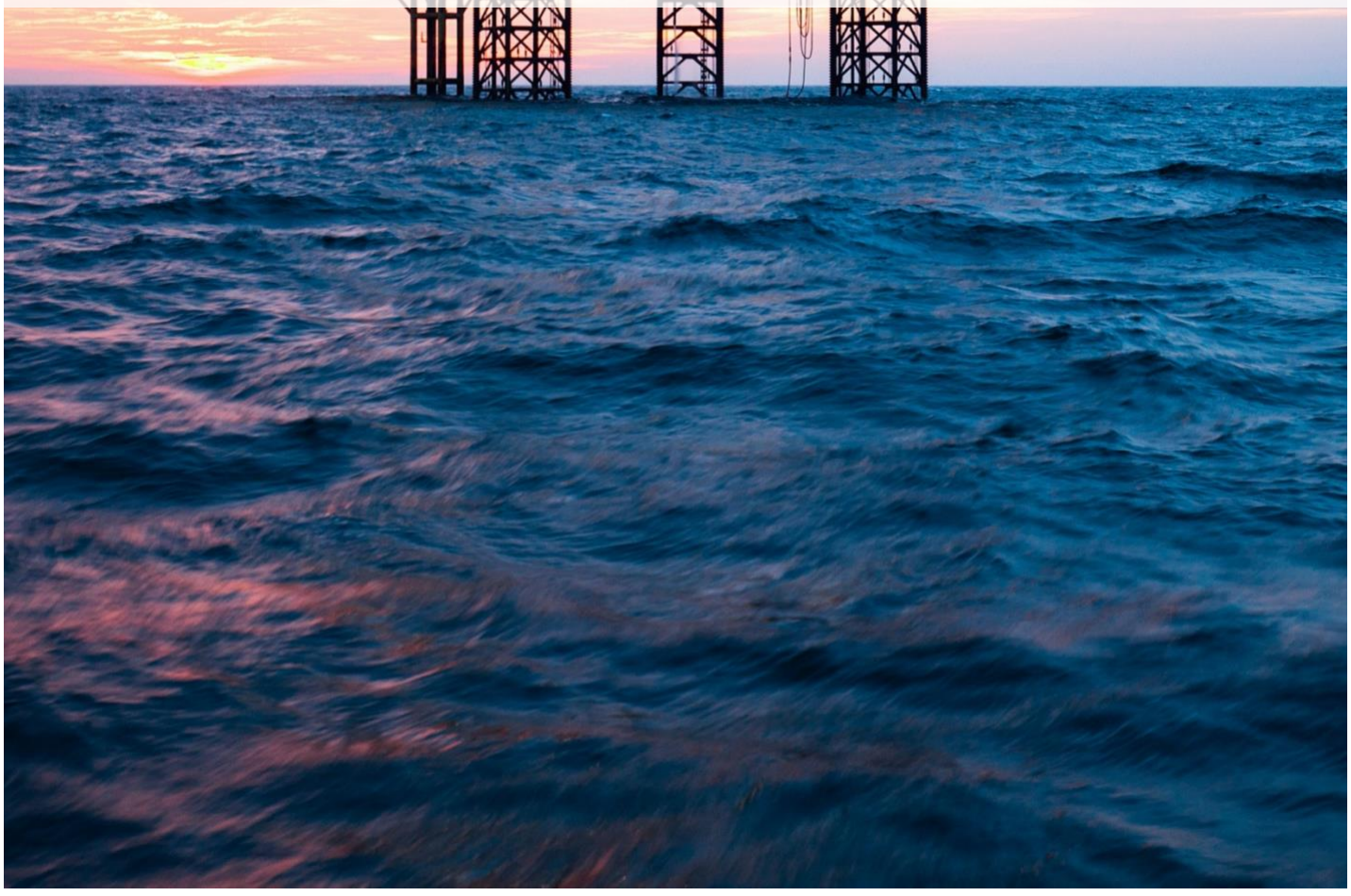
Chapter 6

Organic Chemistry Answers

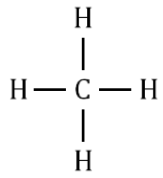
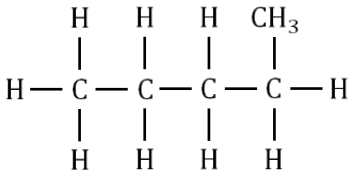
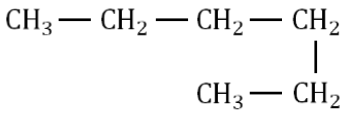
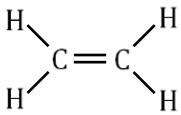
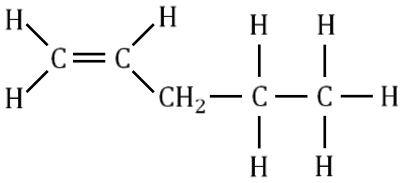
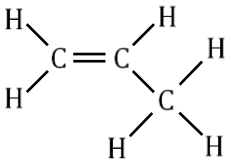
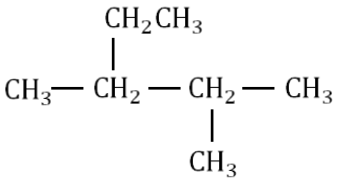
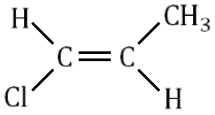
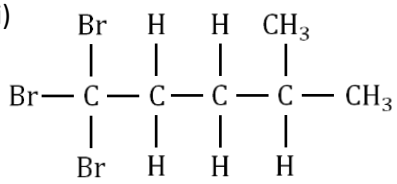
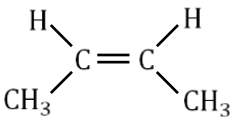
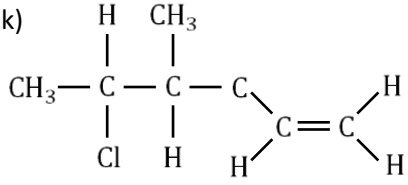
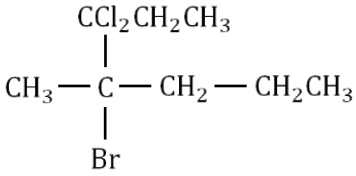


Problem Set 10 – Organic Chemistry BTG
Progressive Questions

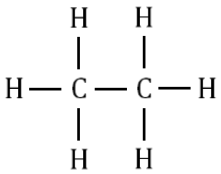
Concept 1
Alkanes and Alkenes – Progressive Questions Answers

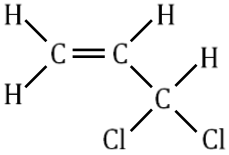
IUPAC Naming of Alkanes and Alkenes: Q1, Q2, Q3

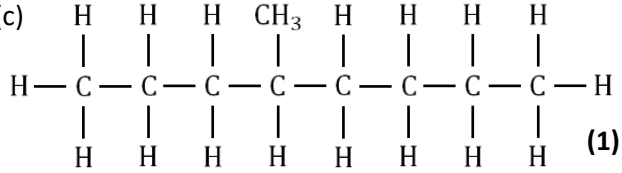
1. **[12 marks]**

(a)  **Methane (1)**	(b)  **Pentane (1)**	(c)  **Hexane (1)**
(d)  **Ethene (1)**	(e)  **Pent-1-ene (1)**	(f)  **Propene (1)**
(g)  **2,3-dimethylpentane (1)**	(h)  **trans-1-chloropropene**	(i)  **1,1,1-tribromo-3-methylpentane (1)**
(j)  **cis-but-2-ene (1)**	(k)  **5-chloro-4-methylhex-1-ene (1)**	(l)  **4-bromo-3,3-dichloro-4-methylheptane (1)**

2. **[12 marks]**

(a)  **(1)**

(b)  **(1)**

(c)  **(1)**

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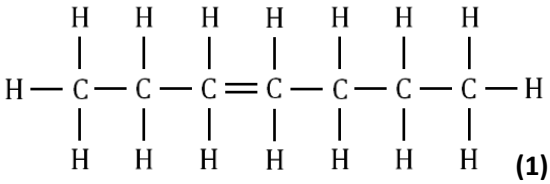

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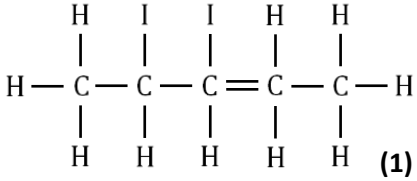
(e)



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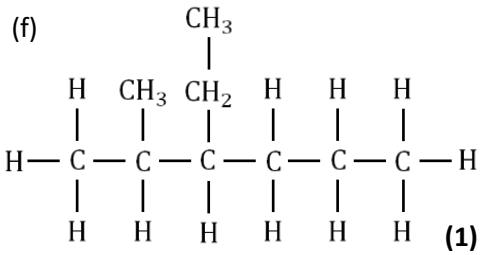
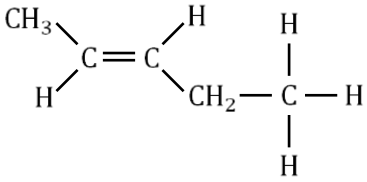


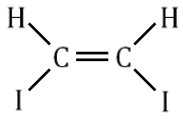
(1)

(g)



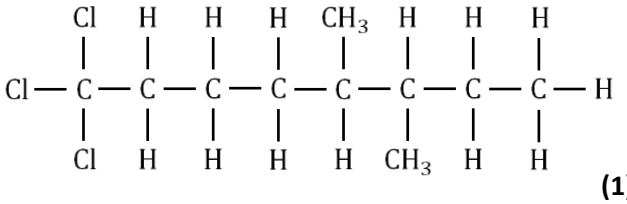
(1)

(h)



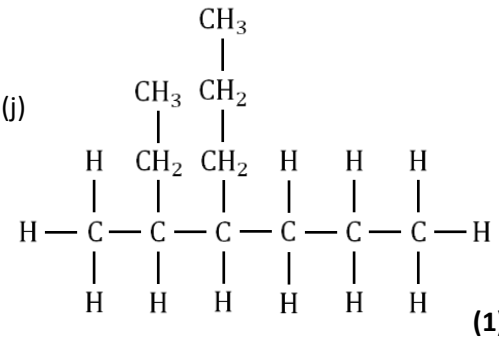
(1)

(i)



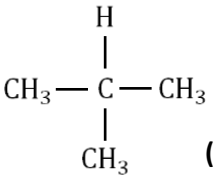
(1)

(j)



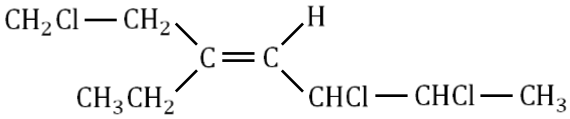
(1)

(k)



(1)

(l)



(1)

3. **[13 marks]**

Name of organic compound:	**Correct**	**Incorrect**
1-methylprop-2-ene		**x (1)**
Correct name if name is incorrect: **cis-but-2-ene** or **trans-but-2-ene** **(1)**		
2-ethylpentane		**x (1)**
Correct name if name is incorrect: **3-methylhexane** **(1)**		
cis-1,1-dichloropropene		**x (1)**
Correct name if name is incorrect: **1,1-dichloropropene**		
3-propyloctane		**x (1)**
Correct name if name is incorrect: **4-ethylnonane** **(1)**		
2-methylbut-2-ene	**✔ (1)**	
Correct name if name is incorrect:		

5,6-diiodo-3-methylhexane		X **(1)**
Correct name if name is incorrect: **1,2-diiodo-4-methylhexane (1)**		
trans-pent-3-ene		X **(1)**
Correct name if name is incorrect: **trans-pent-2-ene (1)**		

Points to note: Draw out the compound as this will allow you to see any issues with the incorrect name given

Marking Criteria	Marks Allocated
• Correctly determines if name is correct or incorrect	1 – 7
• Provides correct name if name is incorrect	1 – 6
Total	**13**

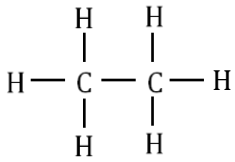
Isomerism: Q4, Q5, Q6

4.

(a) An isomer is a compound with the **same molecular formula** but a **different structural formula** **(1)**. Two types of isomers are **chain isomers** and **position isomers**. **Chain isomers** are those with a **differing parent carbon chain length** whereas **position isomers** are those where the parent carbon chain length is kept constant, but the **position** of the **functional group/attachments** is **changed** **(1)**.

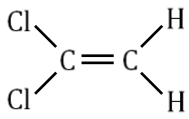
Marking Criteria	Marks Allocated
• Correctly defines isomer	1
• Provides explains structural and positional isomer	1 – 2
Total	**3**

(b) (i) Yes, she is **correct**.

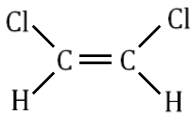


Ethene (1)

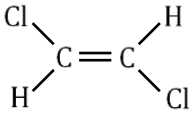
(ii) Yes, she is **correct**.



1,1-dichloroethene (1)

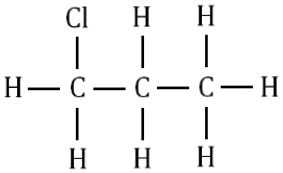


cis-1,2-dichloroethene (1)

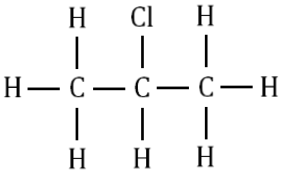


trans-1,2-dichloroethene (1)

(iii) No she is **incorrect**.

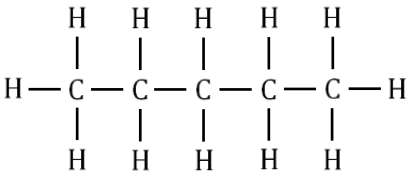


1-chloropropane (1)

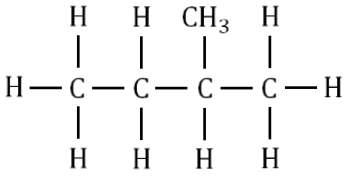


2-chloropropane (1)

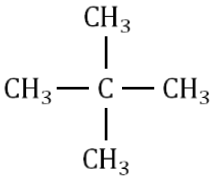
(iv) Yes she is **correct**.



Pentane (1)



Methylbutane (1)



Dimethylpropane (1)

(c) **Alkenes** have a **double bond functional group** which **restricts** the **rotation** of atoms about this double bond and therefore creates cis-trans isomerism **(1)**. **Alkanes** are only comprised of **single bonds** and therefore do not exhibit cis-trans isomerism because their single bonds allow for the **free rotation** of all their atoms **(1)**.

Marking Criteria	Marks Allocated
• Alkenes have double bonds which restricts rotation of connected atoms, alkanes have single bonds which allow for free rotation.	1
• Links the presence of the double bond to cis-trans isomerism	1
Total	**2**

5. (i) Yes (ii) No (iii) Yes (iv) No (v) No (vi) No

Marking Criteria	Marks Allocated
• Correctly determines if cis-trans isomerism is or isn't possible	$1-6$
Total	**6**

6. **[10 marks]**

(a) Position isomer **(1)**

(b) Same compound **(1)**

(c) Structural isomer **(1)**

(d) Structural isomer **(1)**

(e) Different compounds **(1)**

(f) Position isomer **(1)**

(g) Cis-trans isomer **(1)**

(h) Same compound **(1)**

(i) Position isomer **(1)**

(j) Position isomer **(1)**

Marking Criteria	Marks Allocated
• Correct classification the relationship between each pair of substances	$1-10$
Total	**10**

Concept 2

Properties of Alkanes and Alkenes – Progressive Questions Answers

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Boiling Point and Solubility: Q1, Q2, Q3, Q4

1. **[11 marks]**

(a) Dispersion forces

Marking Criteria	Marks Allocated
• Circles dispersion forces	1
Total	**1**

(b) **Dispersion forces** are the result of electrons **moving randomly** between atoms in a covalent bond and therefore **randomly spending more time** on one side of the bond than the other, at different instances. This results in short-lived δ^+ and δ^- charges creating **'temporary dipoles' (1)**. The presence of these temporary dipoles that continually change location, creates an **overall weak electrostatic attraction** between the molecules known as **dispersion forces (1)**.

Marking Criteria	Marks Allocated
• Dispersion forces arise from random movement of electrons in covalent bonds. • Temporary dipoles are formed throughout the molecule. • This creates a weak electrostatic attraction between molecules known as dispersion forces.	$1-3$
Total	**3**

(c) Numbers should be allocated as follows:

⑤ 3-methylhexane ② Methylbutane ① Ethene ⑦ Oct-3-ene

③ Pentane ⑥ Heptane ④ 2,3-dimethylpentane

Marking Criteria	Marks Allocated
• Correctly allocates three of the numbers	1
• Correctly allocates all of the numbers but two	2
• Correctly allocates all of the numbers	3
Total	**3**

Points to note: The more branching in a molecule the lower its boiling point when compared to molecules of the same molar mass.

(d) Branching occurs when organic compounds have **attached carbon chains (1)**. When carbon chains are attached to a hydrocarbon they **can't pack together** as **effectively** and have a **reduced surface area** for **intermolecular interaction (1)**. As a result, despite methylbutane having the same molar mass as pentane it has a **lower boiling point** because its molecules **can't pack together** as **effectively (1)** and it therefore has a **reduced surface area** for intermolecular interaction when compared to the straight chained pentane molecules **(1)**.

Marking Criteria	Marks Allocated
• Correctly defines branching • Branched molecules have a reduced surface area for intermolecular interaction. • Methylbutane is a branched molecule whereas pentane is straight-chained. • Methylbutane has a lower boiling point because there is less surface area for intermolecular interaction.	$1-4$
Total	**4**

2. **[4 marks]**

(a) **Butene**, **methylpentane** and **hexane** all exhibit **dispersion force interactions** between their molecules **(1)**. **Butene** has the **lowest boiling point** because it has a **lower molar mass** than **methylpentane** and **hexane**, and therefore has **weaker dispersion forces** from having **less electrons** within its molecules **(1)**. Despite **methylpentane** having the **same molar mass** as hexane, **methylpentane** has a **lower boiling point** as a result of having **more branching (1)**. With more branching, the methylpentane molecules **pack less effectively** and therefore have **less surface area** for intermolecular interaction than the straight chained hexane molecules **(1)**.

Marking Criteria	Marks Allocated
• States that all molecules exhibit dispersion forces • Butene has the lowest boiling point due to weaker dispersion forces from a lower molar mass and less electrons • Methylpentane is a branched molecule whereas hexane is straight-chained. • Methylpentane has a lower boiling point than hexane because there is less surface area for intermolecular interaction.	$1-4$
Total	**4**

(b) Both **pentane** and **pentene** exhibit **dispersion forces** of a similar size between its molecules **(1)**, and **water** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**. When pentane or pentene is added to water it only forms **weak dispersion forces** which **do not release enough energy** from the solute-solvent attractions to **break** the **solute-solute** and **solvent-solvent** attractions **(1)**. As a result, both **pentane** and **pentene** are **insoluble (1)**.

Marking Criteria	Marks Allocated
• Pentane and pentene exhibit dispersion forces between its molecules • Water exhibits dispersion forces, dipole-dipole forces and hydrogen bonding between its molecules • Only dispersion forces are formed between pentane/pentene and water. • Not enough energy is released from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions, so pentane and pentane are insoluble	$1-4$
Total	**4**

Points to note: The strength of dispersion forces is very similar between alkanes and alkenes, so the difference in solubility between alkanes and alkenes of a similar molar mass is negligible.

3. **[4 marks]**

Hexane and butene exhibit dispersion forces between their molecules, and water exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**. When **water** is added to the hexane the **weak dispersion forces** formed **do not release enough energy** to break the solute-solute and solvent-solvent attractions, making it **insoluble (1)**. However, when **butene** is added to the hexane, **moderate sized dispersion forces** are formed that **release enough energy** to **break** the solute-solute and solvent-solvent attractions, making it **soluble (1)**.

Marking Criteria	Marks Allocated
• Hexane and butane exhibit dispersion forces between its molecules • Water exhibits dispersion forces, dipole-dipole forces and hydrogen bonding between its molecules • The weak dispersion forces formed between hexane and water do not release enough energy to break the solute-solute and solvent-solvent attractions, so water is insoluble. • The moderate dispersion forces formed between butene and hexane release enough energy to break the solute-solute and solvent-solvent attractions, so butane is soluble.	$1-4$
Total	**4**

4. **[5 marks]**

All of the four compounds stated: **octane**, **pentane**, **methylbutane** and **3-methylheptane** exhibit dispersion forces between their molecules **(1)**. **Methylbutane** and **pentane** have **lower boiling points** than 3-methylheptane and octane because they have a **lower molar mass** and therefore have **weaker dispersion forces** from having **less electrons** within its molecules **(1)**. Despite methylbutane and pentane having the same molar mass, **methylbutane** has a **lower boiling point** because it has **more branching**, meaning its molecules **pack less effectively** and therefore have **less surface area** for **intermolecular interaction** than the pentane molecules **(1)**. Despite **octane** and **3-methylheptane** having the same molar mass, **octane** has the **higher boiling point** because **3-methylheptane** has **more branching** meaning its molecules have **less surface area** for intermolecular interaction **(1)**. Thus the order Neil collects the compounds will start with **butane**, then **pentane**, then 3-**methylheptane** and finally **octane (1)**.

Marking Criteria	Marks Allocated
• All of the compounds exhibit dispersion forces of varying sizes • Methylbutane and pentane have a lower boiling point than octane and 3-methylheptane due to a lower molar mass • Methylbutane has the lowest boiling point due to it having more branching than pentane • Octane has the highest boiling point due to it having less branching than 3-methylheptane • Thus the order collected from start to finish will be: butane, pentane, 3-methylheptane and then octane.	$1-5$
Total	**5**

Reactions with Alkanes and Alkenes: Q5, Q6, Q7

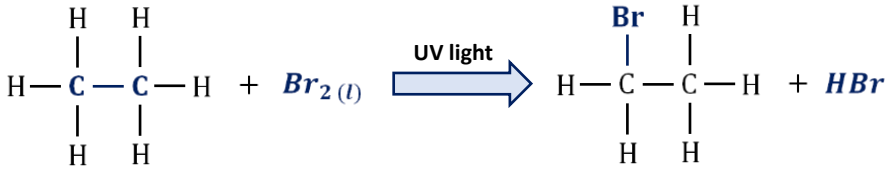
5. **[6 marks]**

(a) Rabea can add **bromine water** to samples from each of the bottles and observe the **addition** or **substitution reactions** that take place **(1)**. From these **observations** he can **determine** which bottle contains ethane and which contains ethene **(1)**.

Marking Criteria	Marks Allocated
• Bromine water can be added to samples from each of the bottles to observe addition or substitution reactions • The recorded observations can be used to determine which bottle is which	$1-2$
Total	**2**

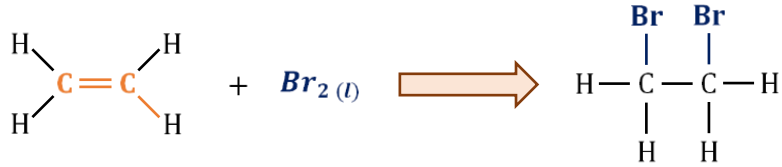
(b)

Bottle with ethane: **No reaction**, or if in **presence** of **UV light**:



(1)

Bottle with ethene:



(1)

(c) As predicted from the reactions in part (b), **bottle one** contains **ethane** because no reaction occurs for ethane **(1)**, and **bottle two** contains **ethene** because an addition reaction takes place **(1)**.

Marking Criteria	Marks Allocated
• Bottle one contains ethane • Bottle two contains ethene	$1-2$
Total	**2**

6. **[8 marks]**

(a) When the hydrogen gas is pumped into the beaker with **butane no reaction** will take place as there is **no UV light** present **(1)**, thus it will be observed that a **colourless, odourless gas** passes through the **colourless solution** in the beaker **(1)**. In the second beaker containing the **but-2-ene** the following addition reaction will take place: $CH_3CHCHCH_3 + H_{2\,(g)} \rightarrow CH_3CH_2CH_2CH_3$ **(1)**, and it will be observed that the **colourless, odourless gas** is absorbed into the **colourless solution** **(1)**.

Marking Criteria	Marks Allocated
• No reaction will occur for beaker containing butane • For butane it will be observed that a "colourless gas will pass through colourless solution" • But-2-ene reaction: $CH_3CHCHCH_3 + H_{2\,(g)} \rightarrow CH_3CH_2CH_2CH_3$ • For butene it will be observed that "a colourless odourless gas will be absorbed into the colourless solution"	$1-4$
Total	**4**

(b) When the chlorine gas is pumped into the beaker with **butane** the following **addition reaction** will take place: $\boldsymbol{CH_3CH_2CH_2CH_3 + Cl_{2\,(g)} \rightarrow CH_3CHClCH_2CH_3}$ **(1)**, and it will be observed that "a **yellowish-green gas** will be **slowly absorbed** by the colourless solution, but most of the yellow-greenish gas will pass through" **(1)**. In the beaker containing the **but-2-ene** the following addition reaction will take place: $\boldsymbol{CH_3CHCHCH_3 + Cl_{2\,(g)} \rightarrow CH_3CHClCHClCH_3}$ **(1)**, and it will be observed that "a **yellowish-green gas** will be **absorbed** by the **colourless solution** to produce a **colourless solution**" **(1)**.

Marking Criteria	Marks Allocated
• Butane reaction: $CH_3CH_2CH_2CH_3 + Cl_{2\,(g)} \rightarrow CH_3CHClCH_2CH_3$ • For butane it will be observed that a "yellowish-green as will be slowly absorbed by the colourless solution." • But-2-ene reaction: $CH_3CHCHCH_3 + Cl_{2\,(g)} \rightarrow CH_3CHClCHClCH_3$ • For butene it will be observed that "a yellowish-green gas will be absorbed into the colourless solution"	$1-4$
Total	**4**

7. **[8 marks]**

(a) $\boldsymbol{CH_{4\,(g)} + 2O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2H_2O_{(g)}}$ **(1)**

(b) $\boldsymbol{C_4H_{8\,(g)} + 4O_{2\,(g)} \rightarrow 4CO_{(g)} + 4H_2O_{(g)}}$ **(1)**

(c) $\boldsymbol{2C_8H_{18\,(g)} + 17O_{2\,(g)} \rightarrow 16CO_{(g)} + 18H_2O_{(g)}}$ **(1)**

(d) $\boldsymbol{2C_7H_{14\,(g)} + 21O_{2\,(g)} \rightarrow 14CO_{2\,(g)} + 14H_2O_{(g)}}$ **(1)**

(e) $\boldsymbol{2C_5H_{12\,(g)} + 11O_{2\,(g)} \rightarrow 10CO_{(g)} + 12H_2O_{(g)}}$ **(1)**

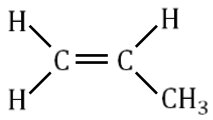
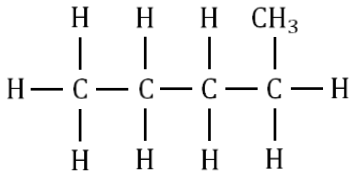
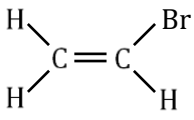
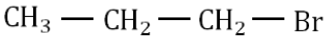
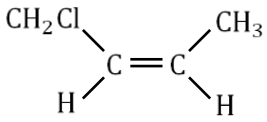
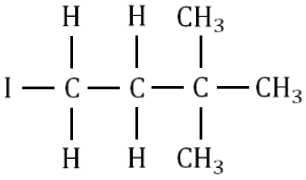
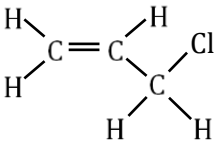
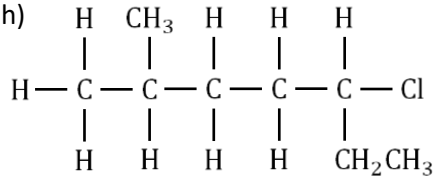
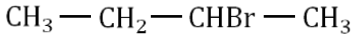
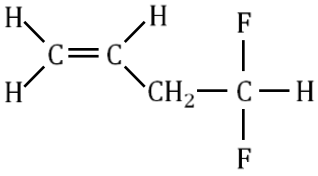
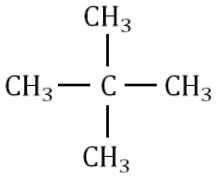
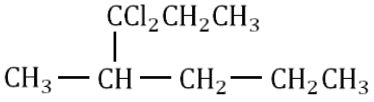
Marking Criteria	Marks Allocated
• Writes correct complete/incomplete combustion equation	$1-5$
Total	**5**

Problem Set 10 – Organic Chemistry BTG
Repetitive Questions

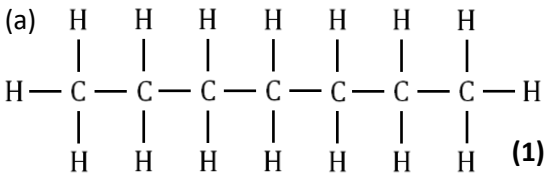
Concept 1
Alkanes and Alkenes – Progressive Questions Answers

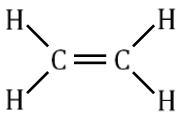
IUPAC Naming of Alkanes and Alkenes: 1.11, 1.21

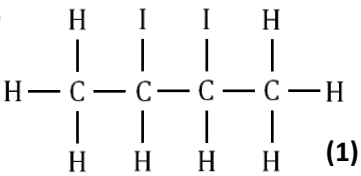
1.1 **[12 marks]**

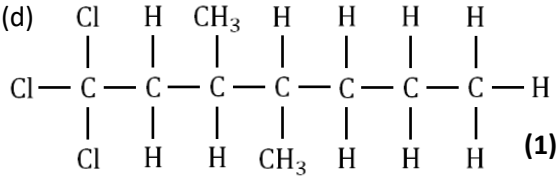
(a)  **Propene (1)**	(b)  **Pentane (1)**	(c)  **1-Bromoethene (1)**
(d)  **1-bromopropane (1)**	(e)  **cis-1-chlorobut-2-ene (1)**	(f)  **1-iodo-3,3-dimethylbutane (1)**
(g)  **3-chloropropene (1)**	(h)  **5-chloro-2-methylheptane (1)**	(i)  **2-bromobutane (1)**
(j)  **4,4-diflurobut-1-ene (1)**	(k)  **2,2-dimethylpropane (1)**	(l)  **3,3-dichloro-4-methylheptane (1)**

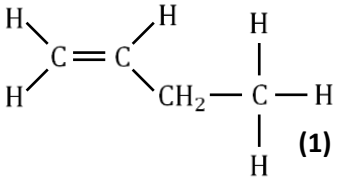
1.21 **[10 marks]**

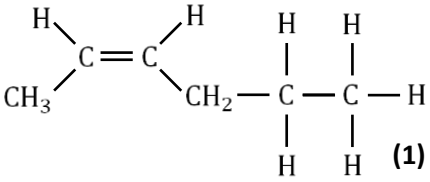
(a)  **(1)**

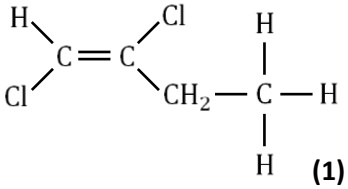
(b)  **(1)**

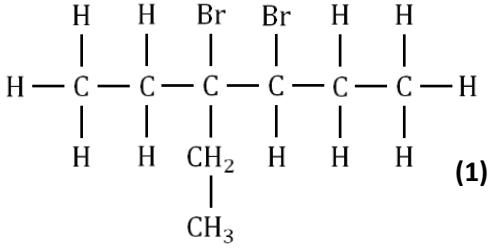
(c)  **(1)**

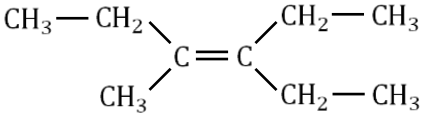
(d)  **(1)**

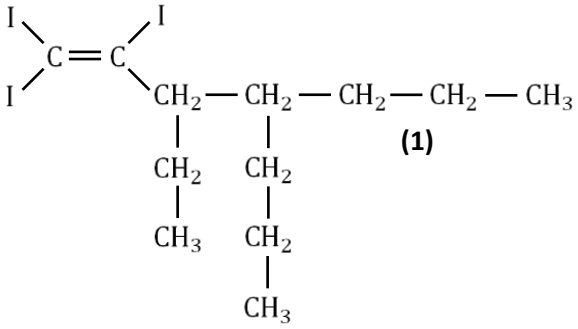
(e)  **(1)**

(f)  **(1)**

(g)  **(1)**

(f)  **(1)**

(h)  **(1)**

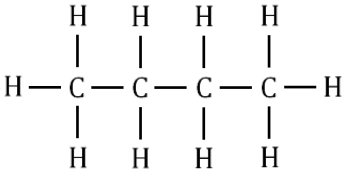
(i)  **(1)**

1.41 **[11 marks]**

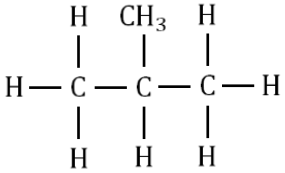
(a) An isomer is a compound with the **same molecular formula** but a **different structural formula** **(1)**.

Marking Criteria	Marks Allocated
• Correctly defines isomer	1
Total	**1**

(b) (i)

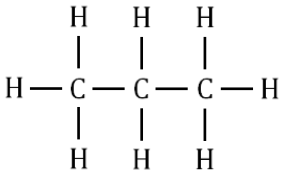


Butane **(1)**



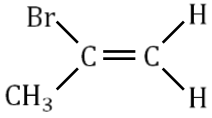
methylpropane **(1)**

(ii)

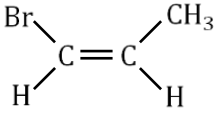


Propane **(1)**

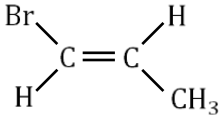
(iii)



1-bromo-1-methylethene **(1)**

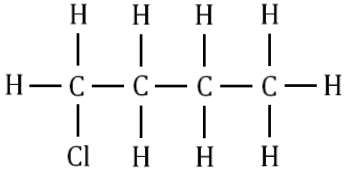


cis-1-bromo-2-methylethene **(1)**

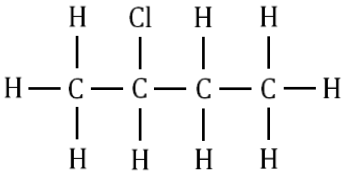


trans-1-bromo-2-methylethene **(1)**

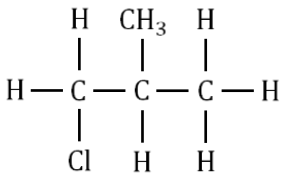
(iv)



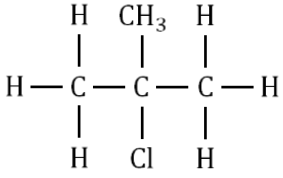
1-chlorobutane (1)



2-chlorobutane (1)



1-chloromethylpropane (1)



2-chloromethylpropane (1)

1.61 **[10 marks]**

(a) Same compound **(1)**

(b) Cis-trans isomer **(1)**

(c) Structural isomer **(1)**

(d) Structural isomer **(1)**

(e) Cis-trans isomer **(1)**

(f) Different compounds **(1)**

(g) Same compound **(1)**

(h) Structural isomer **(1)**

(i) Structural isomer **(1)**

(j) Structural isomer **(1)**

Concept 2

Properties of Alkanes and Alkenes – Progressive Questions Answers

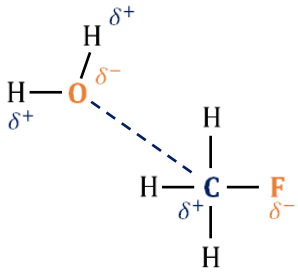
Boiling Point and Solubility: 2.11, 2.21, 2.41

2.11 **[11 marks]**

(a) Dispersion forces **(1)**

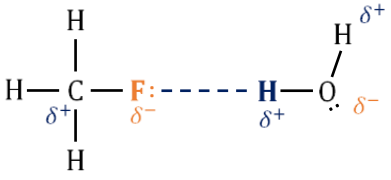
Marking Criteria	Marks Allocated
• Correctly dispersion forces	1
Total	**1**

(b)



(1)

Dispersion forces



(1)

Hydrogen bonding

Dipole-dipole forces are intermolecular forces that arise from the attraction between oppositely charged dipoles between molecules, as shown in the attraction between the δ^+ on the ***C* atom** in **tetrafluoromethane** and the δ^- on the ***O* atom** in **water** **(1)**. **Hydrogen bonds** are a significantly stronger type of dipole-dipole force that arise between two molecules when one molecule has a **lone pair of electrons** from a ***F***, ***O*** or ***N*** atom and the other molecule has a ***H*** atom bonded to a ***F***, ***O*** or ***N*** atom **(1)**. This is shown in the attraction of the lone pair electrons of the ***F* atom** in **tetrafluoromethane** and the δ^+ on the ***H* atom** in **water**.

Marking Criteria	Marks Allocated
• Correct diagram showing dipole-dipole forces. • Correct diagram showing hydrogen bonding. • Dipole-dipole forces are the attraction between oppositely charged dipoles between molecules. • Hydrogen bonds are the attraction between the lone pair of electrons from a F, O or N atom of one molecule and the H atom bonded to a F, O or N atom of another molecule.	$1-4$
Total	**4**

(c)

⑤ Hexane ③ Butane ② Methylpropane ⑥ 2-methylheptane

① Methane ⑦ Octane ④ 2,3-dimethylbutane

Marking Criteria	Marks Allocated
• Correctly allocates three of the numbers	1
• Correctly allocates all of the numbers but two	2
• Correctly allocates all of the numbers	3
Total	**3**

(d) Both **octane** and **tetrabromomethane** are **non-polar molecules** and therefore only exhibit **dispersion forces** between their molecules **(1)**. Despite being a smaller molecule, tetrabromomethane has a higher boiling point because it has a **higher molar mass** ($331.61\ g\ mol^{-1}$ vs $112.208\ g\ mol^{-1}$) **(1)**. With a **higher molar mass**, tetrabromomethane has **stronger dispersion forces** because it has **more electrons** within its molecules to create temporary dipoles **(1)**.

Marking Criteria	Marks Allocated
• Both octane and tetrabromomethane exhibit dispersion forces. • Tetrabromomethane has a higher molar mass and therefore stronger dispersion forces. • A higher molar mass means more electrons to create temporary dipoles, thus giving tetrabromomethane a higher boiling point.	$1-3$
Total	**3**

2.21 **[5 marks]**

All of the four compounds used: **hexane**, **oct-2-ene**, **3-methylpentane** and **1,2-difluorohexane** exhibit **dispersion forces** between their molecules **(1)**. Despite having the same molar mass as hexane, **3-methylpentane** has the **lowest boiling point** because it has more branching between its molecules, meaning its molecules **pack less effectively** and therefore have **less surface area** for **intermolecular interaction** **(1)**. Hexane has a lower boiling point than oct-2-ene because it has a **lower molar mass** and therefore have **weaker dispersion forces** from having **less electrons** within its molecules to form temporary dipoles **(1)**. Finally **1,2-difluorohexane** is a **polar molecule** that exhibits **dipole-dipole forces** between its molecules and as a result has a **higher boiling point** than **oct-2-ene** because the **sum** of its **intermolecular forces** is **greater** **(1)**. Thus the **order** of boiling points from lowest to highest will be: **3-methylpentane**, **hexane**, **oct-2-ene** and then **1,2-difluorohexane** **(1)**.

Marking Criteria	Marks Allocated
• All of the compounds exhibit dispersion forces of varying sizes. • 3-methylpentane has the lowest boiling point due to branching which gives less surface area for intermolecular interaction. • Hexane has a lower boiling point than oct-2-ene from having a lower molar mass and therefore less electrons to form temporary dipoles • 1,2-difluorohexane has the highest boiling point from having dipole-dipole forces between this molecules • The boiling point order will be: 3-methylpentane, hexane, oct-2-ene and then 1,2-difluorohexane.	$1-5$
Total	**5**

2.41 **[10 marks]**

(a) Both hexane and octane exhibit **dispersion forces** of a similar size between its molecules **(1)**, and **water** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**. When hexane or octane are added to water they form **weak dispersion forces** which **do not release enough energy** to **break** the **solute-solute** and **solvent-solvent** attractions **(1)**. As a result, both **hexane** and **octane** are **insoluble** **(1)**.

Marking Criteria	Marks Allocated
• Hexane and octane exhibit dispersion forces between its molecules • Water exhibits dispersion forces, dipole-dipole forces and hydrogen bonding between its molecules • Only weak dispersion forces are formed between hexane/octane and water. • Not enough energy is released from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions, so hexane and octane are insoluble	$1-4$
Total	**4**

(b) Ethane exhibits **dispersion forces** between its molecules **(1)**, pentane exhibits **dispersion forces** between its molecules **(1)**. When **ethane** is added to the **pentane**, **moderate sized dispersion forces** are formed that **release enough energy** to **break** the solute-solute and solvent-solvent attractions, making it **soluble** **(1)**.

Marking Criteria	Marks Allocated
• Ethane and pentane exhibit dispersion forces between their molecules • Moderate sized dispersion forces are formed between ethane and pentane that release enough energy to break the solute-solute and solvent-solvent attractions, so ethane is soluble in pentane	$1-4$
Total	**4**

(c) **Heptane** exhibits **dispersion forces** between its molecules, **water** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**, and **fluoroethane** exhibits **dispersion forces** and **dipole-dipole forces** between its molecules **(1)**. When **heptane** is added to fluoroethane, only **weak dispersion forces** which **do not release enough energy** to **break** the **solute-solute** and **solvent-solvent** attractions **(1)**. However, when **water** is added **dispersion forces**, **dipole-dipole forces** and **hydrogen bonds** are formed which **release enough energy** to **break** the **solute-solute** and **solvent-solvent** attractions. As a result, **heptane** is **insoluble** and **water** is **soluble** in fluoroethane **(1)**.

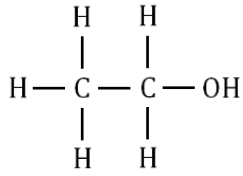
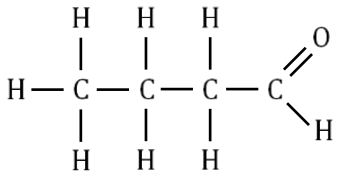
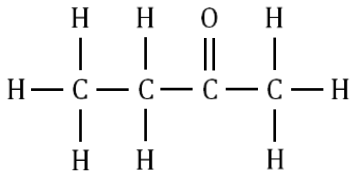
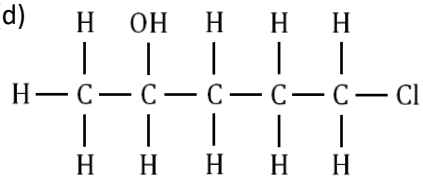
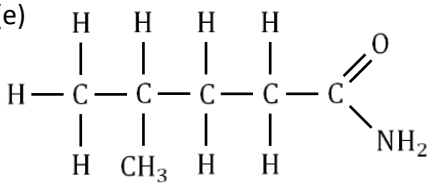
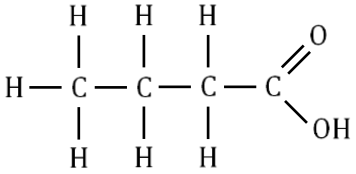
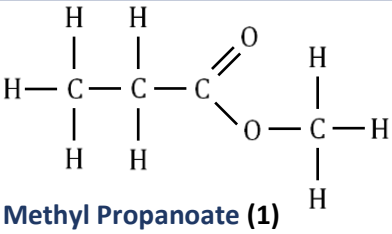
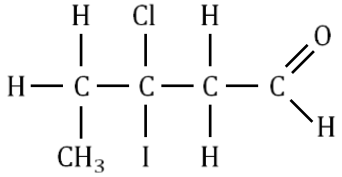
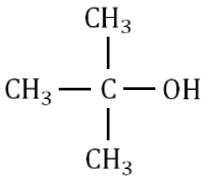
Problem Set 11 – Organic Functional Groups
Progressive Questions

Concept 1

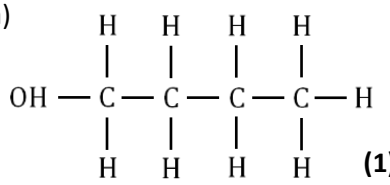
Functional Groups – Progressive Questions Answers

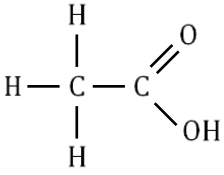
IUPAC Naming of Functional Groups: Q1, Q2, Q3, Q4, Q5, Q6

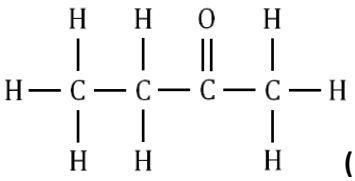
1. **[9 marks]**

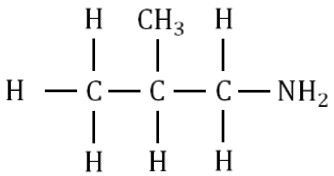
(a)  **Ethanol (1)**	(b)  **Butanal (1)**	(c)  **Butanone (1)**
(d)  **5-chloro-pentan-2-ol (1)**	(e)  **4-methyl pentanamide (1)**	(f)  **Butanoic acid (1)**
(g)  **Methyl Propanoate (1)**	(h)  **3-chloro-3-iodopentanal (1)**	(i)  **2-methyl propan-2-ol (1)**

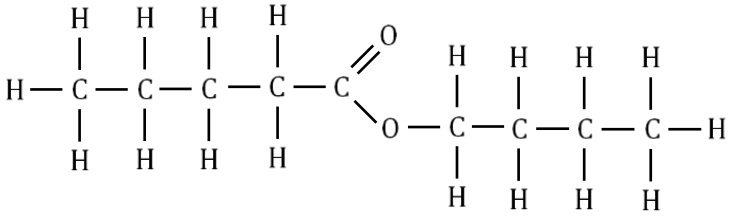
2. **[10 marks]**

(a)  **(1)**

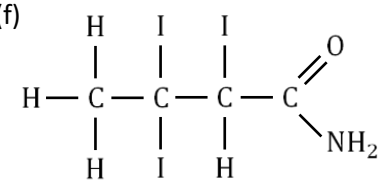
(b)  **(1)**

(c)  **(1)**

(d)  **(1)**

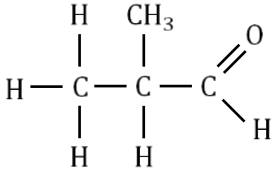
(e)  **(1)**

(f)



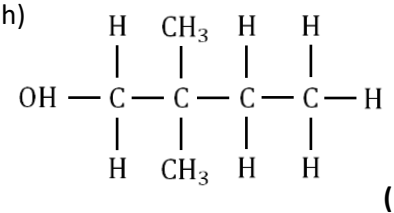
(1)

(g)



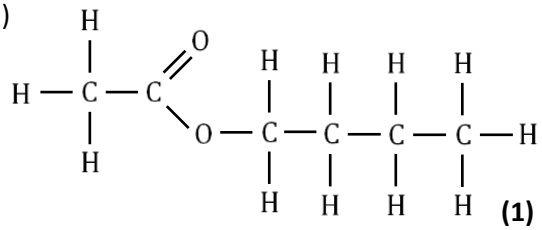
(1)

(h)



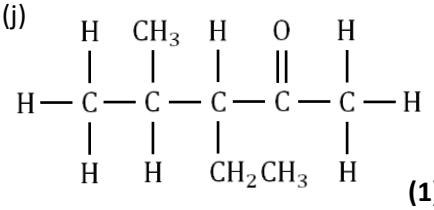
(1)

(i)



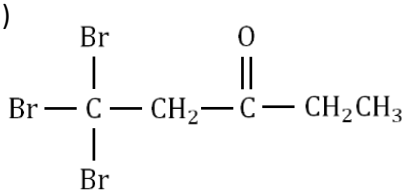
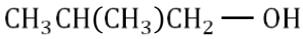
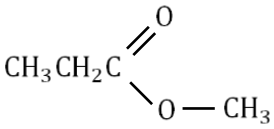
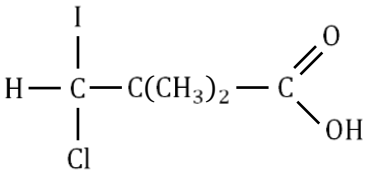
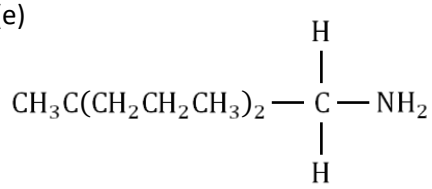
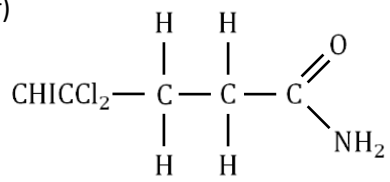
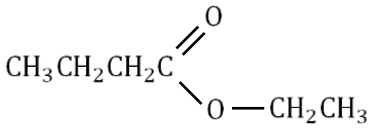
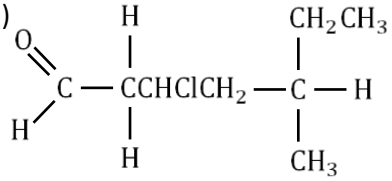
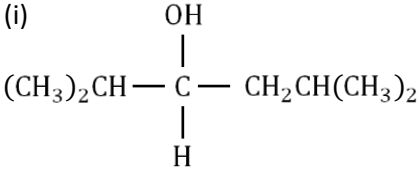
(1)

(j)



(1)

3. **[10 marks]**

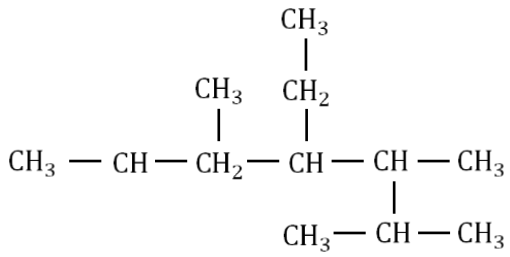
(a)  **5,5,5-tribromo-petan-3-one (1)**	(b)  **2-methylpropan-1-ol (1)**	(c)  **methyl propanoate (1)**
(d)  **3-chloro-3-iodo-2,2-dimethyl propanoic acid (1)**	(e)  **2-methyl-2-propyl-pentan-1-amine (1)**	(f)  **4,4-dichloro-5-iodopentanamide (1)**
(g)  **Ethyl Butanoate (1)**	(h)  **3-chloro-5-methyl-heptanal (1)**	(i)  **2,5-dimethyl-hexan-3-ol (1)**

4. **[10 marks]**

Student	Condensed Compound	Student's Guess	Actual Name	Progresses to next stage (✔ or X)
Janet	CH_3CHO	Ethanal	**Ethanal (1)**	✔
	$CH_3CH(OH)CH_3$	Propan-2-ol	**Propan-2-ol (1)**	
Sarah	$CH_3CH_2CH_2CH_2COOH$	Pentanoic Acid	**Pentanoic Acid (1)**	✔
	$CH_3COCH_2CH_3$	Butanone	**Butanone (1)**	
Jamie	$CH_3COCH_2CH_2CH_3$	Propyl ethanoate	**Pentanone (1)**	X
	$CHOOCH_2CH_2CH_2CH_3$	Butanoic acid	**Methyl Butanoate (1)**	
Alexa	$CHI_2CHBrCH_2CH_2CHO$	4-bromo-5,5-diiodopentanal	**4-bromo-5,5-diiodo-pentanal (1)**	✔
	$CH_3CHICH(CH_3)CONH_2$	3-iodo-2-methyl-butanamide	**3-iodo-2-methyl-butanamide (1)**	
Dylan	$C(CH_3)_3OH$	Butan-1-ol	**Propan-2-ol (1)**	X
	$CH_3CH(NH_2)CH(CH_2CH_3)CH_3$	3-ethyl-butan-2-amine	**3-methyl-pentan-2-amine (1)**	

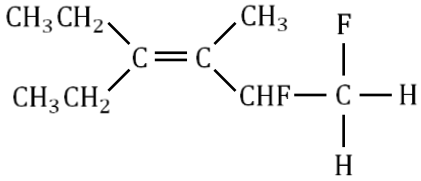
5. **[6 marks]**

(a)



Alexa: 4-ethyl-2,3,5-trimethylheptane

(b)



Sarah: 3-ethyl-5,6-difluoro-4-methylhexene

Alexa's guess of **4-ethyl-2,3,5-trimethylheptane** is **correct**, however Sarah's guess is **incorrect** and it should actually be: **4-ethyl-1,2-difluoro-3-methylhex-3-ene (1)**. Therefore **Alexa will progress** to the next stage and **Sarah will not (1)**.

