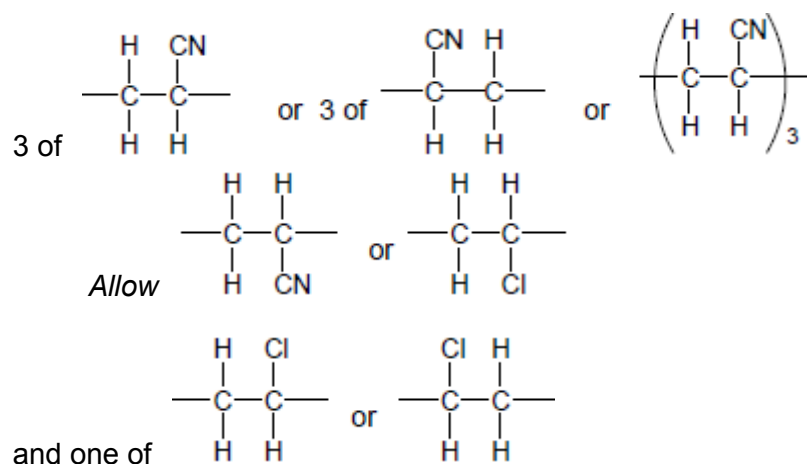


Ignore n.

Must show trailing bonds.

Do not penalise C–NC bond here on this occasion.

Must contain, in any order,



Allow $-\text{CH}_2\text{CH}(\text{CN})\text{CH}_2\text{CHCl}-$ etc.

1

(iii) Addition (polymerization)

Allow self-addition.

Do not allow additional.

1

[15]

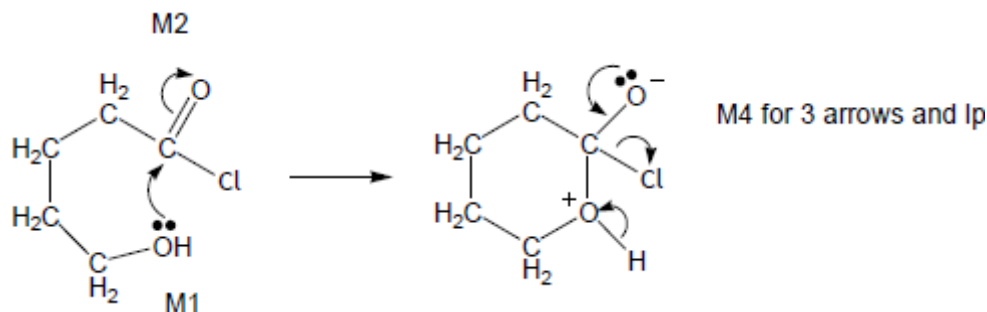
Q9.

(a) (i) (nucleophilic) addition-elimination

Not electrophilic addition-elimination

Ignore esterification

1



M3 for structure

- If wrong nucleophile used or O-H broken in first step, can only score M2.
- M2 not allowed independent of M1, but allow M1 for correct attack on C+
- + rather than $\delta+$ on C=O loses M2.
- If Cl lost with C=O breaking lose M2.
- M3 for correct structure with charges but lone pair on O is part of M4.
- Only allow M4 after correct / very close M3.
- Ignore HCl shown as a product.

4

a 20-50 (ppm) or single value or range entirely within this range

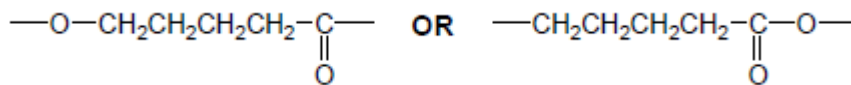
If values not specified as a or b then assume first is a.

1

b 50-90 (ppm) or single value or range entirely within this range

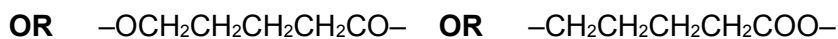
1

(ii)

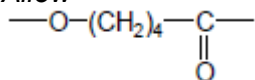


Must have trailing bonds, but ignore n.