Marking Criteria	Marks Allocated
• States Alexa is correct and Sarah is incorrect • Gives the correct name for Sarah of: **4-ethyl-1,2-difluoro-3-methylhex-3-ene**	$1-2$
Total	**2**

Points to note: If the double bond number is the same both ways, the numbering will be based on the substituent group that gives the lowest possible number. Therefore in molecule (b) this case it is correct to count from right to left, rather than left to right as has been done in Sarah's guess.

6.

Name of Organic Compound	Alexa's Guess (✔ or X)	Janet's Guess (✔ or X)	Correct Person (Alexa or Janet)
2-methylpent-3-ene	✔	X	Janet **(1)**
cis-1,1-dichloroprop-1-ene	X	✔	Alexa **(1)**
2,3-difluoro-3-ethylpentanal	X	✔	Janet **(1)**
1,3,3-tribromopropan-3-ol	X	✔	Alexa **(1)**
2-methylbutane	X	X	Both **(1)**
methyl butanoate	✔	X	Alexa **(1)**
1-chloroethanamide	X	✔	Alexa **(1)**
3-ethylbutan-2-one	X	X	Both **(1)**

∴ **Alexa will win** and will remain in her trio **(1)**

Points to note: The correct names are as follows:

- Compound 1 name is: cis or trans-4-methylpent-2-ene
- Compound 2 name is: 1,1-dichloroprop-1-ene
- Compound 3 name is: 3,4-difluoro-3-ethylpentanal
- Compound 4 name is: 1,1,3-tribromopropan-1-ol
- Compound 5 name is: methylbutane
- Compound 6 name is correct
- Compound 8 name is: 2-chloroethanamide
- Compound 9 name is: 3-methylpentan-2-one

7. **[7 marks]**

(a) $CHBrCHBr$ **can exhibit** cis-trans isomerism as there is a bromine group on either side of the double bond **(1)**.

(b) $CH_3CH_2CH(CH_3)CH_2CH_3$ **cannot exhibit** cis-trans isomerism since there is **no double bond** **(1)**.

(c) $CH_3C(CH_3)CHCH_3$ **cannot exhibit** cis-trans isomerism since it has **two methyl groups** on the **same side** of the double bond, so it will be identical on that side irrespective of the rotation **(1)**.

(d) $CH_2CHCH_2CH_3$ **cannot exhibit** cis-trans isomerism since there are **not substituent groups** on **both sides** of the double bond **(1)** (or that there are two hydrogen atoms on one side of the double bond that will be the same irrespective of their rotation).

(a) $CHClCHCH_2CH_3$ **can exhibit** cis-trans isomerism between the chlorine and ethyl groups on either side of the double bond (it doesn't matter that they aren't the same group) **(1)**.

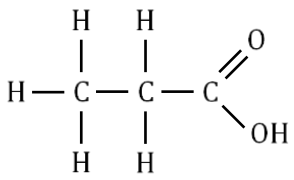
(e) $CH_3COOCHCHOH$ **cannot exhibit** cis-trans isomerism since it doesn't have a double bond in a location where it is bonded to carbons on either side **(1)**.

(f) $CH_3CHCHCl$ **can exhibit** cis-trans isomerism from the methyl group on one side and chlorine group on the other side of the double bond (it doesn't matter that they aren't the same group) **(1)**.

Marking Criteria	Marks Allocated
• Correctly states whether cis-trans isomerism can or cannot be exhibited and provides an appropriate reason	1 – 7
Total	**7**

8. **[8 marks]**

(a)



Propanoic Acid

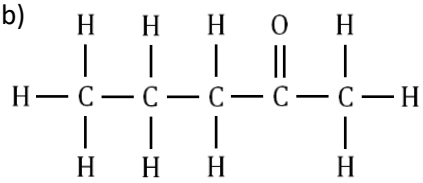
Methyl Ethanoate

Ethyl Methanoate

Propanal

$CH_2CHCH(OH)_2$

(b)



Pentan-2-one

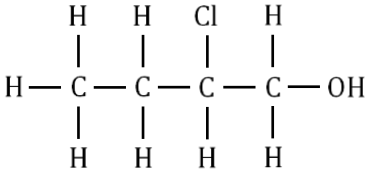
methylpropanal

3-methylbutan-2-one

4-methylbutan-2-one

Pentanal

(c)



2-chlorobutan-1-ol

1-chloro-2-methyl-propan-2-ol

$CH_3C(OH)CHCH_2Cl$

2-chlorobutan-2-ol

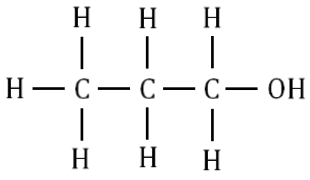
4-chlorobutan-2-ol

Points to note: Draw out each of the compounds, check that they are valid and that they have the same number of each atoms.

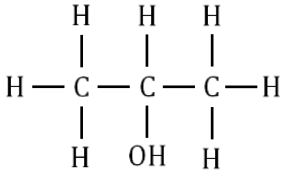
9. **[46 marks]**

(a) C_3H_8O has the **two isomers** shown below.

Isomers of C_3H_8O



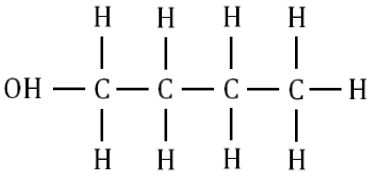
Propanol (1)



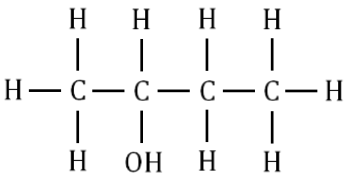
Propan-2-ol (1)

(b) $C_4H_{10}O$ has the **four isomers** shown below.

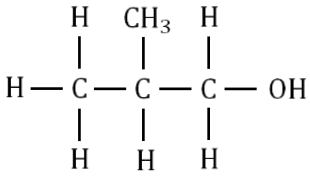
Isomers of $C_4H_{10}O$



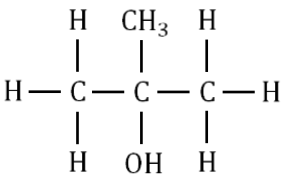
Butanol (1)



Butan-2-ol (1)



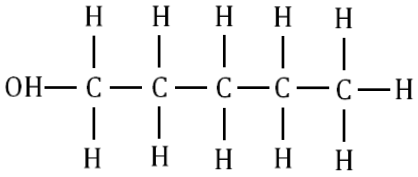
2-methyl propanol (1)



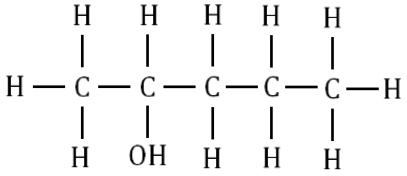
2-methyl propan-2-ol (1)

(c) $C_5H_{12}O$ has the **eight isomers** shown below.

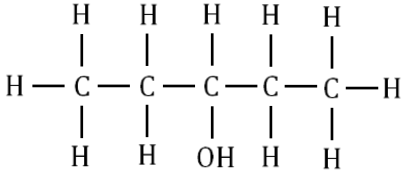
Isomers of $C_5H_{12}O$



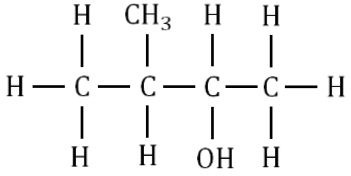
Pentanol (1)



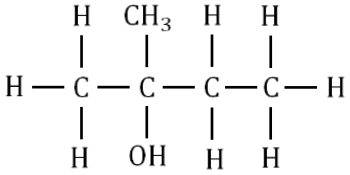
Pentan-2-ol (1)



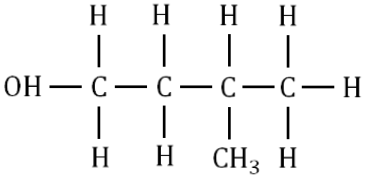
Pentan-3-ol (1)



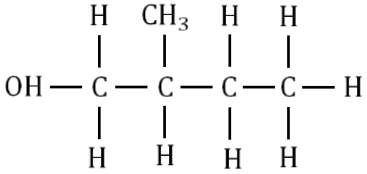
3-methylbutan-2-ol (1)



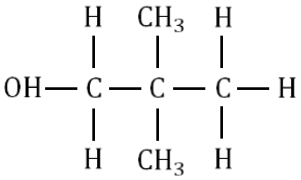
2-methylbutan-2-ol (1)



3-methylbutanol (1)



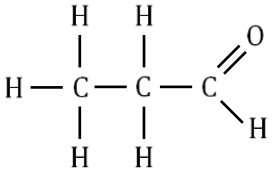
2-methylbutanol (1)



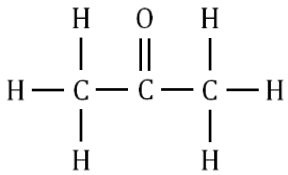
2,2-dimethylpropan-1-ol (1)

(d) C_3H_6O has the **two isomers** shown below.

Isomers of C_3H_6O



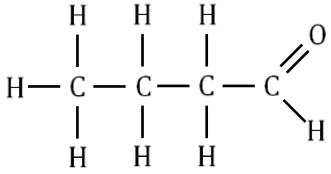
Propanal (1)



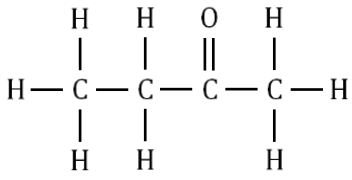
Propanone (1)

(e) C_4H_8O has the **three isomers** shown below.

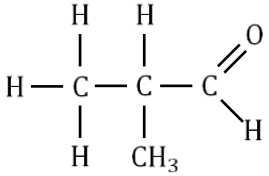
Isomers of C_4H_8O



Butanal (1)



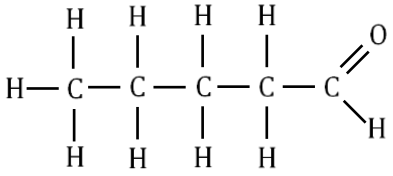
Butanone (1)



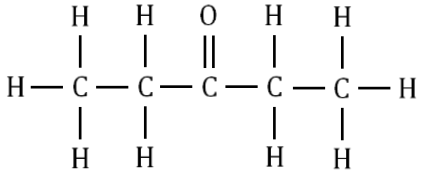
2-methylpropanal (1)

(f) $C_5H_{10}O$ has the **seven isomers** shown below.

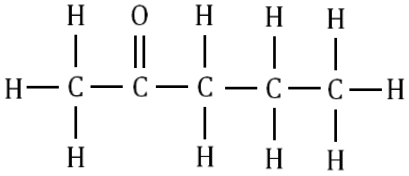
Isomers of $C_5H_{10}O$



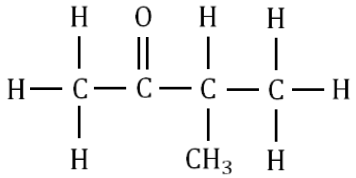
Pentanal (1)



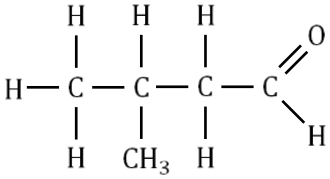
Pentan-3-one (1)



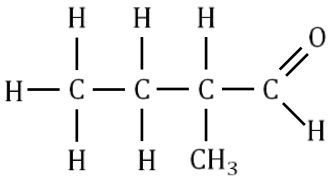
Pentan-2-one (1)



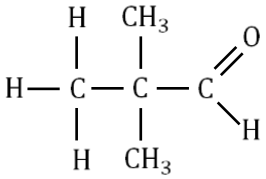
3-methylbutan-2-one (1)



3-methylbutanal (1)



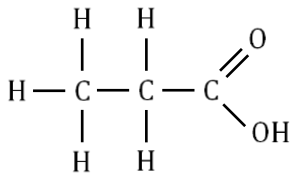
2-methylbutanal (1)



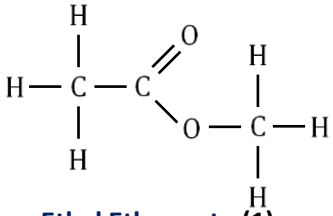
2,2-dimethylpropanal (1)

(g) $C_3H_6O_2$ has the **three isomers** shown below.

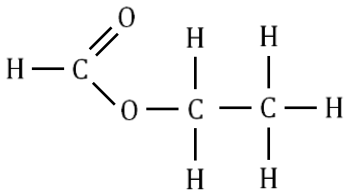
Isomers of $C_3H_6O_2$



Propanoic Acid (1)



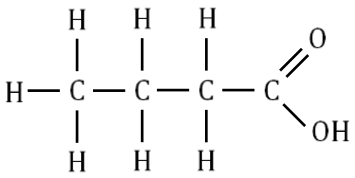
Ethyl Ethanoate (1)



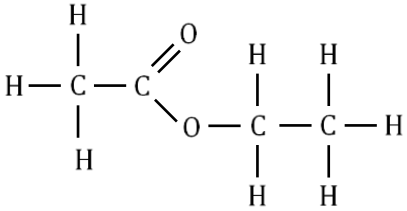
Methyl Ethanoate (1)

(h) $C_4H_8O_2$ has the **five isomers** shown below.

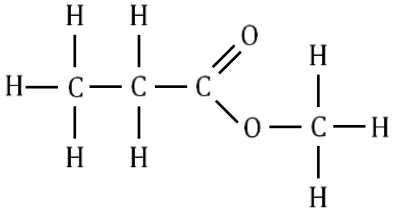
Isomers of $C_4H_8O_2$



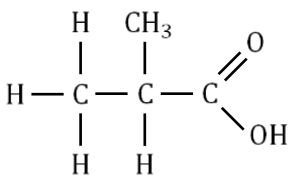
Butanoic Acid (1)



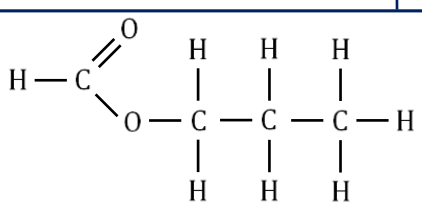
Ethyl Ethanoate (1)



Methyl Propanoate (1)



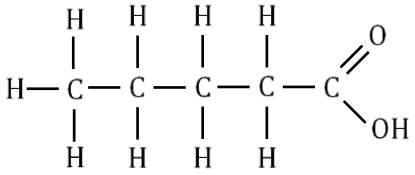
2-methylpropanoic acid (1)



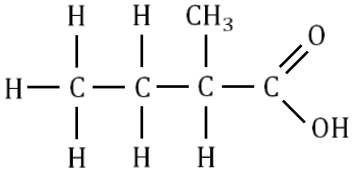
Propyl Methanoate (1)

(i) $C_5H_{10}O_2$ has the **twelve isomers** shown below.

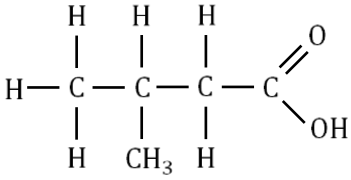
Isomers of $C_5H_{10}O_2$



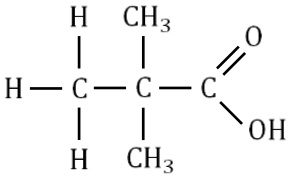
Pentanoic Acid (1)



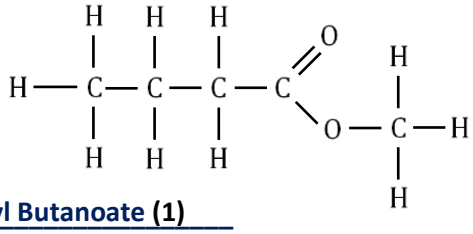
2-methyl Butanoic Acid (1)



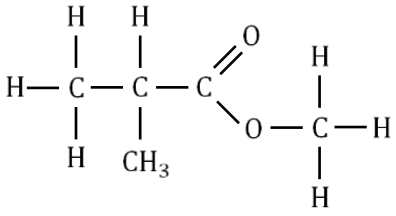
3-methyl Butanoic Acid (1)



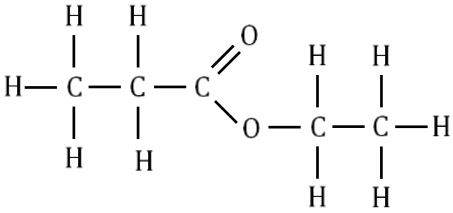
2,2-dimethyl Propanoic Acid (1)



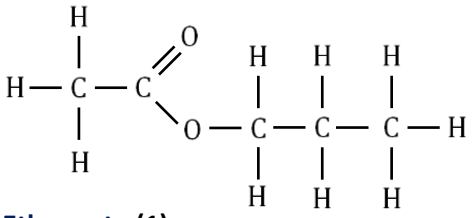
Methyl Butanoate (1)



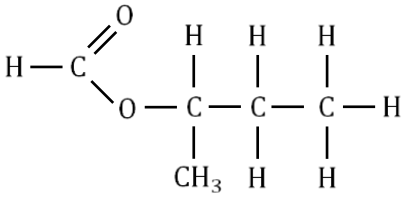
Methyl-2-methyl propanoate (1)



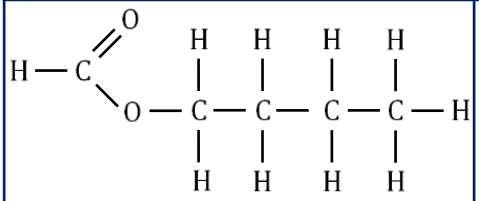
Ethyl Propanoate (1)



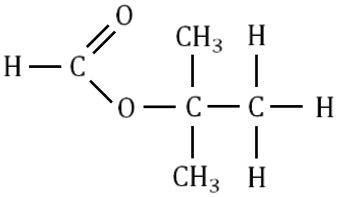
Propyl Ethanoate (1)



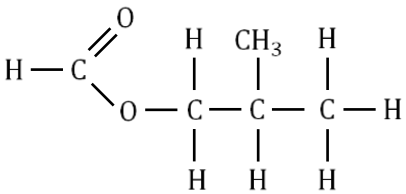
Methyl-2-Propyl methanoate (1)



Butyl Methanoate (1)



dimethyl-2,2- ethyl Methanoate (1)



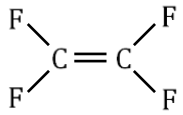
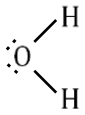
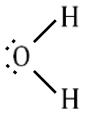
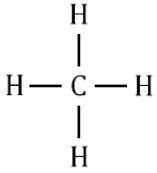
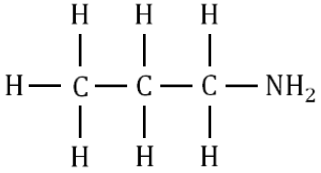
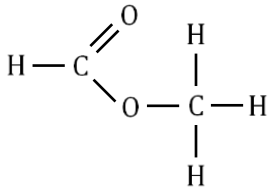
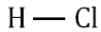
4-methyl-propyl Methanoate (1)

Concept 2

Functional Group Properties – Progressive Questions Answers

Intermolecular Forces: Q1, Q2

1. **[4 marks]**

Substance 1	Substance 2	Types of Intermolecular Forces Exhibited
		Ion-Dipole Forces Hydrogen Bonds Dipole-Dipole Forces **Dispersion Forces**
		**Ion-Dipole Forces** Hydrogen Bonds Dipole-Dipole Forces **Dispersion Forces**
		Ion-Dipole Forces Hydrogen Bonds Dipole-Dipole Forces **Dispersion Forces**
		**Ion-Dipole Forces** Hydrogen Bonds **Dipole-Dipole Forces** **Dispersion Forces**

Marking Criteria	Marks Allocated
• Correct intermolecular forces circled	$1-4$
Total	**4**

2. **[10 marks]**

(a) **Dispersion forces** arise from electrons **moving randomly** between atoms and therefore **randomly spending more time** on one side of the molecule than the other, at different instances **(1)**. This results in short-lived δ^+ and δ^- charges creating **'temporary dipoles'** that from the dispersion force attractions. As the **molar mass** of a molecule **increases** the **number of electrons increase** and as a result the **size** of the **temporary dipoles increases**, thus **increasing** the **strength** of the **dispersion forces (1)**.

Marking Criteria	Marks Allocated
• Dispersion forces arise from the random movement of electrons and randomly spending more time on one side of the molecule • This creates short-lived temporary dipoles (δ^+ and δ^- charges) • As molar mass increases, the number of electrons increases which increases the size of the temporary dipoles which increases the strength of the dispersion forces	$1-3$
Total	**3**

(b) **Yes**, dispersion forces are present between **all molecules (1).** This is because **all molecules** have **electrons** that **move randomly** and can therefore form **temporary dipoles** that create the dispersion force attractions **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces are formed between all molecules • All molecules have electrons that form the temporary dipoles needed	$1-2$
Total	**2**

(c) The order of strength of dispersion forces from **weakest** to **strongest** will be **propane**, **dimethylpropane** and then **pentane (1)**. **Dimethylpropane** and **pentane** have a **stronger dispersion forces** than **propane** because they have a **higher molar mass** and therefore **more electrons** to form **stronger dispersion forces (1)**. **Pentane** has a **higher boiling point** than dimethylpropane because **dimethylpropane** has **more branching** meaning it has **less surface area** for **intermolecular interaction (1)**.

Marking Criteria	Marks Allocated
• Order from weakest to strongest will be propane, dimethylpropane and then pentane • Propane has the lowest boiling point because it has the least electrons to form dispersion forces • Dimethylpropane has a lower boiling point than pentane due to a reduced surface area for intermolecular interaction from branching	$1-3$
Total	**3**

Properties of Functional Groups: Q3, Q4, Q5, Q6, Q7, Q8, Q9

3. **[4 marks]**

Name of Substance	Rank
2,2-dimethylpropane	**1**
Pentanoic acid	**7**
Pent-1-ene	**2**
Pentanamine	**5**

Ethyl ethanoate	**4**
Pentan-1-ol	**6**
Hexane	**3**
Pentanamide	**8**

Points to note: The boiling point is dependent on the sum of intermolecular forces. So consider the intermolecular forces formed between each of the compounds.

Marking Criteria	Marks Allocated
• Half mark for each correctly ranked compound	$1-4$
Total	**4**

4. **[7 marks]**

(a) The first and main reason that **ethanamide** has a **higher boiling point** than **ethanamine** is because **ethanamide** is capable of forming **more hydrogen bonds** than ethanamine because it has the extra **two lone pair electrons** on the **oxygen atom** **(1)**. The second reason is that **ethanamide** has a **greater molar mass** than ethanamine ($59.07\ g\ mol^{-1}$ vs $45.08\ g\ mol^{-1}$) and therefore has **more electrons** and **stronger dispersion forces** **(1)**. As a result, **ethanamide** has a **higher boiling point** because the **sum** of the strength of its **intermolecular forces** is **greater** than for ethanamine **(1)**.

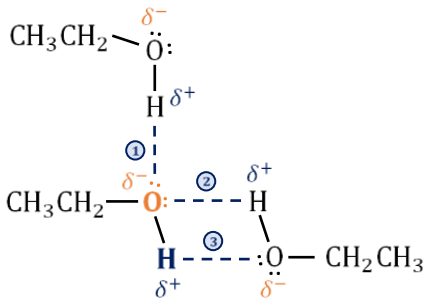
Marking Criteria	Marks Allocated
• Ethanamide can form my hydrogen bonds than ethanamine • Ethanamide has stronger dispersion forces from having a higher molar mass and therefore more electrons to form temporary dipoles • The sum of strength of intermolecular forces in ethanamide is greater than in ethanamine, thus giving it a higher boiling point	$1-3$
Total	**3**

(b) **Ethanamide** and **decanamine** both exhibit the **same intermolecular forces**: dispersion forces, dipole-dipole forces and hydrogen bonding **(1)**. **Ethanamide** has a higher boiling point because it is capable of forming **more hydrogen bonds** than decanamine because it has the extra **two lone pair electrons** on the **oxygen atom** **(1)**. However, **decanamine** also has a similar boiling point because it has a **much higher molar mass** than ethanamide because it has a **higher molar mass** and therefore has **more electrons** to form **stronger dispersion forces** **(1)**. As a result, the **sum** of the **strength** of **intermolecular forces** in each molecule balances out to be **very similar**, giving them **very similar boiling points** **(1)**.

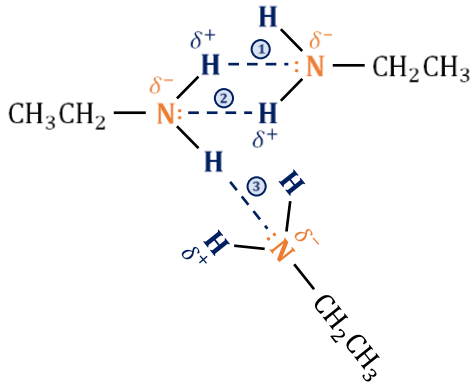
Marking Criteria	Marks Allocated
• Both molecules exhibit the same intermolecular forces • Ethanamide can form more hydrogen bonds than decanamine • Decanamine has stronger dispersion forces from having a higher molar mass • The sum of the strength of intermolecular forces balances out to be similar, giving the compounds similar boiling points	$1-4$
•	
Total	**4**

5. **[6 marks]**

(a)



Ethanol



Ethanamine

Point to note: These are just examples of a hydrogen bonding diagram that could be drawn (you don't necessarily need to draw all three hydrogen bonds for each molecule).

Marking Criteria	Marks Allocated
• Draws correct structure for ethanol and ethanamine	$1-2$
• Draws appropriate hydrogen bonds for ethanol and ethanmine	$1-2$
Total	**4**

(b) Whilst both **ethanol** and **ethanamine** are capable of forming **hydrogen bonds**, the hydrogen capable of hydrogen bonding in **ethanol** is **attached** to an **oxygen atom** and the hydrogen in **ethanamine** is **attached** to a **nitrogen atom** **(1)**. **Oxygen** is a **more electronegative element** than **nitrogen** and as a result a **stronger positive partial charge** is created on the hydrogen of the ethanol, resulting in **stronger hydrogen bonds** and a **higher boiling point** **(1)**.

Marking Criteria	Marks Allocated
• The hydrogen atom capable of hydrogen bonding is attached to an oxygen atom in ethanol and a nitrogen atom in ethanamine. • Oxygen is a more electronegative element and as a result forms a stronger positive partial charge on the H atom resulting in stronger hydrogen bonds and a higher boiling point	$1-2$
Total	**2**

6. **[4 marks]**

Butanoic acid and **ethyl ethanoate** both exhibit **dispersion forces** due to the presence of electrons, and these are of a **similar strength** because both molecules have the **same molar mass** **(1)**. Both molecules are also **polar** and therefore exhibit **dipole-dipole forces** **(1)**. However, only **butanoic acid** has an ***OH* group** that can form **hydrogen bonds** with another **butanoic acid** molecule **(1)**, and as a result butanoic acid has a **higher boiling point** because it has the **strongest sum** of **intermolecular forces** **(1)**.

Marking Criteria	Marks Allocated
• Butanoic acid and ethyl ethanoate exhibit dispersion forces of a similar strength • Butanoic acid and ethyl ethanoate exhibit dipole-dipole forces of a similar strength • Only butanoic acid exhibits hydrogen bonds between its molecules • Butanoic acid has a higher boiling point because the sum of the strength of its intermolecular forces is greater	$1-4$
Total	**4**

7. **[3 marks]**

Name of Substance	Rank
Propan-1-ol	**3**
Methyl propanoate	**5**
Propanal	**4**
Propanoic Acid	**2**
Potassium Nitrate	**1**
Propane	**6**

Point to note: Despite esters and aldehydes having similar solubilities, methyl propanoate has a lower solubility than propanal because it has a higher molar mass and therefore stronger dispersion forces.

Marking Criteria	Marks Allocated
• Half mark for each correctly ranked compound	$1-3$
Total	**3**

8. **[7 marks]**

(a) **Ethanoic acid** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces and hydrogen bonding	1
Total	**1**

(b) **Water** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces and hydrogen bonding	1
Total	**1**

(c) When **ethanoic acid** is **added** to **water** they form **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces and hydrogen bonding	1
Total	**1**

(d) When ethanoic acid is added to water **enough energy** will be **released** from the **solute-solvent** attractions to **break** the existing **solute-solute** and **solvent-solvent** attractions **(1)**. As a result, **ethanoic acid** will be **soluble** in **water** **(1)**.

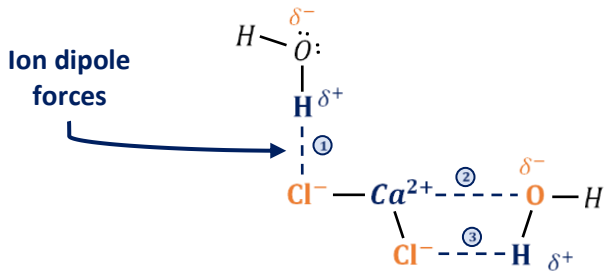
Marking Criteria	Marks Allocated
• Sufficient energy will be released from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions • Thus ethanoic acid is soluble in water	$1-2$
Total	**2**

9. **[5 marks]**

Both **butan-1-ol** and **butanamide** exhibit **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between their molecules **(1)**. Water also exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** betweens its molecules **(1)**. When butan-1-ol or butanamide are added to water they will form **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between the molecules **(1)**. These interactions **release enough energy** from the **solute-solvent** attractions to **break** the existing **solute-solute** and **solvent-solvent** attractions making them both **soluble** in water **(1)**. However, **butanamide** is **more soluble** than **butan-1-ol** because it can form **more hydrogen bonds** per molecule with water **(1)**.

Marking Criteria	Marks Allocated
• Butan-1-ol and butanamide both exhibit dispersion forces, dipole-dipole forces and hydrogen bonding between their molecules • Water exhibits dispersion forces, dipole-dipole forces and hydrogen bonding between its molecules • When added to water both compounds form dispersion forces, dipole-dipole forces and hydrogen bonding between the molecules • For both compounds sufficient energy will be from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions making them soluble • Butanamide is more soluble than butan-1-ol because it can form more hydrogen bonds per molecule with water	$1-5$
Total	**5**

10. **[5 marks]**



(2)

Calcium chloride is an **ionic compound** that forms **strong ionic bonds** between its atoms in a lattice arrangement **(1)**. When **calcium chloride** is added to **water**, it forms **strong ion-dipole forces** between the molecules **(1)**. This interaction **releases enough energy** from the **solute-solvent** attractions to **break** the existing **solute-solute** and **solvent-solvent** attractions making them both **soluble** in water **(1)**.

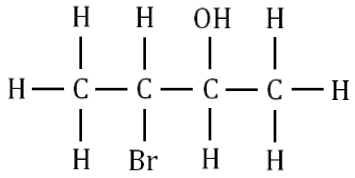
Marking Criteria	Marks Allocated
• Diagram has correct structure of calcium chloride • Diagram shows ion-dipole forces formed between calcium chloride and water	$1-2$
• Calcium chloride forms strong ionic bonds between its atoms • When added to water it forms strong ion dipole forces • Sufficient energy will be released from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions making calcium chloride soluble in water	$1-3$
Total	**5**

Problem Set 11 – Organic Functional Groups
Repetitive Questions

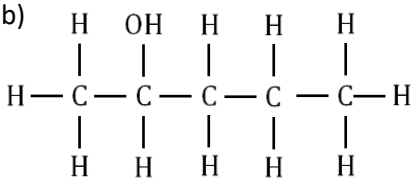
Concept 1

Functional Groups – Repetitive Questions Answers

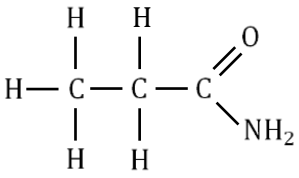
1.11 **[15 marks]**

(a) 

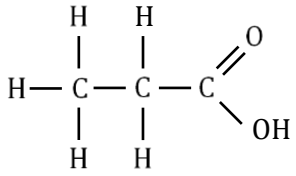
3-bromobutan-2-ol **(1)**

(b) 

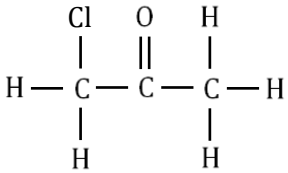
Pentan-2-ol **(2)**

(c) 

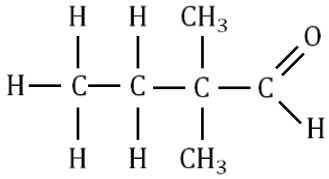
Propanamide **(1)**

(d) 

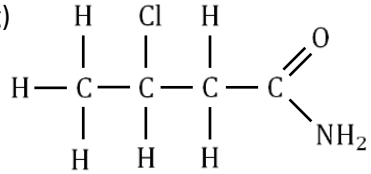
Propanoic Acid **(1)**

(e) 

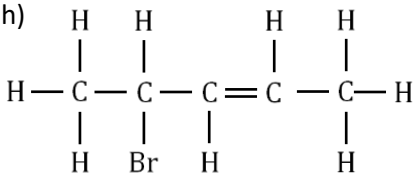
1-chloropropanone **(1)**

(f) 

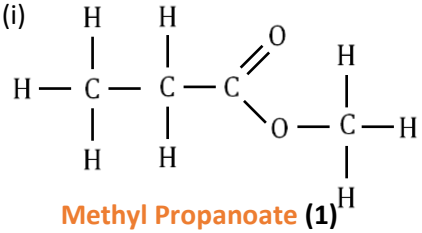
2,2-dimethyl butanoic acid **(1)**

(g) 

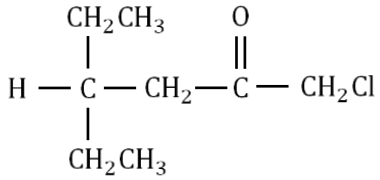
3-chlorobutanamide **(1)**

(h) 

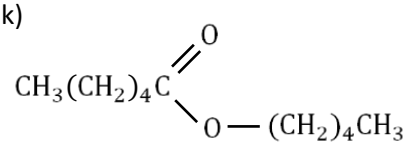
4-bromopent-2-ene **(1)**

(i) 

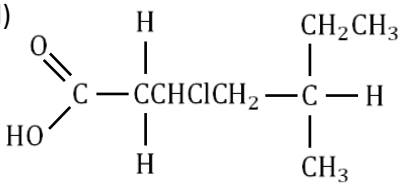
Methyl Propanoate **(1)**

(j) 

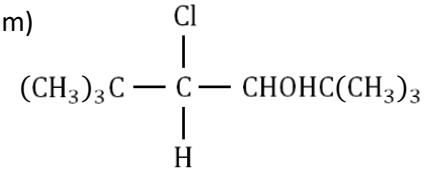
1-chloro-4-ethylhexan-2-one **(1)**

(k) 

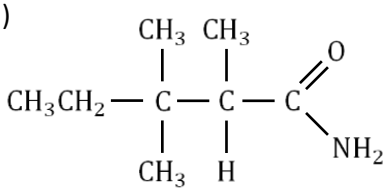
Pentyl hexanoate **(1)**

(l) 

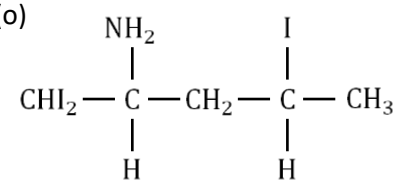
3-chloro-5-methylheptanoic acid **(1)**

(m) 

4-chloro-2,2,5,5-tetramethylhexan-3-ol **(1)**

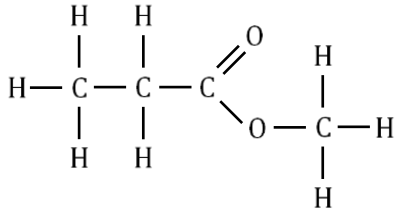
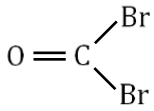
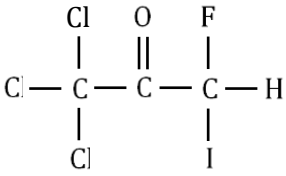
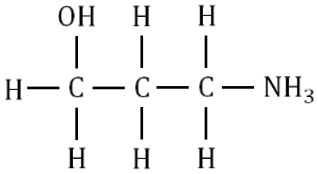
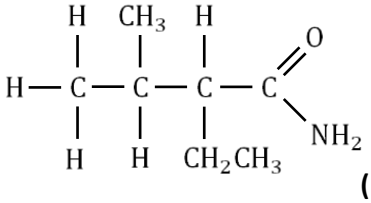
(n) 

2,3,3-trimethylpetanamide **(1)**

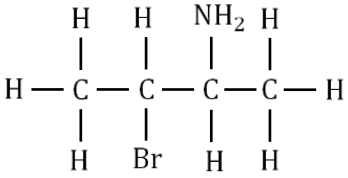
(o) 

1,1,4-triiodopentan-2-amine **(1)**

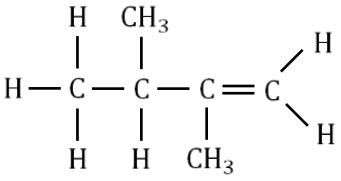
1.12 **[8 marks]**

Structural Formula	Condensed Formula	IUPAC Name of Compound
	$CH_3CH_2COOCH_3$ **(1)**	methyl propanoate **(1)**
	CBr_2O	1,1 dibromomethanal **(1)**
 **(1)**	$CHFICOCCl_3$	1,1,1-trichloro-3-fluro-3-iodo-propanone **(1)**
 **(1)**	$CH_2OHCH_2CH_2NH_3$	
 **(1)**	$CH_3CH(CH_3)CH(CH_2CH_3)CONH_2$ **(1)**	2-ethyl-3-methylbutanamide

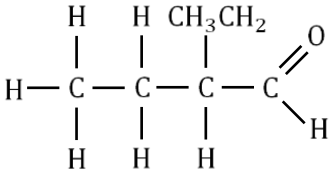
1.21 **[10 marks]**



3-bromobutan-2-amine **(1)**

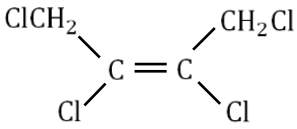


2,3-dimethylbut-1-ene **(1)**



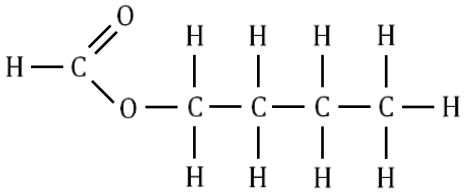
2-ethylbutanal **(1)**

(d)



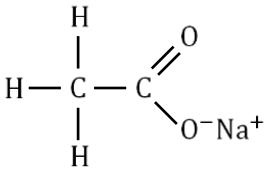
cis-1,2,3,4-tetrachlorobut-2-ene **(1)**

(e)



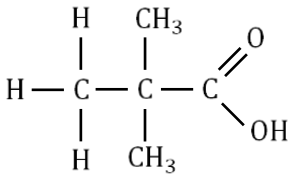
Butyl Ethanoate **(1)**

(f)



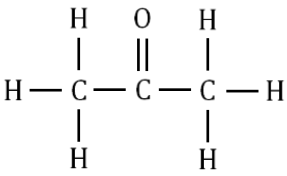
Sodium Ethanoate **(1)**

(g)



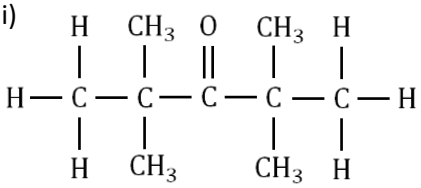
Dimethylpropanoic acid **(1)**

(h)



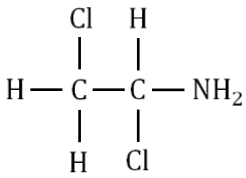
Propanone **(1)**

(i)



2,2,4,4-tetramethylpentan-3-one **(1)**

(j)



1,2-dichloroethanamine **(1)**

1.41 **[10 marks]**

(a) 1-chloro-1-fluro-methanamine **(1)**
(b) 2-bromo-1,1-dichloro-3-ethylpentane **(1)**
(c) Fluromethanamide **(1)**
(d) Ethyl Ethanoate **(1)**
(e) Methanoic Acid **(1)**
(f) Ethan-1,2-diol **(1)**

1.61 **[10 marks]**

Name of organic compound:	**Correct**	**Incorrect**
trans-2,2-difluroethene		X
Reason(s) if naming is incorrect: There is **no cis-trans isomerism** since the **fluorine atoms** are on the **same side** of the double bond, meaning the molecule will always be the same irrespective of the rotation. The numbering of the fluorine atoms should also be 1,1 not 2,2 **(1)**. Thus correct name should be **1,1-difluoroethene**. **(1)**		
4,7-dichloroheptan-2-ol	✔ **(1)**	
Reason(s) if naming is incorrect:		

1-ethyl-2-fluoropentane		X
Reason(s) if naming is incorrect: Having an ethyl group on **carbon 1** would result in the chain being extended by two carbons. The correct name should be **4-fluroheptane**. **(1)**		
2-methylhex-4-ene		X
Reason(s) if naming is incorrect: The **lowest numbering** should be **prioritised** for the **functional group** **(1)**. The correct name would be **4-methyl hex-2-ene**. **(1)**		
1,1-difluromethanamide		X
Reason(s) if naming is incorrect: There would be **more** than **four bonds** attached to carbon one meaning it is **not possible**. **(1)** This compound **does not have a correct name** as it doesn't exist **(1)**		
2-methyl-3,3-dichlorobutanal		X
Reason(s) if naming is incorrect: The **substituents** must go in **alphabetical order**. The correct name should therefore be **3,3-dichloro-2-methylbutanal**. **(1)**		

Isomerism: 1.81, 1.82, 1.91, 1.92

1.81 **[6 marks]**

(a) $CHFCHF$ **can exhibit** cis-trans isomerism between the fluorine groups on either side of the double bond **(1)**.

(b) CH_3CHCH_2 **cannot exhibit** cis-trans isomerism since there are **two hydrogen atoms** on **one side** of the double bond that will be the **same irrespective** of their rotation. **(1)**

(c) $CH_2ClCHCHCH_2Cl$ **can exhibit** cis-trans isomerism between the CH_2Cl groups on either side of the double bond **(1)**.

(d) $CH_2BrCH_2CH_2CH_2Br$ **cannot exhibit** cis-trans isomerism since there is **no double bond** **(1)**.

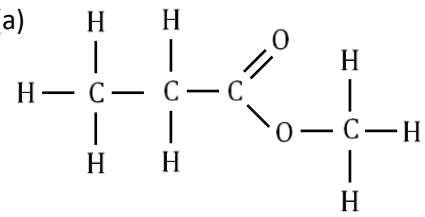
(e) $CH_3CH(CH_3)CH(CH_3)CH_2CH_3$ **cannot exhibit** cis-trans isomerism since there is **no double bond** **(1)**.

(f) $CHFCHBr$ **can exhibit** cis-trans isomerism between the fluorine and bromine atoms on either side of the double bond (it doesn't matter that they aren't the same group) **(1)**.

Marking Criteria	Marks Allocated
• Correctly explains whether cis-trans isomerism can or cannot be exhibited and provides an appropriate reason	$1-6$
Total	**6**

1.82 **[5 marks]**

(a)



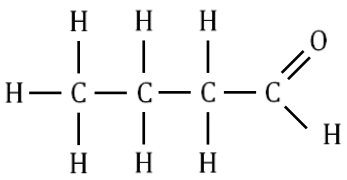
Methyl Propanoate

Butanoic Acid

Propyl Methanoate

Butanal

(b)



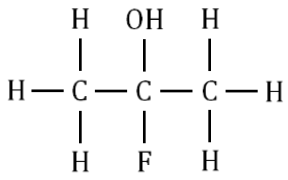
Butanal

Butanone

Butanol

Methyl Propanoate

(c)



2-fluoropropan-2-ol

3-fluropropan-1-ol

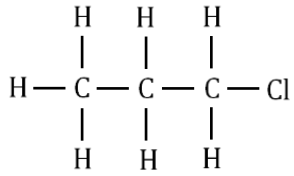
2-fluropropanal

1-fluoropropan-2-ol

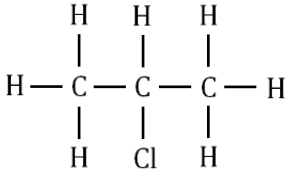
1.91 **[11 marks]**

(a) C_3H_7Cl has the **two isomers** shown below.

Isomers of C_3H_7Cl



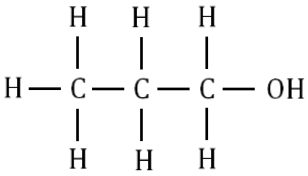
1-chloropropane **(1)**



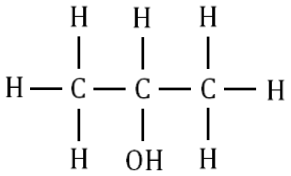
2-chloropropane **(1)**

(b) C_3H_8O has the **two isomers** shown below.

Isomers of C_3H_8O



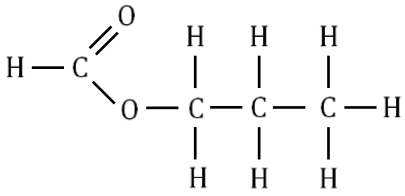
Propan-1-ol **(1)**



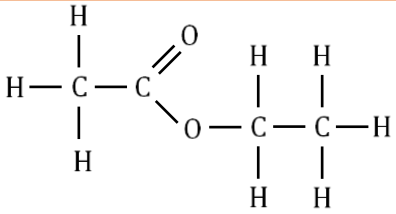
Propan-2-ol **(1)**

(c) $C_4H_8O_2$ has the **three isomers** shown below.