1



Allow



but not $\text{—C}_4\text{H}_8\text{—}$

one unit only

Condensation

1

(b)

	Tollens'	Fehling's / Benedicts	Acidified potassium dichromate
--	----------	-----------------------	--------------------------------

Penalise wrong formula for Tollens or missing acid with potassium dichromate but mark on.

1

J	No reaction / no (visible) change / no silver mirror	No reaction / no (visible) change / stays blue / no red ppt	No reaction / no (visible) change / stays orange / does not turn green
----------	--	---	--

Ignore 'clear', 'nothing'.

Penalise wrong starting colour for dichromate.

1

K	Silver <u>mirror</u> / grey <u>ppt</u>	Red <u>ppt</u> (allow brick red or red-orange)	(orange) turns green
----------	--	---	----------------------

1

J Two (peaks)

Allow trough, peak, spike.

1

K Four (peaks)

Ignore details of splitting.

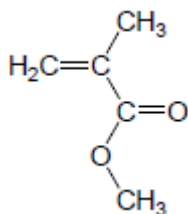
If values not specified as J or K then assume first is J.

1

- (c) If all the structures are unlabelled, assume that the first drawn ester is L, the second ester is M; the first drawn acid is N, the second P. The cyclic compound should be obvious.

L

ester



OR $\text{H}_2\text{C}=\text{C}(\text{CH}_3)\text{COOCH}_3$

All $\text{C}_5\text{H}_8\text{O}_2$ L to P must have $\text{C}=\text{C}$.

Allow CH_3 -.

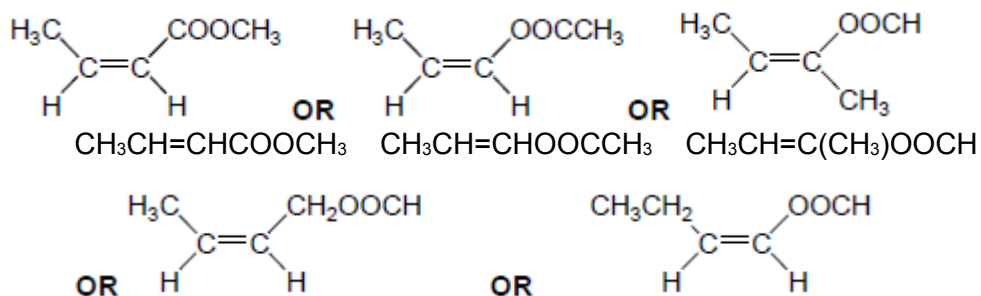
Allow $-\text{CO}_2\text{CH}_3$ etc.

Allow $\text{CH}_2\text{C}(\text{CH}_3)\text{COOCH}_3$.

1

M

ester



$\text{CH}_3\text{CH}=\text{CHCH}_2\text{OOCH}$

$\text{CH}_3\text{CH}_2\text{CH}=\text{CHOOCH}$

Allow either E-Z isomer.

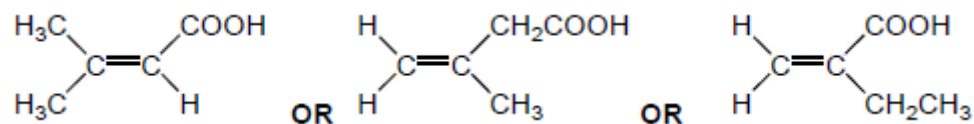
Allow CH_3 - or C_2H_5 - but not CH_2CH_3 -.

Allow $\text{CH}_3\text{CHCHCOOCH}_3$ etc.

1

N

acid



$(\text{CH}_3)_2\text{C}=\text{CHCOOH}$

$\text{H}_2\text{C}=\text{C}(\text{CH}_3)\text{CH}_2\text{COOH}$

$\text{H}_2\text{C}=\text{C}(\text{COOH})\text{CH}_2$

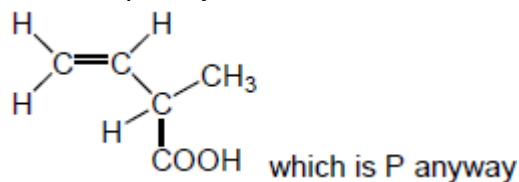
CH_3

Allow CH_3 - or C_2H_5 - but not CH_2CH_3 -.

Allow $-\text{CO}_2\text{H}$.

Not cyclic isomers.

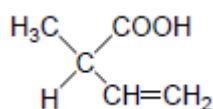
Not the optically active isomer.



Allow $(\text{CH}_3)_2\text{CCHCOOH}$ etc.

1

P
acid



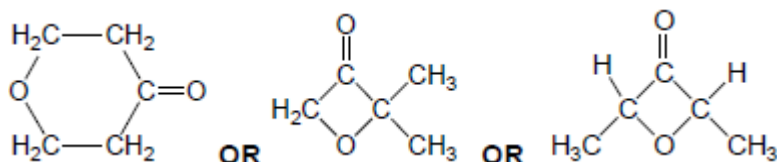
Allow $-\text{CO}_2\text{H}$.



Allow $\text{CH}_3\text{CH}(\text{CO}_2\text{H})\text{CHCH}_2$ or
 $\text{CH}_3\text{CH}(\text{CO}_2\text{H})\text{C}_2\text{H}_3$.

1

Q



Not cyclic esters.

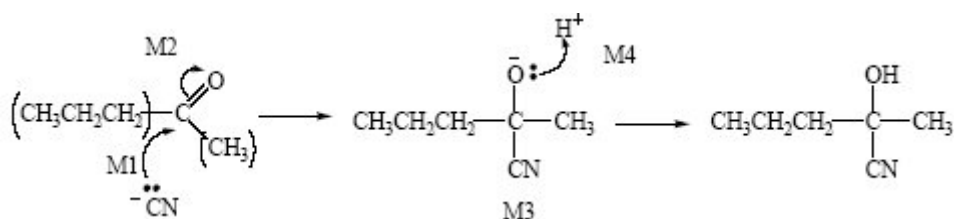
1

[19]

Q10.

(a) nucleophilic addition

1



Attack by HCN loses M1 and M2

M2 not allowed independent of M1, but

allow M1 for correct attack on C^+

$+\text{C}=\text{O}$ loses M2

M2 only allowed if correct carbon attacked

allow minus charge on N i.e. $:\text{CN}^-$

4

M3 for completely correct structure not including lp

allow C_3H_7 in M3

M4 for lp and arrow
allow without –

1

2-hydroxy-2-methylpentan(e)nitrile
allow 2-hydroxy-2-methylpentanonitrile

- (b) Product from **Q** is a racemic mixture/equal amounts of enantiomers
if no reference to products then no marks;

1

racemic mixture is inactive or inactive explained
not **Q** is optically active or has a chiral centre etc

1

Product from **R** is inactive (molecule) or has no chiral centre

1

[9]

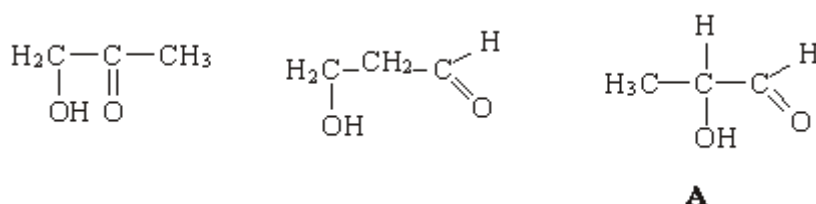
Q11.