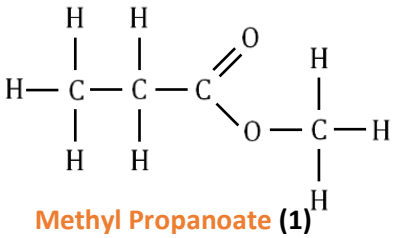
Isomers of $C_4H_8O_2$



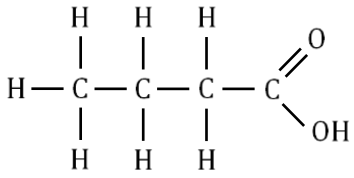
Propyl Methanoate **(1)**



Ethyl Ethanoate **(1)**



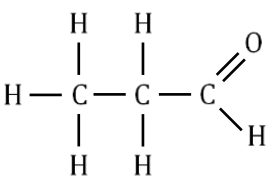
Methyl Propanoate **(1)**



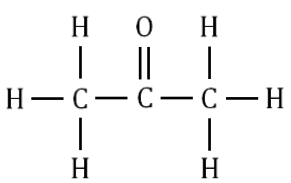
Butanoic acid **(1)**

(d) C_3H_6O has the **two isomers** shown below.

Isomers of C_3H_6O

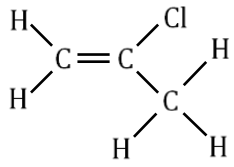
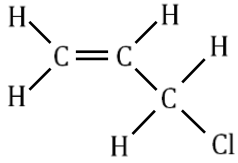
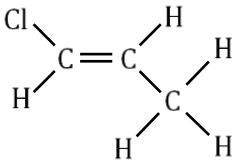
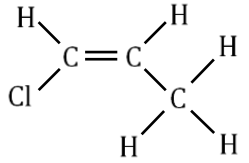


Propanal **(1)**



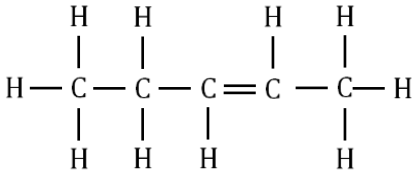
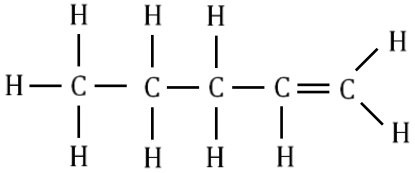
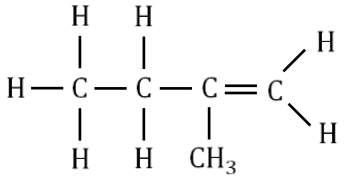
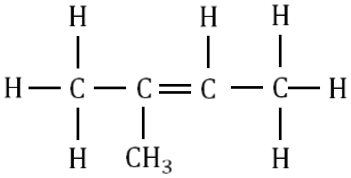
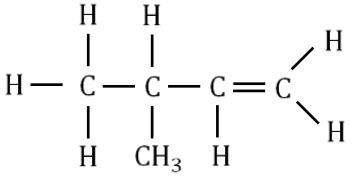
Propanone **(1)**

(e) C_4H_5Cl has the **two isomers** shown below.

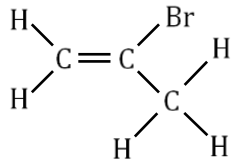
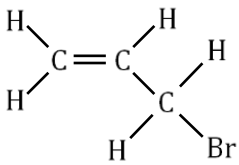
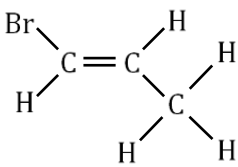
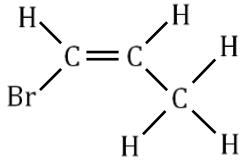
Isomers of C_3H_5Cl		
 2-chloropropene **(1)**	 3-chloropropene **(1)**	 trans-1-chloropropene **(1)**
 cis-1-chloropropene **(1)**		

1.92 **[21 marks]**

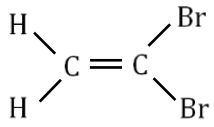
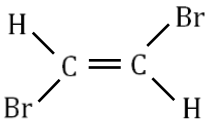
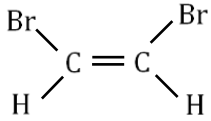
(a) C_5H_{10} has the **five isomers** shown below.

Isomers of C_5H_{10}		
 Pent-2-ene **(1)**	 Pent-1-ene **(1)**	 2-methylbut-1-ene **(1)**
 2-methylbut-2-ene **(1)**	 3-methylbut-1-ene **(1)**	

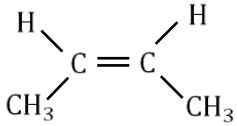
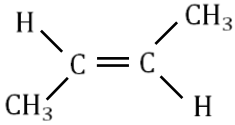
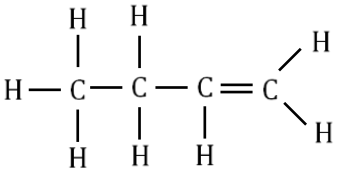
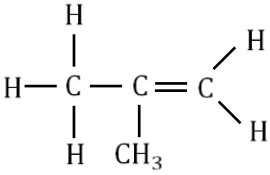
(b) C_3H_5Br has the **four isomers** shown below.

Isomers of C_3H_5Br		
 2-bromopropene **(1)**	 3-bromopropene **(1)**	 trans-1-bromopropene **(1)**
 cis-1-bromopropene **(1)**		

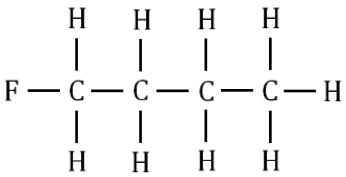
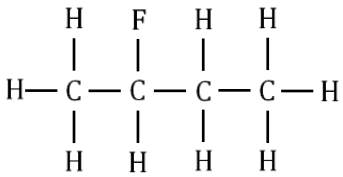
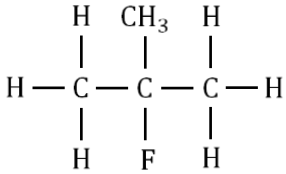
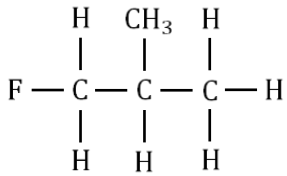
(c) $C_2H_2Br_2$ has the **three isomers** shown below.

Isomers of $C_2H_2Br_2$		
		
1,1-dibromoethene **(1)**	trans-1,2-dibromoethene **(1)**	cis-1,2-dibromoethene **(1)**

(d) C_4H_8 has the **four isomers** shown below.

Isomers of C_4H_8		
		
cis-but-2-ene **(1)**	trans-but-2-ene **(1)**	But-1-ene **(1)**
		
2-methylpropene **(1)**		

(e) C_4H_9F has the **four isomers** shown below.

Isomers of C_4H_9F		
		
1-flurobutane **(1)**	2-flurobutane **(1)**	2-fluro-2-methylpropane **(1)**
		
1-fluro-2-methylbutane **(1)**		

Concept 2

Properties of Functional Groups – Repetitive Questions Answers

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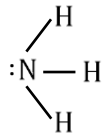
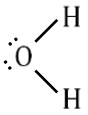
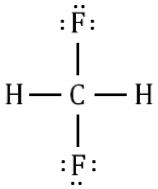
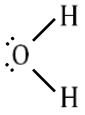
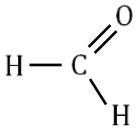
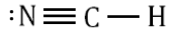
Intermolecular Forces: Qs 2.1, 2.11, 2.21, 2.22

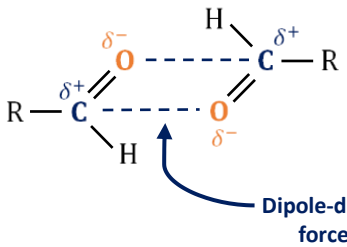
2.1 **[8 marks]**

Substance 1	Substance 2	Types of Intermolecular Forces Exhibited
		Ion-Dipole Forces Hydrogen Bonds Dipole-Dipole Forces Dispersion Forces
		Ion-Dipole Forces Hydrogen Bonds Dipole-Dipole Forces Dispersion Forces
		Ion-Dipole Forces Hydrogen Bonds Dipole-Dipole Forces Dispersion Forces

Marking Criteria	Marks Allocated
• Correct intermolecular forces circled	1 – 4
Total	**4**

2.11 **[8 marks]**

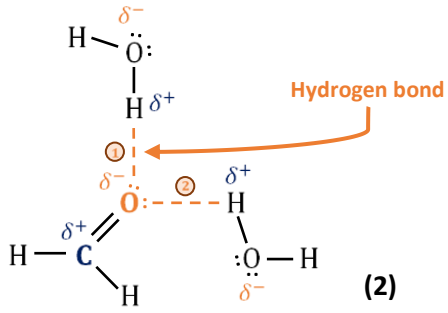
(a)



(2)

Marking Criteria	Marks Allocated
• Correct structure of molecules • Appropriate dipole-dipole forces drawn	1 – 2
Total	**2**

(b)



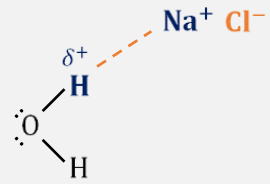
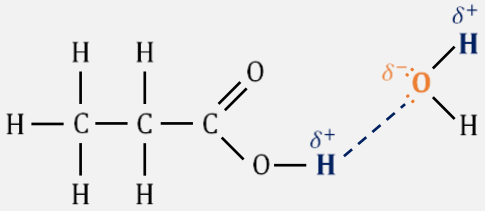
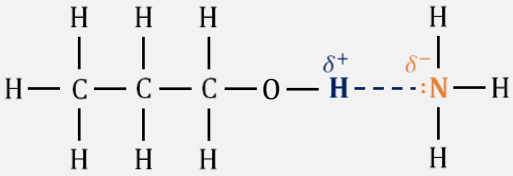
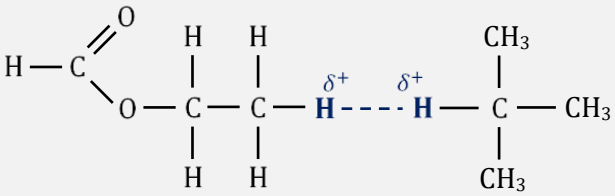
(2)

Marking Criteria	Marks Allocated
• Correct structure of molecules • Appropriate hydrogen bonds drawn	1 – 2
Total	**2**

(c) Methanal is a polar molecule that exhibits **dispersion forces** and **dipole forces** between its molecules **(1)**. **Water** also exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**. **Hexane** is a non-polar molecule that exhibits **moderately strong dispersion forces** between its molecules **(1)**. When **methanal** is added to **water** it forms **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** and these interactions **release enough energy** to break the solute-solute and solvent-solvent attractions, thus making **methanal soluble** in **water** **(1)**. However, when **methanal** is added to **hexane** it only forms **weak dispersion forces** which **do not release enough energy** to break the **solute-solute** and **solvent-solvent** attractions, thus making methanal **insoluble** in **hexane** **(1)**.

Marking Criteria	Marks Allocated
• Methanal exhibits dispersion forces and dipole-dipole forces between its molecules • Water exhibits dispersion forces, dipole-dipole forces and hydrogen bonding between its molecules • Hexane exhibits moderately strong dispersion forces • Methanal added to water forms dispersion forces, dipole-dipole forces and hydrogen bonding which releases enough to break the solute-solute and solvent-solvent attractions, making it soluble. • Methanal added to hexane only forms weak dispersion forces which does not release enough energy to break the solute-solute and solvent-solvent attractions, making it insoluble.	1 – 5
Total	**5**

2.21 **[6 marks]**

Hydrogen bond diagram	Correct (✔)	Incorrect (X)
		X **(1)**
Reason(s) if naming is incorrect: This is an **ion-dipole force interaction** not a hydrogen bond **(1)**.		
	✔ **(1)**	
Reason(s) if naming is incorrect:		
	✔ **(1)**	
Reason(s) if naming is incorrect:		
		X **(1)**
Reason(s) if naming is incorrect: A ***H* atom** attached to a carbon atom **cannot form** a hydrogen bond with another ***H* atom** . It has to be between a **lone pair** of electrons and a ***H* atom** attached to a ***O*, *N* or *F* atom (1)**		

Marking Criteria	Marks Allocated
• Correctly states correct or incorrect	1 – 4
• Provides appropriate reasoning for incorrect hydrogen bonds	1 – 2
Total	**6**

2.22 **[3 marks]**

Ion dipole forces is the attraction between the **partial charge** of a **polar molecule** and the **charge** of an **ion (1)**, whereas a **hydrogen bond** is the attraction between a **lone pair of electrons** and the **strong positive partial charge** of a ***H* atom** attached to a ***O*, *N* or *F* atom (1)**. The **charge** of an **ion** is **much larger** than the **partial charge** of the ***H* atom** and thus **ion-dipole forces** are **much stronger** than hydrogen bonding forces **(1)**.

Marking Criteria	Marks Allocated
• Compares how ion-dipole forces are formed to hydrogen bonds	1 – 2
• The charge of an ion is much larger than a partial charge, so the attraction is significantly stronger for ion-dipole forces	1
Total	**3**

Physical Properties of Functional Groups: Qs 2.31, 2.41, 2.42, 2.43, 2.44, 2.61, 2.71, 2.81, 2.82, 2.83, 2.91, 2.92, 2.93, 2.94

2.31 **[3 marks]**

Name of Substance	Rank
Butane	1
Butanoic Acid	5
Methylpropan-2-ol	3
Butanone	2
Butanamide	6
Butan-2-ol	4

Marking Criteria	Marks Allocated
• Half mark for each correctly ranked compound	$1-3$
Total	**3**

2.41 **[3 marks]**

Both **propan-1-ol** and **propan-2-ol** exhibit **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between their molecules **(1)**. Despite having the same molar mass and intermolecular forces, **propan-2-ol** has **branching** that makes its molecules **pack less effectively** than propan-1-ol molecules **(1)**. As a result, **propan-2-ol** has a **smaller surface area** for **intermolecular interaction** and therefore has **weaker intermolecular forces** and a **lower boiling point** than propan-1-ol **(1)**.

Marking Criteria	Marks Allocated
• Propan-1-ol and propan-2-ol exhibit dispersion forces, dipole-dipole forces and hydrogen bonding between their molecules • Propan-2-ol has branching that makes its molecules pack less effectively • Propan-2-ol has a reduced surface area for intermolecular interaction and therefore a lower boiling point	$1-3$
Total	**3**

2.42 **[3 marks]**

Octan-1-ol and **octanamide** both exhibit the **same intermolecular forces**: dispersion forces, dipole-dipole forces and hydrogen bonding **(1)**. **Octanamide** has a **higher boiling point** because it is capable of forming **more hydrogen bonds** per molecule than octan-1-ol **(1)**. As a result the **sum** of the **strength** of **intermolecular forces** for **octanamide** is **larger**, thus giving it a **higher boiling point (1)**

Marking Criteria	Marks Allocated
• Octan-1-ol and octanamide exhibit dispersion forces, dipole-dipole forces and hydrogen bonding between their molecules • Octanamide is capable of forming more hydrogen bonds per molecule than octan-1-ol • The sum of intermolecular forces is greater for octanamide giving it a higher boiling point	$1-3$
Total	**3**

2.43 **[5 marks]**

Pentane, **pentanone** and **pentanoic acid** all exhibit **dispersion forces** due to the presence of electrons, and these are of a **similar strength** as the molecules all have similar molar masses **(1)**. Both **pentanone** and **pentanoic acid** are **polar** and therefore exhibit **dipole-dipole forces**, giving them a higher boiling point than **pentane** **(1)**. Only **pentanoic acid** has an OH **group** that can form **hydrogen bonds** with the lone pair electrons on another pentanoic acid molecule **(1)**. As a result, **pentanoic acid** has the **highest boiling point** because it has the **strongest sum** of **intermolecular forces** **(1)**. Thus the **order** of boiling points from **lowest** to **highest** is **pentane**, **pentanone** and then **pentanoic acid** **(1)**.

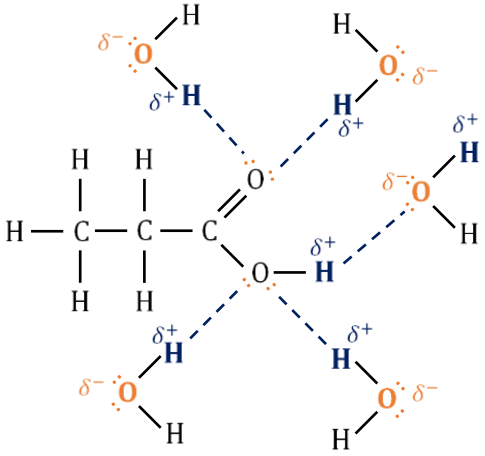
Marking Criteria	Marks Allocated
• Pentane, pentanone and pentanoic acid all exhibit dispersion forces • Pentanone and pentanoic acid exhibit dipole-dipole forces, giving them higher boiling points than pentane • Only pentaoic acid exhibits hydrogen bonding • The sum of intermolecular forces is greatest for pentanoic acid, giving it the highest boiling point • Order of boiling points from lowest to highest is: pentane, pentanone and then pentanoic acid	$1-5$
Total	**5**

2.44 **[5 marks]**

Ethanal, **methyl butanoate** and **butan-2-ol** all exhibit dispersion forces with butan-2-ol and methyl butanoate being slightly stronger because they have larger molar masses **(1)**. **Ethanal**, **methyl butanoate** and **butan-2-ol** are all **polar** and therefore exhibit **dipole-dipole forces**. Only **butan-2-ol** has an OH **group** that can form **hydrogen bonds** with the lone pair electrons on another butan-2-ol molecule **(1)**. As a result, **butan-2-ol** has the **highest boiling point** because it has the **strongest sum** of **intermolecular forces** **(1)**. Furthermore, methyl butanoate has a higher boiling point than ethanal because it has stronger dispersion forces from having a higher molar mass **(1)**. Thus the final order of boiling points from **lowest** to **highest** is **ethanal**, **methyl butanoate** and then **butan-2-ol** **(1)**.

Marking Criteria	Marks Allocated
• Ethanal, methyl butanoate and butan-2-ol all exhibit dispersion forces • All exhibit dipole-dipole forces, but methyl butanoate has a higher boiling point than ethanal because it has stronger dispersion forces from a larger molar mass • Only butan-2-ol acid exhibits hydrogen bonding • The sum of intermolecular forces is greatest for butan-2-ol, giving it the highest boiling point • Order of boiling points from lowest to highest is: ethanal, methyl butanoate and then butan-2-ol	$1-5$
Total	**5**

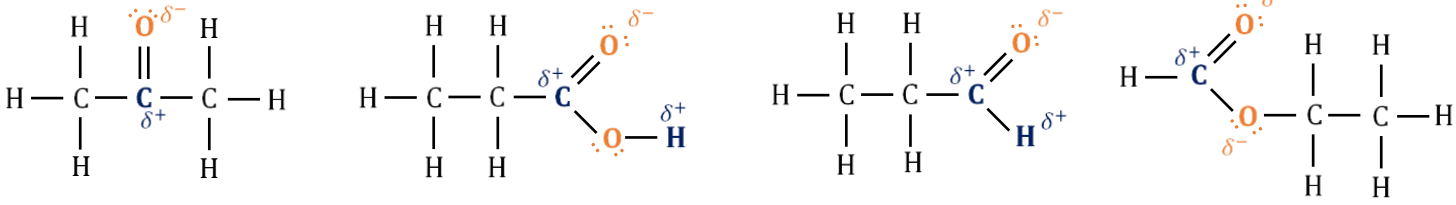
2.61 **[3 marks]**



Marking Criteria	Marks Allocated
• Shows all possible hydrogen bonds • Shows all lone pair electrons • Labels all partial charges	1 – 3
Total	**3**

2.71 **[6 marks]**

(a)



Propanone **Propanoic acid** **Propanal** **Ethyl methanoate**

Marking Criteria	Marks Allocated
• Draws compound structure with all lone pair electrons and partial charges	1 – 4
Total	**4**

(b)

Name of Substance	Rank
Propanone	4
Ethyl Methanoate	3
Propanal	1
Propanoic Acid	2

Marking Criteria	Marks Allocated
• Half mark for each correctly ranked compound	1 – 2
Total	**2**

Points to note: Ethyl methanoate is more soluble than propanone because it has more lone pair electrons to form hydrogen bonds with water

2.81 **[5 marks]**

(e) **Pentan-1-ol** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces and hydrogen bonding	1
Total	**1**

(f) **Ethene** exhibits **weak dispersion forces** between its molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces	1
Total	**1**

(g) When **pentan-1-ol** is **added** to **ethene** they form **weak dispersion forces** between molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces	1
Total	**1**

(h) When **pentan-1-ol** is added to **water not enough energy** is released from the **weak solute-solvent** attractions to break the **strong solute-solute** attractions **(1)**. As a result, **pentan-1-ol** will **not** be **miscible** in **ethene** **(1)**.

Marking Criteria	Marks Allocated
• Not enough energy will be released from the solute-solvent attractions to break the solute-solute attractions • Pentan-1-ol will not be miscible in ethene	$1-2$
Total	**2**

2.82 **[5 marks]**

(a) **Butanamide** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces and hydrogen bonding	1
Total	**1**

(b) **Water** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces and hydrogen bonding	1
Total	**1**

(c) When **butanamide** is **added** to **water** they form **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces and hydrogen bonding	1
Total	**1**

(d) When **butanamide** is added to **sufficient energy** is released from the **solute-solvent** attractions to break the **solute-solute** and **solvent-solvent** attractions **(1)**. As a result, **butanamide** will be **soluble** in **water** **(1)**.

Marking Criteria	Marks Allocated

• Not enough energy will be released from the solute-solvent attractions to break the solute-solute attractions • Pentan-1-ol will not be miscible in ethene	$1-2$
Total	**2**

2.83 **[5 marks]**

Pentane exhibits **moderately strong dispersion forces** between its molecules **(1)**. **Methanol** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**. When **pentane** is added to **methanol** they will form **weak dispersion forces** between the molecules **(1)**. These interactions **will not release enough energy** from the **solute-solvent** attractions to **break** the existing **solute-solute** and **solvent-solvent** attractions **(1)**. As a result, **pentane** is **not miscible** with **methanol** **(1)**.

Marking Criteria	Marks Allocated
• Pentane exhibits moderately strong dispersion forces between its molecules • Methanol exhibits dispersion forces, dipole dipole forces and hydrogen bonding between its molecules • When the two compounds are added together they form weak dispersion forces • Not enough energy will be released from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions • Pentane is not miscible in methanol	$1-5$
Total	**5**

2.91 **[5 marks]**

(a) **Octane** is **soluble** in **heptane** because they both exhibit **strong dispersion forces** and form **strong dispersion forces** that **release enough energy** to break the **solute-solute** and **solvent-solvent** attractions **(1)**. **Octane** is **insoluble** in water because the **weak dispersion forces** formed **cannot release enough energy** to break the **strong hydrogen bonds** between water molecules **(1)**.

Marking Criteria	Marks Allocated
• Soluble in heptane because they form strong dispersion forces that release enough energy to break the solute-solute and solvent-solvent attractions • Insoluble in water because the weak dispersion forces formed don't release enough energy to break strong hydrogen bonds between water molecules	$1-2$
Total	**2**

(b) **Methanal** is **soluble** in water because they form **dispersion forces**, **dipole-dipole forces** and **strong hydrogen bonds** that **release enough energy** to break the **solute-solute** and **solvent-solvent** attractions **(1)**. **Methanal** is insoluble in pentane because weak dispersion forces formed **cannot release enough energy** to break the **solute-solute** and **solvent-solvent** attractions **(1)**.

Marking Criteria	Marks Allocated
• Soluble in heptane because they form dispersion forces, dipole-dipole forces and strong hydrogen bonds that release enough energy to break the solute-solute and solvent-solvent attractions	$1-2$

• Insoluble in pentane because the weak dispersion forces formed don't release enough energy to break solute-solute and solvent-solvent attractions	
Total	**2**

(c) **Propan-1-ol** is **soluble** with both **propanoic acid** and **propanone** because they form **dispersion forces**, **dipole-dipole forces** and **hydrogen bonds** that **release enough energy** to break the **solute-solute** and **solvent-solvent** attractions **(1)**. However, propan-1-ol is **more soluble** in **propanoic acid** because it forms **more hydrogen bonds** than when it is added to **propanone** **(1)**.

Marking Criteria	Marks Allocated
• Soluble in both because they form dispersion forces, dipole-dipole forces and hydrogen bonds that release enough energy to break the solute-solute and solvent-solvent attractions • More soluble in propanoic acid because more hydrogen bonds are formed	$1-2$
Total	**2**

2.92 **[5 marks]**

Both **water** and **ethanal** exhibit **dispersion forces** and **dipole-dipole forces** between their molecules **(1)**. Water also exhibits hydrogen bonding between its molecules. **Ethanamine** exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**. When **water** or **ethanal** are added to **ethanamine** they will form **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between the molecules **(1)**. These interactions **release enough energy** from the **solute-solvent** attractions to **break** the existing **solute-solute** and **solvent-solvent** attractions making them both **soluble** in ethanamine **(1)**. However, **water** is **more soluble** than **ethanal** because it can form **more hydrogen bonds** per molecule with ethamine **(1)**.

Marking Criteria	Marks Allocated
• Water and ethanal both exhibit dispersion forces and dipole-dipole forces between their molecules. Water also exhibits hydrogen bonding • Ethanamine exhibits dispersion forces, dipole-dipole forces and hydrogen bonding between its molecules • When added to ethanamine both compounds form dispersion forces, dipole-dipole forces and hydrogen bonding between the molecules • For both compounds sufficient energy will be from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions making them soluble • Water is more soluble than ethanal because it can form more hydrogen bonds per molecule with ethanamine	$1-5$
Total	**5**

2.93 **[5 marks]**

Both **hept-2-ene** and **heptanol** exhibit **moderately strong dispersion forces** between their molecules **(1)**. Heptanol also exhibits dipole-dipole forces and hydrogen bonding between its molecules. **Octane** exhibits **moderately strong dispersion forces** between its molecules **(1)**. When **hept-2-ene** or heptanol are added to **ethanamine** they will form **moderately strong dispersion forces** between the molecules **(1)**. For **hept-2-ene** these interactions **release enough energy** from the **solute-solvent** attractions to **break** the existing **solute-solute** and **solvent-solvent** attractions making it **soluble** in **octane**. However **heptanol** is **insoluble** because this energy release is **not sufficient** to break its **strong solute-solute** attractions **(1)**.

Marking Criteria	Marks Allocated
• Hept-2-ene and heptanol both exhibit dispersion forces between their molecules. Heptanol also exhibits dipole-dipole forces and hydrogen bonding • Octane exhibits dispersion forces between its molecules • When added to octane both compounds form dispersion forces between the molecules • For hept-2-ene sufficient energy will be from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions making it soluble • Heptanol is insoluble because the energy release is not sufficient to break the solute-solute attractions.	$1-5$
Total	**5**

2.94 **[5 marks]**

Both **butanoic acid** and **butanamide** exhibit **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between their molecules **(1)**. Water also exhibits **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between its molecules **(1)**. When butanoic acid or butanamide are added to water they will form **dispersion forces**, **dipole-dipole forces** and **hydrogen bonding** between the molecules **(1)**. These interactions **release enough energy** from the **solute-solvent** attractions to **break** the existing **solute-solute** and **solvent-solvent** attractions making them both **soluble** in water **(1)**. However, **butanamide** is **more soluble** than **butanoic acid** because it can form **more hydrogen bonds** per molecule with water **(1)**.

Marking Criteria	Marks Allocated
• Butanoic acid and butanamide both exhibit dispersion forces, dipole-dipole forces and hydrogen bonding between their molecules • Water exhibits dispersion forces, dipole-dipole forces and hydrogen bonding between its molecules • When added to water both compounds form dispersion forces, dipole-dipole forces and hydrogen bonding between the molecules • For both compounds sufficient energy will be from the solute-solvent attractions to break the solute-solute and solvent-solvent attractions making them soluble • Butanamide is more soluble than butanoic acid because it can form more hydrogen bonds per molecule with water	$1-5$
Total	**5**

Problem Set 12 – Organic Reactions and Empirical Formula Progressive Questions

Concept 1

Functional Group Reactions – Progressive Questions Answers

Combustion Reactions: Q1

1. **[4 marks]**

(a) $C_4H_{10}O_{(aq)} + 2O_{2\,(g)} \rightarrow 4C_{(s)} + 5H_2O_{(g)}$ **(1)**

Marking Criteria	Marks Allocated
• $C_4H_{10}O_{(aq)} + 2O_{2\,(g)} \rightarrow 4C_{(s)} + 5H_2O_{(g)}$	1
Total	**1**

(b) $C_4H_{10}O_{(aq)} + 6O_{2\,(g)} \rightarrow 4CO_{2\,(g)} + 5H_2O_{(g)}$ **(1)**

Marking Criteria	Marks Allocated
• $C_4H_{10}O_{(aq)} + 6O_{2\,(g)} \rightarrow 4CO_{2\,(g)} + 5H_2O_{(g)}$	1
Total	**1**

(c)

Reaction 1: $\underset{(-2)\ (+1)\ (-2)}{C_4H_{10}O_{(aq)}} + \underset{(0)}{2O_{2\,(g)}} \rightarrow \underset{(0)}{4C_{(s)}} + \underset{(+1)(-2)}{5H_2O_{(g)}}$ **(1)**

Oxidised $C_4H_{10}O$ **Reduced** O_2 **(1)**

Reaction 2: $\underset{(-2)\ (+1)\ (-2)}{C_4H_{10}O_{(aq)}} + \underset{(0)}{6O_{2\,(g)}} \rightarrow \underset{(+4)(-2)}{4CO_{2\,(g)}} + \underset{(+1)(-2)}{5H_2O_{(g)}}$ **(1)**

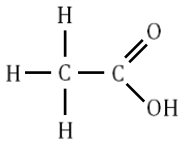
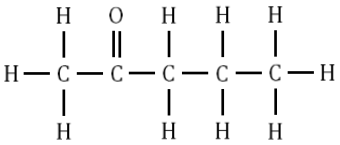
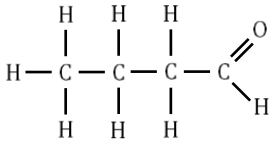
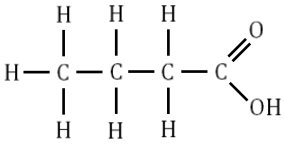
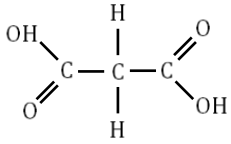
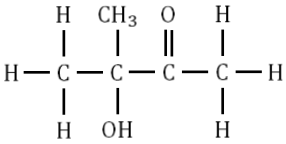
Oxidised $C_4H_{10}O$ **Reduced** O_2 **(1)**

Marking Criteria	Marks Allocated
• States the correct oxidation numbers for each reaction	1 – 2
• States the correct oxidised and reduced species for each reaction	1 – 2
Total	**4**

Oxidation of Alcohols: Q2, Q3, Q4

2. **[16 marks]**

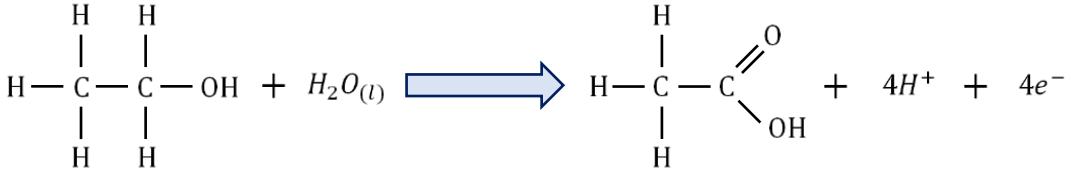
(a)

Alcohol	Oxidant	Reaction?	Structural formula of product
(i) CH_3CH_2OH	MnO_4^-/H^+	**Yes (1)**	
(ii) Pentan-2-ol	$Cr_2O_7^{2-}/H^+$	**Yes (1)**	
(iii) 	$Cr_2O_7^{2-}/H^+$	**Yes (1)**	
(iv) Methylpropan-2-ol	MnO_4^-/H^+	**No (1)**	
(v) $CH_2OHCH_2CH_2OH$	MnO_4^-/H^+	**Yes (1)**	
(vi) $CH_3C(CH_3)OHCHOHCH_3$	$Cr_2O_7^{2-}/H^+$	**Yes (1)**	

Marking Criteria	Marks Allocated
• Determines if oxidation is/isn't possible and draws product diagram	1 – 6
Total	**6**

(b)

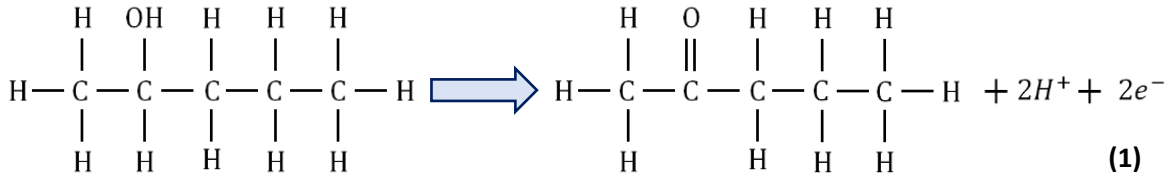
(i)

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $MnO_{4\,(aq)}^- + 8H_{(aq)}^+ + 5e^- \rightarrow Mn_{(aq)}^{2+} + 4H_2O_{(l)}$ **(1)**

$$5CH_3CH_2OH_{(aq)} + 4MnO_{4\,(aq)}^- + 12H_{(aq)}^+ \rightarrow 5CH_3COOH_{(aq)} + 4Mn_{(aq)}^{2+} + 11H_2O_{(l)}$$ **(1)**

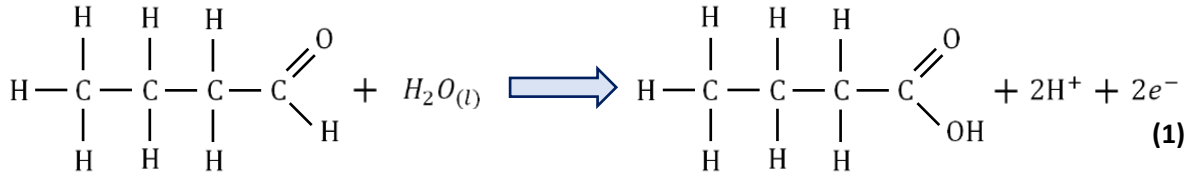
(ii)

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $Cr_2O_{7\,(aq)}^{2-} + 14H_{(aq)}^{+} + 6e^{-} \rightarrow 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$ **(1)**

$$3C_5H_{12}O_{(aq)} + Cr_2O_{7\,(aq)}^{2-} + 8H_{(aq)}^{+} \rightarrow 3C_5H_{10}O_{(aq)} + 2Cr_{(aq)}^{3+} + 7H_2O_{(l)} \quad \textbf{(1)}$$

(iii)

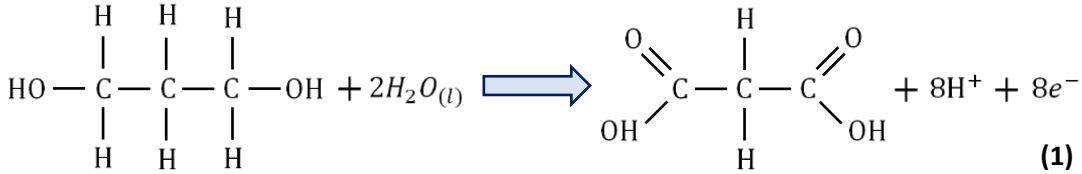
Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $Cr_2O_{7\,(aq)}^{2-} + 14H_{(aq)}^{+} + 6e^{-} \rightarrow 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$ **(1)**

$$3C_4H_8O_{(aq)} + Cr_2O_{7\,(aq)}^{2-} + 8H_{(aq)}^{+} \rightarrow 3C_4H_8O_{2\,(aq)} + 2Cr_{(aq)}^{3+} + 4H_2O_{(l)} \quad \textbf{(1)}$$

(iv) **No reaction**

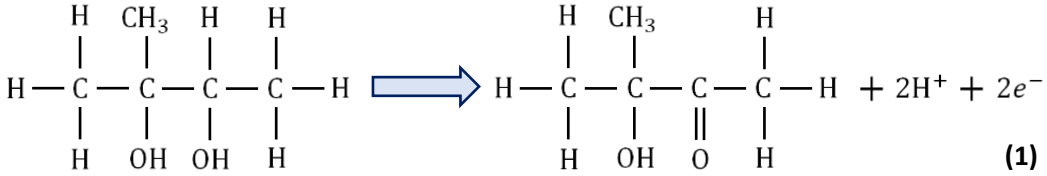
(v)

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $MnO_{4\,(aq)}^{-} + 8H_{(aq)}^{+} + 5e^{-} \rightarrow Mn_{(aq)}^{2+} + 4H_2O_{(l)}$ **(1)**

$$5C_3H_8O_{(aq)} + 8MnO_{4\,(aq)}^{-} + 12H_{(aq)}^{+} \rightarrow 5C_3H_4O_{4\,(aq)} + 8Mn_{(aq)}^{2+} + 22H_2O_{(l)} \quad \textbf{(1)}$$

(vi)

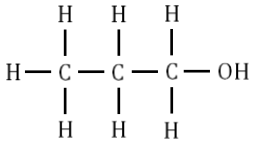
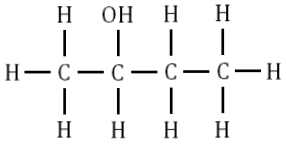
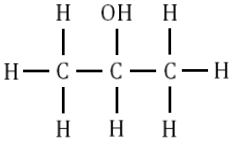
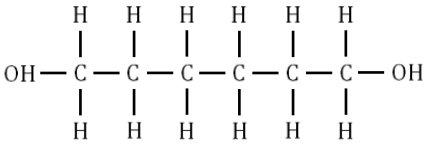
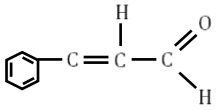
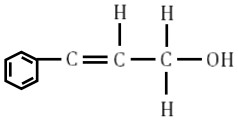
Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $Cr_2O_{7\,(aq)}^{2-} + 14H_{(aq)}^{+} + 6e^{-} \rightarrow 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$ **(1)**

$$3C_5H_{12}O_{2\,(aq)} + Cr_2O_{7\,(aq)}^{2-} + 8H_{(aq)}^{+} \rightarrow 3C_5H_{10}O_{2\,(aq)} + 2Cr_{(aq)}^{3+} + 7H_2O_{(l)} \quad \textbf{(1)}$$

3. **[15 marks]**

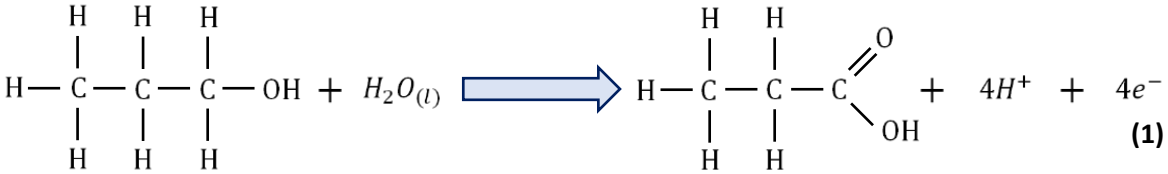
(a)

Molecular formula	Product	Reactant Isomer required
(i) C_3H_8O	Propanoic acid	 **Propan-1-ol (1)**
(ii) $C_4H_{10}O$	Butanone	 **Butan-2-ol (1)**
(iii) C_3H_8O	Propanone (acetone)	 **Propan-2-ol (1)**
(iv) $C_6H_{14}O_2$	Hexan-1,6-dial	 **Hexan-1,6-diol (1)**
(v) C_9H_8O	 Cinnamaldehyde	 **(1)**

Marking Criteria	Marks Allocated
• Draws correct structure and provides correct name	$1-5$
Total	**5**

(b)

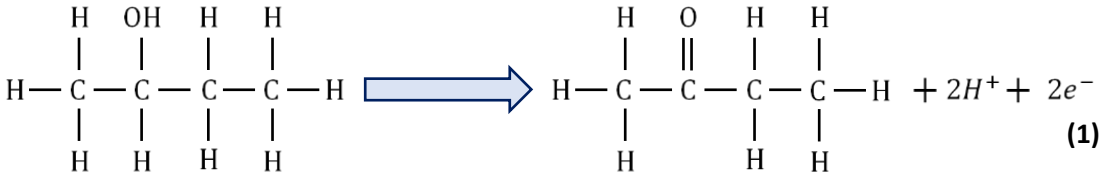
(i)

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $MnO^-_{4\,(aq)} + 8H^+_{(aq)} + 5e^- \rightarrow Mn^{2+}_{(aq)} + 4H_2O_{(l)}$ **(1)**

$$5C_3H_8O_{(aq)} + 4MnO^-_{4\,(aq)} + 12H^+_{(aq)} \rightarrow 5C_3H_6O_{2\,(aq)} + 4Mn^{2+}_{(aq)} + 11H_2O_{(l)}$$ **(1)**

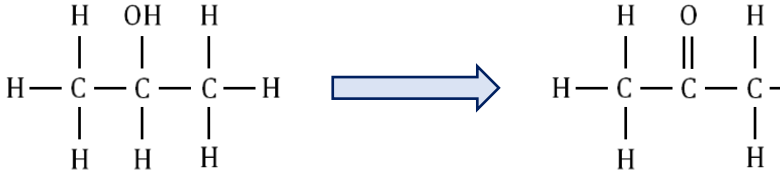
(ii)

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $Cr_2O_{7\,(aq)}^{2-} + 14H_{(aq)}^{+} + 6e^- \rightarrow 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$ **(1)**

$$3C_4H_{10}O_{(aq)} + Cr_2O_{7\,(aq)}^{2-} + 8H_{(aq)}^{+} \rightarrow 3C_4H_8O_{(aq)} + 2Cr_{(aq)}^{3+} + 7H_2O_{(l)} \quad \textbf{(1)}$$

(iii)

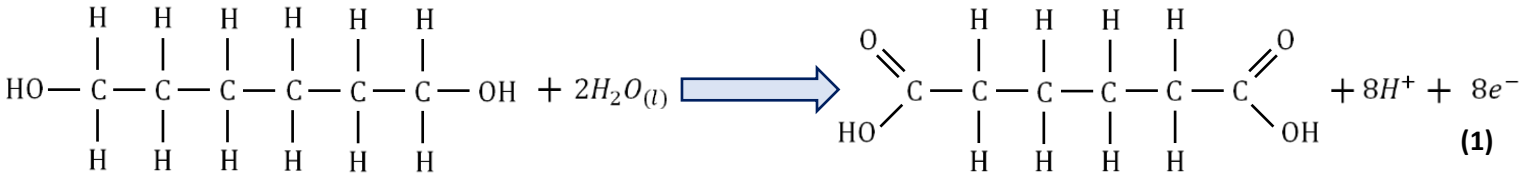
Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $Cr_2O_{7\,(aq)}^{2-} + 14H_{(aq)}^{+} + 6e^- \rightarrow 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$ **(1)**

$$3C_3H_8O_{(aq)} + Cr_2O_{7\,(aq)}^{2-} + 8H_{(aq)}^{+} \rightarrow 3C_3H_6O_{(aq)} + 2Cr_{(aq)}^{3+} + 7H_2O_{(l)} \quad \textbf{(1)}$$

(iv)

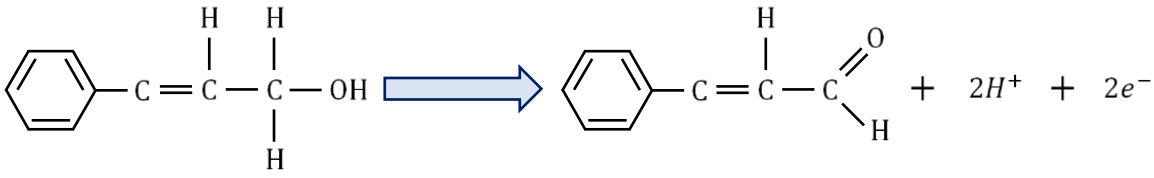
Oxidation Half-Equation:

 **(1)**

Reduction Half-Equation: $MnO_{4\,(aq)}^{-} + 8H_{(aq)}^{+} + 5e^- \rightarrow Mn_{(aq)}^{2+} + 4H_2O_{(l)}$ **(1)**

$$5C_6H_{14}O_{2\,(aq)} + 8MnO_{4\,(aq)}^{-} + 24H_{(aq)}^{+} \rightarrow 5C_6H_{10}O_{4\,(aq)} + 8Mn_{(aq)}^{2+} + 22H_2O_{(l)} \quad \textbf{(1)}$$

(v)

Oxidation Half-Equation: 

Reduction Half-Equation: $MnO_{4\,(aq)}^{-} + 8H_{(aq)}^{+} + 5e^- \rightarrow Mn_{(aq)}^{2+} + 4H_2O_{(l)}$ **(1)**

$$5C_9H_{10}O_{(aq)} + 2MnO_{4\,(aq)}^{-} + 6H_{(aq)}^{+} \rightarrow 5C_9H_8O_{(aq)} + 2Mn_{(aq)}^{2+} + 8H_2O_{(l)} \quad \textbf{(1)}$$

Marking Criteria	Marks Allocated
• Writes correct oxidation equation	1 – 5
• Writes correct reduction equation	1 – 5
• Writes correct overall redox equation	1 – 5
Total	**15**

4. **[8 marks]**

(a)

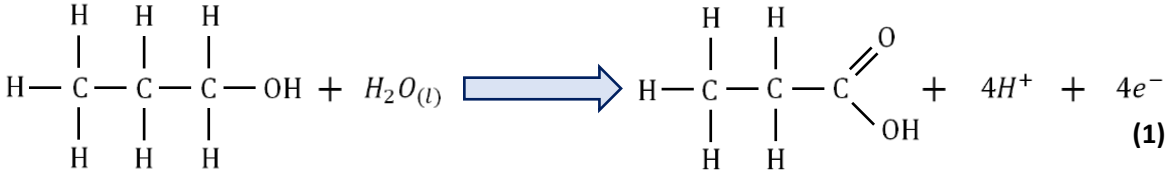
Label	Observation	Oxidant used	IUPAC name of compound
C_3H_8O	An orange solution is added to a colourless solution. The mixture rapidly turns deep green and has a sour taste when heated.	$Cr_2O_7^{2-}$	**Propan-1-ol (1)**
$C_4H_{10}O$	A purple solution is added to a colourless solution. The mixture rapidly turns pale pink when heated and has a sour taste.	MnO_4^-	**Butan-1-ol (1)**
C_3H_8O	An orange solution is added to a colourless solution. The mixture slowly turns deep green when heated and does not have a sour taste.	$Cr_2O_7^{2-}$	**Propan-2-ol (1)**
$C_4H_{10}O$	An orange solution is added to a colourless solution. The mixture remains orange when heated.	$Cr_2O_7^{2-}$	**Methylpropan-2-ol (1)**

Marking Criteria	Marks Allocated
• Determines correct oxidant and IUPAC name of compound	$1-4$
Total	**4**

(b)

(i)

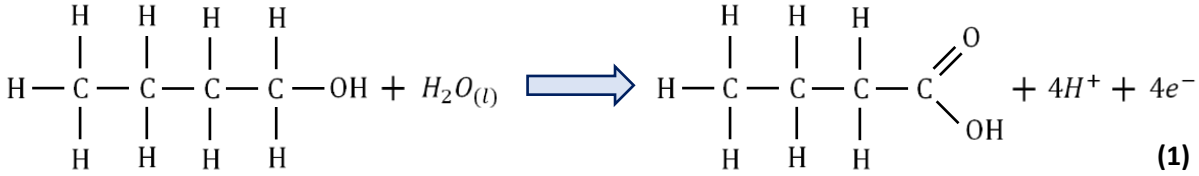
Oxidation Half-Equation:



(1)

(ii)

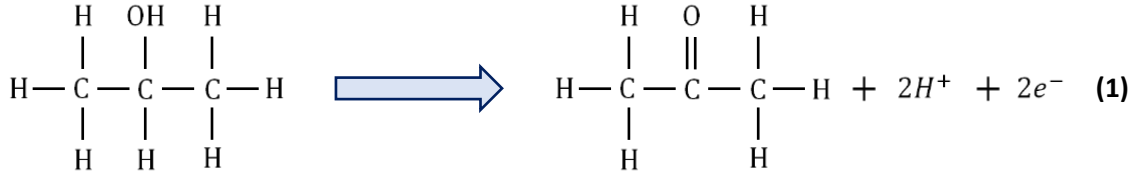
Oxidation Half-Equation:



(1)

(iii)

Oxidation Half-Equation:



(1)

(iv) **No reaction (1)**

Marking Criteria	Marks Allocated
• Writes correct oxidation equations	$1-4$
Total	**4**

Carboxylic Acids and Esterification: Q5, Q6, Q7

5. **[12 marks]**

(a)

(i) $2ClCH_2COOH_{(aq)} + CaCO_{3\,(s)} \rightarrow Ca(ClCH_2COO)_{2\,(aq)} + CO_{2\,(g)} + H_2O_{(l)}$ **(1)**

(ii) $6ClCH_2COOH_{(aq)} + 2Al_{(s)} \rightarrow 2Al(ClCH_2COO)_{3\,(aq)} + 3H_{2\,(g)}$ **(1)**

(iii) $6ClCH_2COOH_{(aq)} + Fe_2O_{3(s)} \rightarrow 2Fe(ClCH_2COO)_{3\,(aq)} + 3H_2O_{(l)}$ **(1)**

(iv) $ClCH_2COOH_{(aq)} + NaOH_{(s)} \rightarrow Na(ClCH_2COO)_{(aq)} + H_2O_{(l)}$ **(1)**

Marking Criteria	Marks Allocated
• Writes correct balanced equations	$1-4$
Total	**4**

(b)

(i) A **colourless solution** is added to a **white solid** **(1)**, to produce a **colourless solution** and a **colourless**, **odourless gas** **(1)**.