- (a) **X** (O–H) (alcohols)
penalise acid or missing “alcohol”

1

Y C=O
allow carbonyl

1



NOT acid

4

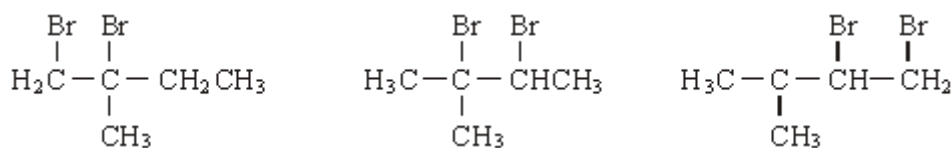
- (b) $\begin{array}{c} \text{H}_2\text{C}=\text{C}-\text{CH}_2\text{CH}_3 \\ | \\ \text{CH}_3 \end{array}$ $\begin{array}{c} \text{H}_3\text{C}-\text{C}=\text{CHCH}_3 \\ | \\ \text{CH}_3 \end{array}$ $\begin{array}{c} \text{H}_3\text{C}-\text{CH}-\text{CH}=\text{CH}_2 \\ | \\ \text{CH}_3 \end{array}$

Allow conseq dibromocompounds following incorrect unbranched alkenes

NOT allow dibromocompound consequent on a duplicate alkene

NOT allow monobromocompounds if HBr added

3



3

6:3:1 either next to correct structure or to none

1

Allow a mark for identifying correct dibromocompound with three peaks even if integration ratio is wrong

1

if 6:3:1 missing or wrong, no marks for splitting

Only award a mark for splitting if it is clear which integration number it refers to

6 singlet or drawn

1

3 doublet or drawn

1

1 quartet/quadruplet or drawn

1

(max 10 marks)

[16]

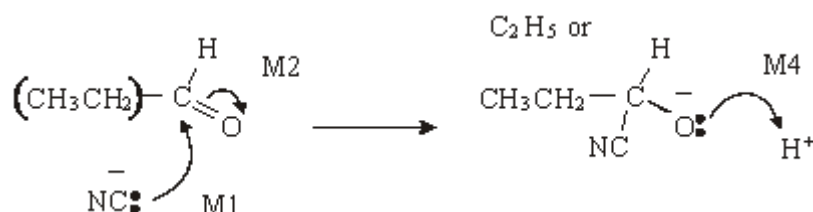
Q12.

B

[1]

Q13.

(a) nucleophilic addition;



1

M3 structure;

(be lenient on position of charge on CN⁻)

(M2 not allowed independent of M1,

but allow M1 for correct attack on C⁺

if M2 show as independent first.)

(+on C of C=O loses M2 but ignore δ⁺ if correct)

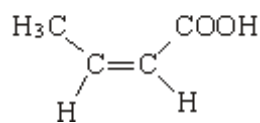
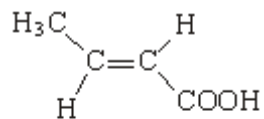
(M4 for arrow and lone pair (only allow for correct M3 or close))

4

(b) (i) 2-hydroxybutanoic acid

1

(ii)

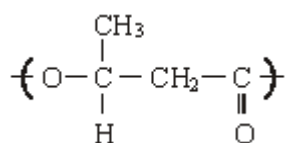


1

geometric(al) or cis-trans

1

(c) (i)



(one unit only) (ignore brackets or n) (trailing bonds are needed)

1

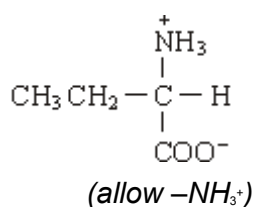
(ii) can be hydrolysed

OR

can be reacted with/attacked by acid/base/nucleophiles/H₂O/OH⁻;

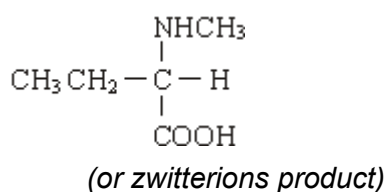
1

(d) (i)



1

(ii)



1

(iii) nucleophilic substitution;

1

[14]

Q14.