(ii) A **colourless solution** is added to a **silver solid** **(1)**, to produce a **colourless solution** and a **colourless**, **odourless gas** **(1)**.

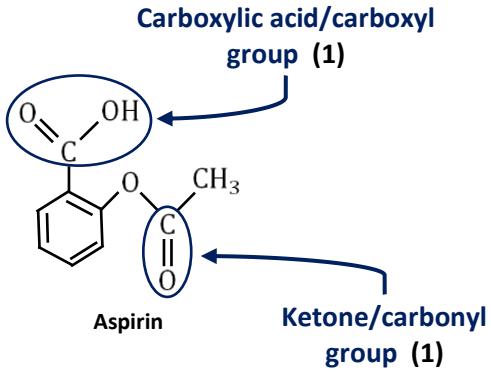
(iii) A **colourless solution** is added to a **pale brown solid** **(1)**, to produce a **pale brown solution** **(1)**.

(iv) A **colourless solution** is added to a **white solid** **(1)**, to produce a **colourless solution** **(1)**.

Marking Criteria	Marks Allocated
• Provides correct observations for reactants	$1-4$
• Provides correct observations for products	$1-4$
Total	**8**

6. **[5 marks]**

(a)

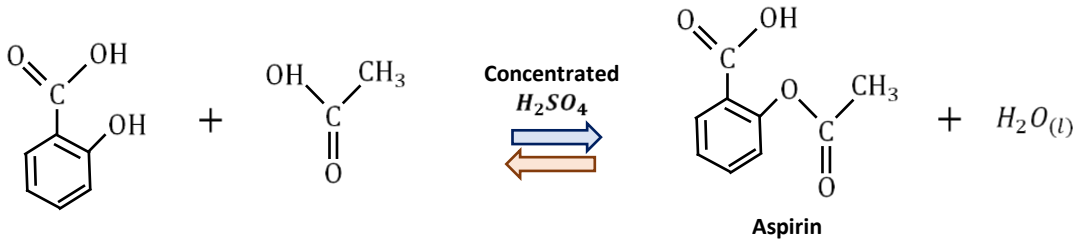


Marking Criteria	Marks Allocated
• Circles carboxylic acid and ketone groups	$1-2$
Total	**2**

(b) **Ethanoic acid** and **2-hydroxylbenzene-1-oic acid** (you don't need to know this), and **esterification reaction** **(1)**

Marking Criteria	Marks Allocated
• Names the two compounds and states esterification reaction	1
Total	**1**

(c)



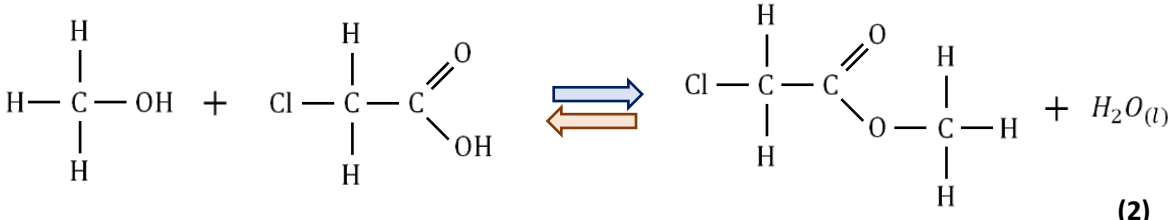
Aspirin

(2)

Marking Criteria	Marks Allocated
• Correct reactants drawn • Correct products drawn	1 – 2
Total	**2**

7. **[11 marks]**

(a)



Methanol Chloroethanoic Acid Chloromethyl ethanoate

(2)

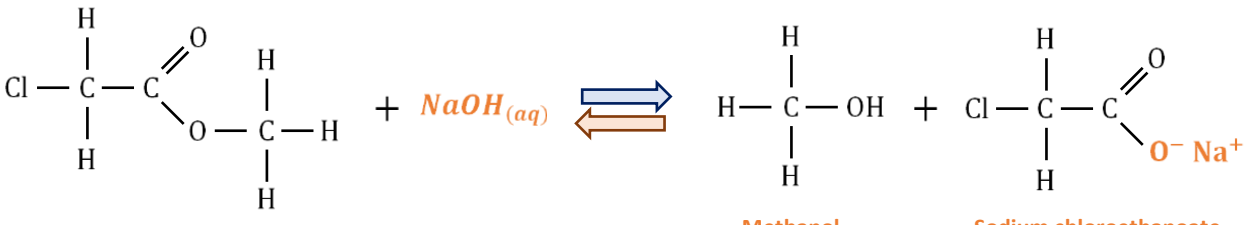
Marking Criteria	Marks Allocated
• Correct reactants drawn • Correct products drawn	1 – 2
Total	**2**

(b) The following three things could be done to increase the reaction rate:

- Add a **concentrated sulfuric acid catalyst** **(1)**
- **Increase** the **temperature** of the system **(1)**
- **Increase** the **concentration** of **methanol** and/or **chloroethanoic acid** **(1)**

Marking Criteria	Marks Allocated
• Add concentrated sulfuric acid catalyst • Increase the temperature • Increase the reactant concentration	1 – 3
Total	**3**

(c)



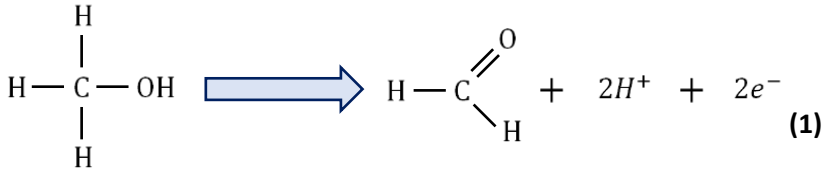
Chloromethyl ethanoate Methanol Sodium chloroethanoate

(2)

Marking Criteria	Marks Allocated
• Correct reactants drawn • Correct products drawn	1 – 2
Total	**2**

(d) An **oxidant** such as **acidified potassium permanganate ($KMnO_4$)** or **acidified potassium dichromate ($K_2Cr_2O_7$)**. **(1)**

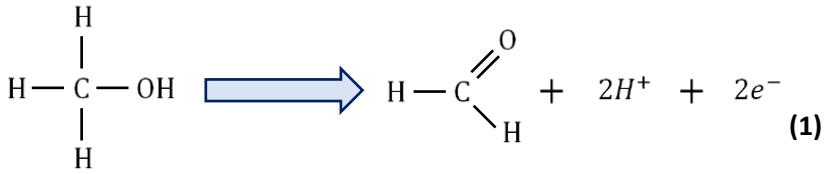
For **acidified potassium permanganate ($KMnO_4$)**:

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $MnO^-_{4\,(aq)} + 8H^+_{(aq)} + 5e^- \rightarrow Mn^{2+}_{(aq)} + 4H_2O_{(l)}$ **(1)**

$$5CH_4O_{(aq)} + 2MnO^-_{4\,(aq)} + 6H^+_{(aq)} \rightarrow 5CH_2O_{(aq)} + 2Mn^{2+}_{(aq)} + 8H_2O_{(l)}$$ **(1)**

For **acidified potassium dichromate ($K_2Cr_2O_7$)**:

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $Cr_2O^{2-}_{7\,(aq)} + 14H^+_{(aq)} + 6e^- \rightarrow 2Cr^{3+}_{(aq)} + 7H_2O_{(l)}$ **(1)**

$$3CH_4O_{(aq)} + Cr_2O^{2-}_{7\,(aq)} + 8H^+_{(aq)} \rightarrow 3CH_2O_{(aq)} + 2Cr^{3+}_{(aq)} + 7H_2O_{(l)}$$ **(1)**

Marking Criteria	Marks Allocated
• States an appropriate oxidant • Writes the correct oxidation equation • Writes the correct reduction equation • Writes the correct overall equation	$1-4$
Total	**4**

Concept 2

Empirical Formula – Progressive Questions Answers

Empirical Formula: Q1, Q2, Q3

1. **[5 marks]**

C_8H_{18}

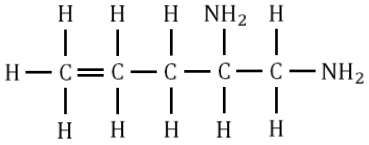
C_4H_9 **(1)**

$C_5H_{11}COOH$

C_3H_6O **(1)**

Hexan-1,4-diol

C_3H_7O **(1)**



$C_5H_{12}N_2$ **(1)**

3-ethylhexane-1,6-dial

C_4H_7O **(1)**

2. **[10 marks]**

(a)

(i)

$$\%(C) = \frac{m(C)}{m(sample)} \times 100$$
$$= \frac{8.265}{30} \times 100$$
$$= \mathbf{27.6\%} \quad \textbf{(1)}$$

(ii)

$$\boldsymbol{m(H)} = 30 - 18.610 - 8.265$$
$$= 3.125g \quad \textbf{(1)}$$
$$\%(\boldsymbol{H}) = \frac{3.125}{30} \times 100$$
$$= 10.4\% \ \textbf{(1)}$$

(b)

$\boldsymbol{m(C)} = 0.62 \times 10.00$
$= 6.2g$ **(1)**

$\boldsymbol{m(O)} = 0.186 \times 10.00$
$= 1.86g$ **(1)**

$\%(\boldsymbol{H}) = 100 - \%(C) - \%(O)$
$= 100 - 62.0 - 18.6$
$= \mathbf{19.4\%}$ **(1)**

$\boldsymbol{m(H)} = 0.186 \times 10.00$
$= 1.86g$ **(1)**

(c)

$$\textit{Unknown Compound} + O_{2\,(g)} \rightarrow \underset{\boxed{m(CO_2) = 18.49g}}{CO_{2\,(g)}} + \underset{\boxed{m(H_2O) = 8.52g}}{H_2O_{(g)}}$$

$$\boldsymbol{n(CO_2)} = \frac{18.49}{12.01+32}$$
$$= \mathbf{0.420\ mol}$$

$$\boldsymbol{n(C)} = n(CO_2)$$
$$= \mathbf{0.420\ mol}$$

$$\boldsymbol{m(C)} = nM$$
$$= 0.420 \times 12.01$$
$$= \mathbf{5.044g} \quad \textbf{(1)}$$

$$\%(\boldsymbol{C}) = \frac{m(C)}{m(Sample)} \times 100$$
$$= \frac{5.044}{7.305} \times 100$$
$$= \mathbf{69.1\%} \quad \textbf{(1)}$$

$$\boldsymbol{n(H_2O)} = \frac{8.52}{2.016+16}$$
$$= \mathbf{0.4729\ mol}$$

$$\boldsymbol{n(H)} = n(H_2O) \times 2$$
$$= 0.4729 \times 2$$
$$= \mathbf{0.9458\ mol}$$

$$\boldsymbol{m(H)} = nM$$
$$= 0.9458 \times 1.008$$
$$= \mathbf{0.9534g} \quad \textbf{(1)}$$

$$\%(\boldsymbol{H}) = \frac{m(H)}{m(Sample)} \times 100$$
$$= \frac{0.9534}{7.305} \times 100$$
$$= \mathbf{13.1\%} \quad \textbf{(1)}$$

3. **[16 marks]**

(a) $\%(C) = \frac{m(C)}{m(Sample)} \times 100$
$= \frac{1.117}{1.602} \times 100$
$= \mathbf{69.7\%}$ **(1)**

$\%(O) = \frac{m(O)}{m(Sample)} \times 100$
$= \frac{0.298}{1.602} \times 100$
$= \mathbf{18.6\%}$ **(1)**

$\%(H) = 100 - \%(C) - \%(O)$
$= 100 - 69.7 - 18.6$
$= \mathbf{11.7\%}$ **(1)**

	C	H	O	
Mass in $100g$	$69.7g$	$11.7g$	$18.6g$	
Moles	$\frac{69.7}{12.01} = 5.806\ mol$	$\frac{11.7}{1.008} = 11.580\ mol$	$\frac{18.6}{16.00} = 1.163\ mol$	**(1)**
Simple Ratio	$\frac{5.806}{1.163} = 4.992$	$\frac{11.580}{1.163} = 9.957$	$\frac{1.163}{1.163} = 1$	
Whole Ratio	5	10	1	**(1)**

∴ the empirical formula is $\boldsymbol{C_5H_{10}O}$ **(1)**

(b) $\%(O) = 100 - \%(C) - \%(H)$
$= 100 - 39.99 - 6.71$
$= \mathbf{53.30\%}$ **(1)**

	C	H	O	
Mass in $100g$	$39.99g$	$6.71g$	$53.3g$	
Moles	$\frac{39.99}{12.01} = 3.33\ mol$	$\frac{6.71}{1.008} = 6.657\ mol$	$\frac{53.3}{16.00} = 3.331\ mol$	**(1)**
Simple Ratio	$\frac{3.33}{3.331} = 0.9997$	$\frac{6.6567}{3.331} = 1.998$	$\frac{3.331}{3.331} = 1$	
Whole Ratio	1	2	1	**(1)**

The empirical formula is $\boldsymbol{CH_2O}$ which is **not valuable** because the empirical formula is not $\boldsymbol{C_5H_{10}O}$ **(1)**

(c) **Combustion:** $Unknown + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(g)}$
$m(CO_2) = 11.809g$ $m(H_2O) = 4.834g$

$\boldsymbol{n(CO_2)} = \frac{11.809}{44.01}$
$= \mathbf{0.2683\ mol}$

$\boldsymbol{n(C)} = n(CO_2)$
$= \mathbf{0.2683\ mol}$

$\boldsymbol{m(C)} = nM$
$= 0.2683 \times 12.01$
$= \mathbf{3.223g}$ **(1)**

$\boldsymbol{n(H_2O)} = \frac{4.834}{18.016}$
$= \mathbf{0.2683\ mol}$

$\boldsymbol{n(H)} = n(H_2O) \times 2$
$= 0.2683 \times 2$
$= \mathbf{0.5366\ mol}$

$\boldsymbol{m(H)} = nM$
$= 0.5366 \times 1.008$
$= \mathbf{0.541g}$ **(1)**

$\boldsymbol{m(O)} = 4.622 - m(C) - m(H)$
$= 4.622 - 3.223 - 0.5410$
$= \mathbf{0.858g}$ **(1)**

	C	H	O	
Mass in $100g$	$3.223g$	$0.541g$	$0.858g$	
Moles	$\frac{3.223}{12.01} = 0.2684\ mol$	$\frac{0.541}{1.008} = 0.5367\ mol$	$\frac{0.858}{16.00} = 0.0536\ mol$	**(1)**
Simple Ratio	$\frac{0.2684}{0.0536} = 5.007$	$\frac{0.5367}{0.0536} = 10.01$	$\frac{0.0536}{0.0536} = 1$	
Whole Ratio	5	10	1	**(1)**

∴ the empirical formula is $C_5H_{10}O$ and it is a **valuable compound (1)**

Difficult Empirical Formula Calculations: Q4, Q5

4. **[8 marks]**

(a)

$$Ratio = \frac{M(Compound)}{M(Empirical)} = \frac{726.902}{12.01\times4+1.008\times4+14.01} = 11 \quad (1)$$

$$Molecular = Empirical \times 11 = C_4H_4N \times 11 = C_{44}H_{44}N_{11} \quad (1)$$

∴ it is **not** the compound **(1)**

(b)

$$n(Compound) = \frac{PV}{RT} = \frac{101.35\times28.39\times10^{-3}}{8.314\times(21+273.15)} = 1.177\times10^{-3}\ mol \quad (1)$$

$$M(Compound) = \frac{m}{n} = \frac{0.933}{1.177\times10^{-3}} = 792.7g\ mol^{-1} \quad (1)$$

$$Ratio = \frac{M(Compound)}{M(Empirical)} = \frac{792.7}{12.01\times4+1.008\times4+14.01} = 12 \quad (1)$$

$$Molecular = Empirical \times 12 = C_4H_4N \times 12 = C_{48}H_{48}N_{12} \quad (1)$$

∴ this is the **valuable compound (1)**

5. **[16 marks]**

(a)

$$Unknown + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(g)} + N_{2\,(g)}$$

$n(CO_2) = 0.800g$ $\quad$ $m(H_2O) = 0.382g$

$$n(CO_2) = \frac{0.800}{44.01} = 0.0182\ mol$$

$$n(C) = n(CO_2) = 0.0182\ mol$$

$$m(C) = nM = 0.0182 \times 12.01 = 0.2186g \quad (1)$$

$$n(H_2O) = \frac{0.382}{18.016} = 0.0212\ mol$$

$$n(H) = n(H_2O) \times 2 = 0.0212 \times 2 = 0.0424\ mol$$

$$m(H) = nM = 0.0424 \times 1.008 = 0.04274g \quad (1)$$

$$n(N_2) = \frac{101.2 \times 0.074984}{8.314 \times 301.15} = 3.031\times10^{-3}\ mol \quad (1)$$

$$n(N) = n(N_2) \times 2 = 3.031 \times 10^{-3} \times 2 = 6.062\times10^{-3}\ mol$$

$$m(N) = nM = 6.062 \times 10^{-3} \times 14.01 = 0.08493g \quad (1)$$

$$m(O) = 0.540 - m(C) - m(H) - m(N)$$
$$= 0.540 - 0.2186 - 0.04274 - 0.08493$$
$$= 0.1937g \quad \textbf{(1)}$$

	C	H	N	O
Mass	$0.2186g$	$0.04274g$	$0.08493g$	$0.1937g$
Moles	$\frac{0.2186}{12.01} = 0.0182\ mol$	$\frac{0.04274}{1.008} = 0.0424\ mol$	$\frac{0.08493}{14.01} = 0.00606\ mol$	$\frac{0.1937}{16.00} = 0.0121\ mol$ **(1)**
Simple Ratio	$\frac{0.0182}{0.00606} = 3.003$	$\frac{0.0424}{0.00606} = 6.9967$	$\frac{0.00606}{0.00606} = 1$	$\frac{0.0121}{0.00606} = 1.997$
Whole Ratio	3	7	1	2 **(1)**

∴ the empirical formula is $C_3H_7NO_2$ **(1)**

(b)

$$Sample + NaOH_{(aq)} \rightarrow Salt + H_2O_{(l)}$$

$$n(NaOH) = cV$$
$$= 0.0200 \times 0.02334$$
$$= 4.668 \times 10^{-4}\ mol \quad \textbf{(1)}$$

$$n(Sample)_{10mL} = n(NaOH)$$
$$= 4.668 \times 10^{-4}\ mol \quad \textbf{(1)}$$

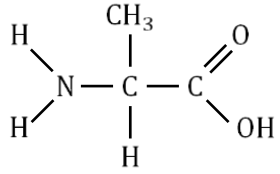
$$n(Sample)_{100mL} = n(Sample)_{10mL} \times 10$$
$$= 4.668 \times 10^{-4} \times 10$$
$$= 4.668 \times 10^{-3}\ mol \quad \textbf{(1)}$$

$$M(Compound) = \frac{m}{n}$$
$$= \frac{0.4159}{4.668 \times 10^{-3}}$$
$$= 89.096g\ mol^{-1} \quad \textbf{(1)}$$

$$Ratio = \frac{M(Compound)}{M(Empirical)}$$
$$= \frac{89.096}{12.01 \times 3 + 1.008 \times 7 + 14.01 + 2 \times 16}$$
$$= 1 \quad \textbf{(1)}$$

$$Molecular = Empirical \times 1$$
$$= C_3H_7NO_2 \quad \textbf{(1)}$$

(c) The common amino acid it is **alanine (1)**:



(1)

Alanine (Ala)

Problem Set 12 – Organic Reactions and Empirical Formula Repetitive Questions

Concept 1

Functional Group Reactions – Repetitive Questions Answers

Combustion Reactions: Qs 1.11

1.11 **[6 marks]**

(a) $2C_8H_{18\,(g)} + 25O_{2\,(g)} \rightarrow 16CO_{2\,(g)} + 18H_2O_{(l)}$ **(1)**

(b) $C_4H_{10}O_{(g)} + 4O_{2\,(g)} \rightarrow 4CO_{(g)} + 5H_2O_{(g)}$ **(1)**

(c) $C_3H_8O_{(g)} + 3O_{2\,(g)} \rightarrow 3CO_{(g)} + 4H_2O_{(g)}$ **(1)**

(d) $C_3H_{8\,(g)} + 5O_{2\,(g)} \rightarrow 3CO_{2\,(g)} + 4H_2O_{(g)}$ **(1)**

(e) $2C_3H_6O_{2\,(g)} + 7O_{2\,(g)} \rightarrow 6CO_{2\,(g)} + 6H_2O_{(g)}$ **(1)**

(f) $CH_3OH_{(g)} + O_{2\,(g)} \rightarrow CO_{(g)} + 2H_2O_{(g)}$ **(1)**

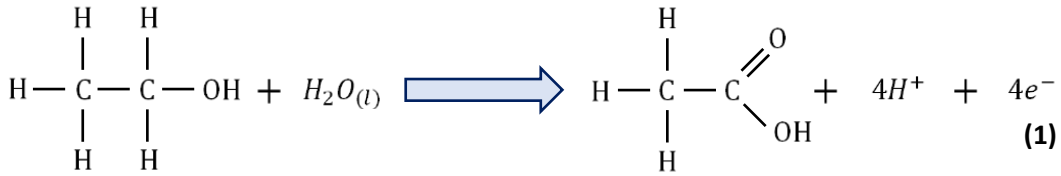
Marking Criteria	Marks Allocated
• Correct combustion and incomplete combustion equations written	1 – 6
Total	**6**

Oxidation of Alcohols: Qs 1.21, 1.22, 1.41, 1.42

1.21 **[10 marks]**

(a)

Oxidation Half-Equation:



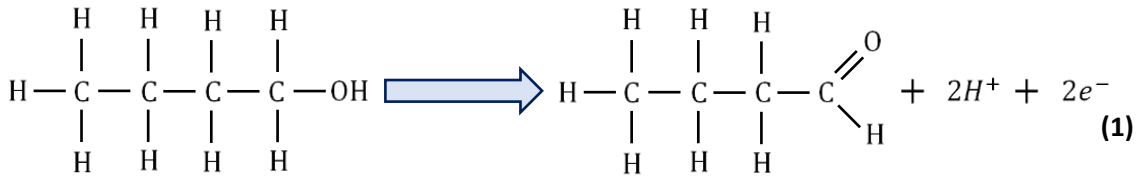
(1)

Reduction Half-Equation: $MnO_{4\,(aq)}^- + 8H_{(aq)}^+ + 5e^- \rightarrow Mn_{(aq)}^{2+} + 4H_2O_{(l)}$ **(1)**

$$5C_2H_6O_{(aq)} + 4MnO_{4\,(aq)}^- + 12H_{(aq)}^+ \rightarrow 5C_2H_4O_{2\,(aq)} + 4Mn_{(aq)}^{2+} + 11H_2O_{(l)}$$ **(1)**

(b)

Oxidation Half-Equation:



(1)

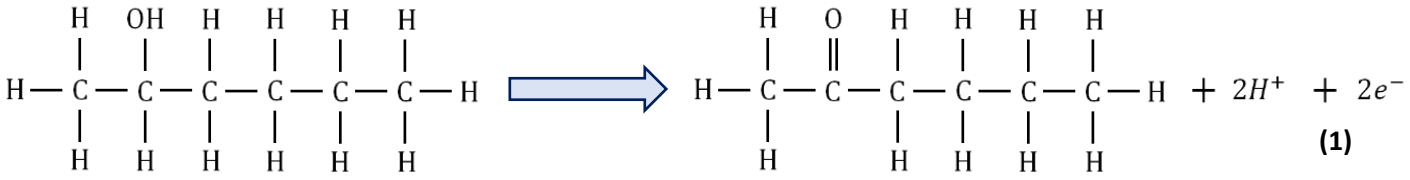
Reduction Half-Equation: $Cr_2O_{7\,(aq)}^{2-} + 14H_{(aq)}^+ + 6e^- \rightarrow 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$ **(1)**

$$3C_4H_{10}O_{(aq)} + Cr_2O_{7\,(aq)}^{2-} + 8H_{(aq)}^+ \rightarrow 3C_4H_8O_{(aq)} + 2Cr_{(aq)}^{3+} + 7H_2O_{(l)}$$ **(1)**

(c) **No reaction (1)**

(d)

Oxidation Half-Equation:



(1)

Reduction Half-Equation: $MnO^-_{4\,(aq)} + 8H^+_{(aq)} + 5e^- \rightarrow Mn^{2+}_{(aq)} + 4H_2O_{(l)}$ **(1)**

$$5C_6H_{14}O_{(aq)} + 2MnO^-_{4\,(aq)} + 6H^+_{(aq)} \rightarrow 5C_6H_{12}O_{(aq)} + 2Mn^{2+}_{(aq)} + 8H_2O_{(l)}$$ **(1)**

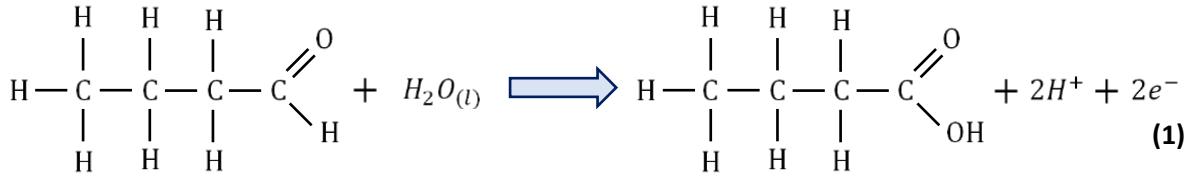
Marking Criteria	Marks Allocated
• Correct oxidation equation	1 – 3
• Correct reduction equation	1 – 3
• Correct overall balanced equation	1 – 3
• States 'no reaction' for reaction (c)	1
Total	**10**

1.22 **[7 marks]**

(a) **No reaction (1)**

(b)

Oxidation Half-Equation:



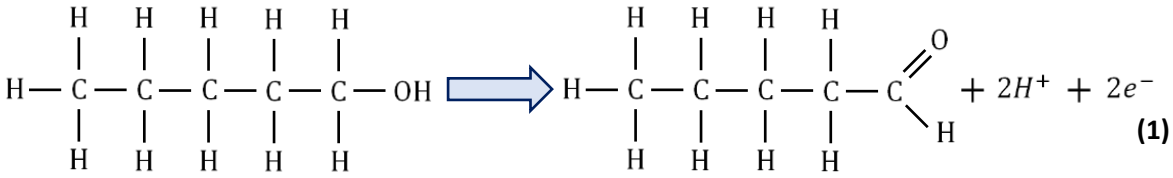
(1)

Reduction Half-Equation: $Cr_2O^{2-}_{7\,(aq)} + 14H^+_{(aq)} + 6e^- \rightarrow 2Cr^{3+}_{(aq)} + 7H_2O_{(l)}$ **(1)**

$$3C_4H_8O_{(aq)} + Cr_2O^{2-}_{7\,(aq)} + 8H^+_{(aq)} \rightarrow 3C_4H_8O_{2\,(aq)} + 2Cr^{3+}_{(aq)} + 4H_2O_{(l)}$$ **(1)**

(c)

Oxidation Half-Equation:



(1)

Reduction Half-Equation: $Cr_2O^{2-}_{7\,(aq)} + 14H^+_{(aq)} + 6e^- \rightarrow 2Cr^{3+}_{(aq)} + 7H_2O_{(l)}$ **(1)**

$$3C_5H_{12}O_{(aq)} + Cr_2O^{2-}_{7\,(aq)} + 8H^+_{(aq)} \rightarrow 3C_5H_{12}O_{(aq)} + 2Cr^{3+}_{(aq)} + 7H_2O_{(l)}$$ **(1)**

Marking Criteria	Marks Allocated
• Correct oxidation equation	1 – 2
• Correct reduction equation	1 – 2
• Correct overall balanced equation	1 – 2
• States 'no reaction' for reaction (a)	1
Total	**10**

1.41 **[8 marks]**

(a) A **purple solution** is added to a **colourless solution** **(1)**, to produce a **pale pink solution** **(1)**.

(b) A **orange solution** is added to a **colourless solution** **(1)**, to produce a **deep green solution** **(1)**.

(c) A **purple solution** is added to a **colourless solution** **(1)**, to produce a **pale pink solution** **(1)**.

(d) A **orange solution** is added to a **colourless solution** **(1)**, and will **remain** an **orange colour** **(1)**.

Marking Criteria	Marks Allocated
• Correct observations for reactants	$1-4$
• Correct observations for products	$1-4$
Total	**8**

1.42 **[5 marks]**

To distinguish between the three compounds **small amounts** of acidified potassium permanganate could be added to **samples** of each of the three bottles **(1)**. In the bottle containing **butan-1-ol**, it will be observed that the **purple solution** is added to a **colourless solution** to produce a **pale pink solution** that has a **sour taste** **(1)**. In the bottle containing methylpropan-2-ol it will be observed that the **purple solution** is added to a **colourless solution** and the solution will **remain** an **orange colour** **(1)**. In the bottle containing pentan-2-ol, the **purple solution** is added to a **colourless solution** to produce a **pale pink solution**. Using these observations each of the bottle can be identified by matching these **predicted observations** to the **actual observations**. **(1)**

Marking Criteria	Marks Allocated
• Acidified potassium permanganate can be added to samples of each of the three bottles • The predicted observations can be matched to the actual observations to determine which compound is in each bottle	$1-2$
• Correct observations for each of the bottles	$1-3$
Total	**5**

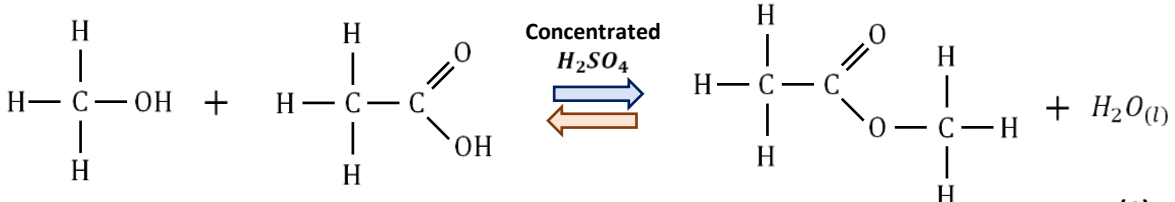
Carboxylic Acids and Esterification: Qs 1.61, 1.62, 1.71, 1.72

1.61 **[7 marks]**

(a) $CH_3CH_2CH_2COOH_{(aq)} + NaOH_{(aq)} \rightarrow Na(CH_3CH_2CH_2COOH)_{2\,(aq)} + H_2O_{(l)}$ **(1)**

(b) $2CH_3CH(CH_3)COOH_{(aq)} + Na_2CO_{3\,(s)} \rightarrow 2Na(CH_3CH(CH_3)COO)_{(aq)} + CO_{2\,(g)} + H_2O_{(aq)}$ **(1)**

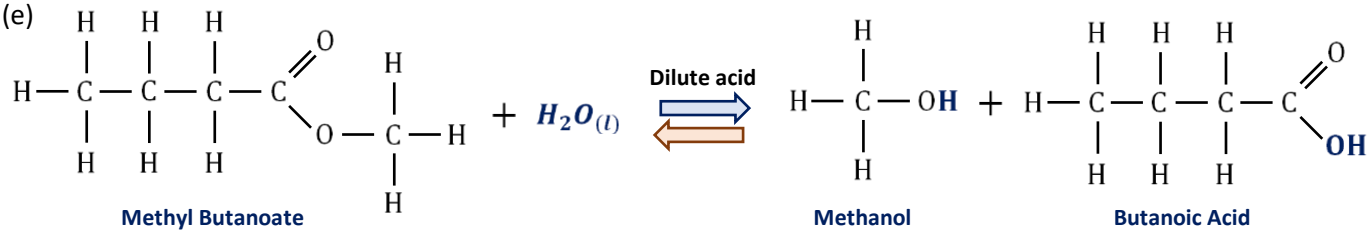
(c)



Methanol Ethanoic Acid Methyl ethanoate **(1)**

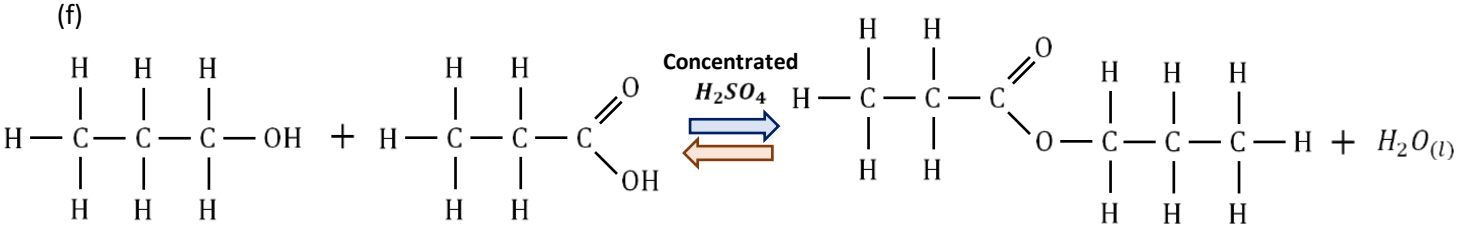
(d) $6CH_3CH_2COOH_{(aq)} + 2Cr_{(s)} \rightarrow 2Cr(CH_3CH_2COO)_{(aq)} + 3H_{2\,(g)}$ **(1)**

(e)



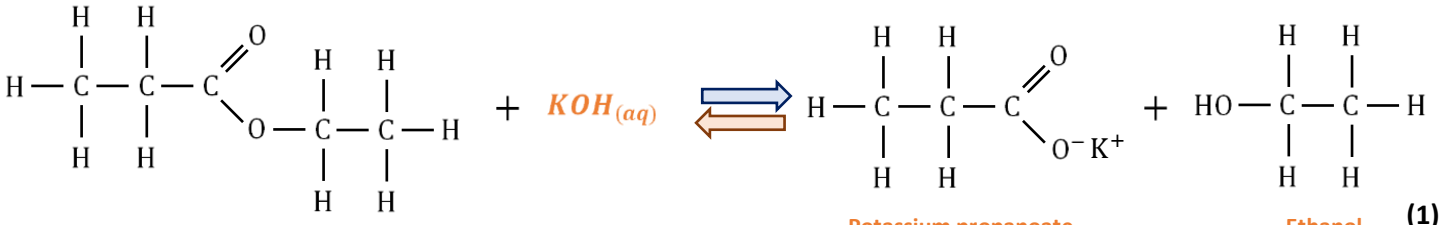
Methyl Butanoate Methanol Butanoic Acid

(f)



Propan-1-ol + Propanoic Acid → Propyl propanoate **(1)**

(g)



Ethyl propanoate + $KOH_{(aq)}$ → Potassium propanoate + Ethanol **(1)**

1.62 **[9 marks]**

(a) Various tests could be used:

- A **smell test (1)** could be used where **ethyl ethanoate** would have a **fruity smell (1)** and **butanoic acid** would have **no smell (1)**; or
- A piece of **metal**, **metal carbonate**, **base** etc. could be **added** to each beaker **(1)**. For instance, if **aluminium metal** was added it would be observed that **nothing would occur** in the beaker with **ethyl ethanoate (1)**, and in the beaker with **butanoic acid** the **silver metal** would **dissolve** and a **colourless**, **odourless gas** would be **produced (1)**.

(b) The addition of an **oxidising agent** such as **acidified potassium permanganate** or **acidified potassium dichromate** to both beakers could be used **(1)**. For instance, if **acidified potassium dichromate** was added to both beakers in the beaker with **propanoic acid** it would be observed that an **orange solution** is added to a **colourless solution** and the solution will **remain orange (1)**. In the beaker with **methanol** it would be observed that an **orange solution** is added to a **colourless solution** and the solution will turn a **deep green colour (1)**.

(c) Two tests could be used:

- A piece of **metal**, **metal carbonate**, **base** etc. could be **added** to each beaker **(1)**. For instance if **chromium metal** was added it would be observed that **nothing would occur** in the beaker with **butan-2-ol (1)**, and in the beaker with **pentanoic acid** the **silver metal** would **dissolve** and a **deep green solution** and **colourless**, **odourless gas** would be **produced (1)**.
- The addition of an **oxidising agent** such as **acidified potassium permanganate** or **acidified potassium dichromate** to both beakers could be used **(1)**. For instance, if **acidified potassium permanganate** was added to both beakers in the beaker with **pentanoic acid** it would be observed that a **purple solution** is added to a **colourless solution** and the solution will **remain purple (1)**. In the beaker with **butan-2-ol** it would be observed that a **purple solution** is added to a **colourless solution** and the solution will turn a **pale pink colour (1)**.

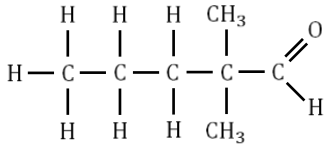
Marking Criteria	Marks Allocated
• Provides appropriate test	1 – 3
• States observations that will occur for the first compound	1 – 3
• States observations that will occur for the second compound	1 – 3
Total	**9**

Concept 2

Empirical Formula – Repetitive Questions Answers

Empirical Formula Calculations: Qs 2.1, 2.21, 2.22, 2.31, 2.32

2.11 **[9 marks]**



$C_7H_{14}O$ **(1)**

1,4-butanediol

C_2H_5O **(1)**

$C_{10}H_{22}$

C_5H_{11} **(1)**

2,3-dimethylbutanoic acid

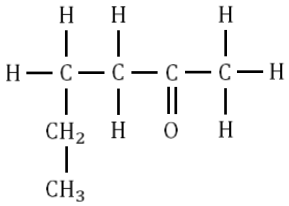
C_3H_6O **(1)**

C_3H_6

CH_2 **(1)**

Propyl propanoate

C_3H_6O **(1)**



$C_6H_{12}O$ **(1)**

Benzene

CH **(1)**

CH_3CO_2H

CH_2O **(1)**

2.21 **[3 marks]**

(a)

$$\%(C) = \frac{m(C)}{m(sample)} \times 100$$
$$= \frac{36.00}{50.00} \times 100$$
$$= 72.0\% \quad \textbf{(1)}$$

(b)

$$m(H) = 50.00 - m(C) - m(O)$$
$$= 50.00 - 36.00 - 8.00$$
$$= 6.00 \quad \textbf{(1)}$$

$$\%(H) = \frac{6.00}{50.00} \times 100$$
$$= 12.0\% \ \textbf{(1)}$$

2.22 **[10 marks]**

(a)

$$n(CO_2) = \frac{36.64}{44.01}$$
$$= 0.8325\ mol$$

$$n(C) = n(CO_2)$$
$$= 0.8325\ mol$$

$$m(C) = nM$$
$$= 0.8325 \times 12.01$$
$$= 9.998g \quad \textbf{(1)}$$

$$\%(C) = \frac{m(C)}{m(sample)} \times 100$$
$$= \frac{9.998}{25.00} \times 100$$
$$= 39.99\% \quad \textbf{(1)}$$

(b)

$$n(H_2O) = \frac{15.00}{18.016}$$
$$= 0.8326\ mol$$
$$n(H) = n(H_2O) \times 2$$
$$= 0.8326 \times 2$$
$$= 1.665\ mol$$
$$m(H) = nM$$
$$= 1.665 \times 1.008$$
$$= 1.678g \quad \textbf{(1)}$$

$$\%(H) = \frac{m(H)}{m(Sample)} \times 100$$
$$= \frac{1.678}{25.00} \times 100$$
$$= 6.71\% \quad \textbf{(1)}$$

(c)

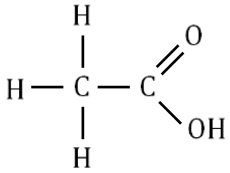
$$m(O) = 25.00 - m(C) - m(H)$$
$$= 25.00 - 9.998 - 1.678$$
$$= 13.324g \quad \textbf{(1)}$$

(d)

	C	H	O	
Mass	$9.998g$	$1.678g$	$13.324g$	
Moles	$\frac{9.998}{12.01} = 0.8325\ mol$	$\frac{1.678}{1.008} = 1.665\ mol$	$\frac{13.324}{16} = 0.8328\ mol$	**(1)**
Simple Ratio	$\frac{0.8325}{0.8325} = 1$	$\frac{1.665}{0.8325} = 2$	$\frac{0.8328}{0.8325} = 1$	
Whole Ratio	1	2	1	**(1)**

∴ the empirical formula is CH_2O **(1)**

(e) The sample must be a carboxylic acid because carboxylic acids react with sodium carbonate to form carbon dioxide **(1)**. A possible structure and name is **ethanoic acid**:



Ethanoic acid (1)

Points to note: As the molecular formula is not known, any carboxylic acid could be drawn and named for part (e)

2.31 **[6 marks]**

$$Unknown + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(g)}$$
$$n(CO_2) = 1.238g \qquad m(H_2O) = 0.6756g$$

$$n(CO_2) = \frac{1.238}{44.01}$$
$$= 0.02813\ mol$$
$$n(C) = n(CO_2)$$
$$= 0.02813\ mol$$
$$m(C) = nM$$
$$= 0.02813 \times 12.01$$
$$= 0.3378\ g \quad \textbf{(1)}$$

$$n(H_2O) = \frac{0.6756}{18.016}$$
$$= 0.0375\ mol$$
$$n(H) = n(H_2O) \times 2$$
$$= 0.0375 \times 2$$
$$= 0.0750\ mol$$
$$m(H) = nM$$
$$= 0.0750 \times 1.008$$
$$= 0.0756\ g \quad \textbf{(1)}$$

$$m(O) = 0.5634 - m(C) - m(H)$$
$$= 0.5634 - 0.3378 - 0.0756$$
$$= 0.150g \quad \textbf{(1)}$$

	C	H	O	
Mass	0.3378	0.0756	0.150	
Moles	$\frac{0.3378}{12.01} = 0.02813\ mol$	$\frac{0.0756}{1.008} = 0.750\ mol$	$\frac{0.150}{16.00} = 0.009375$	**(1)**
Simple Ratio	$\frac{0.02813}{0.009375} = 3$	$\frac{0.0750}{0.009375} = 8$	$\frac{0.009375}{0.009375} = 1$	
Whole Ratio	3	8	1	**(1)**

∴ the empirical formula is C_3H_8O **(1)**

2.32 **[10 marks]**

$$Unknown + O_{2\,(g)} \rightarrow \underset{n(CO_2) = 1.238g}{CO_{2\,(g)}} + \underset{m(H_2O) = 0.6756g}{H_2O_{(g)}}$$

$$n(CO_2) = \frac{1.866}{44.01} = 0.0424\ mol$$

$$n(H_2O) = \frac{0.7641}{18.016} = 0.0424\ mol$$

$$n(C) = n(CO_2) = 0.0424\ mol$$

$$n(H) = n(H_2O) \times 2 = 0.0424 \times 2 = 0.0848\ mol$$

$$m(C) = nM = 0.0424 \times 12.01 = 0.5092\ g \quad \textbf{(1)}$$

$$m(H) = nM = 0.0848 \times 1.008 = 0.08548\ g \quad \textbf{(1)}$$

$$m(O) = 0.7647 - m(C) - m(H)$$
$$= 0.7647 - 0.5092 - 0.08548$$
$$= 0.170g \quad \textbf{(1)}$$

	C	H	O	
Mass	0.5092	0.0855	0.170	
Moles	$\frac{0.5092}{12.01} = 0.0424\ mol$	$\frac{0.08548}{1.008} = 0.0848\ mol$	$\frac{0.170}{16.00} = 0.01063\ mol$	**(1)**
Simple Ratio	$\frac{0.0424}{0.01063} = 3.989$	$\frac{0.0848}{0.01063} = 7.977$	$\frac{0.01063}{0.01063} = 1$	
Whole Ratio	4	8	1	**(1)**

∴ the empirical formula is C_4H_8O **(1)**

Difficult Empirical Formula Calculations: Qs 2.41, 2.42, 2.51, 2.52, 2.53

2.41 **[9 marks]**

$$Unknown\ Compound + O_{2\,(g)} \rightarrow \underset{m(CO_2)=15.08g}{CO_{2\,(g)}} + \underset{m(H_2O)=6.69g}{H_2O_{(g)}}$$

$$n(CO_2) = \frac{15.08}{44.01} = 0.3426\ mol$$

$$n(C) = n(CO_2) = 0.3426\ mol$$

$$m(C) = nM = 0.3426 \times 12.01 = 4.114\ g \quad \textbf{(1)}$$

$$n(H_2O) = \frac{6.69}{18.016} = 0.3713\ mol$$

$$n(H) = n(H_2O) \times 2 = 0.3713 \times 2 = 0.7426\ mol$$

$$m(H) = nM = 0.7426 \times 1.008 = 0.7485\ g \quad \textbf{(1)}$$

$$NH_{3\,(aq)} + HCl_{(aq)} \rightarrow NH_4Cl_{(aq)}$$

$$n(HCl) = cV = 1 \times 0.00571 = 0.00571\ mol$$

$$n(NH_3)_{10mL} = n(HCl) = 0.00571\ mol \quad \textbf{(1)}$$

$$n(NH_3)_{100mL} = n(NH_3)_{10mL} \times \frac{100}{10} = 0.00571 \times 10 = 0.0571\ mol \quad \textbf{(1)}$$

$$n(N) = n(NH_3) = 0.0571\ mol \quad \textbf{(1)}$$

$$m(N) = nM = 0.0571 \times 14.01 = 0.800g$$

$$m(O) = 0.7647 - m(C) - m(H) - m(N) = 7.49 - 4.114 - 0.7485 - 0.800 = 1.828g \quad \textbf{(1)}$$

	C	H	N	O	
Mass	$4.114g$	$0.7485g$	$0.800g$	$1.828g$	
Moles	$\frac{4.114}{12.01} = 0.3425\ mol$	$\frac{0.7485}{1.008} = 0.7426\ mol$	$\frac{0.800}{14.01} = 0.0571\ mol$	$\frac{1.828}{16.00} = 0.1143\ mol$	**(1)**
Simple Ratio	$\frac{0.3425}{0.0571} = 5.998$	$\frac{0.7426}{0.0571} = 13.005$	$\frac{0.0571}{0.0571} = 1$	$\frac{0.1143}{0.0571} = 2.002$	
Whole Ratio	6	13	1	2	**(1)**

∴ the empirical formula is $C_6H_{13}NO_2$ **(1)**

2.42 **[7 marks]**

$$\textit{Unknown Compound} + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(g)}$$

$m(CO_2) = 15.08g$ $m(H_2O) = 6.69g$

$n(CO_2) = \frac{6.285}{44.01}$
$= 0.1428\ mol$

$n(C) = n(CO_2)$
$= 0.1428\ mol$

$m(C) = nM$
$= 0.1428 \times 12.01$
$= 1.715\ g$ **(1)**

$n(H_2O) = \frac{3.22}{18.016}$
$= 0.1787\ mol$

$n(H) = n(H_2O) \times 2$
$= 0.1787 \times 2$
$= 0.3574\ mol$

$m(H) = nM$
$= 0.3574 \times 1.008$
$= 0.3603\ g$ **(1)**

$n(N_2) = \frac{0.500}{2 \times 14.01}$
$= 0.01784\ mol$ **(1)**

$n(N) = n(N_2) \times 2$
$= 0.01784 \times 2$
$= 0.03568\ mol$

$m(N) = nM$
$= 0.03568 \times 14.01$
$= 0.500g$ **(1)**

	C	H	N	
Mass	$1.715g$	$0.360g$	$0.500g$	
Moles	$\frac{1.715}{12.01} = 0.1428\ mol$	$\frac{0.360}{1.008} = 0.3571\ mol$	$\frac{0.500}{14.01} = 0.03569\ mol$	**(1)**
Simple Ratio	$\frac{0.1428}{0.03569} = 4.001$	$\frac{0.3571}{0.03569} = 10.006$	$\frac{0.03569}{0.03569} = 1$	
Whole Ratio	4	10	1	**(1)**

∴ the empirical formula is $C_4H_{10}N$ **(1)**

2.51 **[10 marks]**

(a)

$$\textit{Unknown Compound} + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(g)}$$

$m(CO_2) = 3.147g$ $m(H_2O) = 1.417g$

$n(CO_2) = \frac{3.147}{44.01}$
$= 0.07151\ mol$

$n(C) = n(CO_2)$
$= 0.07151\ mol$

$m(C) = nM$
$= 0.07151 \times 12.01$
$= 0.8588\ g$ **(1)**

$n(H_2O) = \frac{1.417}{18.016}$
$= 0.07865\ mol$

$n(H) = n(H_2O) \times 2$
$= 0.07865 \times 2$
$= 0.1573\ mol$

$m(H) = nM$
$= 0.1573 \times 1.008$
$= 0.1586\ g$ **(1)**

$NH_{3\,(aq)} + HCl_{(aq)} \rightarrow NH_4Cl_{(aq)}$

$n(HCl) = cV$
$= 2 \times 0.00715$
$= 0.0143\ mol$

$n(NH_3) = n(HCl)$
$= 0.0143\ mol$ **(1)**

$n(N) = n(NH_3)$
$= 0.0143mol$ **(1)**

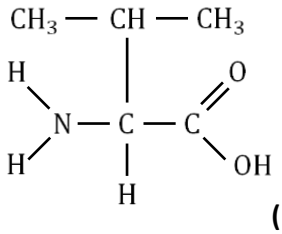
$m(N) = nM$
$= 0.0143 \times 14.01$
$= 0.2003g$

$m(O) = 0.7647 - m(C) - m(H) - m(N)$
$= 1.675 - 0.8588 - 0.1586 - 0.2003$
$= 0.4573g$ **(1)**

	C	H	N	O
Mass	$0.8588g$	$0.1586g$	$0.2003g$	$0.4573g$
Moles	$\frac{0.8588}{12.01} = 0.07151\ mol$	$\frac{0.1586}{1.008} = 0.1573\ mol$	$\frac{0.2003}{14.01} = 0.0143\ mol$	$\frac{0.4573}{16.00} = 0.02858\ mol$ **(1)**
Simple Ratio	$\frac{0.07151}{0.0143} = 5.001$	$\frac{0.1573}{0.0143} = 11$	$\frac{0.0143}{0.0143} = 1$	$\frac{0.02858}{0.0143} = 1.999$
Whole Ratio	5	11	1	2 **(1)**

∴ the empirical formula is $C_5H_{11}NO_2$ **(1)**

(b) The amino acid is **valine (1)**:



(1)

Valine (Val)

2.52 **[12 marks]**

(a) $Unknown\ Compound + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(g)}$

$m(CO_2) = 4.709g$ $m(H_2O) = 1.735g$

$n(CO_2) = \frac{4.709}{44.01}$
$= 0.1070\ mol$

$n(C) = n(CO_2)$
$= 0.1070\ mol$

$m(C) = nM$
$= 0.1070 \times 12.01$
$= 1.2851\ g$ **(1)**

$\%\ (C) = \frac{1.2851}{2.464} \times 100$
$= 52.16\%$ **(1)**

$n(H_2O) = \frac{1.735}{18.016}$
$= 0.0963\ mol$

$n(H) = n(H_2O) \times 2$
$= 0.0963 \times 2$
$= 0.1926\ mol$

$m(H) = nM$
$= 0.1926 \times 1.008$
$= 0.1941\ g$ **(1)**

$\%(H) = \frac{0.1941}{2.464} \times 100$
$= 7.88\%$ **(1)**

$n(HCl) = cV$
$= 1 \times 0.02140$
$= 0.03176\ mol$

$n(NH_3) = n(HCl)$
$= 0.03176\ mol$ **(1)**

$n(N) = n(NH_3)$
$= 0.03176\ mol$ **(1)**

$m(N) = nM$
$= 0.03176 \times 14.01$
$= 0.445g$

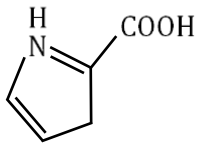
$\%(N) = \frac{0.445}{3.653} \times 100$
$= 12.18\%$ **(1)**

$\%(O) = 100 - \%(C) - \%(H) - \%(N)$
$= 100 - 52.16 - 7.88 - 12.18$
$= 27.78\%$ **(1)**

	C	H	N	O
Mass in $100g$	$52.16g$	$7.88g$	$12.18g$	$27.78g$
Moles	$\frac{52.16}{12.01} = 4.343\ mol$	$\frac{7.88}{1.008} = 7.817\ mol$	$\frac{12.18}{14.01} = 0.8693\ mol$	$\frac{27.78}{16.00} = 1.736\ mol$ **(1)**
Simple Ratio	$\frac{4.343}{0.8693} = 4.996$	$\frac{7.817}{0.8693} = 8.992$	$\frac{0.8693}{0.8693} = 1$	$\frac{1.736}{0.8693} = 1.997$
Whole Ratio	5	9	1	2 **(1)**

∴ the empirical formula is $C_5H_9NO_2$ **(1)**

(c) The amino acid is proline **(1)**



Proline (Pro)

2.53 **[8 marks]**

$$Unknown\ Compound + O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{(g)}$$

$m(CO_2) = 1.913g$ $m(H_2O) = 2.115g$

$$n(CO_2) = \frac{2.861}{44.01} = 0.06501\ mol$$

$$n(C) = n(CO_2) = 0.06501\ mol$$

$$m(C) = nM = 0.06501 \times 12.01 = 0.7808\ g \quad (1)$$

$$\%\,(C) = \frac{0.7808}{1.50} \times 100 = 52.05\% \quad (1)$$

$$n(H_2O) = \frac{2.115}{18.016} = 0.1174\ mol$$

$$n(H) = n(H_2O) \times 2 = 0.1174 \times 2 = 0.2348\ mol$$

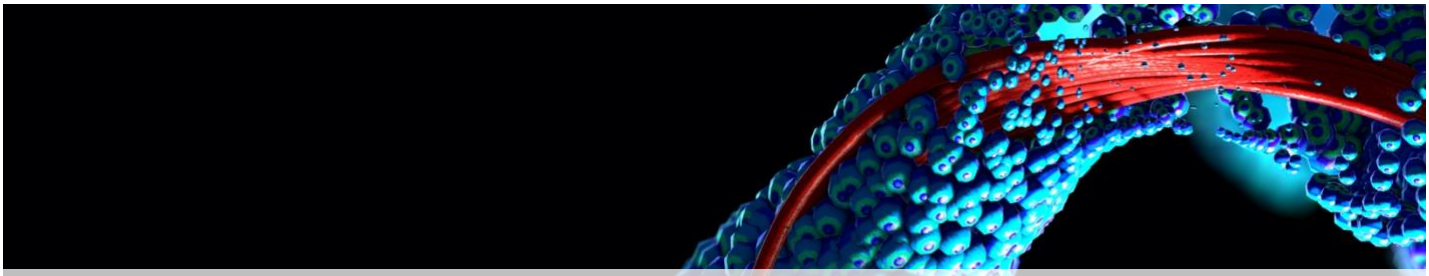
$$m(H) = nM = 0.2348 \times 1.008 = 0.2367\ g \quad (1)$$

$$\%(H) = \frac{0.2367}{1.80} \times 100 = 13.15\% \quad (1)$$

$$\%(O) = 100 - \%(C) - \%(H) = 100 - 52.05 - 13.15 = 34.80\% \quad (1)$$

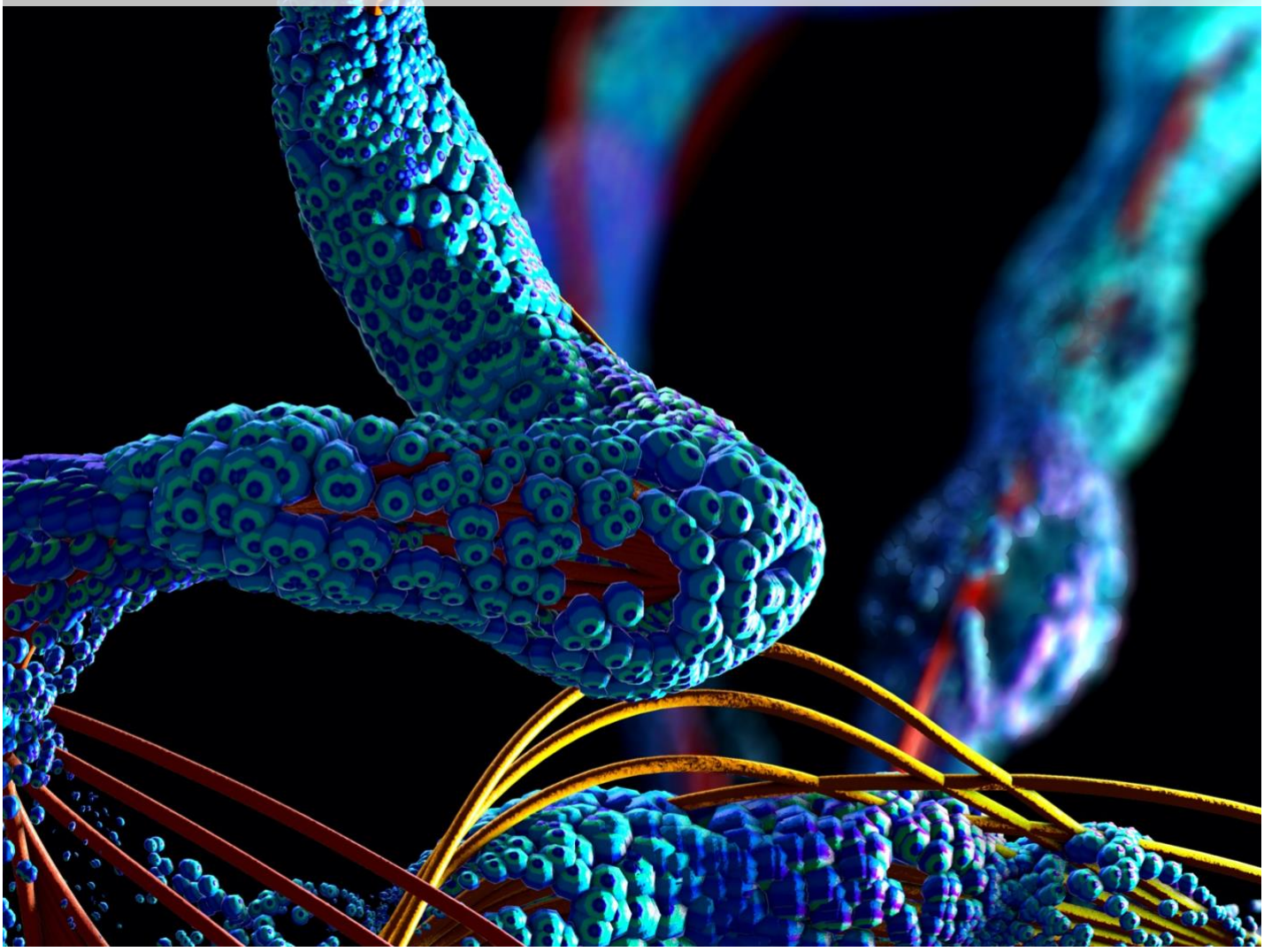
	C	H	O	
Mass in $100g$	52.05	13.15	34.80	
Moles	$\frac{52.05}{12.01} = 4.334\ mol$	$\frac{13.15}{1.008} = 13.046\ mol$	$\frac{34.80}{16.00} = 2.175\ mol$	**(1)**
Simple Ratio	$\frac{4.334}{2.175} = 1.9926$	$\frac{13.046}{2.175} = 5.998$	$\frac{2.175}{2.175} = 1.000$	
Whole Ratio	2	6	1	**(1)**

∴ the empirical formula is C_2H_6O **(1)**



Chapter 7

Polymers, Proteins and Soaps Answers



Problem Set 13 – Polymers, Proteins and Soaps Progressive Questions Answers

Concept 1

Polymers – Progressive Questions Answers

Addition and Condensation Polymerisation: Q1, Q2, Q3, Q4

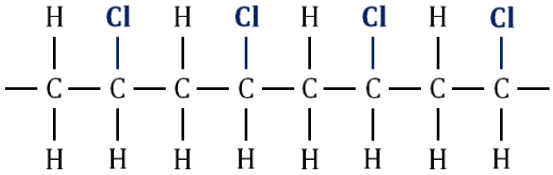
1. **[5 marks]**

(a) **Alkene functional group (1)**

Marking Criteria	Marks Allocated
• Alkene functional group or carbon-to-carbon double bond	1
Total	**1**

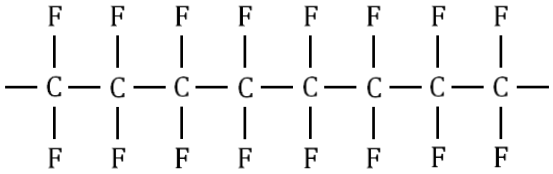
(b)

(i)



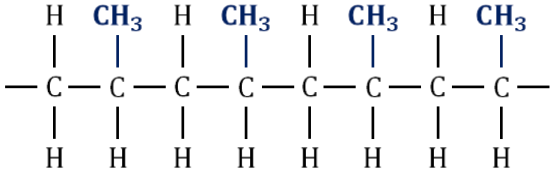
Polychloroethene (1)

(ii)



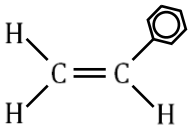
Polytetrafluoroethene (1)

(iii)



Polypropene (1)

(c)



(1)

Points to note: If the monomers have complicated names like this one, you won't be expected to write its name.

2. **[8 marks]**

(a) Some **differences** between addition and condensation polymerisation include but are not limited to:

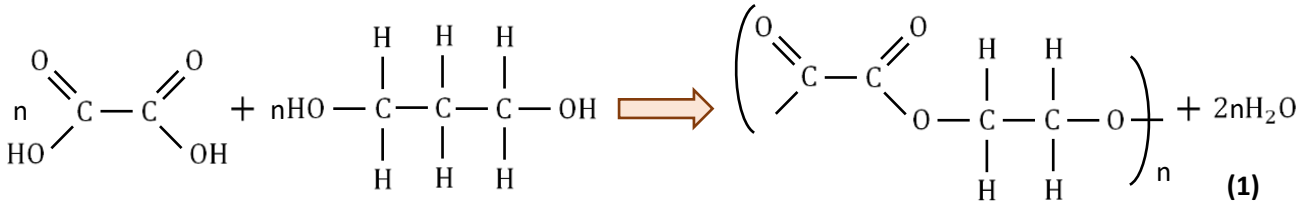
- **Addition polymerisation** uses a **single monomer**, **condensation polymerisation** uses **two different** of monomers **(1)**.
- **Addition polymerisation** has **no by-products**, **condensation polymerisation** reactions **water** as a by-product **(1)**.
- **Addition polymerisation** requires a **double bond** to be **broken**, **condensation polymerisation** requires **two functional groups** to **react** with one another **(1)**

Marking Criteria	Marks Allocated
• States three appropriate differences	1 – 3
Total	**3**

(b)

(i) **Cannot undergo** condensation polymerisation – chloroethene monomer is not appropriate **(1)**

(ii) **Can undergo** condensation polymerisation **(1)**

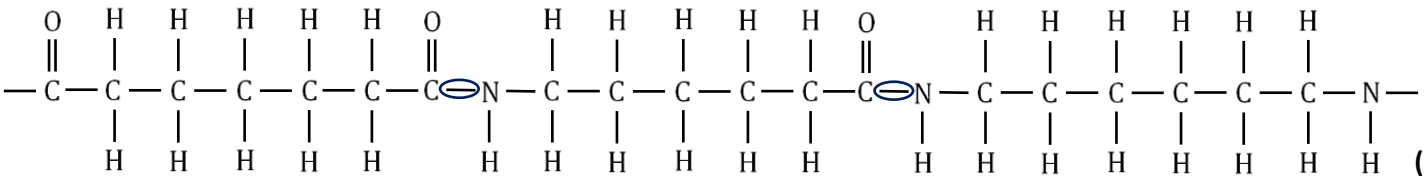


Ethanedioc acid Propandiol

(iii) **Cannot undergo** condensation polymerisation – ethene monomer is not appropriate **(1)**

Marking Criteria	Marks Allocated
• Correctly states whether condensation polymerisation can/cannot occur	1 – 3
Total	**3**

(c)



(1)

Monomers: Hexandioc acid and **1,6-hexandiamine** **(1)**

Marking Criteria	Marks Allocated
• Circles amide linkages • Monomers: hexandioc acid and 1,6-hexandiamine	1 – 2
Total	**2**

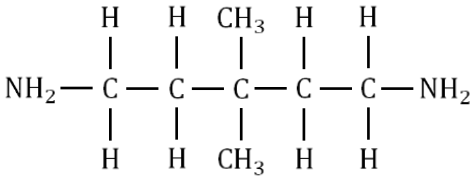
Point to note: Part 2(c) doesn'tactually work, but hopefully the process for determing the monomers is understood

3. **[11 marks]**

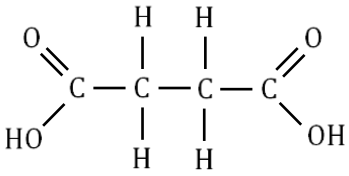
(a)

(i) **Condensation polymerisation (1)**

Monomers:



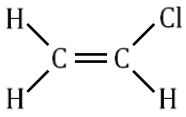
3,3-dimethyl-1,6-pentandiamine (1)



Butanedioc acid (1)

(ii) **Addition polymerisation (1)**

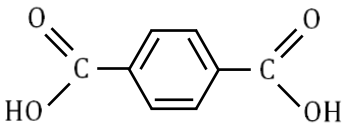
Monomers:



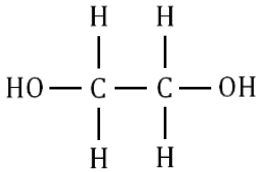
Chloroethene (1)

(iii) **Condensation polymerisation (1)**

Monomers:



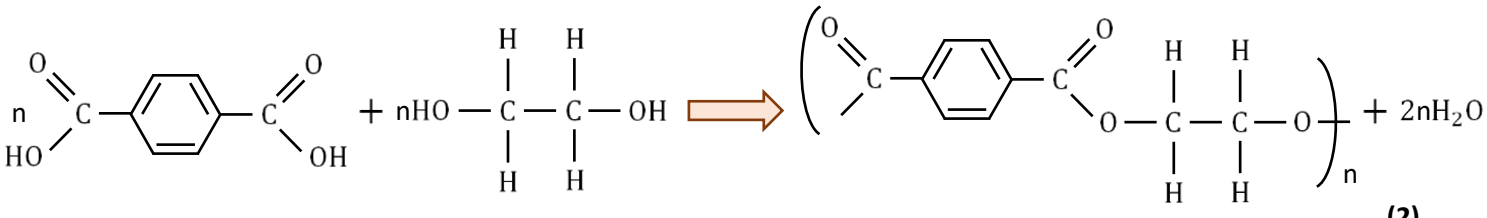
Benzene-1,4-dioic acid (1)



Ethandiol (1)

Marking Criteria	Marks Allocated
• Correct type of polymerisation stated	1 – 3
• Correct monomers drawn and named	1 – 5
Total	**8**

(b)

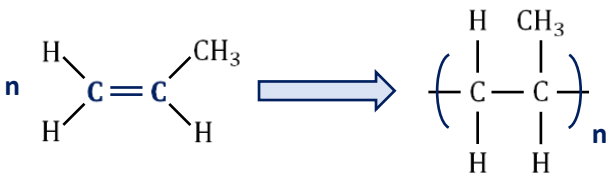


Benzenedioc acid **Ethanediol** **Polyethene terephthalate (PET)** **(2)**

Marking Criteria	Marks Allocated
• Draws correct reactants • Draws correct products • Equation balanced correctly (either using 'n' or actual numbers)	1 – 3
Total	**3**

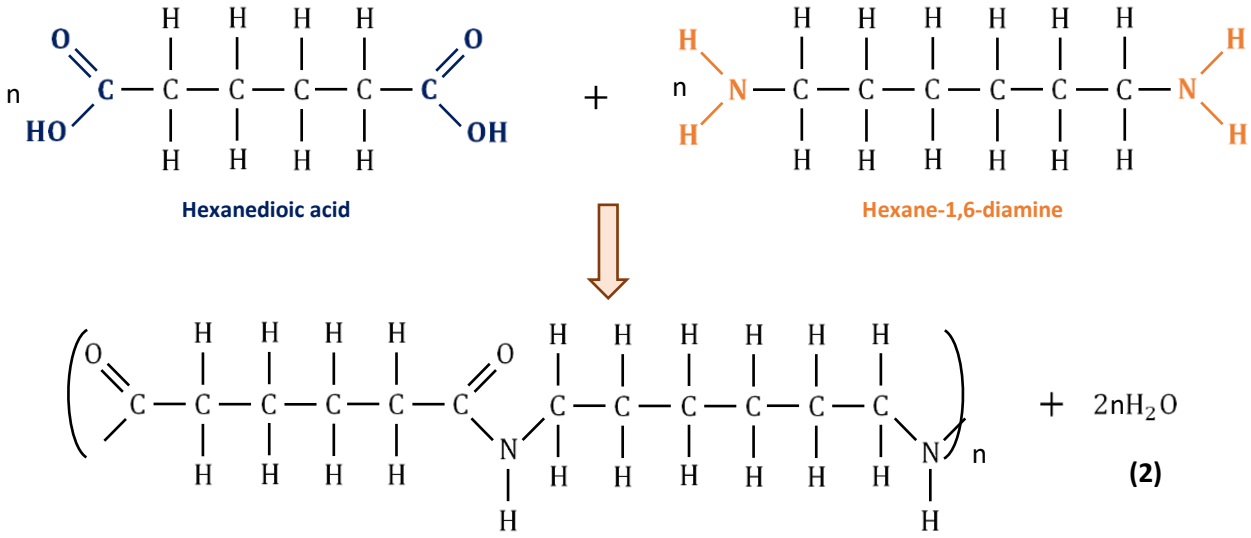
4. **[6 marks]**

(a)



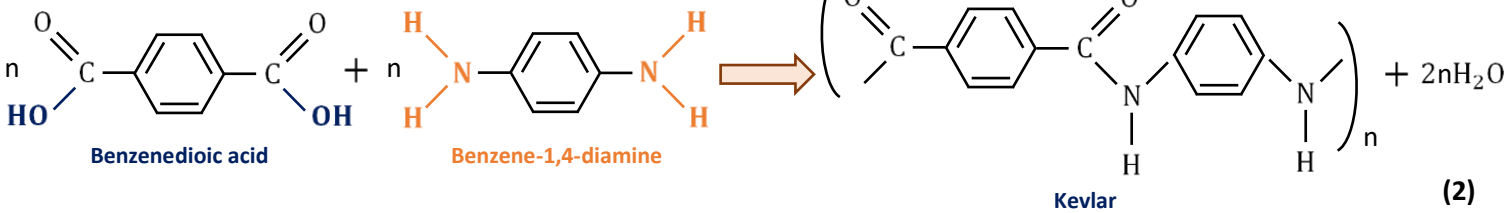
Propene **Polypropene** **(2)**

(b)



(2)

(c)

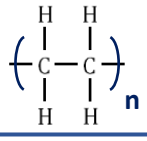
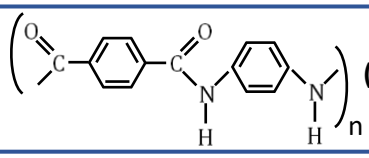
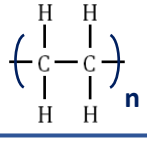
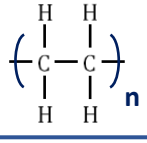
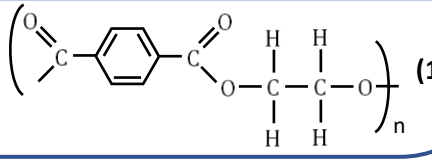


(2)

Marking Criteria	Marks Allocated
• Correct reactant and products drawn	1 – 3
• Equations balanced correctly	1 – 3
Total	**6**

Applications of Polymers: Q5, Q6, Q7, Q8

5. **[10 marks]**

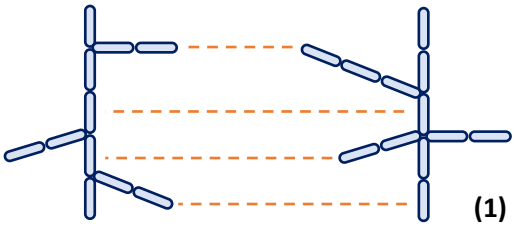
Requirement	Suggested Polymer	Polymer Structure
(i) Very high strength, low-friction material for joints	**Ultra-high molecular weight polyethene (1)**	 **(1)**
(ii) Ductile and high strength fibres for tendons to control fingers	**Nylon/Kevlar (1)**	**Kevlar:**  **(1)**
(iii) High density, low transparency material to form the bones	**High density polyethene (1)**	 **(1)**
(iv) Soft, flexible material to cover joints	**Low density polyethene (1)**	 **(1)**
(v) High strength material that can be heated and moulded for the skin layer	**Polyethene terephthalate (1)**	 **(1)**

Marking Criteria	Marks Allocated
• States correct polymer	$1-5$
• Draws appropriate polymer structure	$1-5$
Total	**10**

Points to note: For polyethene you can draw short, medium and long chains to show the different structures of polyethene instead.

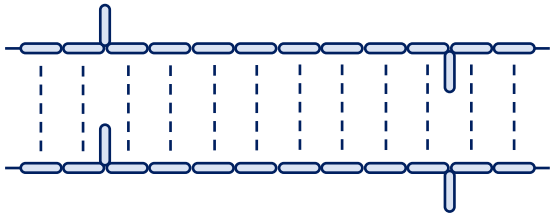
6. **[9 marks]**

(a) The **hardness** and **boiling point** of both **LDPE** and **HDPE** can be attributed to the **strength** of the **dispersion forces** between their molecules **(1)**. **LDPE** is **relatively weak** and has a **low boiling point**, due to the significant presence of **significant branching**, which means the LDPE molecules **pack less efficiently** and have **less surface area** for dispersion force interaction **(1)**. In contrast, HDPE has much **longer molecules** with **little branching** which means they have a **greater surface area** for dispersion force interaction **(1)**. As a result, HDPE has a higher boiling point and hardness because **more energy** is required to **separate** the molecules than in LDPE **(1)**.



(1)

Low Density Polyethene = Weak dispersion forces



(1)

High Density Polyethene = Moderately strong dispersion forces

Marking Criteria	Marks Allocated
• Hardness and boiling point are dependent on the strength of the intermolecular forces • LDPE has significant branching and therefore has a reduced surface area for dispersion force interaction • HDPE has long chains with little branching and therefore have a larger surface area for dispersion force interaction • HDPE has a higher hardness and boiling point because more energy is required to separate the molecules	$1-4$
• Appropriate LDPE diagram • Appropriate HDPE diagram	$1-2$
Total	**6**

(b) As the length of a polymer chain **increases**, the **dispersion forces** that between the molecules **increase** from there being **more electrons** to form temporary dipoles **(1)**. Its dispersion forces also become **stronger** from there being a **greater surface area** to allow for intermolecular interaction **(1)**. As a result as the **polymer chain length increases**, the polymers **strength increases** because **more energy** is required to **break apart** the molecules **(1)**.

Marking Criteria	Marks Allocated
• Dispersion forces increase with an increasing chain length from an increase in electrons being able to form temporary dipoes • Dispersion forces also increase with increasing chain length from there being a greater surface area for intermolecular interaction	$1-3$

• Strength increases with increasing chain length because more energy is required to break the intermolecular forces	
Total	**3**

7. **[4 marks]**

(a) **Covalent bonds (1)**

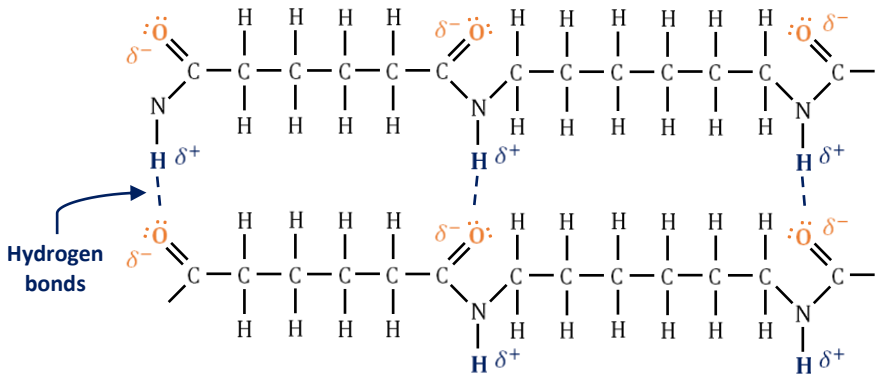
Marking Criteria	Marks Allocated
• Covalent bonds	1
Total	**1**

(b) In order for a polymer to be able to be heated and moulded, the molecules need to be able to be **shifted out of their locations** by applying force **(1)**. When there is **extensive cross-links** formed between the PET molecules these **strong covalent bonds lock** the molecules into place and **prevent** the PET from being **moulded without breaking (1)**. As a result, the cross-linking means that PET **cannot** be heated and moulded into the skin that needs to wrap around the joints **(1)**.

Marking Criteria	Marks Allocated
• Molecules need to be able to move to be moulded • Cross-linking locks the molecules into place and prevents the PET from being moulded without breaking • This means the PET cannot be heated and moulded to from the skin that wraps around the joints	1 – 3
Total	**3**

8. **[4 marks]**

The polymer Jamie is using would be **nylon** or **Kevlar (1)**. As shown in the diagram below, nylon and Kevlar form **strong hydrogen bonds** between their chains **(1)**. This **hydrogen bonding** significantly increases the **strength** of nylon whilst still leaving it ductile, making it suitable to be **drawn** into **fibres** for the tendons **(1)**.



(1)

Extensive hydrogen bonding = Very strong nylon fibres

Marking Criteria	Marks Allocated
• Nylon or Kevlar could be used • Nylon and Kevlar form many hydrogen bonds • These hydrogen bonds make it strong but ductile, making it suitable for the tendons	1 – 3
• Appropriate diagram drawn	1
Total	**4**

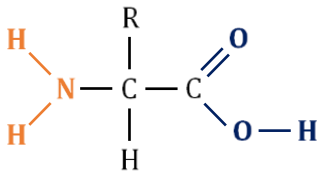
Concept 2

Proteins – Progressive Questions Answers

Addition and Condensation Polymerisation: Q1, Q2, Q3, Q4

1. **[8 marks]**

(a)

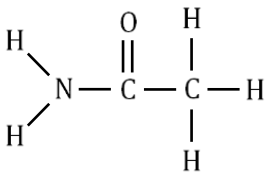
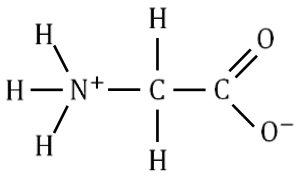
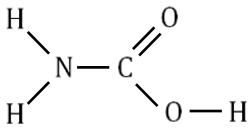
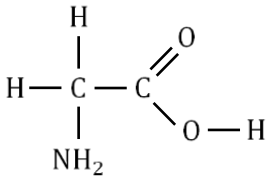
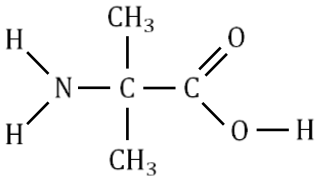
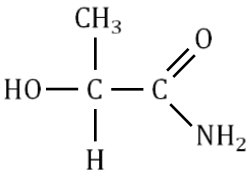


General Structure for α-amino acid

(2)

Marking Criteria	Marks Allocated
• Draws α-amino acid structure • Draws R group	$1-2$
Total	**2**

(b)

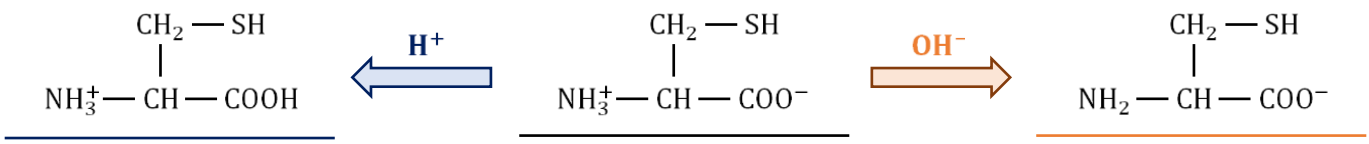
(i)  α –amino acid/not α –amino acid	(ii)  α –amino acid/not α –amino acid	(iii)  α –amino acid/not α –amino acid
(iv)  α –amino acid/not α –amino acid	(v)  α –amino acid/not α –amino acid	(vi)  α –amino acid/not α –amino acid

Marking Criteria	Marks Allocated
• Circles correct option	$1-6$
Total	**6**

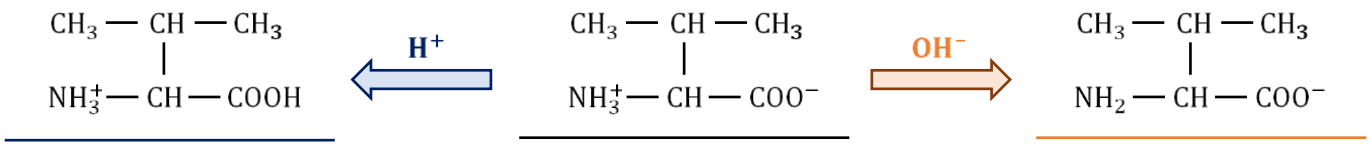
2. **[18 marks]**

(a)

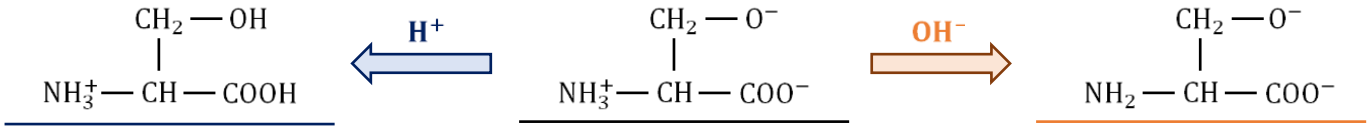
(i)



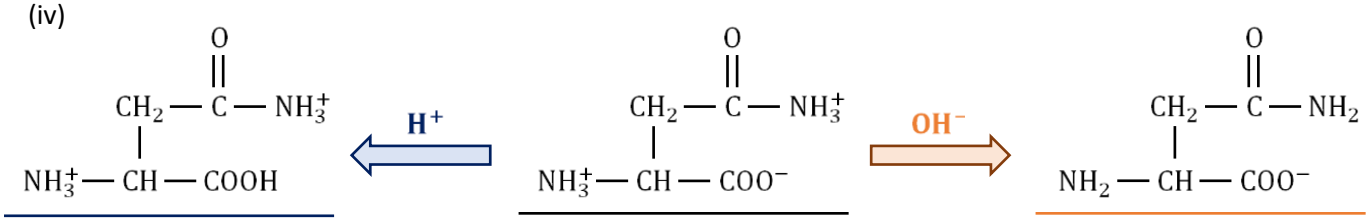
(ii)



(iii)



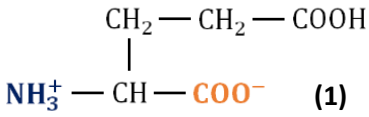
(iv)



Marking Criteria	Marks Allocated
• Draws correct acidic form	$1-4$
• Draws correct neutral form	$1-4$
• Draws correct basic form	$1-4$
Total	**12**

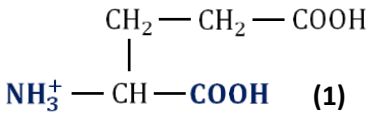
(b)

(i)



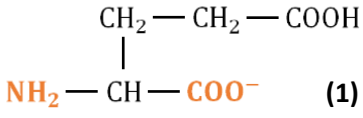
(1)

(ii)



(1)

(iii)



(1)

(c) α-amino acid naturally occur in their **zwitterion form** when in solution **(1)**. As a result, they form **strong ionic bonds** with other amino acids to create a **crystalline solid (1)**. These **strong ionic bonds** require a much **larger amount of heat energy** than the **intermolecular forces** between similar sized organic molecules, thus giving α-amino acid **higher boiling points (1)**.

Marking Criteria	Marks Allocated
• α-amino acids are naturally in their zwitterion form • They form strong ionic bonds • These strong ionic bonds require more heat energy than intermolecular forces, giving α-amino acids higher boiling points	$1-3$
Total	**3**

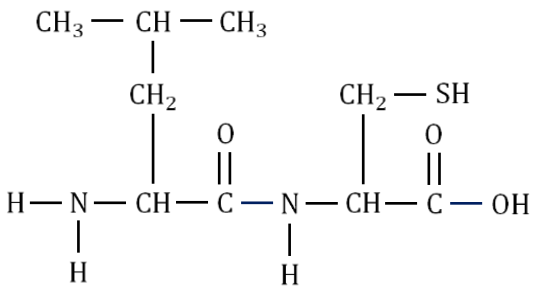
3. **[12 marks]**

(a) The **two products** are: **polypeptides** and **water**. **(2)**

Marking Criteria	Marks Allocated
• Polypeptides • Water	1 – 2
Total	**2**

(b)

(i)

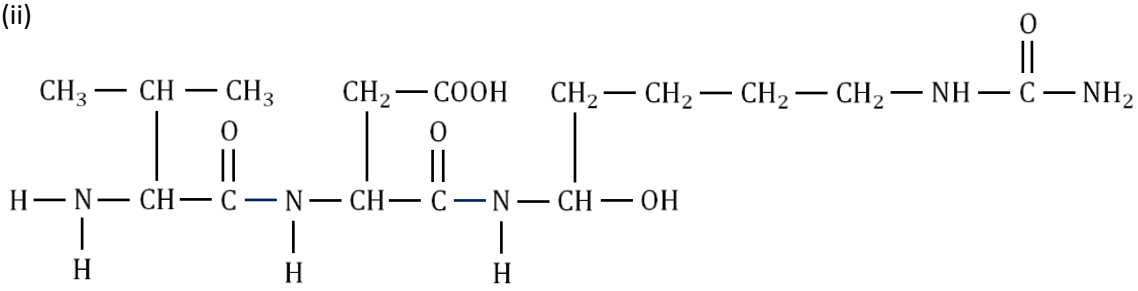


+ H_2O

(2)

Leu-Cys

(ii)

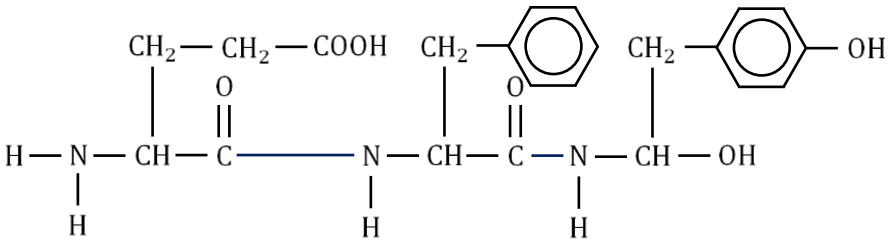


+ $2H_2O$

(2)

Val-Asp-Arg

(iii)

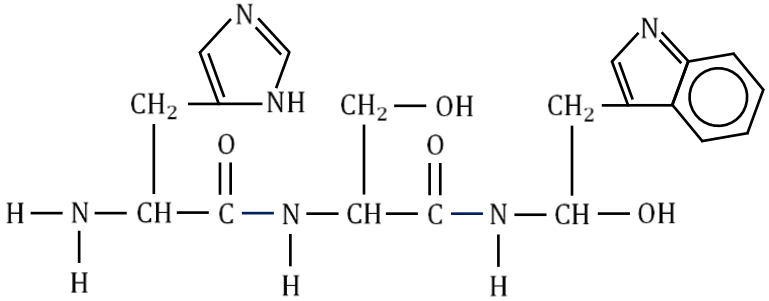


+ $2H_2O$

(2)

Glu-Phe-Tyr

(iv)

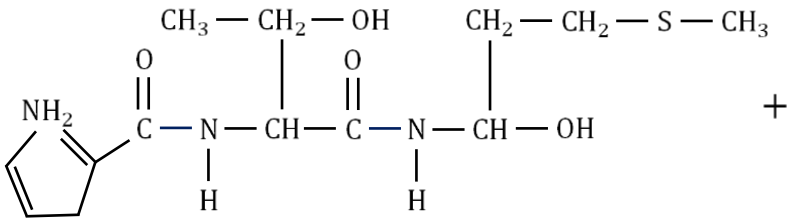


+ $2H_2O$

(2)

His-Ser-Tyr

(v)



$+ \quad 2H_2O$

(2)

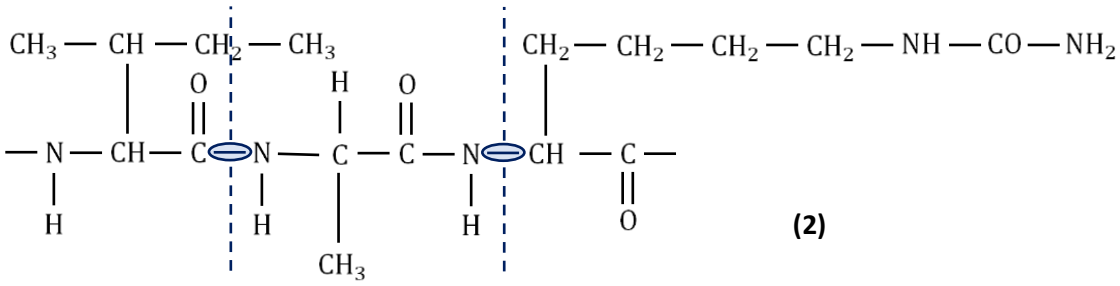
Pro-Thr-Met

Marking Criteria	Marks Allocated
• Draws correct polymer structure	1 – 5
• Includes water molecules and provides correct name	1 – 5
Total	**10**

4. **[6 marks]**

(a)

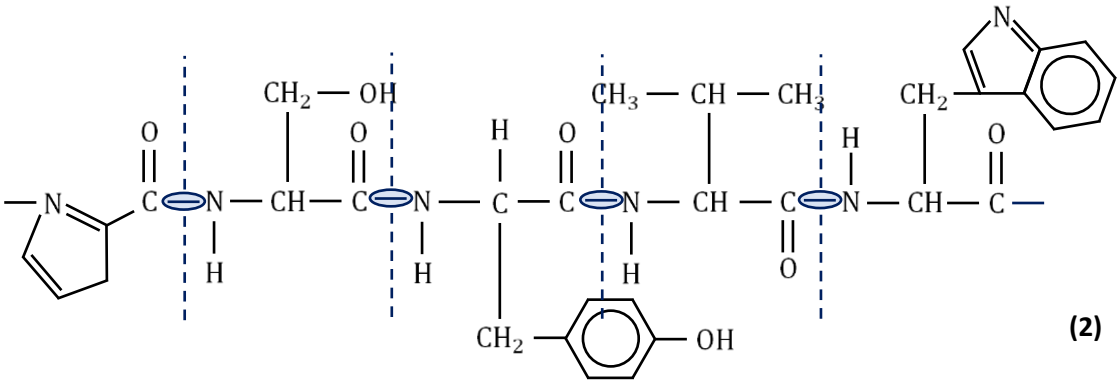
(i)



(2)

Isoleucine **Alanine** **N/A (not a real monomer)**

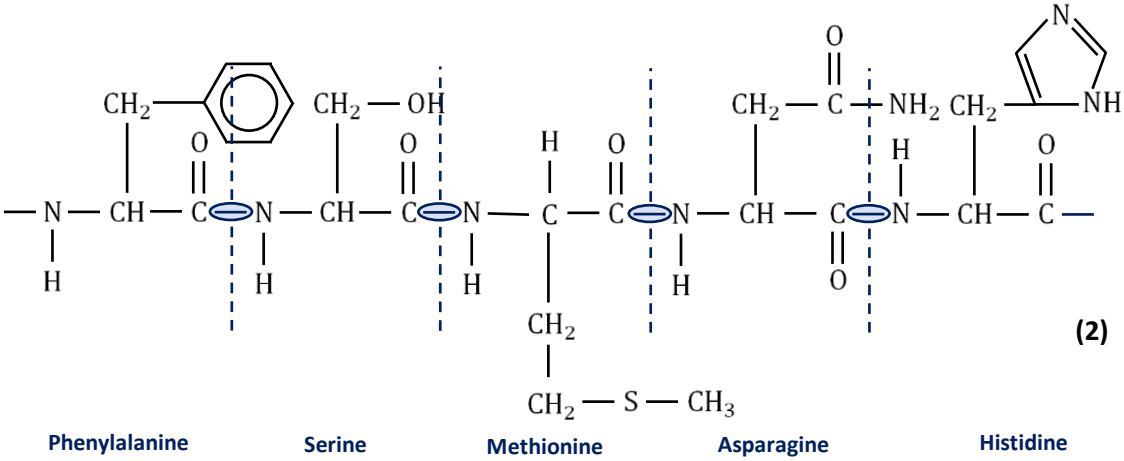
(ii)



(2)

Proline **Serine** **Tyrosine** **Valine** **Tryptophan**

(iii)



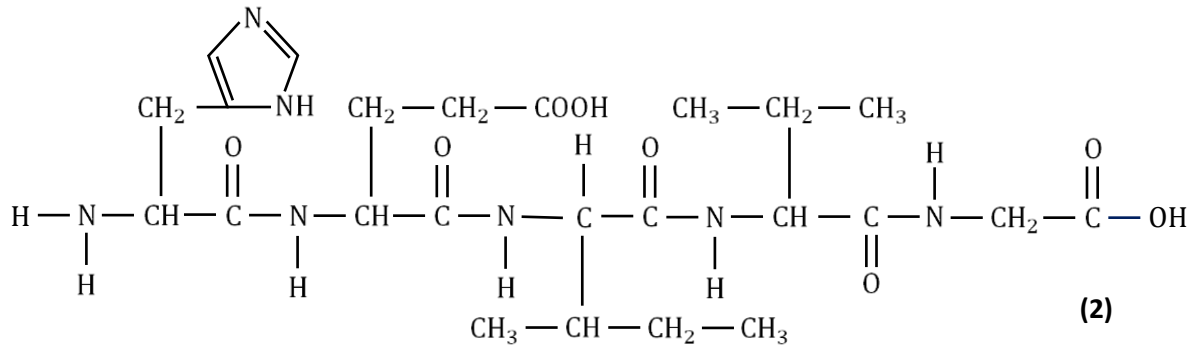
(2)

Phenylalanine **Serine** **Methionine** **Asparagine** **Histidine**

5. **[11 marks]**

(a)

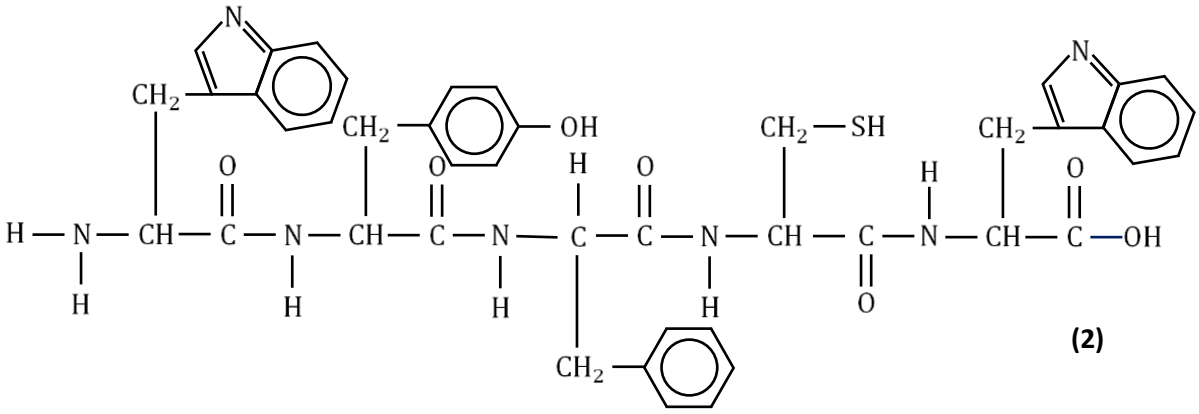
(i)



(2)

His-Glu-Iso-Ala-Val-Gly

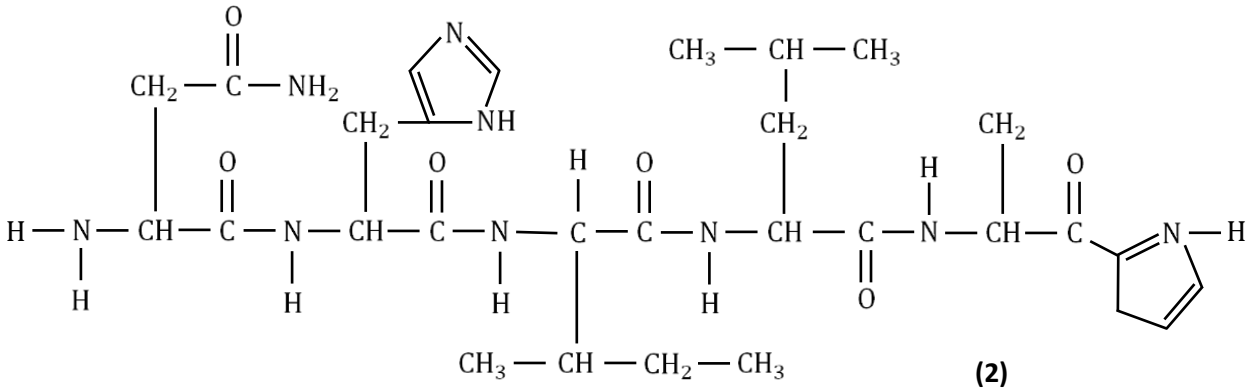
(ii)