D

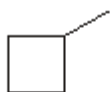
[1]

Q15.

(a) **A** any C₅ alkene

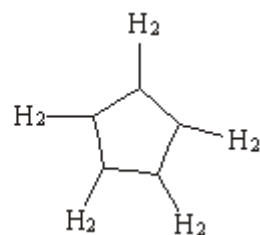
1

B



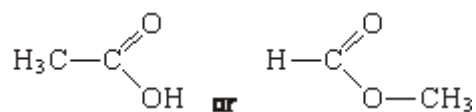
etc

penalise



1

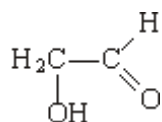
(b) **C**



or CH₃COOH or HCOOCH₃

1

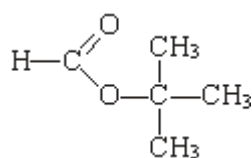
D



or HOCH₂CHO

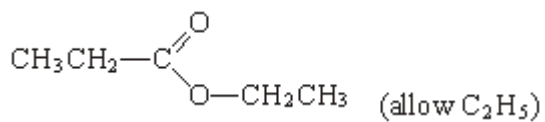
1

(c) **E**



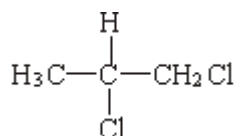
1

F



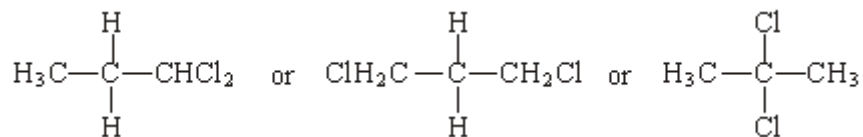
1

(d) **G**



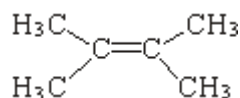
1

H



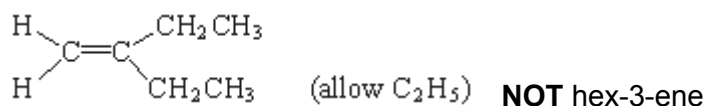
1

(e) I



1

J



1

[10]

Q16.

D

[1]

Q17.

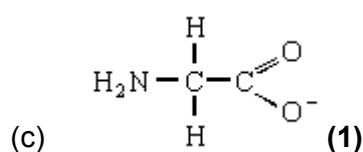
(a) 2-amino(e) propanoic acid (1)

1

(b) (i) molecules with same structure / structural formula (1)
but with bonds (**atoms or groups**) arranged differently in space (3D) (1)

(ii) Plane polarised light (1)
Rotated (equally) in opposite directions (1)

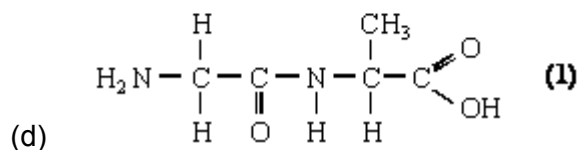
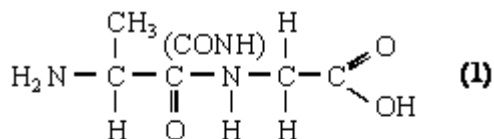
4



allow $\text{H}_2\text{NCH}_2\text{COO}^-$

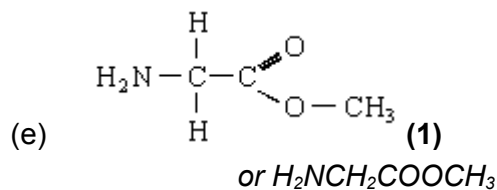
Penalise NH_2^- and OH^- once per paper
but CH_3^- is allowed

1



Not anhydrides; not repeating units

2



1

[9]

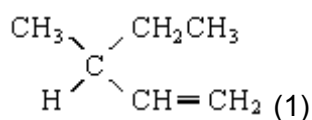
Q18.