(2)

Trp-Tyr-Phe-Cys-Trp

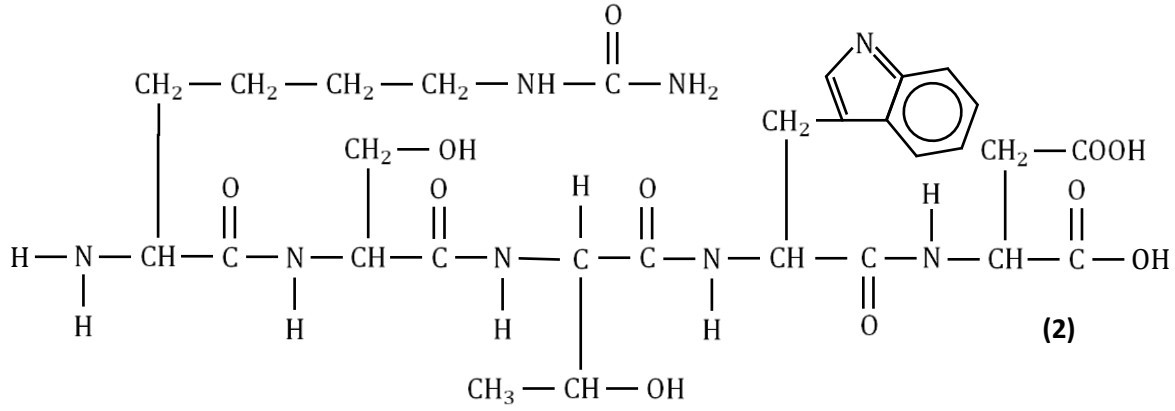
(iii)



(2)

Asn-His-Iso-Leu-Pro

(iv)



(2)

Arg-Ser-Thr-Trp-Asp

(b) Joining five monomers requires **four peptide linkages**, so **four moles** of water are produced.

$$n(H_2O) = 4\ mol \quad \textbf{(1)}$$

$$\begin{aligned} m(H_2O) &= nM \\ &= 4 \times (2.016 + 16) \\ m(H_2O) &= 72.064g \end{aligned} \quad \textbf{(2)}$$

Proteins Structure and Function: Q6, Q7, Q8, Q9, Q10

6. **[8 marks]**

(a) The **primary structure** of a protein refers to the **sequence** of **amino acids** that are present within a protein **(1)**. The primary structure is important, because the identity and order of the amino acids will determine the **interactions** that occur between the **side chains** of the amino acids **(1)**, which will determine the **overall shape** of the protein **(1)**. The **shape** of a protein is what determines its **function**, so the primary structure is crucial in determining the function of the protein **(1)**

Marking Criteria	Marks Allocated
• Primary structure is the sequence of amino acids • The sequence of amino acids determines the interactions between side chains in the protein • The interactions determine the shape of the protein • The shape of the protein determines the protein's function, so the primary structure determines the function	$1-4$
Total	**4**

(b) The sequence begins from the end with the **amine group**. **(1)**

Marking Criteria	Marks Allocated
• Amine/NH_2 group	1
Total	**1**

(c) Trp-Tyr-Phe-Cys-Trp-Asn-His-Ile-Leu-Pro-His-Glu-Ile-Ala-Val-Gly-Arg-Ser-Thr-Trp-Asp **(3)**

Marking Criteria	Marks Allocated
• Correctly writes sequence (deduct one mark for each error)	$1-3$
Total	**3**

7. **[4 marks]**

(a) The secondary structure of a protein refers to the **hydrogen bonding** between the **polar** $\mathbf{C=O}$ and $\mathbf{N-H}$ groups in the backbone of the protein, forming either **an alpha (α) helix structure** or **beta (β) pleated sheets** **(1)**. These interactions lead to proteins having **different shapes**, which affects its **function**. **(1)**

Marking Criteria	Marks Allocated
• Secondary structure is the hydrogen bonding in the backbone of the protein, forming α-helix structure or β-pleated sheets • This affects the shape of the protein and therefore its function	$1-2$
Total	**2**

(b) **Hydrogen bonding (1)**, between the **polar C = O** and **N – H** groups in the **backbone** of the polypeptides (in the **peptide linkages** themselves). **(1)**

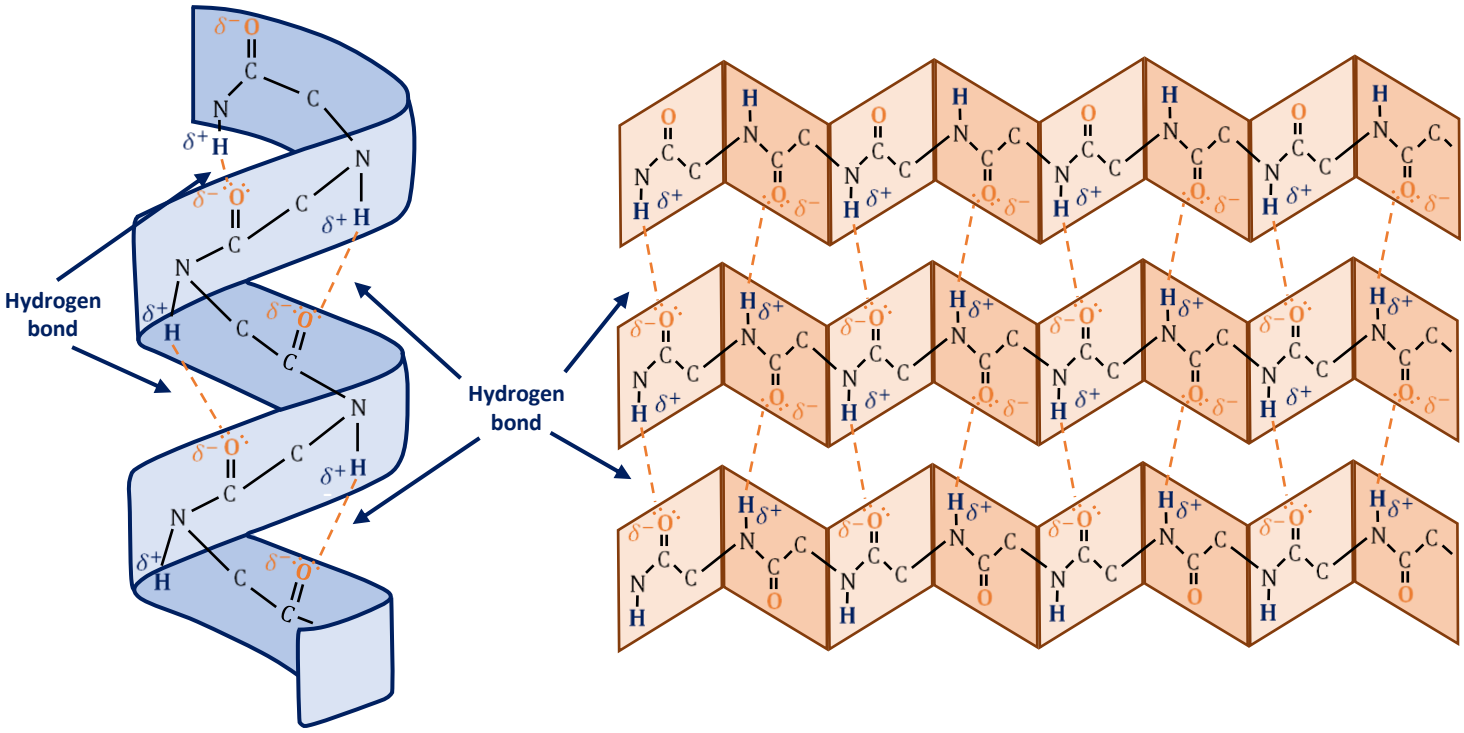
Marking Criteria	Marks Allocated
• Secondary structure is the hydrogen bonding in the backbone of the protein, forming α-helix structure or β-pleated sheets • This affects the shape of the protein and therefore its function	1 – 2
Total	**2**

8. **[6 marks]**

(a) The **α-helix structure** form due to **hydrogen bonds** between **C = O** and **N – H** groups in the **same peptide chain (1)**, whereas **β-pleated sheets** result from hydrogen bonds between **C = O** and **N – H** groups in **different peptide chains (1)**.

Marking Criteria	Marks Allocated
• α-helix structure occur from hydrogen bonds in the same peptide chains • β-pleated sheets occur from hydrogen bonds in different peptide chains	1 – 2
Total	**2**

(b) **α-Helix Structure** **β-pleated Sheets**



Marking Criteria	Marks Allocated
• Sketches hydrogen bonds in both scenarios	1 – 2
• Labels hydrogen bonds • Draws general protein backbone structure	1 – 2
Total	**4**

9. **[13 marks]**

(a) The **tertiary structure** of a protein refers to the **overall three-dimensional shape** of a protein **(1)**, which is dependent on the different **types** of **interactions** that occur between the **side chains** **(1)**. The **shape** of the protein determines the **function** of the protein, so the tertiary structure determines the function of a protein **(1)**

Marking Criteria	Marks Allocated
• Tertiary structure refers to the overall three dimensional shape of the protein • This is dependent on the interactions between side chains • The 3D shape determines the function of the protein, so tertiary structure determines the function of the protein	$1-3$
Total	**3**

(b) The types of bonding that can occur are:

- **Dispersion forces**
- **Dipole-dipole forces**
- **Hydrogen bonding**
- **Disulfide bridges**
- **Ionic bonding**

Marking Criteria	Marks Allocated
• Dispersion forces, dipole-dipole forces, hydrogen bonding, disulfide bridges and ionic bonding	$1-5$
Total	**5**

(c)

Interaction	Type of Interaction
A	**Dispersion forces (1)**
B	**Ionic bonding (1)**
C	**Disulfide bridge (1)**
D	**Hydrogen bonding (1)**
E	**Dipole-dipole forces (1)**

Marking Criteria	Marks Allocated
• States correct type of interaction	$1-5$
Total	**5**

10. **[21 marks]**

(a)

(i) **Disulfide bridges**, **dipole-dipole forces**, **dispersion forces** **(1)**

(ii) **Hydrogen bonding**, **dipole-dipole forces**, **dispersion forces** (*also accept ionic bonding if they assume zwitterion form) **(1)**

(iii) **Dispersion forces** **(1)**

(iv) **Hydrogen bonding**, **dipole-dipole forces**, **dispersion forces** **(1)**

(v) **Dispersion forces** **(1)**

(vi) **Dispersion forces** (*also accept no interactions because no side chains) **(1)**

(vii) **Hydrogen bonding**, **dipole-dipole forces**, **dispersion forces** (*also accept ionic bonding if they assume zwitterion form) **(1)**

(viii) **Dipole-dipole forces**, **dispersion forces** **(1)**

Marking Criteria	Marks Allocated
• States correct types of interactions	$1-8$
Total	**8**

(b) The replacement of all the Glycine residues with Asparagine will mean that **hydrogen bonding** and **dipole-dipole interactions** will now also be able to form at these side chains **(1)**. When added to water, **more energy** will be released from the **solute-solvent** interactions to **break** the **solute-solute** and **solvent-solvent** interactions **(1)**. Therefore, protein F will now be **more soluble** in water **(1)**.

Marking Criteria	Marks Allocated
• Hydrogen bonds and dipole-dipole forces will now also be formed at these side chains • More energy will be released from the solute-solvent interactions to break the solute-solute and solvent-solvent intearctions • Protein F will be more soluble in water	$1-8$
Total	**8**

(c) Changing the **primary structure** of a protein **changes** the **sequence of amino acids** in the chain **(1)**, which alters the **type** and **strength** of the **side chain interactions** that occurs within the protein molecules **(1)**. This can be seen through the change made in part (b), where **replacing glycine** with **asparagine** means the side chains now form **dipole-dipole forces** and **hydrogen bonds** making the **interactions stronger** **(1)**. Stronger side-chain interactions require **more heat energy** to be broken, thus giving it a **higher boiling point** **(1)**.

Marking Criteria	Marks Allocated
• Altering the primary structure changes the amino acid sequence • This affects the type and strength side chain interactions • Refers to part (b) and explains how side chain intermolecular forces change • Explains how changing the intermolecular interactions affects the boiling point by requiring more/less energy to break them	$1-4$
Total	**4**

(d) The **Protein Data Bank** is a **worldwide**, **free** and updated **database** **(1)** that allows scientists worldwide to **view** a protein's structure **(1)**. It informs users about **primary**, **secondary** and **tertiary** protein structure **(1)**.

Marking Criteria	Marks Allocated
• The Protein Data Bank is a world wide database with all the recorded protein structures • It allows scientists to view different protein structures • Includes the primary, secondary and tertiary structures	$1-3$
Total	**3**

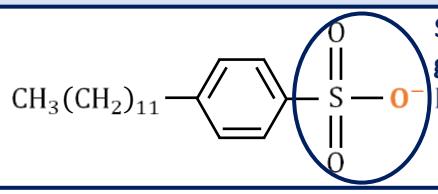
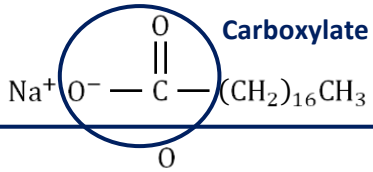
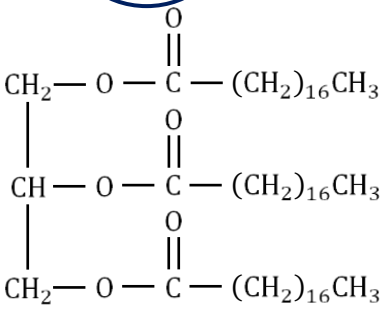
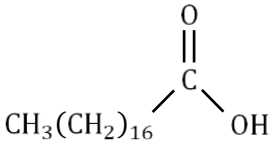
Concept 3

Soaps and Detergents - Progressive Questions Answers

Soaps and Detergents: Q1, Q2, Q3, Q4, Q5, Q6

Repetitive: 1.1 → 1.2 (3 questions)

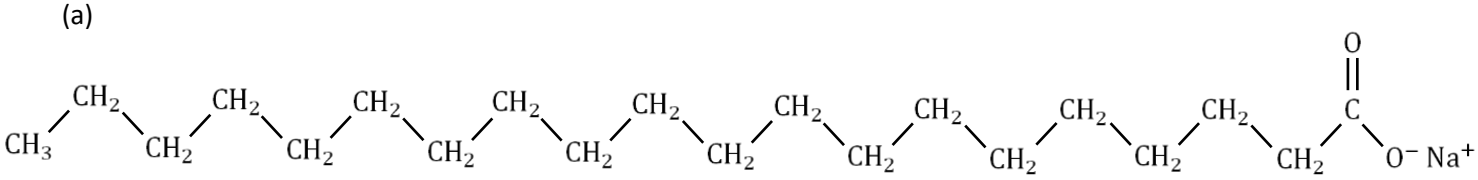
1. **[6 marks]**

Compound shown on bottle	Compound Type (e.g. soap, detergent etc.)
 **Sulfonate group (1)**	**Detergent (1)**
 **Carboxylate group (1)**	**Soap (1)**
	**Triglyceride (1)**
	**Fatty acid (1)**

Marking Criteria	Marks Allocated
• Correctly identifies compound	1 – 4
• Circles carboxylate and sulfonate groups on soap and detergent	1 – 2
Total	**6**

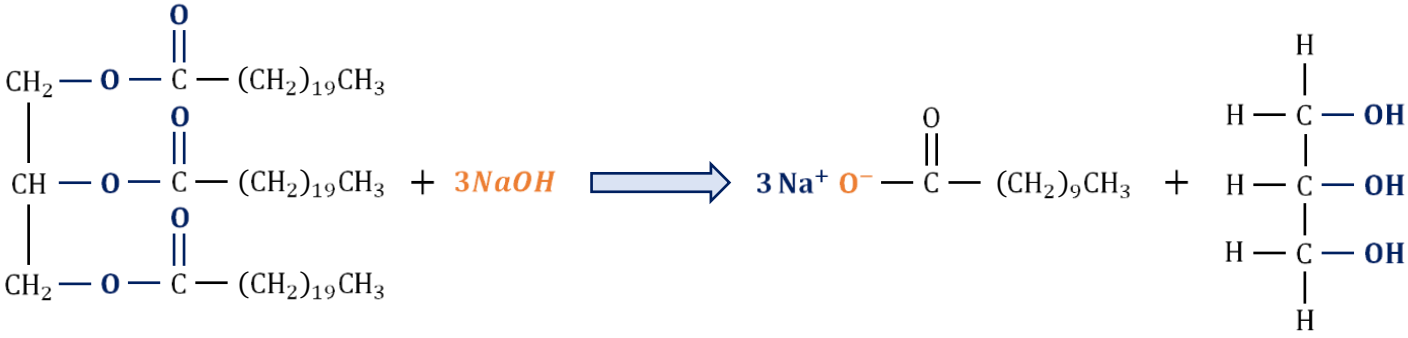
2. **[4 marks]**

(a)



Marking Criteria	Marks Allocated
• Draws correct structure of arachidic acid	1 – 2
Total	**2**

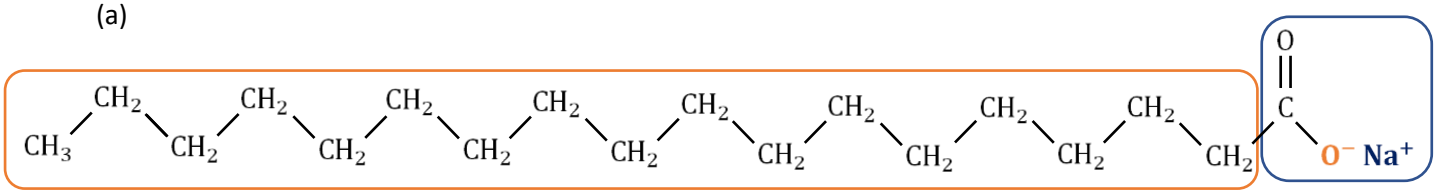
(b)



Marking Criteria	Marks Allocated
• Draws correct structure of reactants and products	1 – 2
Total	**2**

3. **[13 marks]**

(a)



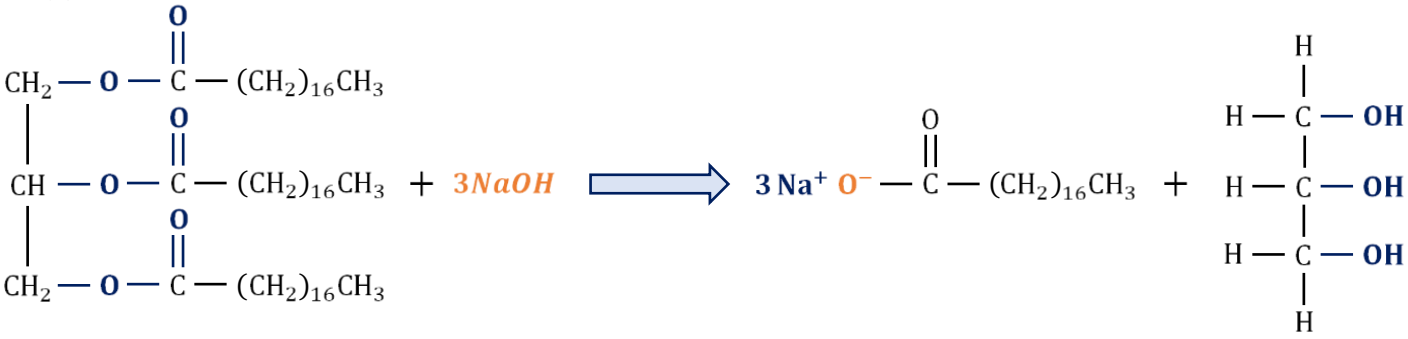
Non-polar tail **Polar head**

Marking Criteria	Marks Allocated
• Circles non-polar tai and polar head	1 – 2
Total	**2**

(b) When there is a **grease stain**, the **soap micelle positions itself around** the **grease stain** **(1)**. The **ionic polar head** remains on the outside, being **dissolved** in the **water** from **forming strong hydrogen bonds** **(1)** and **ion-dipole forces** **(1)**. The non-polar tail dissolves in the grease stain because they are both **large hydrocarbons** with **similar sized dispersion forces** **(1)**. Vigorous **agitation** of the mixture allows the micelles to be **released** from the object **(1)**. Once released, the grease particles are in a **stable micelle arrangement**, allowing them to be **suspended** in the **water** and can be **washed away** **(1)**.

Marking Criteria	Marks Allocated
• Soap forms a micelle arrangement around the grease stain • The ionic polar head forms strong hydrogen bonds with water (allowing it to dissolve) • The ionic polar head also forms ion-dipole forces with water (allowing it to dissolve) • The non-polar tail forms dispersion forces with the grease stain (allowing it to dissolve) • Agitation releases the mixture from the object • The grease and soap are in a micelle arrangement, allowing it to be suspended in water and washed away	1 – 6
Total	**8**

(c)



Triglyceride **Sodium hydroxide** **Soap (sodium stearate)** **Glycerol**

Marking Criteria	Marks Allocated
• Draws correct structure of reactants and products	1 – 2
Total	**2**

(d) Soaps are made of sodium stearate ions, which the **loosely bonded sodium ion** is removed when the soap is **dissolved** in solution **(1)**. This leaves an O^- **ion** which **accepts** a H^+ **ion** from water, acting as a **Brønsted-Lowry base (1)**. This **decrease** in the H^+ **concentration**, **decreases** the **pH** of the solution and makes it **basic (1)**

Marking Criteria	Marks Allocated
• Sodium ion is removed when soap is dissolved in water • O^- ion accepts a H^+ ion from water, acting as a Brønsted-Lowry base • The decrease in the H^+ concentration, makes the solution basic	1 – 3
Total	**3**

4. **[7 marks]**

(a) Hard water is water that contains Ca^{2+} and Mg^{2+} **ions** in **high concentrations (1)**. When soap is used in hard water it will **precipitate** with these ions (e.g. $Ca^{2+}_{(aq)} + 2CH_3(CH_2)_{16}COO^-_{(aq)} \rightarrow Ca(CH_3(CH_2)_{16}COO)_{2\,(s)}$) **(1).** This **scum** means that the soap is **wasted** so it **does not clean** as **effectively (1).**

Marking Criteria	Marks Allocated
• Hard water is water that contains Ca^{2+} and Mg^{2+} ions in high concentrations • The soap will precipitate with these ions • The scum formed means soap is wasted so it doesn't clean as effectively	1 – 3
Total	**3**

(b) Detergents are a synthetic alternative to soaps **(1)**. Detergents are **different** to soaps in the following ways:

- Has a **sulfonate head** rather than carboxylate head **(1)**
- Has a **benzene group** in the non-polar tail **(1)**
- **Do not form precipitates** in hard water **(1)**
- Are **produced synthetically (1)**

Marking Criteria	Marks Allocated
• Appropriate definition of detergents	1
• States three differences	1 – 3
Total	**4**

Problem Set 13 – Polymer, Proteins and Soaps
Repetitive Questions

Concept 1

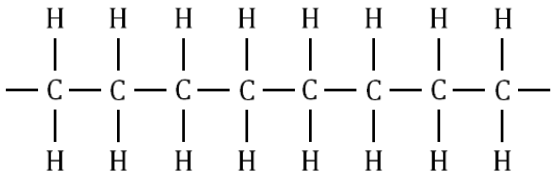
Polymers – Repetitive Questions Answers

Addition and Condensation Polymerisation: Qs 1.11, 1.31

1.11 **[7 marks]**

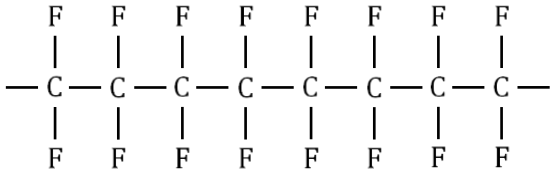
(a)

(i)



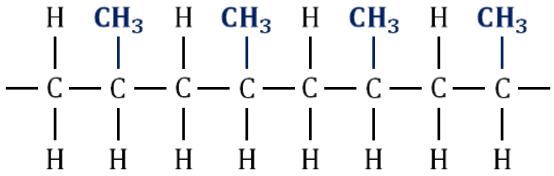
Polyethene (1)

(ii)



Polytetrafluoroethene (1)

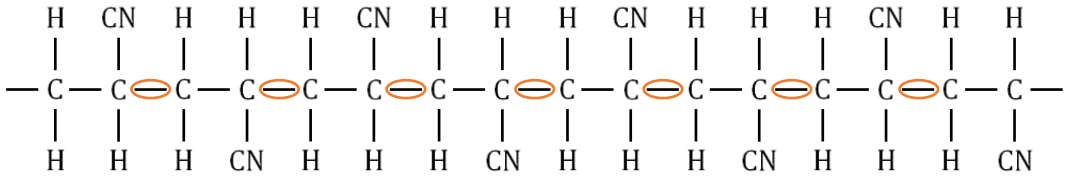
(iii)



Polypropene (1)

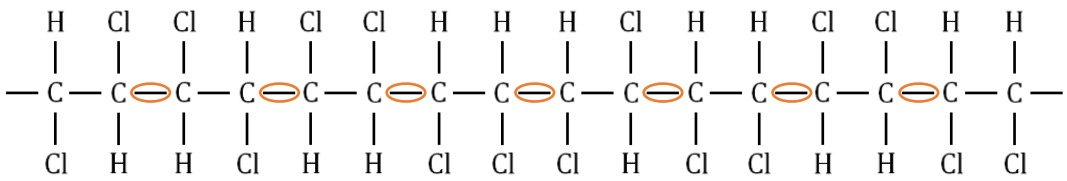
(b)

(i) Monomer: **Cyanoethene (1)**



(1)

(ii) Monomer: **1,2-dichloroethene (1)**



(1)

Marking Criteria	Marks Allocated
• Monomer linkages circled • Correct monomer name	1 – 2
Total	**2**

1.31 **[7 marks]**

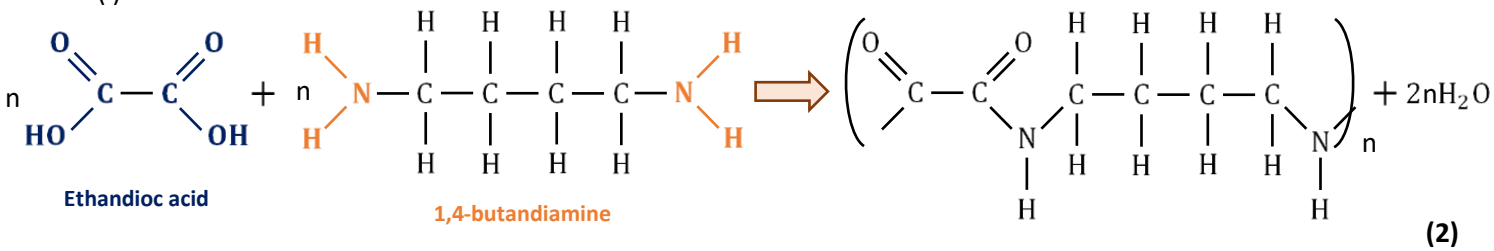
(a) **Polyesters** have are formed from a **diol** and **dicarboxylic acid**, whereas **polyamides** are formed from a **diamine** and **dicarboxylic acid** **(1)**.

Marking Criteria	Marks Allocated
• Polyesters are formed from diol and dicarboxylic acid, polyamides are formed from diamine and dicarboxylic acid (or other appropriate difference)	1
Total	**1**

Points to note: Other appropriate differences can be said such as polyesters have an ester linkage whereas polyamides have an amide linkage.

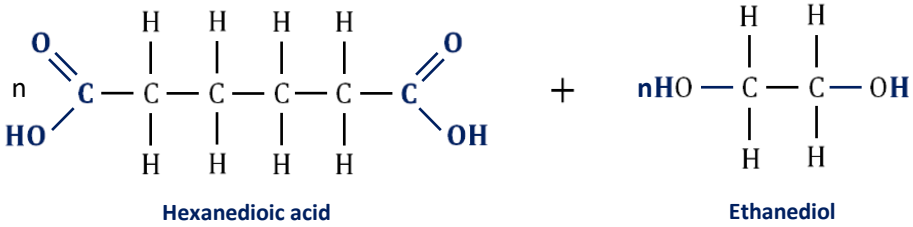
(b)

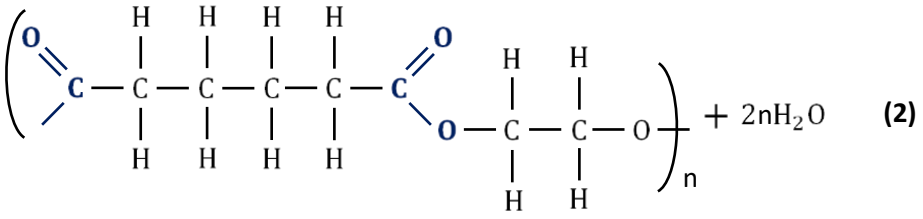
(i)



(2)

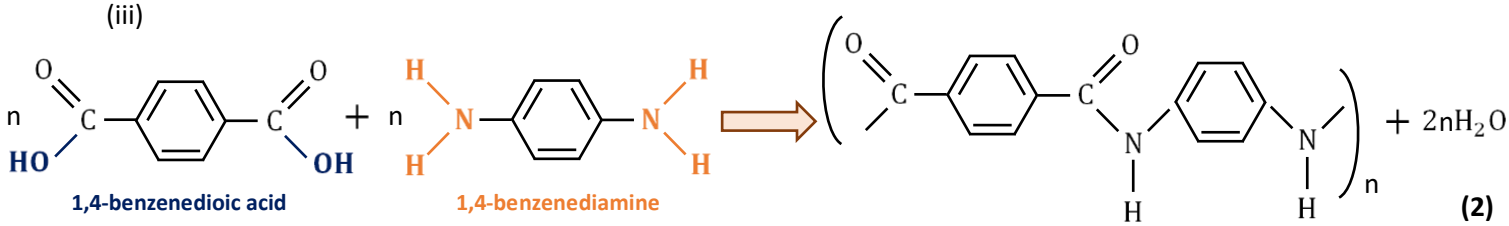
(ii)





(2)

(iii)

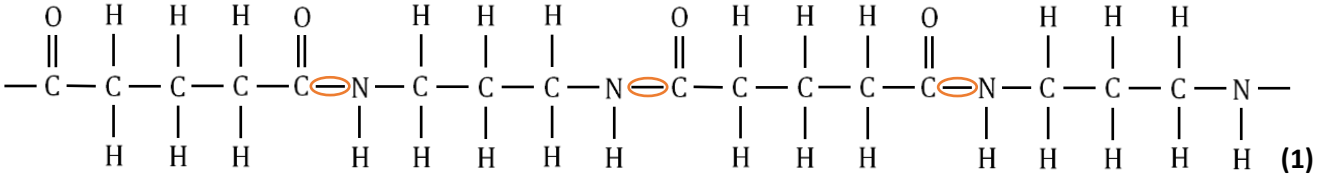


(2)

Marking Criteria	Marks Allocated
• Correct reactants and products drawn	1 – 3
• Equation balanced	1 – 3
Total	**6**

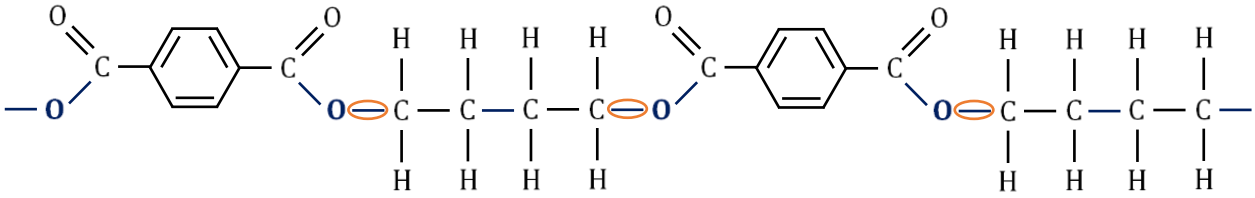
(c)

(i) Monomers: **Pentanedioc acid** and **1,3-propanediamine** **(1)**



(1)

(ii) Monomers: **1,4-benzenedioc acid** and **1,4-butanediol** **(1)**



(1)

Applications of Polymers: Qs 1.51, 1.61, 1.71

1.51 **[10 marks]**

Polymer	Property and how its structure links to this	Application
Teflon/Polytetrafluoroethene	Chemically inert/low friction from having highly electronegative fluorine atoms **(1)**	Non-stick coatings on pans **(1)**
Polyethylene terephthalate	High strength from strong dipole-dipole forces and dispersion forces **(1)**	Fibres in clothing **(1)**
Ultra-high molecular weight polyethene (UHMWPE)	Very high strength/hardness from long chains creating very strong dispersion forces **(1)**	Bearings for hip and knee replacements **(1)**
Nylon	High strength/ductility from strong hydrogen bonds formed between molecules **(1)**	Sails, parachutes, tents **(1)**
Low density polyethene	Weak/soft from short chains with branching creating weak dispersion forces **(1)**	Plastic bottles, food wrap **(1)**

Marking Criteria	Marks Allocated
• Appropriate property stated and linked to structure	1 – 5
• Appropriate application provided	1 – 5
Total	**10**

1.61 **[7 marks]**

(a) The **properties** of **LDPE** and **HDPE** can be attributed to the **strength** of the **dispersion forces** between their molecules **(1)**. **LDPE** is **relatively weak**, due to the significant presence of **significant branching**, which means the LDPE molecules **pack less efficiently** and have **less surface area** for dispersion force interaction **(1)**. In contrast, HDPE has much **longer molecules** with **little branching** which means they have a **greater surface area** for dispersion force interaction and is therefore **stronger (1)**. As a result, **HDPE** is used for **applications** such as **rigid plastic bottles**, **pipes**, **containers** etc. **(1)** whereas **LDPE** is for **soft plastic bottles**, **cable insulation** etc. **(1)**

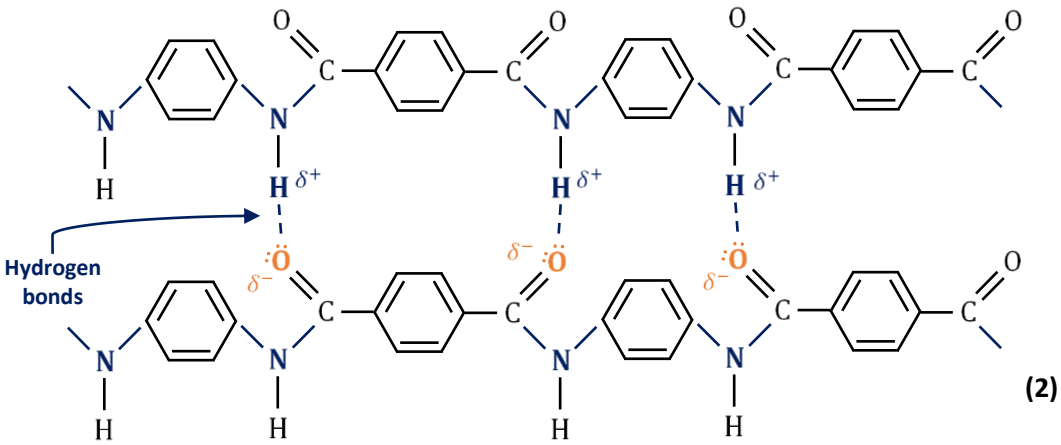
Marking Criteria	Marks Allocated
• Properties are dependent on the strength of the intermolecular forces • LDPE has significant branching and therefore has a reduced surface area for dispersion force interaction • HDPE has long chains with little branching and therefore have a larger surface area for dispersion force interaction	1 – 3
• Appropriate application given for LDPE • Appropriate application given for HDPE	1 – 2
Total	**5**

(b) In order for a polymer to be able to be heated and moulded (recycled), the molecules need to be able to be **shifted out of their locations** by applying force **(1)**. When there is **extensive cross-links** formed between the polyethene molecules, the **strong covalent bonds lock** the molecules into place and **prevent** the polyethene from being **moulded without breaking** **(1)**. As a result, the cross-linking means that polyethene **cannot** be heated and moulded, and therefore **cannot** be **recycled** **(1)**.

Marking Criteria	Marks Allocated
• Molecules need to be able to move to be moulded • Cross-linking locks the molecules into place and prevents the polyethene from being moulded without breaking • This means the crosslinked polyethene cannot be heated and moulded and therefore cannot be recycled	1 – 3
Total	**3**

1.81 **[5 marks]**

Kevlar forms **strong hydrogen bonds** between its chains **(1)**. This **hydrogen bonding** significantly increases the **strength** of Kevlar whilst still leaving it ductile, making it suitable to be **drawn** into **fibres** for the sails and bullet proof vests **(1)**.



(2)

Marking Criteria	Marks Allocated
• Kevlar forms many hydrogen bonds between its molecules • These hydrogen bonds make Kevlar both strong and ductile, making it suitable to be drawn into fibres for sails and bullet proof vests	1 – 2
• Correctly draws Kevlar molecules • Draws appropriate hydrogen bonds between Kevlar molecules	1 – 2
Total	**4**

Proteins – Repetitive Questions Answers

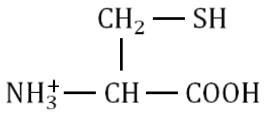
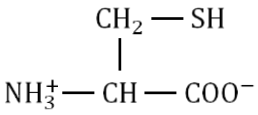
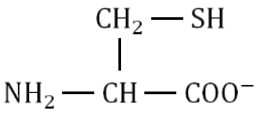
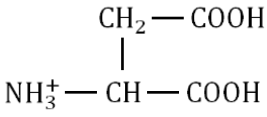
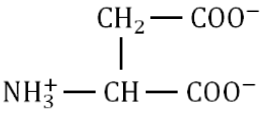
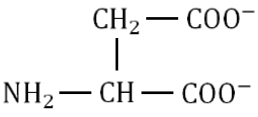
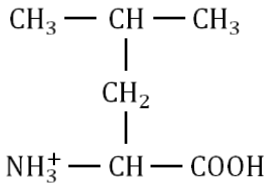
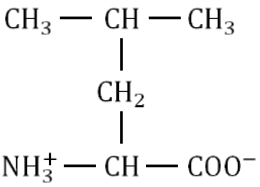
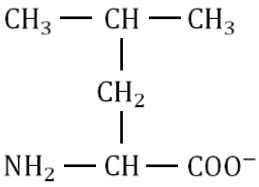
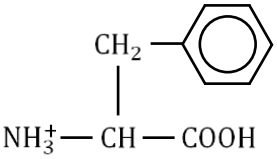
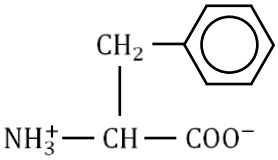
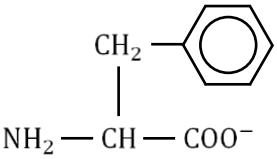
Amino Acids, Zwitterions and Polypeptides: Qs 2.11, 2.21, 2.41, 2.42

2.21 **[10 marks]**

(a) A **zwitterion** is a molecule that contains **positive** and **negative charges** but has **no overall charge** **(1)**.

Marking Criteria	Marks Allocated
• Zwitterion contains positive and negative charges but has no overall charge	1
Total	**1**

(b)

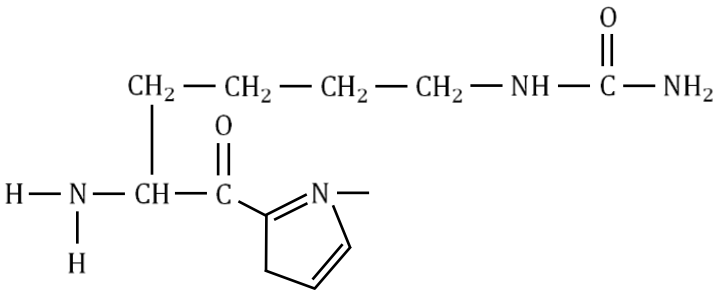
	Acidic form	Neutral form	Basic form
(i)			
(ii)			
(iii)			
(iv)			

Marking Criteria	Marks Allocated
• Draws main chain form correctly	1 – 4
• Draws side chain form correctly	1 – 4
Total	**8**

2.31 **[11 marks]**

(a)

(i)

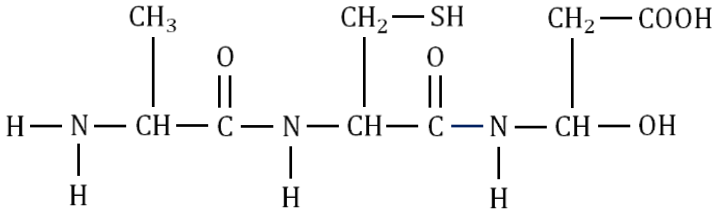


$+ \ H_2O$

(2)

Arg-Pro

(ii)

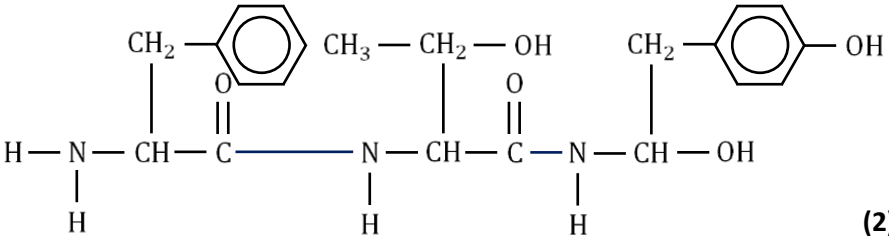


$+ \ 2H_2O$

(2)

Ala-Cys-Asp

(iii)

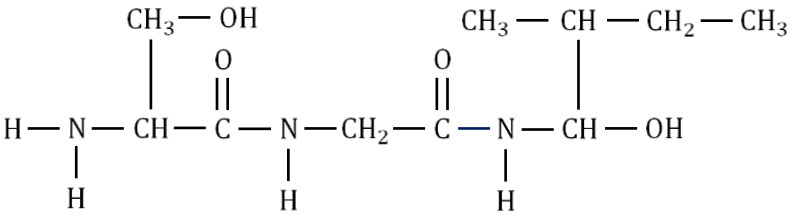


$+ \ 2H_2O$

(2)

Phe-Thr-Tyr

(iv)

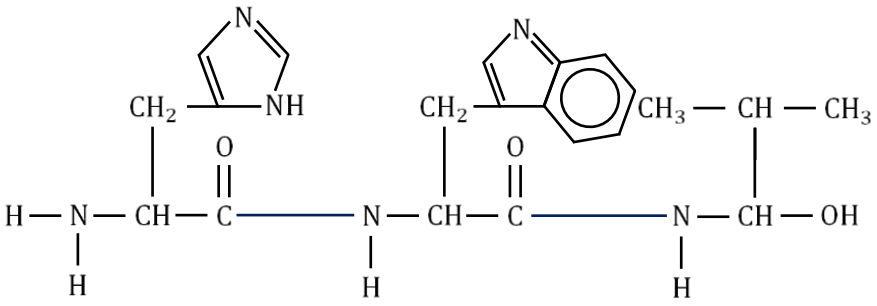


$+ \ 2H_2O$

(2)

Ser-Gly-Ile

(v)



$+ \ 2H_2O$

His-Trp-Val

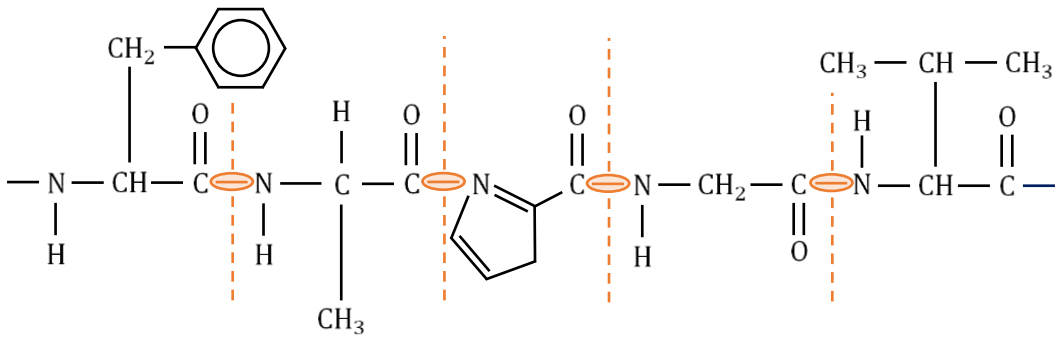
(b) Joining three monomers requires **two peptide linkages**, so **two moles** of water are produced.

$$n(H_2O) = 2\ mol$$

$$m(H_2O) = nM$$
$$= 2 \times (2.016 + 16)$$
$$m(H_2O) = 36.032g \quad \textbf{(1)}$$

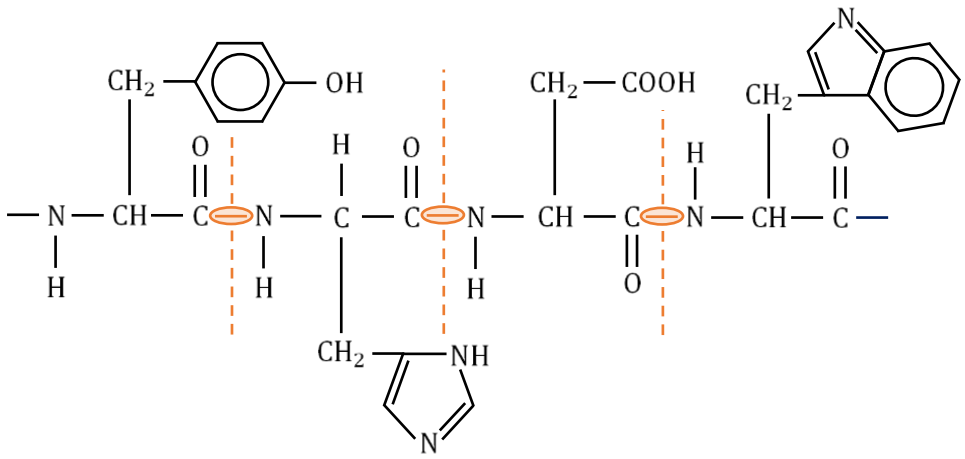
2.41 **[9 marks]**

(a)



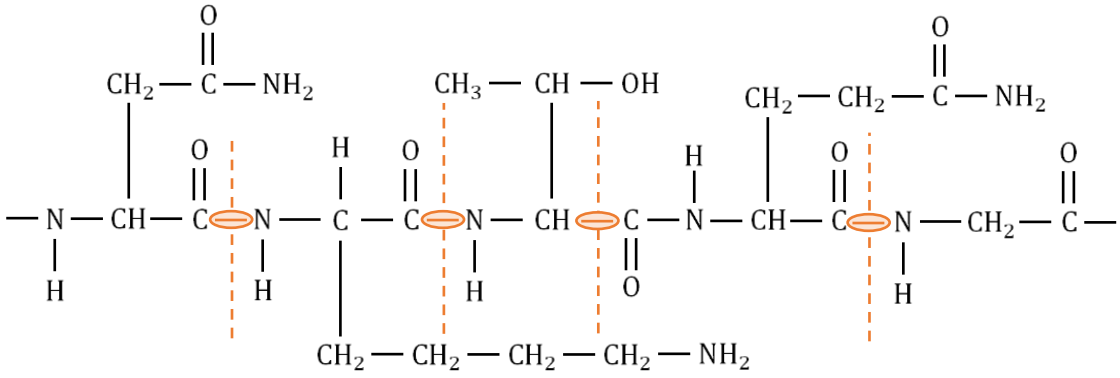
Phenylalanine Alanine Proline Glycine Valine

(b)



Tyrosine Histidine Aspartic acid Tryptophan

(c)



Asparagine Lysine Threonine Glutamine Glycine

Protein Structure: Qs 2.51, 2.61, 2.71, 2.101

2.51 **[3 marks]**

(a) The **primary structure** of a protein refers to the **sequence** of **amino acids** that are present within a protein **(1)**. The primary structure is important, because the identity and order of the amino acids will determine the **interactions** that occur between the **side chains** of the amino acids, which will determine the **overall shape** of the protein **(1)**. The **shape** of a protein is what determines its **function**, so the primary structure is crucial in determining the function of the protein **(1)**

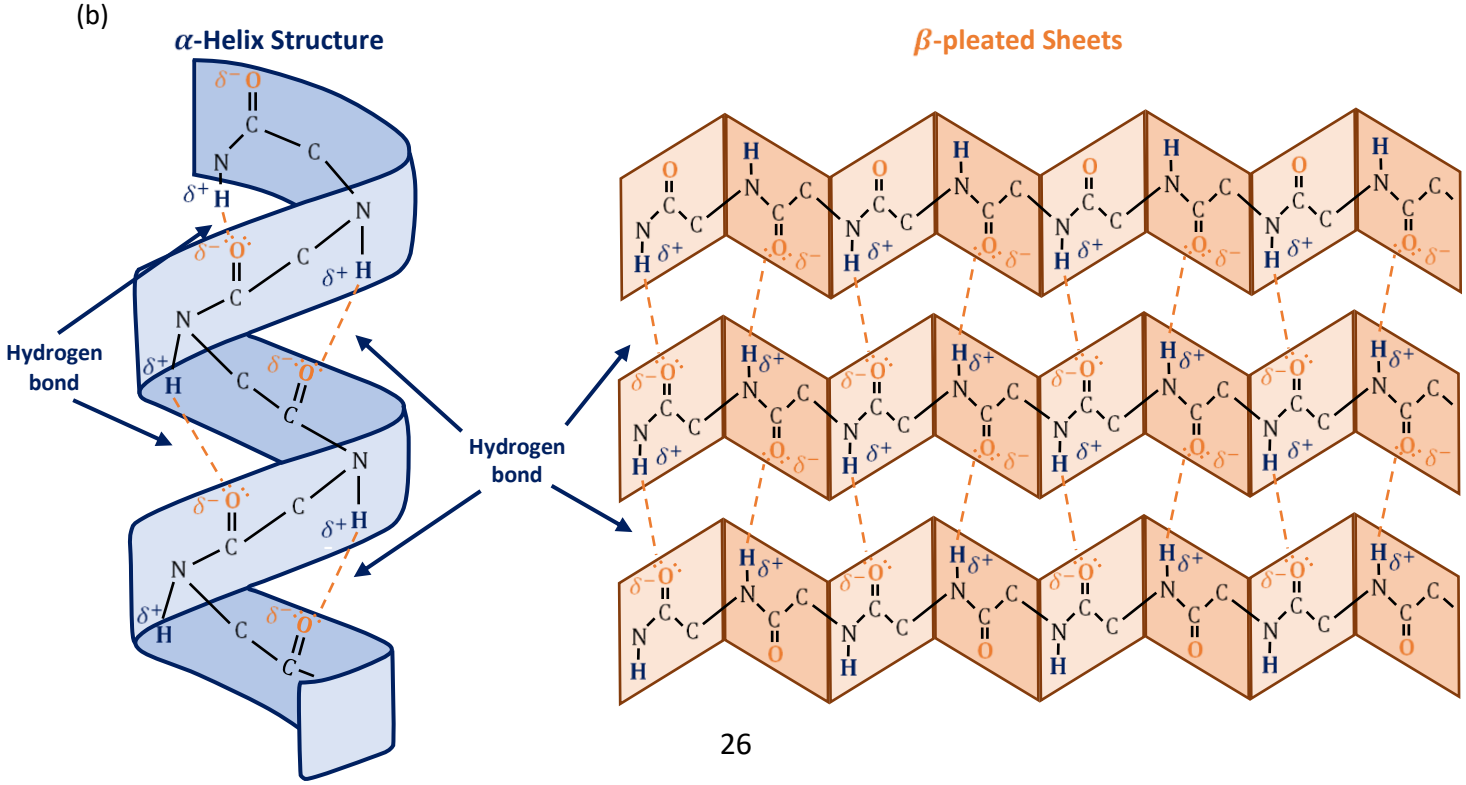
Marking Criteria	Marks Allocated
• Primary structure is the sequence of amino acids • The sequence of amino acids determines the interactions between side chains in the protein, which determines the protein shape • The shape of the protein determines the protein's function, so the primary structure determines the function	$1-3$
Total	**3**

2.61 **[10 marks]**

(a)

	α-helix	β-pleated sheets
Types of bonds formed	Hydrogen bonds **(1)**	Hydrogen bonds **(1)**
Location of bonds	Between $\mathbf{C=O}$ and $\mathbf{N-H}$ groups in the **same peptide chain (1)**	Between $\mathbf{C=O}$ and $\mathbf{N-H}$ groups in the **different peptide chains (1)**
Shape of structure formed	**Double helix (1)**	Zig-zag sheets, stacked on top of each other **(1)**

(b)



Marking Criteria	Marks Allocated
• Sketches hydrogen bonds in both scenarios	$1-2$
• Labels hydrogen bonds • Draws general protein backbone structure	$1-2$
Total	**4**

2.101 **[15 marks]**

(a) The **tertiary structure** of a protein refers to the **overall three-dimensional shape** of a protein **(1)**, which is dependent on the different **types** of **interactions** that occur between the **side chains** **(1)**. The **shape** of the protein determines the **function** of the protein, so the tertiary structure determines the function of a protein **(1)**. The types of interactions that can occur are: **dispersion forces**, **dipole-dipole forces**, **hydrogen bonding**, **disulfide bridges** and **ionic bonding** **(1)**.