D

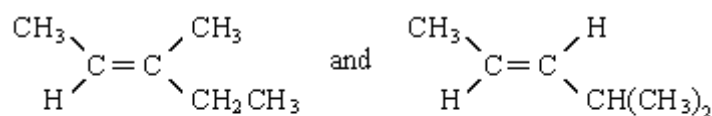
[1]

Q19.

(a) *Structure of P:*



Structures of **Q** and **R**:



NOT C_3H_7

(1)

(1)

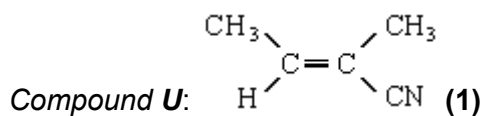
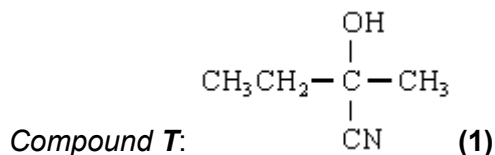
Q and R in any order

3

- (b) (i) *Racemic mixture: equal mixture of optical isomers / enantiomers*
OR in explanation

Explanation: planar ($>\text{C}=\text{O}$) (1)
attack from either side is equally likely (1)

- (ii) *Reagent S: HCN or (KCN / HCl or H_2SO_4) (1)*



6

[9]

Q20.

(a) (i) 0.86 (1)

(ii) total moles = 0.86 + 0.43 + 0.085 = 1.375 (1)

$$\therefore \text{mole fraction of H}_2 = \frac{0.86}{1.375} = 0.625 \quad (1)$$

(0.62 - 0.63)

Conseq on (i)

(iii) pp = mole fractⁿ × total P (1)
 $= 0.625 \times 1.75 \times 10^4$
 $= 1.09 \times 10^4 \text{ (kPa)} \quad (1)$

or 1.1(0)

Ignore units

Conseq on (ii)

5

(b) (i) $K_p = \frac{P_{\text{CH}_3\text{OH}}}{P_{\text{H}_2}^2 \times P_{\text{CO}}} \quad (1)$
Penalise []

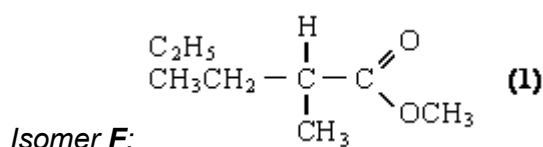
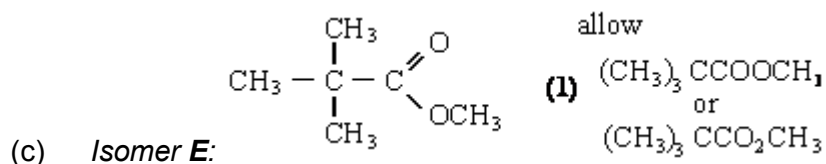
(ii) $K_p = \frac{2710}{(12300)^2 \times (7550)} = 2.37 \text{ (2.4)} \times 10^{-9} \quad (1)$
OR 2.37 × 10⁻¹⁵

Units: kPa⁻² (1)

or Pa⁻²

not conseq to wrong K_p expression

3



2

[10]

Q21.
B

[1]

Q22.
D

[1]

Examiner reports

Q4.

- (a) As usual, naming nitriles proved difficult for some, but 56% of students gave the correct answer.
- (b) Although this question was answered well by most, an appreciable number of students were careless with language and appeared to say that the enantiomers themselves rotate, or that the plane polarised light is 'refracted' or 'bent' rather than 'rotated in opposite directions'.
- (c) The first mark was less commonly scored than expected as many students wrote about a planar molecule or a planar bond rather than planar carbonyl group; the other two marks were frequently awarded.
- (d) A significant number were not able to deduce the correct product and many incorrect products were seen. These included the cyanohydrin formed from pentanal. This showed a lack of care in reading the question.

Q7.

Both parts of question (a) were answered very well and it was good to see the correct use of curly arrows. Part (b)(i) was well done but in (b)(ii) many students simply stated what stereoisomers do to plane polarised light and so failed to answer the question. Part (c)(i) was answered extremely well and the K_c expression in part (c)(ii) was also answered well. The calculation was well done but a frequent error was to use amounts, in moles, rather than concentrations by not using the volume. Better students answered part (d) correctly while others showed only one hydroxyl group from the diol reacting and so produced an answer for the acetal which did not match the given molecular formula.

Q8.

In part (a), the nucleophilic addition mechanism was very well done; common errors included missing the charge on the nucleophile or on the intermediate structure and showing a bond between the carbonyl carbon and the N of CN in the intermediate. In part (b)(i), students were not used to drawing 3D structures, and credit was given where attempts showed a pair of mirror images. Again there were some problems with wrongly bonded OH, CN and CH_2CH_3 groups in these structures. The method needed to distinguish between two enantiomers was well known, although to gain M2 polarised light had to be 'rotated' not turned or reflected, and rotated in 'opposite' directions not just different directions. A few students suggested wrongly that the molecules polarised the light or that the molecules themselves were rotated. The name in part (c) was well answered but part (d) was answered poorly. There was confusion of K_a , the acid dissociation constant, with a rate constant, and many students missed the link to low concentrations of cyanide ions from the weak acid HCN and focused mainly on the rate of the dissociation of the acid. Parts (e)(i) and (e)(iii) were answered well but responses to part (e)(ii) sometimes included the C=C bond or the CN group as part of the polymer chain.

Q9.

The nucleophilic addition-elimination mechanism in part (a)(i) presented a real challenge to many students, who were confused by the cyclic nature of the product, failed to identify the correct nucleophile and suggested either separate nucleophiles such as H_2O , CH_3OH

and OH⁻ or alternatively loss of the proton from the OH group before nucleophilic attack. Most students gave the correct range for the carbon atom labelled **b**, but often the range for the carbon atom labelled **a** was given as 160–185 as for a carbonyl carbon. In part (a)(ii), the repeating unit for the polyester was answered well although some students gave twice the repeating unit.

The distinguishing test in part (b) was well done, although a significant number of students thought that substance **K** was an acid and wrongly suggested NaHCO₃ or Na₂CO₃ to distinguish between the compounds. It was common for students to fail to see the symmetry of **J** and so to predict, incorrectly, three peaks in its proton n.m.r. spectrum. Five peaks was a common incorrect answer for **K**, suggesting that students had misread the question and given the ¹³C n.m.r. result.

Part (c) of this question proved to be very challenging and fewer than 10% of students scored full marks. Isomer **Q** was found particularly difficult where many students omitted one of the O atoms from their suggested structure. Other common errors included missing the double bond in **L**, giving the structure of **P** as the structure of **N** (which suggests a failure to recognise that optical isomerism is a form of stereoisomerism) or writing an unbranched carbon chain for the acid **N**. Answers to part (c) were often very badly presented, with a great deal of crossing out, duplication of answers and poor labelling of structures.

Q10.

In part (a), large numbers of candidates were able to write a correct mechanism for the nucleophilic addition of HCN to ketone **Q**. By contrast, most found it difficult to name the product correctly and so only 15% scored full marks overall. In part (b) many answers discussed the optical activity of the original ketones **Q** and **R** rather than that of the products of their reactions with HCN. Many also thought that both ketones produced racemic mixtures.

Q11.

In part (a) most candidates were able to identify the absorption labelled X as due to the presence of the alcohol O–H bond and that labelled Y as due to the presence of the C=O bond. Yet many then drew a carboxylic acid or even an ester as a possible structure. An appreciable number failed to label one of their structures as A. Better candidates scored highly here.