Marking Criteria	Marks Allocated
• Tertiary structure refers to the overall three dimensional shape of the protein • This is dependent on the interactions between side chains • The 3D shape determines the function of the protein, so tertiary structure determines the function of the protein • Types of interactions: dispersion forces, dipole-dipole forces, hydrogen bonding, disulfide bridges and ionic bonding	$1-4$
Total	**4**

(b)

(i) **Dispersion forces** **(1)**

(ii) **Dispersion forces** **(1)**

(iii) **Hydrogen bonding**, **dipole-dipole forces**, **dispersion forces** (*also accept ionic bonding if they assume zwitterion form) **(1)**

(iv) **Disulfide bridges**, **dipole-dipole forces**, **dispersion forces** **(1)**

(v) **Hydrogen bonding**, **dipole-dipole forces**, **dispersion forces** **(1)**

(vi) **Hydrogen bonding**, **dipole-dipole forces**, **dispersion forces** (*also accept ionic bonding if they assume zwitterion form) **(1)**

(vii) **Dipole-dipole forces**, **dispersion forces** **(1)**

(viii) **Hydrogen bonding**, **dipole-dipole forces**, **dispersion forces** **(1)**

Marking Criteria	Marks Allocated
• States correct types of interactions	$1-8$
Total	**8**

(c) The **Protein Data Bank** is a **worldwide**, **free** and updated **database** **(1)** that allows scientists worldwide to **view** a protein's structure **(1)**. It informs users about **primary**, **secondary** and **tertiary** protein structure **(1)**.

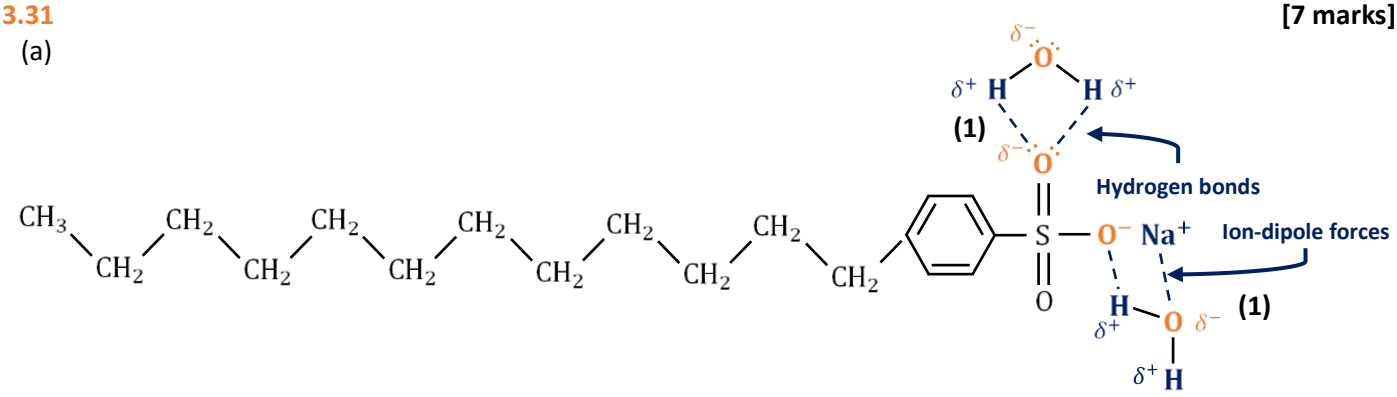
Marking Criteria	Marks Allocated
• The Protein Data Bank is a world wide database with all the recorded protein structures • It allows scientists to view different protein structures • Includes the primary, secondary and tertiary structures	$1-3$
Total	**3**

Soaps and Detergents – Repetitive Questions Answers

Soaps and Detergents: Qs 3.31, 3.41

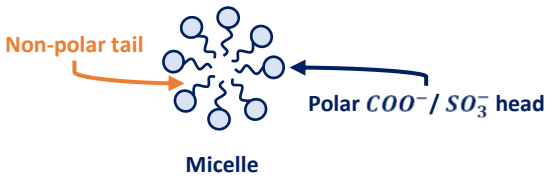
3.31 **[7 marks]**

(a)



Marking Criteria	Marks Allocated
• Draws water molecule showing hydrogen bonding • Draws water molecule showing ion-dipole forces	1 – 2
Total	**2**

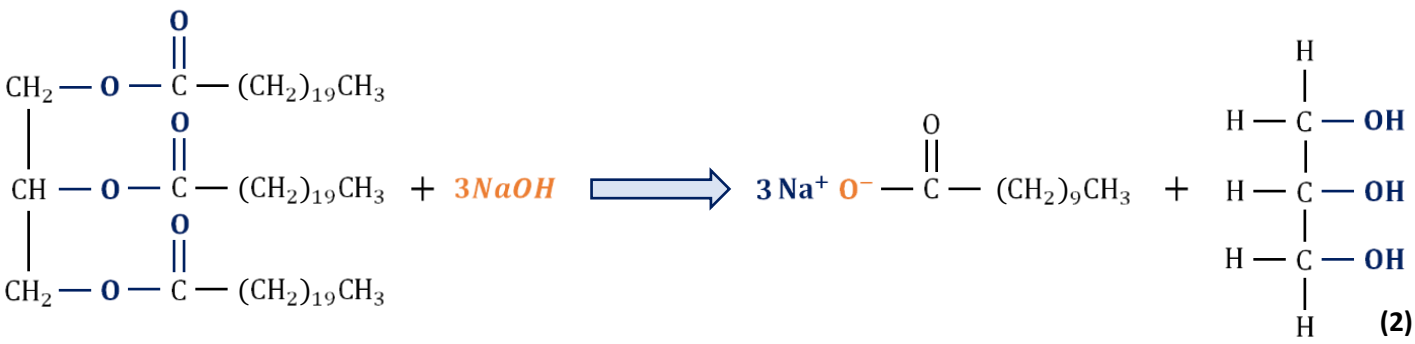
(b)



When soap molecules are **dissolved**, they form a **spherical structure** known as a **micelle**. In a **micelle**, the **non-polar tails** point **inwards** towards the **centre** because they are **hydrophobic** **(1)**, while the **polar heads** point **outwards** towards the **water** because they are **hydrophilic** **(1)**.

Marking Criteria	Marks Allocated
• Draws appropriate micelle diagram • The micelle is a spherical arrangement of the soap molecules • In the micelle, the non-polar tails point inwards because they are hydrophobic,the polar head points outwards towards the water because they are hydrophilic	1 – 3
Total	**3**

(c)



3.41 **[10 marks]**

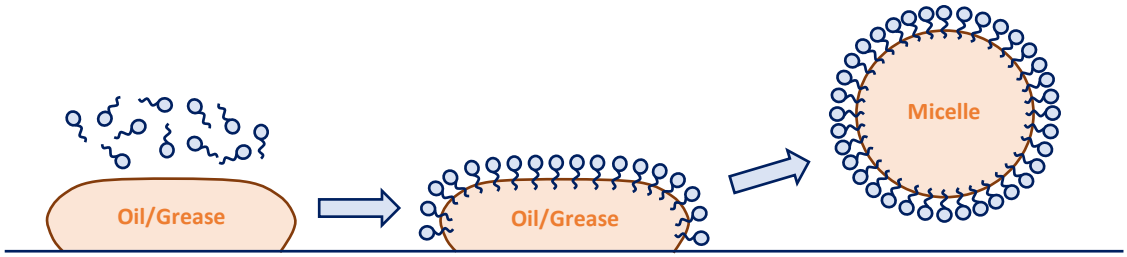
(a) **Water** is **polar** and **grease/oil stains** are **large non-polar carbon chains**, meaning the grease/oil stains will be **insoluble** in water **(1)**.

Marking Criteria	Marks Allocated
• Grease/oil stains are insoluble in water	1
Total	**1**

(b) Bore water is hard water, which contains Ca^{2+} and Mg^{2+} **ions** in **high concentrations (1)**. When soap is used in hard water it will **precipitate** with the ions: $Ca^{2+}_{(aq)} + 2CH_3(CH_2)_{16}COO^-_{(aq)} \rightarrow Ca(CH_3(CH_2)_{16}COO)_{2\,(s)}$ and $Mg^{2+}_{(aq)} + 2CH_3(CH_2)_{16}COO^-_{(aq)} \rightarrow Mg(CH_3(CH_2)_{16}COO)_{2\,(s)}$ **(1).** This **scum** means that the soap is **wasted** so it **does not clean** as **effectively (1)**.

Marking Criteria	Marks Allocated
• Hard water is water that contains Ca^{2+} and Mg^{2+} ions in high concentrations • The soap will precipitate with these ions • The scum formed means soap is wasted so it doesn't clean as effectively	$1-3$
Total	**3**

(c) Detergents do not precipitate with ions in hard water, so they can clean more effectively in hard water **(1)**. When there is an **oil stain** on a frying pan, the **detergent micelle positions itself around** the **oil stain (1)**. The **ionic polar sulfonate head** remains on the outside, being **dissolved** in the **water** from **forming strong hydrogen bonds (1)** and **ion-dipole forces (1)**. The non-polar tail dissolves in the oil stain because they are both **large hydrocarbons** with **similar sized dispersion forces (1)**. Vigorous **agitation** of the mixture allows the micelles to be **released** from the object **(1)**. Once released, the oil particles are in a **stable micelle arrangement**, allowing them to be **suspended** in the **water** and can be **washed away (1)**.



① **Detergent** molecules are **dissolved** in **water**

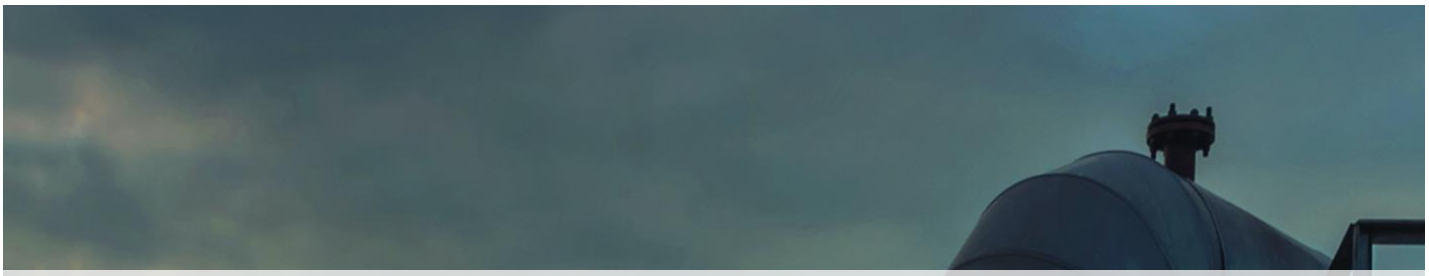
② **Non-polar tails surround** and **dissolve** in the **non-polar oil**

③ **Vigorous agitation removes** the oil and is **held** within the **micelle** which can be **washed away**.

Point to note: Your diagram does not have to be this complicated, you could just draw the micelle and be awarded the marks if it matches your explanation

Marking Criteria	Marks Allocated
• Detergent forms a micelle arrangement around the oil stain • The ionic polar head forms strong hydrogen bonds with water (allowing it to dissolve) • The ionic polar head also forms ion-dipole forces with water (allowing it to dissolve) • The non-polar tail forms dispersion forces with the oil stain (allowing it to dissolve)	$1-6$

• Agitation releases the mixture from the object • The oil and detergent are in a micelle arrangement, allowing it to be suspended in water and washed away	
• Appropriate diagram to support explanation	1
Total	**7**



Chapter 8

Chemical Synthesis Answers

Problem Set 14 – Chemical Synthesis
Progressive Questions

Concept 1
Chemical Synthesis – Progressive Questions Answers

Haber Process and Contact Process: Q1, Q2, Q3

1. **[12 marks]**

(a)

Reaction	Optimum Temperature	Optimum Pressure
(i) $CH_{4\,(g)} + H_2O_{(l)} \rightleftharpoons CO_{(g)} + 3H_{2\,(g)}$ $\Delta H = 206kJ/mol$	**(High)** / Moderate / Low	High / **(Moderate)** / Low
(ii) $P_{4\,(l)} + 5O_{2\,(g)} \rightleftharpoons 2P_2O_{5\,(g)}$ $\Delta H < 0$	High / **(Moderate)** / Low	**(High)** / Moderate / Low
(iii) $NH_4NO_{2\,(s)} + 420kJ \rightleftharpoons N_{2\,(g)} + 2H_2O_{(g)}$	**(High)** / Moderate / Low	High / **(Moderate)** / Low
(iv) $4NH_{3\,(g)} + 5O_{2\,(g)} \rightleftharpoons 4NO_{(g)} + 6H_2O_{\,(g)}$ $\Delta H < 0$	High / **(Moderate)** / Low	High / **(Moderate)** / Low

Marking Criteria	Marks Allocated
• Correct optimum temperature and pressure conditions circled	$1-4$
Total	**4**

(b) A **higher temperature** will favour the **forward endothermic reaction** in order to cool down the system, which will **increase** the **reaction yield** **(1)**. A **higher temperature** will also **increase** the **reaction rate** from an **increase** in the **collision frequency** and **proportion of successful collisions** **(1)**. An **increase** in pressure will favour the reverse reaction due to a $1:4$ gaseous molar ratio, which will **decrease** the **reaction yield** **(1)**. However, a **higher**

pressure will **increase** the **reaction rate** from an **increase** in the **collision frequency** **(1)**. Therefore, to find a compromise between **yield** and **reaction rate**, a **moderate pressure** is used **(1)**.

Marking Criteria	Marks Allocated
• A higher temperature will increase the yield from a favoured forward endothermic reaction • A higher temperature will increase the reaction rate from an increase in collision frequency and proportion of successful collisions • A pressure increase will decrease the yield from a favoured reverse reaction due to a 1:4 gaseous molar ratio • A pressure increase will increase the reaction rate from an increase in the collision frequency • Stating a moderate pressure must be used as a compromise	$1-5$
Total	**5**

2. **[11 marks]**

(a)

Student	Change made	Effect on reaction rate	Effect on Yield	Correct or Incorrect Prediction (✔ or X)
Sarah	**Increase temperature**	⇧	⇩	X **(1)**
Janet	**Remove catalyst**	⇩	⇩	X **(1)**
Jamie	**Decrease pressure**	⇩	⇩	✔ **(1)**
Dylan	**Decrease reactant concentrations**	⇩	⇧	X **(1)**
Alexa	**Decrease temperature**	⇩	⇧	X **(1)**

∴ Sarah and Janet (**will**) / **will not** join the trio. **[1]**

Points to note: For the answers that were incorrect:

- Sarah's prediction: an increase in temperature will also **increase** the **yield** as the **forward reaction** will be **favoured**
- Janet's prediction: Removal of the catalyst will have **no effect** on the **yield** as the forward and reverse reaction rates decrease equally, so neither is favoured
- Dylan's prediction: Decreasing the reactant concentrations will **decrease** the **yield** as the **reverse reaction** will be **favoured**.

Marking Criteria	Marks Allocated
• Correctly states if prediction is correct or incorrect	$1-5$
• States Sarah and Janet will join the trio	1
Total	**6**

(b) To optimise the **reaction rate** and **yield** a **high temperature** and **high pressure** should be used **(1)**. A **higher temperature** will favour the **forward endothermic reaction** in order to cool down the system, which will **increase** the **reaction yield** **(1)**. A **higher temperature** will also **increase** the **reaction rate** from an **increase** in the **collision frequency** and **proportion of successful collisions** **(1)**. A **higher pressure** will favour the **forward reaction** due to a $2:1$ gaseous molar ratio, which will **increase** the **reaction yield** **(1)**. A **higher pressure** will also **increase** the **reaction rate** from an **increase** in the **collision frequency** **(1)**.

Marking Criteria	Marks Allocated
• To optimise reaction rate and yield a high temperature and high pressure should be used • A higher temperature will increase the yield from a favoured forward endothermic reaction • A higher temperature will increase the reaction rate from an increase in collision frequency and proportion of successful collisions • A pressure increase will increase the yield from a favoured forward reaction due to a $2:1$ gaseous molar ratio • A pressure increase will increase the reaction rate from an increase in the collision frequency	$1-5$
Total	**5**

3. **[9 marks]**

(a)

Time	Change made
T_1	**Volume increased/pressure decrease (1)**
T_2	**Catalyst added (1)**
T_3	**Temperature increase (1)**

Marking Criteria	Marks Allocated
• Correct changes determined	$1-3$
Total	**3**

(b) When the temperature of the system is **decrease**, the system will act to partially oppose this **temperature decrease** by favouring the **exothermic** **forward reaction** in order to heat up the system **(1)**. A favoured forward reaction means the **yield** of **ammonia** will **increase** from more of it being produced **(1)**.

Marking Criteria	Marks Allocated
• Increasing the temperature will favour the endothermic reverse reaction • A favoured reverse reaction will decrease the yield ammonia from it being consumed	$1-2$
Total	**2**

(c) Catalysts are only **specific** to certain reactions **(1)**. As a result when the **vanadium oxide catalyst** is **removed** and the **iron oxide catalyst** is **added** it is **not specific** to the Haber process so it will have **no effect** **(1)**. Thus removing

the vanadium oxide catalyst will mean the **reaction rate decreases** from the **proportion of successful collisions decreasing** from the **loss** of an alternate pathway with a lower activation energy **(1)**. However, the **yield** will **remain unaffected** because the forward and reverse reaction rates **decrease equally** so there is **no favoured reaction** **(1)**.

Point to note: This question should say that the reaction rate increases, because the iron oxide catalyst is actually specific to the Haber Process. However, based on the information of this question you should just assume that the iron oxide catalyst is not specific to the Haber Process.

Marking Criteria	Marks Allocated
• Catalysts are specific to certain reactions • The iron oxide catalyst is not specific to this process so it has no effect • Removing the vanadium oxide catalyst will decrease the reaction rate from a decrease in the proportion of successful collisions from an increase in activation energy (from the loss of the catalysed pathway) • The yield will remain unaffected as no reaction is favoured	$1-4$
Total	**4**

4. **[20 marks]**

(a)

Equation 1 $\times 2$	$2S_{(l)} + 2O_{2\,(g)} \rightleftharpoons 2SO_{2\,(g)}$
Equation 2	$2SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2SO_{3\,(g)}$
Equation 3 $\times 2$	$2SO_{3\,(g)} + 2H_2SO_{4\,(l)} \rightleftharpoons 2H_2S_2O_{7\,(l)}$
Equation 4 $\times 2$	$2H_2S_2O_{7\,(l)} + 2H_2O_{(l)} \rightarrow 4H_2SO_{4\,(l)}$ **(1)**

$$2S_{(l)} + 2O_{2\,(g)} \rightleftharpoons \cancel{2SO_{2\,(g)}}$$

$$\cancel{2SO_{2\,(g)}} + O_{2\,(g)} \rightleftharpoons \cancel{2SO_{3\,(g)}}$$

$$\cancel{2SO_{3\,(g)}} + \cancel{2H_2SO_{4\,(l)}} \rightleftharpoons \cancel{2H_2S_2O_{7\,(l)}}$$

$$\cancel{2H_2S_2O_{7\,(l)}} + 2H_2O_{(l)} \rightarrow \cancel{2}\,4H_2SO_{4\,(l)} \quad \textbf{(1)}$$

$$2S_{(l)} + 3O_{2\,(g)} + 2H_2O_{(l)} \rightarrow 2H_2SO_{4\,(aq)} \quad \textbf{(1)}$$

Marking Criteria	Marks Allocated
• Balances equations correctly • Cancels reactants/products correctly • States correct overall equation: $2S_{(l)} + 3O_{2\,(g)} + 2H_2O_{(l)} \rightarrow 2H_2SO_{4\,(aq)}$	$1-3$
Total	**3**

(b) **Step 2** of the contact process is a **reversible reaction** meaning the conditions must be optimised to achieve the highest reaction rate and yield before equilibrium is established **(1)**. To **optimise** the reaction rate and yield a **high temperature** **(1)** and **high pressure** should be used **(1)**.

Points to note: In real life a **low pressure** is used as the increase in yield and reaction rate is not justified by the **cost** of operating at high pressures.

Marking Criteria	Marks Allocated
• Step 2 is a reversible reaction so conditions must be optimised to optimise yield and reaction rate before equilibrium is established • A high temperature should be used • A high pressure should be used	$1-3$
Total	**3**

(c)

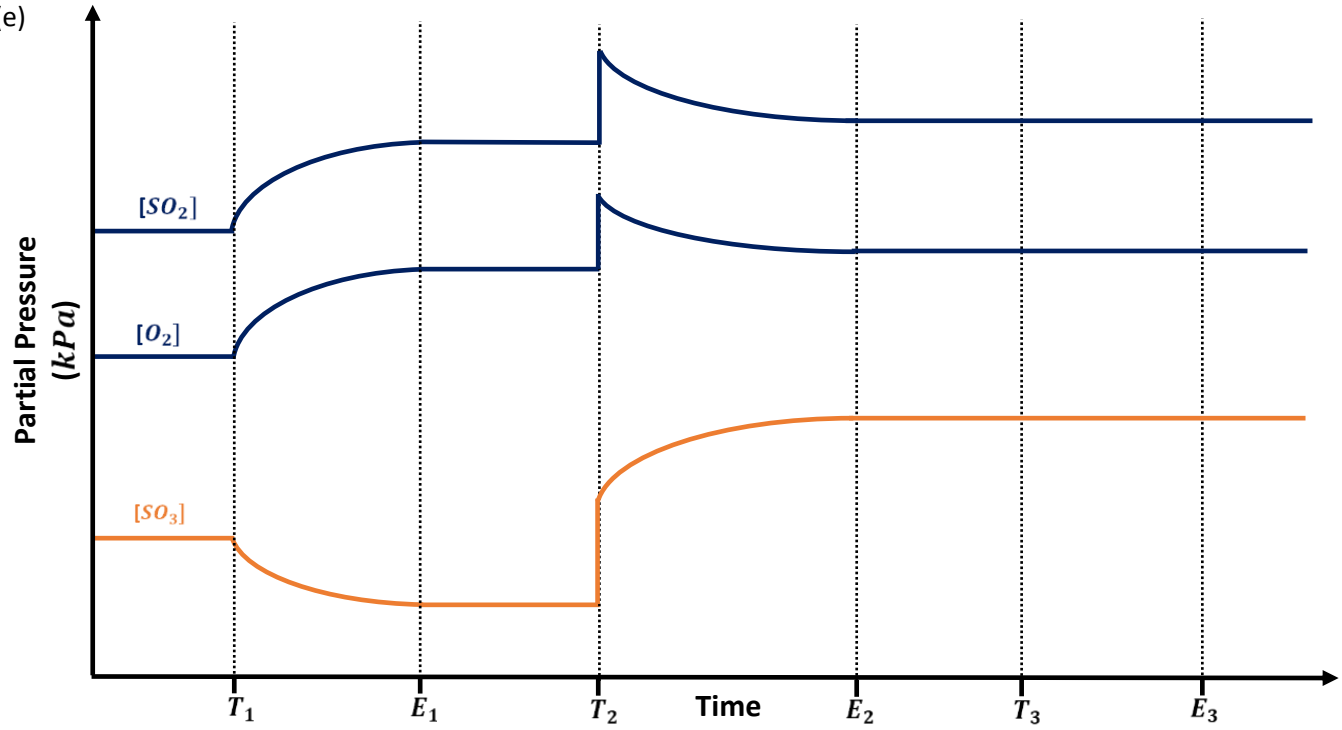
Time	Change made	Effect on Reaction Rate (↑ or ↓)
T_1	**Temperature increased**	↑ **(1)**
T_2	**Pressure increased**	↑ **(1)**
T_3	**V_2O_5 catalyst added**	↑ **(1)**

Marking Criteria	Marks Allocated
• States correct effect on reaction rate	$1-3$
Total	**3**

(d) When the **temperature** is **increased**, the **average kinetic energy** of the particles increases meaning the **collision frequency** and **proportion of successful collisions** increases for both **forward** and **reverse** reactions, thus **increasing** the **reaction rate** **(1).** There will be a greater increase in the **proportion of successful collisions** in the **endothermic reverse reaction** thus creating a **net reverse reaction** which **decreases** the **yield** **(1)**. Therefore, a compromise is made between the reaction rate and yield thus a **moderate temperature** is selected **(1).** When the **pressure** is **increased**, the **collision frequency** increases for both **forward** and **reverse** reactions, thus **increasing** the **reaction rate** **(1).** There will be a greater increase in the **collision frequency** in the **forward** reaction due to the **3 : 2 gaseous molar ratio** thus creating a **net forward reaction** which increases the **yield** **(1).** Thus a **high pressure** is selected **(1)**.

Marking Criteria	Marks Allocated
• A temperature increase will increase the collision frequency and proportion of successful collisions, increasing the reaction rate • The proportion of successful collisions will increase more for the endothermic reverse reaction, decreasing the yield • Thus a moderate temperature is used • A pressure increase will increase the collision frequency, increasing the reaction rate • The collision frequency will increase more for the forward reaction due to a 3 : 2 gaseous molar ratio, increasing the yield • Thus a high pressure is used	$1-6$
Total	**6**

(e)



Points to note: A catalyst only affects the reaction rate, not the yield. Thus there is no change at T_3

Marking Criteria	Marks Allocated
From T_1 to E_1: • Correct curvature and orientation for all curves to reach equilibrium at E_1	1
From T_2 to E_2: • Instantaneous spike in all concentration curves at T_2, proportional to 2: 1: 2 ratio • Correct curvature and orientation for all curves to reach equilibrium at E_1	$1-2$
From T_3 to E_3: • Continuation of equilibrium lines	1
• Equilibrium lines from E_1 to T_2, E_2 to T_3 and E_3 onwards	1
Total	**5**

Ethyl Ethanoate Production: Q5, Q6

5. **[8 marks]**

Statement	True (✔)	False (X)
"The overall reaction equation is: $CH_2CH_{2\,(g)} + H_2O_{(g)} + CH_3COOH_{(g)} \rightleftharpoons CH_3COOCH_2CH_{3\,(g)} + H_2O_{(g)}$"		X **(1)**
Explanation (for the box you ticked): The overall equation should be $CH_2CH_{2\,(g)} + CH_3COOH_{(g)} \rightleftharpoons CH_3COOCH_2CH_{3\,(g)}$ since the water vapour molecules cancel each other out **(1)**		
"For reaction 1, **increasing** the temperature of the reaction chamber will **increase** the **rates** of **both** the forward and reverse reactions but the **reverse reaction rate** will **increase more**"	✔ **(1)**	
Explanation (for the box you ticked): The **proportion of successful collisions** for the **reverse reaction** will **increase more** since it is **endothermic**, thus this statement is **correct** **(1)**.		

"The **rate of reaction** in **step 2** is determined by the **rate of reaction** in **step 1**, when it is assumed that **ethanoic acid** is at a **maximum concentration**."	✔ **(1)**	
Explanation (for the box you ticked): Since the second reaction is **dependent** on the **ethanol produced** in the **first reaction,** when the ethanoic acid is at full concentration, the second reaction should occur at the same rate as the first, meaning that this statement is true **(1)**.		
"An acidic catalyst such as **sulfuric acid** is used in step 2 in order to **increase** the **reaction rate** and **yield** of **ethyl ethanoate**."		X **(1)**
Explanation (for the box you ticked): The use of a catalyst **does not** have an **impact** on the **yield** of ethyl ethanoate since the **forward** and **reverse** **reaction rates** are **increased equally**. **(1)**		

Marking Criteria	Marks Allocated
• Correct true or false box is ticked	$1-4$
• Appropriate explanation provided for box ticked	$1-4$
Total	**8**

6. **[16 marks]**

(a) The first step will remain the same **(1)**, but the **ethanoic acid** in the second step must be changed to **propanoic acid** **(1).**

Marking Criteria	Marks Allocated
• The reactants in the first stage will remain unchanged • The ethanoic acid in the second step will need to be changed to propanoic acid	$1-2$
Total	**2**

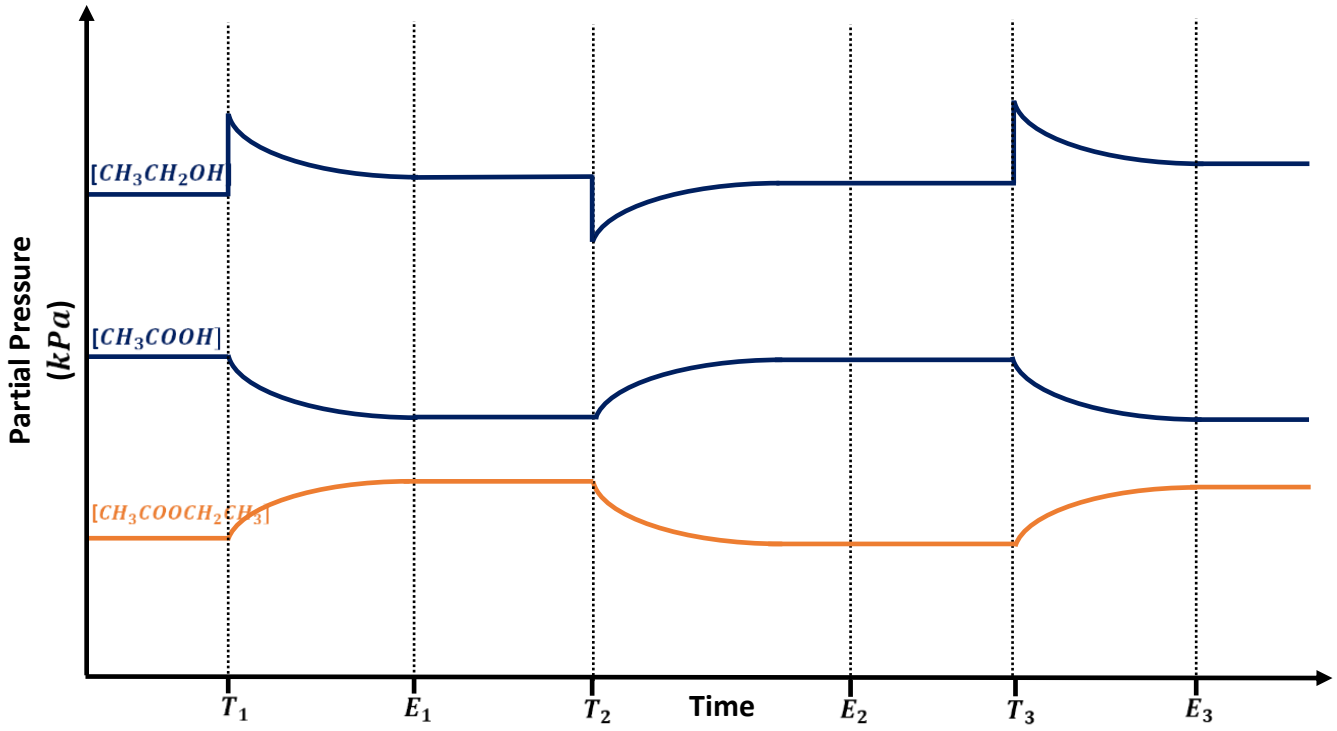
(b) When the temperature of a system is **decreased**, according to Le Chatelier's Principle, the system will act to partially oppose this **temperature decrease** by favouring the **forward** **exothermic reaction** in order to **heat up** the system **(1)**. With a favoured **forward reaction**, the **yield** will **increase**. When the pressure of the system is decreased, the system will act to partially oppose this change by favouring the **reverse reaction** due to a **2 : 1** gaseous molar ratio **(1)**, which will **decrease** the **reaction yield** **(1)**.

Marking Criteria	Marks Allocated
• A temperature decrease will favour the forward exothermic reaction • A favoured forward reaction will increase the yield • A pressure decrease will favour the reverse reaction due to a $2:1$ gaseous molar ratio • A favoured reverse reaction will decrease the yield	$1-4$
Total	**4**

(c)

Time	Change made to reaction 1	Effect on Concentration of Ethanol (↑ or ↓)
T_1	**Addition of CH_2CH_2**	↑ **(1)**
T_2	**Pressure decreased**	↓ **(1)**

T_3	Temperature decreased	↑ (1)



Points to note: This question can be confusing and you really need to think about it (it is a good critical thinking question).

- For the table just focus on the step 1 reaction and use LCP to determine the concentration of ethanol will increase or decrease.
- For the graph, you essentially need to sketch the effect of an ethanol concentration increase or decrease

Marking Criteria	Marks Allocated
• Correct effect on ethanol concentration stated for table	$1-3$
From T_1 to E_1: • Instantaneous spike in ethanol concentration curve at T_1 • Correct curvature and orientation for all curves to reach equilibrium at E_1	$1-2$
From T_2 to E_2: • Instantaneous drop in ethanol concentration curve at T_2 • Correct curvature and orientation for all curves to reach equilibrium at E_2	$1-2$
From T_3 to E_3: • Instantaneous spike in ethanol concentration curve at T_1 • Correct curvature and orientation for all curves to reach equilibrium at E_3	$1-2$
• Equilibrium lines from E_1 to T_2, E_2 to T_3 and E_3 onwards	1
Total	**10**

Ethanol and Biodiesel Production: Q7, Q8, Q9, Q10

7. **[12 marks]**

(a) **Green Chemistry** is an ideology based on **twelve principles** that aim to promote processes and design products that **minimise** the use and generation of **hazardous substances** and **wastes** **(1)**.

Marking Criteria	Marks Allocated
• Provides brief statement about the purpose of green chemistry	1
Total	**1**

(b)

Factor	Optimum condition	Explanation using LCP
Temperature	**High** **Moderate** (circled) **Low**	When the temperature of a system is **increased**, according to Le Chatelier's Principle, the **endothermic reverse reaction** will be favoured **(1)**. A favoured reverse reaction will **decrease** the **yield**, so a **moderate temperature** must be used **(1)**.
Pressure	**High** (circled) **Moderate** **Low**	The reaction has a **1 : 1 gaseous molar ratio** meaning that **neither side** is **favoured** when the pressure is changed **(1)**. The **reaction rate** is **increased** when the pressure is increased, so a **high pressure** is **optimum (1).**

Marking Criteria	Marks Allocated
• Circles optimum condition	1 – 2
• Applies LCP to determine which reaction is favoured	1 – 2
• Explain how this affects yield and reaction rate	1 – 2
Total	**6**

(c) This statement is **false (1)**. While the **reaction rate** does **increase** from an **increase** in the **proportion of successful collisions**, the **yield** is **not impacted** because the forward and reverse reaction rates **increase equally**. **(1)**

Marking Criteria	Marks Allocated
• The statement is false • Yield does not change because the forward and reverse reaction rates increase equally	1 – 2
Total	**2**

(d) Some **disadvantages** of using hydration to produce ethanol over fermentation are:

- It operates at **high temperatures** which requires a **large energy input (1)**
- It operates at **high pressures** which requires a **large energy input (1)**
- The reaction uses ethene from crude oil which is a **non-renewable resource (1)**

Marking Criteria	Marks Allocated
• States three appropriate disadvantages	1 – 3
Total	**3**

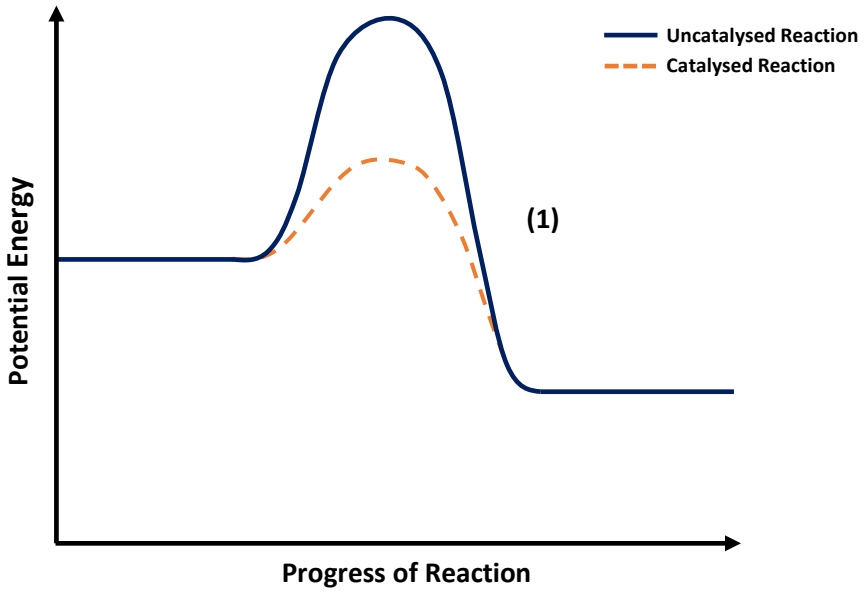
8. **[13 marks]**

(a)

$$C_6H_{12}O_{6\,(aq)} \xrightarrow{\text{Yeast enzymes}} 2CH_3CH_2OH_{(aq)} + 2CO_{2\,(g)} \quad \Delta H = -92kJ$$

Marking Criteria	Marks Allocated
• States equation • Enzyme: yeast enzymes	1 – 2
Total	**2**

(b)



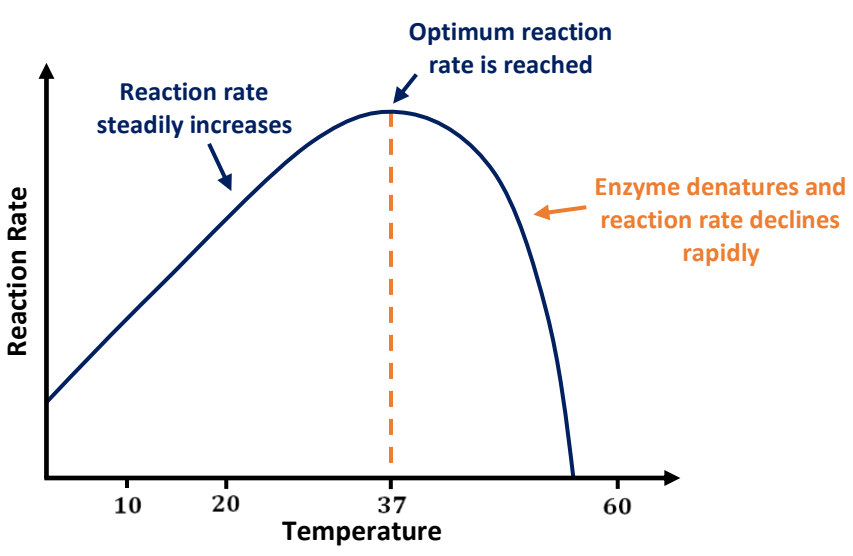
Marking Criteria	Marks Allocated
• Draws appropriate catalysed reaction line	1
Total	**1**

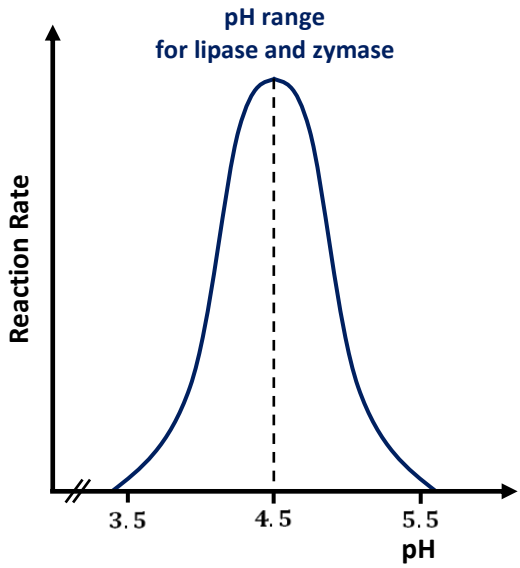
(c) Advantages of enzymes over inorganic catalysts include but are not limited to:

- Enzymes are **most effective at biological temperatures** which is cheaper **(1)**
- Enzymes are **highly specific**, so they will only **catalyse** a specific reaction **(1)**
- Enzymes can be **reused (1)**
- Enzymes are **biodegradable (1)**

Marking Criteria	Marks Allocated
• States three appropriate advantages	1 – 3
Total	**3**

(d) Despite higher temperatures allowing for a higher rate of reaction, enzymes are **temperature** and **pH sensitive (1).** If the **temperature** is raised above 37℃, or pH above 3-5, this enzyme risks being **denatured (1).**





Marking Criteria	Marks Allocated
• Enzymes are temperature and pH sensitive • If they go outside of their temperature or pH ranges the enzymes can become denatured	$1-2$
• Appropriate temperature and pH diagrams drawn	$1-2$
Total	**4**

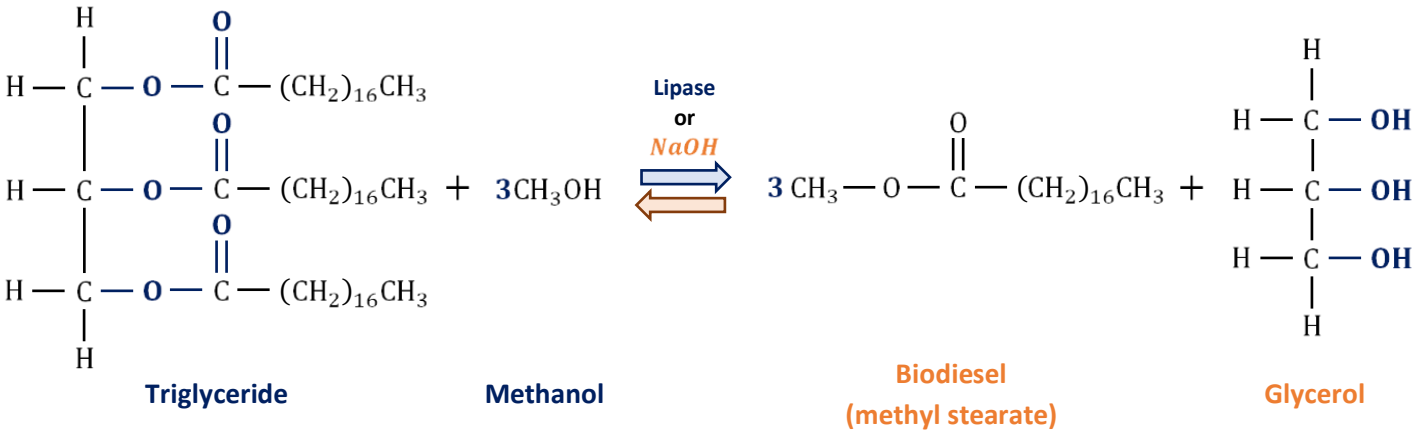
(e) Reasons fermentation is in alignment with the **green chemistry** principles include but are not limited to:

- Fermentation occurs at **biological temperatures** which is more energy efficient **(1)**
- Yeast enzymes are biodegradable **(1)**
- The yeast enzymes can be **reused** **(1)**
- The reactants are made from **renewable plant material** **(1)**
- Yeast enzymes are **specific** and **do not produce unwanted by-products** **(1)**

Marking Criteria	Marks Allocated
• States three appropriate reasons why fermentation is in alignment with green chemistry principles	$1-3$
Total	**3**

9. **[9 marks]**

(a) The **inorganic catalyst** used is a **strong base** such as $NaOH$ **(1)**, and the **enzyme lipase** can also be used **(1)**.



Triglyceride **Methanol** **Biodiesel (methyl stearate)** **Glycerol**

Marking Criteria	Marks Allocated
• Inorganic catalyst used is a strong base (e.g. $NaOH$) • Enzyme used is lipase	$1-2$
• Equation correctly balanced • Reversible reaction and catalyst/enzyme included	$1-2$
Total	**4**

(b) When the temperature of the system is **increased**, the system will act to partially oppose this **temperature increase** by favouring the **endothermic** **reverse reaction** in order to cool down the system **(1)**. A favoured reverse reaction means the **yield** of **biodiesel** will **decrease** from it being consumed **(1)**. As a result a **moderate temperature** of $60°C$ is used to find a compromise between the **reaction rate** and **yield** **(1)**.

Marking Criteria	Marks Allocated
• Increasing the temperature will favour the endothermic reverse reaction • A favoured reverse reaction will decrease the yield biodiesel from it being consumed	$1-3$

• A moderate temperature of $60℃$ is used to find a compromise between reaction rate and yield	
Total	**3**

(c) **Biodiesel** can often contain **free fatty acids** and if its concentration is too high then the base catalyst (e.g. $NaOH$) will react with the **free fatty acids** to create **soap (1)**. This is an **unwanted reaction** and makes the resulting biodiesel require **additional purification (1)**.