Part (b) discriminated well. Better candidates were able to score (almost) full marks but weak candidates struggled to score more than a few marks. Many had difficulty with the structure of the three branched-chain C₅ alkenes; unbranched alkenes were commonly given as were duplicates of a previous answer.

Only the better candidates were able to identify which dibromoalkane gave only three n.m.r. peaks and only the most able were able to deduce correctly the integration ratio and the splitting pattern of the three peaks.

Q13.

The name of the mechanism was well answered in part (a) but the actual mechanism itself was much more discriminating. Too many candidates are still careless in their drawing of curly arrows and fail to start every arrow either at a bond or a lone pair. Attack by the cyanide ion must show a lone pair on the carbon atom as the source of the curly arrow. The carbonyl group carbon has a δ⁺ charge not a full positive charge as suggested by several. Part (b) was less well done. Although many answered part (b)(i) correctly, several omitted the number 2 in the name or failed to count the number of carbons carefully. Part

(b)(ii) was misread by many, who simply drew the two optical isomers of **Q** rather than the two geometrical isomers of the dehydration product of **Q**. The repeating unit was usually correct in part (c) although some gave an extra oxygen in their structure and others gave more than the single repeating unit requested. The zwitterion in part (d)(i) was generally well known, but many drew incorrectly a quaternary ammonium salt in part (d)(ii).

Q15.

Parts (a) and (d) were the least discriminating, but only the most able were able to identify both **E** and **J** correctly.

In part (b), most were able to identify **C** correctly as either ethanoic acid or methyl methanoate, but many suggested that **D** was ethanoic acid, despite the wavenumber given for the O-H infra-red absorption being that for O-H in alcohols not that for O-H in acids.

Most found **F** easy to deduce, but several forgot that both compounds were esters and suggested dimethylpropanoic acid for **E**.

In part (d), **G** was better answered than H and in part (e), more were able to deduce the structure of I correctly than that of **J**.

Q17.

Part (a) was answered correctly by all except the weakest candidates. Part (b) was less well answered. Too many answers failed to say that stereoisomers have the same structure but that the bonds are arranged differently in space. The statement that they have the *same molecular formula* is insufficient, and another common error was to say that stereoisomers have *different structures*. In part (b)(ii), the use of plane polarised light was necessary with a statement that the isomers rotated the plane of polarised light equally in opposite directions.

Too many answers were not precise enough to gain the marks.

Parts (c), (d) and (e) were well answered by all except the weakest candidates and the structures required were drawn accurately. A few candidates muddled pH 14 in part (c) and gave the protonated form; others misread the question and used *alanine* when *glycine* should have been used in parts (c) and (e) or ethanol in part (e) instead of methanol.

Q19.

This question was found difficult by many candidates and some marks were lost by candidates who did not read the question carefully. The second line of the question stated that P, Q and R were all branched-chain molecules, but many answers included unbranched isomers. Part (b) was better answered, but again the question asked for the reason a racemic mixture was formed and many answers contained only a description of what a racemic mixture is. Part (c) was found to be difficult and only the most able candidates gained all three marks here.

Q20.

The equilibrium parts of this question were generally answered well. In part (a)(i), the correct value of 0.86 was the most common answer but this was the least well-answered section of part (a). Full marks were awarded in parts (ii) and (iii) if the number of moles of hydrogen given in part (i) was used correctly. Even if the numbers were not used correctly, a mark was given in part (iii) for the correct statement that partial pressure

equals mole fraction multiplied by the total pressure. In part (b) common errors were to include square brackets in the expression for K_p or to forget that the partial pressure of hydrogen should be squared. The units of K_p expected were kPa^{-2} but Pa^{-2} were accepted as long as the value given for K_p was 2.37×10^{-15} . Part (c) was poorly answered. Many structures were not esters at all and of those which were, few were methyl esters of C_5 acids. F was answered better than E but only the better candidates scored any marks here.