Marking Criteria	Marks Allocated
• Free fatty acids can react with the base catalyst to form soap • This makes the biodiesel require additional purification	$1-2$
Total	**2**

10. **[11 marks]**

Factor	Prediction using LCP
Temperature decrease	When the temperature of a system is **decreased**, according to Le Chatelier's Principle, the system will act to partially oppose this by favouring the **exothermic forward reaction** in order to **heat up** the system **(1)**. With a favoured **forward reaction** the **yield** will **increase** from more biodiesel being produced**(1)**.
Volume decrease	When the volume of the system is **decreased**, according to Le Chatelier's Principle, the system will act to partially oppose this by **favouring no reaction** due to a $4:4$ **molar ratio**. With a **no favoured reaction** the **yield** will **remain unaffected (1)**.
Replacing $NaOH$ catalyst with lipase enzyme at temperature of $60℃$	When $NaOH$ is changed to lipase, according to Le Chatelier's Principle **no change** to the **yield** will occur since catalysts have **no effect** on the **yield** of the system **(1)**. At $60℃$ the lipase will also **denature** but the yield of the reaction will **remain unaffected (1)**.
Decreasing methanol concentration	By **decreasing** the concentration of the methanol, according to Le Chatelier's principle the system will act to partially oppose this by **favouring** the **reverse reaction** to increase its concentration **(1).** With a favoured **reverse reaction** the **yield** will **decrease** from biodiesel being consumed **(1)**.
Continually removing biodiesel as it is produced	Continually removing biodiesel as it is produced **reduces** the **concentration** of **biodiesel (1)**. By **decreasing** the **biodiesel concentration**, according to Le Chatelier's principle the system will act to partially oppose this by **favouring** the **forward reaction** to increase its concentration **(1)**. With a favoured **forward reaction** the **yield** will **increase** from more biodiesel being produced**(1)**.

Marking Criteria	Marks Allocated
• Uses LCP to determine which reaction will be favoured	$1-5$
• Explains how yield will be affected based on which reaction is favoured	$1-5$
• For final change states that continually removing biodiesel lowers its concentration	1
Total	**11**

Challenging Stoichiometry – Progressive Questions Answers

Challenging Stoichiometry: Q1, Q2, Q3, Q4, Q5

1. **[10 marks]**

(a)

Equation 1 $\times 3$	$12NH_{3\,(g)} + 15O_{2\,(g)} \rightarrow 12NO_{(g)} + 18H_2O_{(g)}$
Equation 2 $\times 6$	$12NO_{(g)} + 6O_{2\,(g)} \rightarrow 12NO_{2\,(g)}$
Equation 3 $\times 4$	$12NO_{2\,(g)} + 4H_2O_{(l)} \rightarrow 8HNO_{3\,(aq)} + 4NO_{(g)}$

$$12NH_{3\,(g)} + \overset{21}{\cancel{15}}O_{2\,(g)} \rightarrow \cancel{12NO_{(g)}} + \overset{14}{\cancel{18}}H_2O_{(g)}$$

$$\cancel{12NO_{(g)}} + \cancel{6O_{2\,(g)}} \rightarrow \cancel{12NO_{2\,(g)}}$$

$$\cancel{12NO_{2\,(g)}} + \cancel{4H_2O_{(l)}} \rightarrow 8HNO_{3\,(aq)} + 4NO_{(g)}$$

$$12NH_{3\,(aq)} + 21O_{2\,(g)} \rightarrow 14H_2O_{(l)} + 8HNO_{3\,(aq)} + 4NO_{(g)} \quad \textbf{(2)}$$

(b)

$$n(HNO_3) = cV$$
$$= 1 \times 15$$
$$= 15\ mol \quad \textbf{(1)}$$

$$n(NH_3) = n(HNO_3) \times \frac{12}{8}$$
$$= 15 \times \frac{3}{2}$$
$$= 22.5\ mol \quad \textbf{(1)}$$

$$V(NH_3) = \frac{nRT}{P}$$
$$= \frac{22.5 \times 8.314 \times (140 + 273.15)}{110}$$
$$= 703L \quad \textbf{(1)}$$

(c)

$$n(O_2) = \frac{V}{22.71}$$
$$= \frac{500}{22.71}$$
$$= 22.02\ mol \quad \textbf{(1)}$$

$$n(NH_3) = \frac{m}{M}$$
$$= \frac{3 \times 10^3}{14.01 + 3 \times 1.008}$$
$$= 176.1\ mol \quad \textbf{(1)}$$

Either Option

$$n(O_2)_{required} = n(NH_3) \times \frac{21}{12}$$
$$= 176.1 \times \frac{21}{12}$$
$$= 308.2\ mol$$
$$n(O_2) < n(O_2)_{required}$$
$$\therefore O_2 \text{ is limiting reagent} \quad \textbf{(1)}$$

$$n(NH_3)_{required} = n(O_2) \times \frac{12}{21}$$
$$= 22.02 \times \frac{12}{21}$$
$$= 12.58\ mol$$
$$n(NH_3) > n(NH_3)_{required}$$
$$\therefore O_2 \text{ is limiting reagent} \quad \textbf{(1)}$$

$$n(HNO_3) = n(O_2) \times \frac{8}{21} \times Efficiency$$
$$= 22.02 \times \frac{8}{21} \times 0.96$$
$$= 8.053\ mol \quad \textbf{(1)}$$

$$m(HNO_3) = nM$$
$$= 8.053 \times (1.008 + 14.01 + 3 \times 16)$$
$$= 507.5g \quad \textbf{(1)}$$

2. **[11 marks]**

(a)

Equation 1	$N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons 2NH_3$
Equation 2 $\times 2$	$2NH_{3\,(g)} + 2HNO_{3\,(aq)} \rightarrow 2NH_4NO_{3\,(s)}$

$$N_{2\,(g)} + 3H_{2\,(g)} \rightleftharpoons \cancel{2NH_3}$$

$$\cancel{2NH_{3\,(g)}} + 2HNO_{3\,(aq)} \rightarrow 2NH_4NO_{3\,(s)}$$

$$N_{2\,(g)} + 3H_{2\,(g)} + 2HNO_{3\,(aq)} \rightarrow 2NH_4NO_{3\,(s)} \quad \textbf{(1)}$$

$$n(N_2) = \frac{PV}{RT} = \frac{8000 \times 3}{8.314 \times 1000} = \mathbf{2.887\ mol}$$

$$n(HNO_3) = cV = 1.00 \times 6 = \mathbf{6\ mol} \quad \textbf{(1)}$$

$$n(N_2)_{required} = n(HNO_3) \times \frac{1}{2} = 6 \times \frac{1}{2} = \mathbf{3\ mol}$$

$n(N_2) < n(N_2)_{required}$

$\therefore$ **N_2 is limiting reagent** **(1)**

Either Option

$$n(HNO_3)_{required} = n(N_2) \times \frac{2}{1} = 2.887 \times 2 = \mathbf{5.774\ mol}$$

$n(HNO_3) > n(HNO_3)_{required}$

$\therefore$ **N_2 is limiting reagent** **(1)**

$$n(NH_4NO_3)_{theoretical} = n(N_2) \times 2 = 2.887 \times 2 = \mathbf{5.774\ mol} \quad \textbf{(1)}$$

$$m(NH_4NO_3)_{theoretical} = n \times M = 5.774 \times (14.01 \times 2 + 1.008 \times 4 + 16 \times 3) = \mathbf{462.2\ g} \quad \textbf{(1)}$$

$$Efficiency = \frac{m(NH_4NO_3)_{actual}}{m(NH_4NO_3)_{theoretical}} \times 100 = \frac{462.2}{500} \times 100 = \mathbf{92.4\%} \quad \textbf{(1)}$$

(b)

$$n(NH_4NO_3) = \frac{m}{M} = \frac{25 \times 10^3}{2 \times 14.01 + 4 \times 1.008 + 3 \times 16} = \mathbf{312.3\ mol} \quad \textbf{(1)}$$

$$n(HNO_3) = \frac{n(NH_4NO_3)}{\%\ Efficiency} \times \frac{1}{1} = \frac{312.3}{0.92} = \mathbf{339.5\ mol} \quad \textbf{(1)}$$

$$[HNO_3]_{dilute} = \frac{c_1V_1}{V_2} = \frac{1 \times 2.5}{12.5} = \mathbf{0.2\ mol\ L^{-1}} \quad \textbf{(1)}$$

$$V(HNO_3)_{dilute} = \frac{n(HNO_3)}{[HNO_3]_{dilute}} = \frac{339.5}{0.2} = \mathbf{1698\ L} \quad \textbf{(2)}$$

Points to note: Part (b) can be confusing because it is asking for the volume of **diluted** nitric acid. When dealing with questions that have tricky wording take time to establish what the question is actually asking and what information you are provided to help you get the answer.

3. **[8 marks]**

(a)

Equation 1 $\times 2$	$2S_{(l)} + 2O_{2\,(g)} \rightleftharpoons 2SO_{2\,(g)}$
Equation 2	$2SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2SO_{3\,(g)}$
Equation 3 $\times 2$	$2SO_{3\,(g)} + 2H_2O_{(l)} \rightleftharpoons 2H_2SO_{4\,(aq)}$

$$2S_{(l)} + 2O_{2\,(g)} \rightleftharpoons \cancel{2SO_{2\,(g)}}$$

$$\cancel{2SO_{2\,(g)}} + O_{2\,(g)} \rightleftharpoons \cancel{2SO_{3\,(g)}}$$

$$\cancel{2SO_{3\,(g)}} + 2H_2O_{(l)} \rightleftharpoons 2H_2SO_{4\,(aq)}$$

$$2S_{(l)} + 3O_{2\,(g)} + 2H_2O_{(l)} \rightarrow 2H_2SO_{4\,(aq)} \quad \textbf{(2)}$$

(b)

$$n(S) = \frac{m}{M}$$
$$= \frac{10\times10^6}{32.07}$$
$$= 311818\ mol \quad \textbf{(1)}$$

$$n(O_2) = \frac{PV}{RT}$$
$$= \frac{200\times(2\times10^6)}{8.314\times600}$$
$$= 80186\ mol \quad \textbf{(1)}$$

$$n(S)_{required} = n(O_2) \times \frac{2}{3}$$
$$= 80186 \times \frac{2}{3}$$
$$= 53457.3\ mol$$
$$n(S) > n(S)_{required}$$
$\therefore O_2$ is limiting reagent **(1)**

Either Option

$$n(O_2)_{required} = n(S) \times \frac{3}{2}$$
$$= 311818 \times \frac{3}{2}$$
$$= 467727\ mol$$
$$n(O_2) < n(O_2)_{required}$$
$\therefore O_2$ is limiting reagent **(1)**

$$n(H_2SO_4)_{theoretical} = n(O_2) \times \frac{2}{3}$$
$$= 35638.2\ mol \quad \textbf{(1)}$$
$$Energy = 35638.2 \times 230$$
$$= 8196786\ KJ$$
$$= 8196.8\ MJ \quad \textbf{(1)}$$

$\therefore$ since $8196.8MJ > 7000MJ$, the factory **will burn down** **(1)**

4. **[7 marks]**

$$CH_2CH_{2\,(g)} + \cancel{H_2O_{(g)}} \rightleftharpoons \cancel{CH_3CH_2OH_{(g)}}$$

$$\cancel{CH_3CH_2OH_{(g)}} + CH_3COOH_{(g)} \rightleftharpoons CH_3COOCH_2CH_{3\,(g)} + \cancel{H_2O_{(g)}}$$

$$CH_2CH_{2\,(g)} + CH_3COOH_{(g)} \rightleftharpoons CH_3COOCH_2CH_{3\,(g)} \quad \textbf{(1)}$$

$$n(CH_2CH_2) = \frac{PV}{RT}$$
$$= \frac{800\times4000}{8.314\times600}$$
$$= 641.5\ mol \quad \textbf{(1)}$$

$$n(CH_3COOH) = \frac{V}{22.71}$$
$$= \frac{6500}{22.71}$$
$$= 287.2\ mol \quad \textbf{(1)}$$

$$n(CH_2CH_2)_{required} = n(CH_3COOH) \times \frac{1}{1}$$
$$= 287.2\ mol \quad (1)$$
$$n(CH_2CH_2) > n(CH_2CH_2)_{required}$$
$$\therefore CH_3COOH \text{ is limiting reagent} \quad (1)$$

Either Option

$$n(CH_3COOH)_{required} = n(CH_2CH_2) \times \frac{1}{1}$$
$$= 641.5\ mol \quad (1)$$
$$n(CH_3COOH) < n(CH_3COOH)_{required}$$
$$\therefore CH_3COOH \text{ is limiting reagent} \quad (1)$$

$$n(CH_3COOCH_2CH_3) = n(CH_3COOH) \times \frac{1}{1} \times Efficiency$$
$$= 287.2 \times 0.85$$
$$= 244.1\ mol \quad (1)$$

$$V(CH_3COOCH_2CH_3) = \frac{nRT}{P}$$
$$= \frac{244.1 \times 8.314 \times (1000 + 273.15)}{500}$$
$$= 5167\ L \quad (1)$$

$\therefore$ since $5100L > 5000L$, the chamber **will crack** and destroy the plant **(1)**

5. **[7 marks]**

$$M(Triglyceride) = 57 \times 12.01 + 110 \times 1.008 + 6 \times 16$$
$$= 891.45\ g\ mol^{-1} \quad (1)$$

$$n(Triglyceride) = \frac{m}{M} \times 0.97$$
$$= \frac{500 \times 10^3}{891.45} \times 0.97$$
$$= 544.1\ mol \quad (1)$$

$$n(CH_3OH) = cV$$
$$= 0.820 \times 1000$$
$$= 820\ mol \quad (1)$$

$$n(Triglyceride)_{required} = n(CH_3OH) \times \frac{1}{3}$$
$$= 820 \times \frac{1}{3}$$
$$= 273.3\ mol$$
$$n(Triglyceride) > n(Triglyceride)_{required}$$
$$\therefore CH_3OH \text{ is limiting reagent} \quad (1)$$

Either Option

$$n(CH_3OH)_{required} = n(Triglyceride) \times 3$$
$$= 544.1 \times 3$$
$$= 1632.3\ mol$$
$$n(CH_3OH) < n(CH_3OH)_{required}$$
$$\therefore CH_3OH \text{ is limiting reagent} \quad (1)$$

$$n(Biodiesel) = n(CH_3OH) \times \frac{3}{3} \times Efficiency$$
$$= 820 \times 0.83$$
$$= 680.6\ mol \quad (1)$$

$$Energy = 680.6 \times 11$$
$$= 7487\ kJ$$
$$= 7.487\ MJ \quad (1)$$

$\therefore$ since $7.487MJ > 2MJ$, the enzymes **will denature** and finish off BCM! **(1)**

Problem Set 14 – Chemical Synthesis
Repetitive Questions

Concept 1
Chemical Synthesis – Repetitive Questions Answers

Haber Process and Contact Process: Qs 1.11, 1.21, 1.31, 1.32

1.11 **[12 marks]**

(a)

Reaction	Optimum Temperature	Optimum Pressure
(i) $H_2O_{(g)} + C_{(s)} \rightleftharpoons CO_{(g)} + H_{2\,(g)} + 107kJ$	High **Moderate** **(1)** Low	High **Moderate** **(1)** Low
(ii) $2HI_{(g)} \rightleftharpoons I_{2\,(g)} + H_{2\,(g)} \quad \Delta H = 23kJ/mol$	**High** **(1)** Moderate Low	**High** **(1)** Moderate Low
(iii) $2SO_{3\,(g)} + CO_{2\,(g)} \rightleftharpoons CS_{2\,(g)} + 4O_{2\,(g)}$ $\Delta H < 0$	High **Moderate** **(1)** Low	High **Moderate** **(1)** Low
(iv) $CoCl_{2\,(g)} \rightleftharpoons Co_{(g)} + Cl_{2\,(g)}$ $\Delta H < 0$	High **Moderate** **(1)** Low	High **Moderate** **(1)** Low

(b) When a catalyst is added to the system, the catalyst will provide an **alternate reaction pathway** with a **lower activation energy** for both the **forward** and **reverse** reactions **(1)**. An **equal decrease** in the **activation energies** means there will be an **equal increase** in the **proportion of successful collisions** **(1)**. This will increase the **reaction rate** for the **forward** and **reverse** **reactions equally** **(1)**. With an equal increase in reaction rates, there will be **no net forward** or **reverse** reaction created, so the **yield** will **remain unchanged** throughout **(1)**.

Marking Criteria	Marks Allocated
• Catalysts provide an alternate reaction pathway with a lower activation energy • An equal decrease in activation energies creates an equal increase in the proportion of successful collisions	$1-4$

• The reaction rate will increase equally for the forward and reverse reactions • No net reaction is created so the yield will remain unchanged	
Total	**4**

1.31 **[12 marks]**

(a)

Time	Change
T_1	**Increased H_2 Concentration (1)**
T_2	**Volume increased (doubled)/pressure decreased (halved) (1)**
T_3	**Temperature Decreased (1)**

Marking Criteria	Marks Allocated
• States correct change at T_1, T_2 and T_3	$1-3$
Total	**3**

(b) Collisions can **only take place** at the **surface** of **solids (1)**. As a result, when you **increase** the **surface area** of the catalyst by changing it from a block to a mesh, the catalyst **increases** the **number of particles** it can catalyse at a given instant **(1)**. This will **increase** the **reaction rate** of this reaction **(1)**, however it will have **no effect** on the **yield** as the **forward** and **reverse reaction rates** will **increase equally (1)**.

Points to note: This question is asking about the effect of surface area as this is the factor being changed, not the presence/absence of a catalyst. So don't fall for the trick of writing about the effect of the adding/removing a catalyst!

Marking Criteria	Marks Allocated
• Collisions can only take place at the surface of solids • Increasing the surface area increases the number of particles that can be catalysed at a given instant • This will increase the reaction rate equally for the forward and reverse reactions • No net reaction is created so the yield will remain unchanged	$1-4$
Total	**4**

(c) To optimise the **reaction rate** and **yield** a **moderate temperature** and **high pressure** should be used **(1)**. A **higher temperature** will favour the **reverse endothermic reaction** in order to cool down the system, which will **decrease** the **reaction yield (1)**. However, a **higher temperature** will **increase** the **reaction rate** from an **increase** in the **collision frequency** and **proportion of successful collisions**, so a **moderate temperature** should be used **(1)**. A **higher pressure** will favour the **forward reaction** due to a $4:2$ gaseous molar ratio, which will **increase** the **reaction yield (1)**. A **higher pressure** will also **increase** the **reaction rate** from an **increase** in the **collision frequency (1)**.

Marking Criteria	Marks Allocated
• To optimise reaction rate and yield a moderate temperature and high pressure should be used	$1-5$

• A higher temperature will decrease the yield from a favoured reverse endothermic reaction • A higher temperature will increase the reaction rate from an increase in collision frequency and proportion of successful collisions • A pressure increase will increase the yield from a favoured forward reaction due to a $4:2$ gaseous molar ratio • A pressure increase will increase the reaction rate from an increase in the collision frequency	
Total	**5**

1.41 **[12 marks]**

(a) When the temperature of the system is **increased**, the system will act to partially oppose this **temperature increase** by favouring the **endothermic** **reverse reaction** in order to cool down the system **(1)**. A favoured reverse reaction means the **yield** of **sulfur trioxide** will **decrease** from it being consumed **(1)**. As a result a **moderate temperature** is used to find a compromise between the **reaction rate** and **yield** **(1)**.

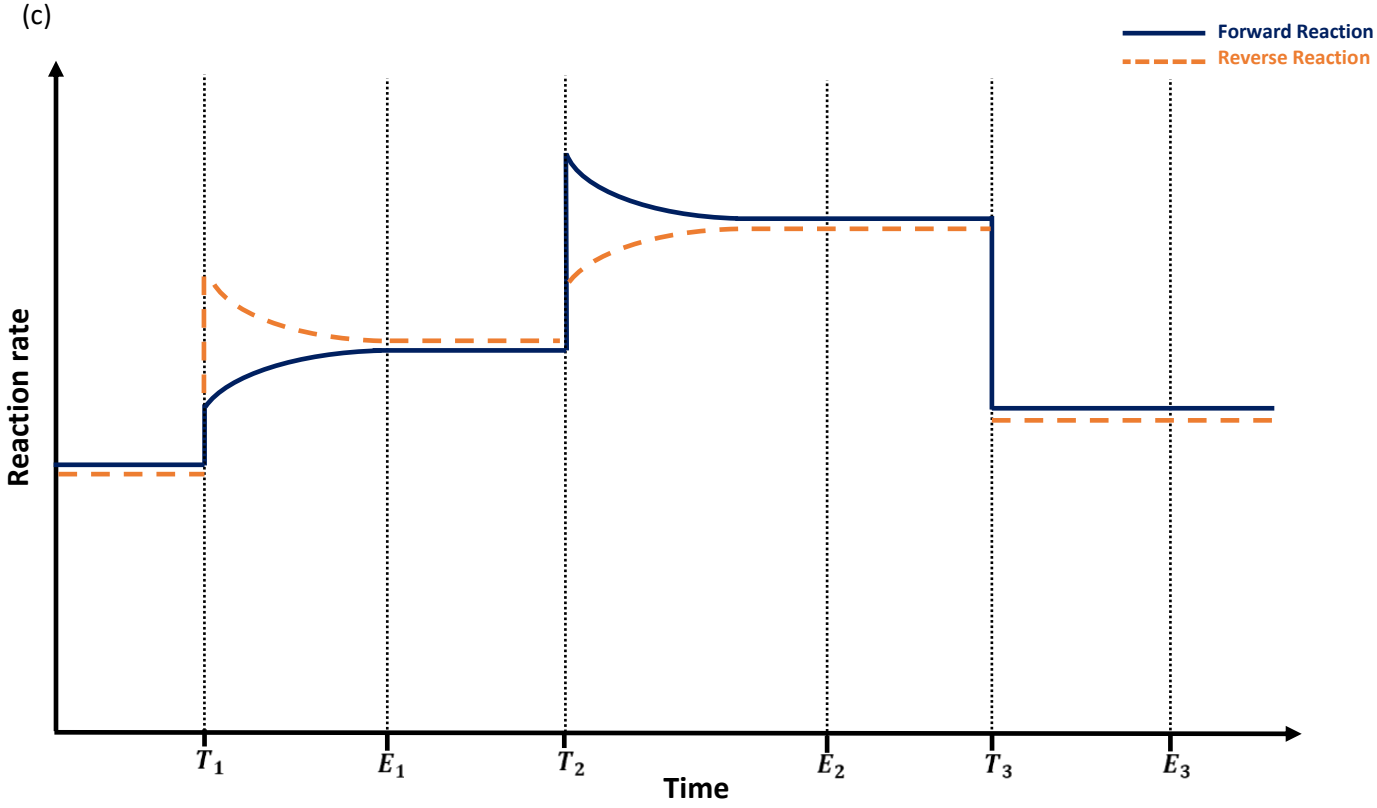
Marking Criteria	Marks Allocated
• Increasing the temperature will favour the endothermic reverse reaction • A favoured reverse reaction will decrease the yield sulfur trioxide from it being consumed • A moderate temperature is used to find a compromise between reaction rate and yield	$1-3$
Total	**3**

(b)

Time	Change made	Effect on Yield (↑ or ↓)
T_1	**Temperature increase**	↓
T_2	**Pressure increase**	↑
T_3	**Fe_2O_3 catalyst removed**	**No Effect**

Marking Criteria	Marks Allocated
• States correct effect on yield at T_1, T_2 and T_3	$1-3$
Total	**3**

(c)



Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous spike in both reaction rates at T_1 with greater increase in reverse reaction rate • Correct curvature and orientation for all curves to reach equilibrium at E_1	$1-2$
From T_2 to E_2: • Instantaneous spike in both reaction rates at T_2 with greater increase in forward reaction rate • Correct curvature and orientation for all curves to reach equilibrium at E_2	$1-2$
From T_3 to E_3: • Equal instantaneous drop in both reaction rates	1
• Equilibrium lines from E_1 to T_2, E_2 to T_3 and E_3 onwards	1
Total	**6**

Ethyl Ethanoate Production: Qs 1.51

1.51 **[13 marks]**

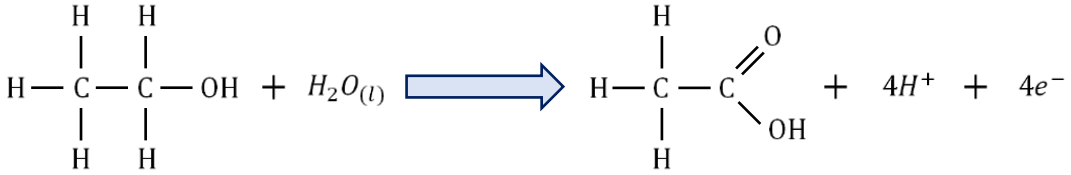
(a) When the **temperature** is **increased**, the **average kinetic energy** of the particles increases meaning the **collision frequency** and **proportion of successful collisions** increases for both **forward** and **reverse** reactions, thus **increasing** the **reaction rate** **(1).** There will be a greater increase in the **proportion of successful collisions** in the **endothermic reverse reaction** thus creating a **net reverse reaction** which **decreases** the **yield** **(1)**. Therefore, a compromise is made between the reaction rate and yield thus a **moderate temperature** is selected **(1).** When the **pressure** is **increased**, the **collision frequency** increases for both **forward** and **reverse** reactions, thus **increasing** the **reaction rate** **(1)**. There will be a **greater increase** in the **collision frequency** in the **forward** reaction due to the **2 : 1 gaseous molar ratio** thus creating a **net forward reaction** which increases the **yield** **(1).** Thus a **high pressure** is selected **(1)**.

Marking Criteria	Marks Allocated
• A temperature increase will increase the collision frequency and proportion of successful collisions, increasing the reaction rate • The proportion of successful collisions will increase more for the endothermic reverse reaction, decreasing the yield • Thus a moderate temperature is used • A pressure increase will increase the collision frequency, increasing the reaction rate • The collision frequency will increase more for the forward reaction due to a $2:1$ gaseous molar ratio, increasing the yield • Thus a high pressure is used	$1-6$
Total	**6**

(b) **Esterification reaction (1)**

Marking Criteria	Marks Allocated
• Esterification reaction	1
Total	**1**

(c)

Oxidation Half-Equation:  **(1)**

Reduction Half-Equation: $MnO_{4\,(aq)}^{-} + 8H_{(aq)}^{+} + 5e^{-} \rightarrow Mn_{(aq)}^{2+} + 4H_2O_{(l)}$ **(1)**

$$5CH_3CH_2OH_{(aq)} + 4MnO_{4\,(aq)}^{-} + 12H_{(aq)}^{+} \rightarrow 5CH_3COOH_{(aq)} + 4Mn_{(aq)}^{2+} + 11H_2O_{(l)} \quad \textbf{(1)}$$

Marking Criteria	Marks Allocated
• Correct oxidation half-equation • Correct reduction half-equation • Balanced overall equation	$1-3$
Total	**3**

(d) When the **pressure** is **increased**, the **collision frequency** increases for both **forward** and **reverse** reactions, thus **increasing** the **reaction rate** **(1)**. However, the **collision frequency** will **increase equally** for the **forward** and **reverse** **reactions** due to the **2 : 2 gaseous molar ratio**, creating **no net reaction**. Thus with **no net reaction** the **yield** will **remain unaffected** **(1)**.

Marking Criteria	Marks Allocated
• A pressure increase will increase the collision frequency, increasing the reaction rate • The collision frequency will increase equally for the forward and reverse reactions due to a $2:2$ gaseous molar ratio • With no net reaction the yield will remain unaffected	$1-3$
Total	**3**

Ethanol and Biodiesel Production: Qs 1.81, 1.91

1.81 **[12 marks]**

(a) Some of the **advantages** of the **hydration** of ethanol relative to the **fermentation** are:

- It is a **much faster process** because it occurs at **higher temperatures** **(1)**
- It is a **much faster process** because it occurs at **higher pressures** **(1)**
- Its phosphoric acid catalyst **does not denature** so it can be used at higher temperatures making it a **faster process** **(1)**
- It has a **higher yield** because it produces a **higher purity** of ethanol **(1)**

Marking Criteria	Marks Allocated
• States three appropriate advantages	1 – 3
Total	**3**

(b) Some **advantages** of fermentation in relation to green chemistry are:

- Fermentation occurs at **biological temperatures** which is more energy efficient **(1)**
- Yeast enzymes are biodegradable **(1)**
- The yeast enzymes can be **reused** **(1)**
- The reactants are made from **renewable plant material** **(1)**
- Yeast enzymes are **specific** and **do not produce unwanted by-products** **(1)**

Marking Criteria	Marks Allocated
• States three appropriate reasons why fermentation is in alignment with green chemistry principles	1 – 3
Total	**3**

(c) Some **advantages** of enzymes over catalysts are:

- Enzymes are **most effective at biological temperatures** which is cheaper **(1)**
- Enzymes are **highly specific**, so they will only **catalyse** a specific reaction **(1)**
- Enzymes can be **reused** **(1)**
- Enzymes are **biodegradable** **(1)**

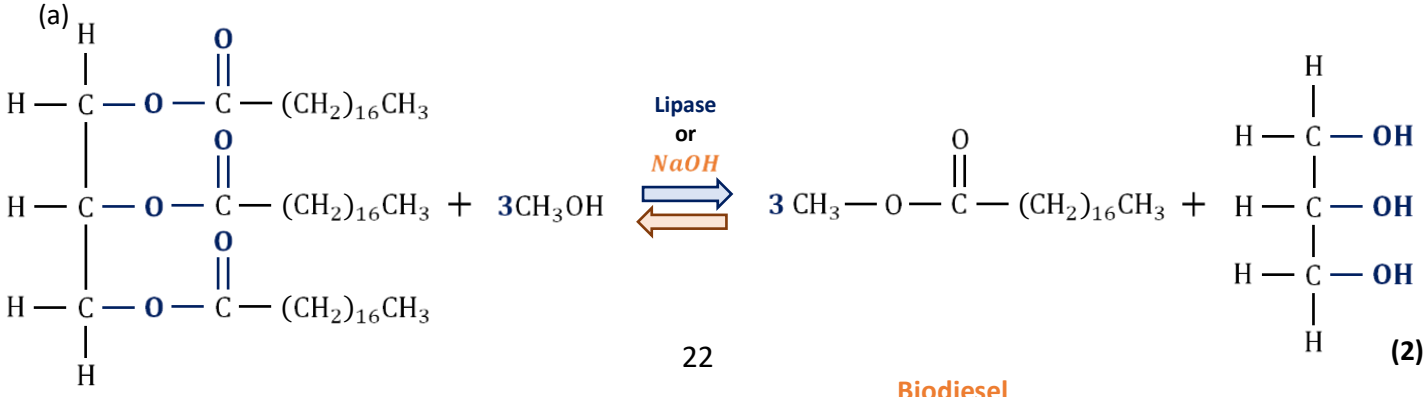
Some **disadvantages** of enzymes over catalysts are:

- Enzymes are **temperature** and **pH sensitive**, so their environment must be **regulated closely** **(1)**
- Enzymes can **denature**, becoming ineffective **(1)**
- Enzymes are generally **expensive** to produce **(1)**
- Reactions with enzymes are slower because they must occur at **biological temperatures** **(1)**

Marking Criteria	Marks Allocated
• States three appropriate advantages	1 – 3
• States three appropriate disadvantages	1 – 3
Total	**6**

1.91 **[13 marks]**

(a)



(2)

Marking Criteria	Marks Allocated
• Correct reactants and products stated • Enzyme and reversible nature of reaction shown	$1-2$
Total	**2**

(b) Some **advantages** of the **base catalyst** over the **lipase enzyme** are:

- **High temperatures** can be used allowing for a **higher reaction rate** **(1)**
- It is **cheaper** to source than lipase enzymes **(1)**
- The base catalyst **will not denature** so it **doesn't need to be monitored** **(1)**

Some **disadvantages** of enzymes over catalysts are:

- The base catalyst is **toxic** and can create **disposal issues** **(1)**
- The base can react with free fatty acids to form **unwanted soap** **(1)**
- The base catalyst **cannot be reused**, new base is need for each reaction **(1)**
- **Higher temperatures** require a **larger energy input** and **higher cost** **(1)**

Marking Criteria	Marks Allocated
• States three appropriate advantages	$1-3$
• States three appropriate disadvantages	$1-3$
Total	**6**

(c)

Temperature	Explanation using Collision Theory
High **Moderate** **Low**	When the **temperature** is **increased**, the **average kinetic energy** of the particles increases meaning the **collision frequency** and **proportion of successful collisions** increases for both **forward** and **reverse** reactions, thus **increasing** the **reaction rate** **(1).** There will be a greater increase in the **proportion of successful collisions** in the **endothermic reverse reaction** thus creating a **net reverse reaction** which **decreases** the **yield** **(1)**. Therefore, a compromise is made between the reaction rate and yield thus a **moderate temperature** is selected **(1).**

Marking Criteria	Marks Allocated
• A temperature increase will increase the collision frequency and proportion of successful collisions, increasing the reaction rate • The proportion of successful collisions will increase more for the endothermic reverse reaction, decreasing the yield • Thus a moderate temperature is used	$1-3$
Total	**3**

(d) If **free fatty acids** are added and its concentration is too high then the $NaOH$ will react with the **free fatty acids** to create **soap** **(1)**. This is an **unwanted reaction** and makes the resulting biodiesel require **additional purification** **(1)**.

Marking Criteria	Marks Allocated
• Free fatty acids can react with the base catalyst to form soap • This makes the biodiesel require additional purification	$1-2$
Total	**2**

Challenging Stoichiometry – Repetitive Questions Answers

2.21 **[12 marks]**

(a)

$$n(N_2) = \frac{PV}{RT} = \frac{100\times50}{8.314\times300} = \mathbf{2.005\ mol}\ \textbf{(1)}$$

$$n(H_2) = \frac{V}{22.71} = \frac{62}{22.71} = \mathbf{2.730\ mol}\ \textbf{(1)}$$

$$n(N_2)_{required} = n(H_2)\times\frac{1}{3} = 2.730\times\frac{1}{3} = \mathbf{0.91\ mol}$$

$n(N_2) > n(N_2)_{required}$

$\therefore$ **H_2 is limiting reagent** **(1)**

Either Option

$$n(H_2)_{required} = n(N_2)\times3 = 2.005\times3 = \mathbf{6.015mol}$$

$n(H_2) < n(H_2)_{required}$

$\therefore$ **H_2 is limiting reagent** **(1)**

$$n(NH_3)_{theoretical} = n(H_2)\times\frac{2}{3} = \mathbf{2.73\ mol}\times\frac{2}{3} = \mathbf{1.82\ mol}\ \textbf{(1)}$$

$$m(NH_3)_{theoretical} = n\times M = 1.82\times(14.01+3\times1.008) = \mathbf{31\ g}\ \textbf{(1)}$$

(b)

$$Efficency = \frac{m(NH_3)_{actual}}{m(NH_3)_{theoretical}}\times100 = \frac{29}{31}\times100\ \textbf{(1)} = \mathbf{93.6\%}\ \textbf{(1)}$$

(c)

$$n(HNO_3) = cV = 1\times100 = \mathbf{100\ mol}\ \textbf{(1)}$$

$$n(NH_3) = n(HNO_3)\times\frac{12}{8} = 100\times1.5 = \mathbf{150\ mol}\ \textbf{(1)}$$

$$V(NH_3) = \frac{nRT}{P} = \frac{150\times8.314\times300}{200} = \mathbf{1871\ L}\ \textbf{(1)}$$

(d)

$$V_2(HNO_3) = \frac{c_1V_1}{c_2}\ \textbf{(1)} = \frac{1\times100}{0.330} = \mathbf{303\ L}\ \textbf{(1)}$$

2.31 **[12 marks]**

(a)

Equation 1 $\times 2$	$2S_{(l)} + 2O_{2\,(g)} \rightarrow 2SO_{2\,(g)}$
Equation 2	$2SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2SO_{3\,(g)}$
Equation 3 $\times 2$	$2SO_{3\,(g)} + 2H_2SO_{4\,(l)} \rightarrow 2H_2S_2O_{7\,(l)}$
Equation 4 $\times 2$	$2H_2S_2O_{7\,(l)} + 2H_2O_{(l)} \rightarrow 4H_2SO_{4\,(l)}$

$$2S_{(l)} + 2O_{2\,(g)} \rightarrow \cancel{2SO_{2\,(g)}}$$

$$\cancel{2SO_{2\,(g)}} + O_{2\,(g)} \rightleftharpoons \cancel{2SO_{3\,(g)}}$$

$$\cancel{2SO_{3\,(g)}} + \cancel{2H_2SO_{4\,(l)}} \rightarrow \cancel{2H_2S_2O_{7\,(l)}}$$

$$\cancel{2H_2S_2O_{7\,(l)}} + 2H_2O_{(l)} \rightarrow \cancel{2}H_2SO_{4\,(l)}$$

$$2S_{(l)} + 3O_{2\,(g)} + 2H_2O_{(l)} \rightarrow 2H_2SO_{4\,(aq)}$$ **(3)**

(b)

$$n(S) = \frac{m}{M} \times 0.48$$
$$= \frac{250}{32.07} \times 0.48$$
$$= 3.742\ mol$$ **(1)**

$$n(O_2) = \frac{V}{22.71} \times 0.20$$
$$= \frac{122}{22.71} \times 0.20$$
$$= 1.074\ mol$$ **(1)**

Either Option

$$n(S)_{required} = n(O_2) \times \frac{2}{3}$$
$$= 1.074 \times \frac{2}{3}$$
$$= 0.718\ mol$$
$$n(S) > n(S)_{required}$$
$\therefore O_2$ is limiting reagent **(1)**

$$n(O_2)_{required} = n(S) \times \frac{3}{2}$$
$$= 3.742 \times \frac{3}{2}$$
$$= 5.613\ mol$$
$$n(O_2) < n(O_2)_{required}$$
$\therefore O_2$ is limiting reagent **(1)**

$$n(H_2SO_4) = n(O_2) \times \frac{2}{3}$$
$$= 1.074 \times \frac{2}{3}$$
$$= 0.716\ mol$$ **(1)**

$$[H_2SO_4] = \frac{n}{V}$$
$$= \frac{0.716}{50}$$
$$= 0.0143\ mol\ L^{-1}$$ **(1)**

(c)

$$n(H_2SO_4) = cV$$
$$= 0.1 \times 72$$
$$= 7.2\ mol$$ **(1)**

$$n(S) = n(H_2SO_4)$$
$$= 7.2\ mol$$ **(1)**

$$m(S) = nM$$
$$= 7.2 \times 32.07$$
$$= 230.9\ g$$ **(1)**

$$\%\ by\ mass\ (S) = \frac{m(S)}{m(S)_{impure}} \times 100$$
$$= \frac{230.9}{250} \times 100$$
$$= 92.4\ \%$$ **(1)**

2.41 **[8 marks]**

$$CH_2CH_{2\,(g)} + \cancel{H_2O_{(g)}} \rightleftharpoons \cancel{CH_3CH_2OH_{(g)}}$$

$$\cancel{CH_3CH_2OH_{(g)}} + CH_3COOH_{(g)} \rightleftharpoons CH_3COOCH_2CH_{3\,(g)} + \cancel{H_2O_{(g)}}$$

$$CH_2CH_{2\,(g)} + CH_3COOH_{(g)} \rightleftharpoons CH_3COOCH_2CH_{3\,(g)} \quad \textbf{(1)}$$

$$n(CH_2CH_2) = \frac{PV}{RT} \times 0.93$$
$$= \frac{400 \times 150}{8.314 \times 300} \times 0.93$$
$$= \mathbf{22.37\ mol} \quad \textbf{(1)}$$

$$[CH_3COOH]_{dilute} = \frac{c_1V_1}{V_2} \quad \textbf{(1)}$$
$$= \frac{1 \times 300}{350}$$
$$= \mathbf{0.857\ mol\ L^{-1}} \quad \textbf{(1)}$$

$$n(CH_3COOH) = cV$$
$$= 0.857 \times 100$$
$$= \mathbf{85.7\ mol} \quad \textbf{(1)}$$

Either Option

$$n(CH_2CH_2)_{required} = n(CH_3COOH) \times \frac{1}{1}$$
$$= \mathbf{85.7\ mol} \quad \textbf{(1)}$$
$$n(CH_2CH_2) < n(CH_2CH_2)_{required}$$
$\therefore$ **CH_2CH_2 is the limiting reagent** **(1)**

$$n(CH_3COOH)_{required} = n(CH_2CH_2) \times \frac{1}{1}$$
$$= \mathbf{22.37\ mol} \quad \textbf{(1)}$$
$$n(CH_3COOH) > n(CH_3COOH)_{required}$$
$\therefore$ **CH_2CH_2 is the limiting reagent** **(1)**

$$n(CH_3COOCH_2CH_3) = n(CH_2CH_2) \times \frac{1}{1} \times Efficiency$$
$$= 22.37 \times 0.82$$
$$= \mathbf{18.34\ mol} \quad \textbf{(1)}$$
$$V(CH_3COOCH_2CH_3) = n \times 22.71$$
$$= 18.34 \times 22.71$$
$$= \mathbf{416.5L} \quad \textbf{(1)}$$

Points to note: Some of the initial information provided is not actually relevant to the calculations. It is important to be able to determine what information you actually need to use and what information you don't.

2.51 **[13 marks]**

$$M(Triglyceride) = 57 \times 12.01 + 110 \times 1.008 + 6 \times 16$$
$$= 891.45g\ mol^{-1} \quad \textbf{(1)}$$

$$M(Glycerol) = 3 \times 12.01 + 8 \times 1.008 + 3 \times 16$$
$$= 92.094g\ mol^{-1} \quad \textbf{(1)}$$

$$M(Biodiesel) = 19 \times 12.01 + 38 \times 1.008 + 2 \times 16$$
$$= 298.494\ g\ mol^{-1} \quad \textbf{(1)}$$

$$n(Biodiesel) = \frac{m}{M}$$
$$= \frac{2500 \times 10^3}{298.494}$$
$$= \mathbf{8375.4\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{n(Glycerol)} = \frac{m}{M}$$
$$= \frac{3\times10^6}{92.094}$$
$$= \mathbf{32575.4\ mol} \quad \textbf{(1)}$$

Since $\boldsymbol{n(Glycerol) > 3 \times n(Biodiesel)}$ the maximum production time will be based on producing the glycerol **(1)**

$$\boldsymbol{n(Triglyceride)_{required}} = \frac{n(Glycerol) \times \frac{1}{1}}{Efficiency}$$
$$= \frac{32575.4}{0.94}$$
$$= \mathbf{34654.7\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{n(Triglyceride)_{per\ minute}} = \frac{V\times0.86}{M}$$
$$= \frac{10\times10^3\times0.86}{891.45}$$
$$= \mathbf{9.647\ mol\ per\ min} \quad \textbf{(1)}$$

$$\boldsymbol{time(triglyceride)} = \frac{n(triglyceride)_{required}}{n(triglyceride)_{per\ minute}}$$
$$= \frac{34654.7}{9.647}$$
$$= \mathbf{3592.3\ min} \quad \textbf{(1)}$$
$$\approx 2.5\ days$$

$$\boldsymbol{n(CH_3OH)_{required}} = \frac{n(Glycerol) \times \frac{3}{1}}{Efficiency}$$
$$= \frac{32575.4\times3}{0.94}$$
$$= \mathbf{103964\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{n(CH_3OH)_{per\ minute}} = \frac{m}{M}$$
$$= \frac{50\times10^3}{12.01+4\times1.008+16}$$
$$= \mathbf{1560.45\ mol\ per\ min}$$

$$\boldsymbol{time(CH_3OH)} = \frac{n(CH_3OH)_{required}}{n(CH_3OH)_{per\ minute}}$$
$$= \frac{103964}{1560.45}$$
$$= \mathbf{66.6\ min} \quad \textbf{(1)}$$
$$\approx 1\ hour\ 7\ mins$$

∴ the maximum time to make this order will be **1 hour 7 minutes (1)**

Points to note: Whilst this question is very difficult and would likely never get asked it is a good example of the critical thinking calculations they like to ask in exams. In these types of questions you need to consider the information you have, the equations you can use and the final result you want and then slowly work towards getting the final answer. When you start large questions like these don't worry if you don't know how to do it exactly, just start with the information that you think is relevant and you will likely find you can figure it out as you go.

Also note that $1L\ of\ trigliceride = 1kg\ of\ triglyceride$, which can be used to determine the mass of the triglyceride added per minute. This will usually be stated in an exam question.

Chemistry College
Exam Answers

Multiple Choice Answer Sheet

1.	(a)	**(b)**	(c)	(d)	15.	(a)	**(b)**	(c)	(d)
2.	(a)	(b)	**(c)**	(d)	16.	(a)	(b)	(c)	**(d)**
3.	(a)	**(b)**	(c)	(d)	17.	(a)	(b)	**(c)**	(d)
4.	(a)	**(b)**	(c)	(d)	18.	(a)	(b)	(c)	**(d)**
5.	(a)	**(b)**	(c)	(d)	19.	(a)	(b)	(c)	**(d)**
6.	(a)	(b)	**(c)**	(d)	20.	**(a)**	(b)	(c)	(d)
7.	(a)	(b)	**(c)**	(d)	21.	**(a)**	(b)	(c)	(d)
8.	(a)	**(b)**	(c)	(d)	22.	(a)	(b)	**(c)**	(d)
9.	(a)	**(b)**	(c)	(d)	23.	(a)	(b)	**(c)**	(d)
10.	(a)	(b)	(c)	**(d)**	24.	**(a)**	(b)	(c)	(d)
11.	(a)	(b)	(c)	**(d)**	25.	(a)	**(b)**	(c)	(d)
12.	(a)	(b)	(c)	**(d)**					
13.	(a)	**(b)**	(c)	(d)					
14.	(a)	(b)	**(c)**	(d)					

1. Answer – **(b)** – Both the pipette and burette need rinsing in the solution they will contain. The conical flask will always be rinsed in water.
2. Answer – **(c)** – Addition polymerization involves the joining of two monomer units by the double bond breaking. Condensation polymerization involves the joining of two different monomer units which contain two functional groups. Only i), ii) and v) contain either a double bond or two functional groups on the end of the molecule.
3. Answer – **(b)** – the oxidation number of chromium increases from $+3$ to $+6$, meaning it is the reductant. The oxidation number on the hydrogen peroxide decreases from -1 to -2, meaning it is the oxidant. Note: an oxidant undergoes reduction, and a reductant undergoes oxidation.

4. Answer – **(b)** – there are four possible isomers (in the WACE syllabus): butan-1-ol, butan-2-ol, methylpropan-1-ol and methylpropane-2-ol.
5. Answer – **(b)** – $CH_2OHCH_2CH_3$ is an alcohol which has a higher solubility than similar sized alkanes, amines and aldehydes.
6. Answer – **(c)** – statement (ii) is incorrect because soap forms a scum from calcium ions and magnesium ions in hard water, not sodium hydroxide. Statement (iii) is incorrect because the head of the soap micelle head points outwards, while the tail points inwards to the center.
7. Answer – **(c)** – whilst reaction (ii) shows the production of carbon dioxide it is not an ocean equilibrium system, and reaction (iii) is not a relevant equilibrium system.
8. Answer – **(b)** – reaction at anode: $Pb_{(s)} + SO_{4\,(aq)}^{2-} \rightleftharpoons PbSO_{4\,(s)} \quad E_0 = 0.36V$ **,** reaction at cathode: $PbO_{2\,(s)} + SO_{4\,(aq)}^{2-} + 4H_{(aq)}^{+} + 2e^- \rightleftharpoons PbSO_{4\,(s)} + 2H_2O_{(l)} \quad E_0 = 1.69V$. Whilst there are other half-reactions that could occur, these have the highest voltage and are therefore the reactions that actually occur.
9. Answer – **(b)** – Even though the forward reaction will be favored to decrease the pH again, overall the pH will remain slightly higher. The concentration of $H_3O_{(aq)}^{+}$ will not increase 'overall' because it will neutralised by the base, causing an initial drop in the $H_3O_{(aq)}^{+}$ concentration that cannot be recovered. The concentration of the $HCO_{3\,(aq)}^{-}$ will be the only one increasing from a favoured forward reaction.
10. Answer – **(d)** – this answer will be determined from your knowledge of the advantages and disadvantages of inorganic catalysts versus enzymes
11. Answer – **(d)** – Ketones are formed by the oxidation of secondary alcohols. Both i) and v) are secondary alcohols.
12. Answer – **(d)** – the concentration of both the products and reactants (excluding water) will decrease because they have been diluted. Water is a liquid so its concentration will remain unaffected. The reverse reaction will also be favoured meaning the solution will become more pink and less blue. (note it could also be argued that the solution becomes less pink and less blue because the solution is being diluted, however this option is not provided with the correct concentration changes).
13. Answer – **(b)** – the order and placement is only correct in b.
14. Answer – **(c)** – The question asks which statement is definitely true. Whilst statements (a) and (d) could be correct, they are not definitely correct. Statement (c) is the only statement that is definitely true as pH is dependent upon the combination of strength and concentration.
15. Answer – **(b)** – Ni, Pb, Mg and Zn will all be oxidised because they have a higher oxidation potential than Cu but only Cu^{2+} will be reduced because it is the only ion with a reduction potential greater than zero.
16. Answer – **(d)** – Answers (a) through to (c) are all incorrect. The reaction is exothermic so increasing the temperature will result in the yield decreasing as reverse reaction is favoured. The 2:1 gaseous molar ratio means high pressure and temperature optimize both reaction rate and yield. A catalyst increases the rate of reaction for both the forward and reverse reactions equally so it has no effect on yield
17. Answer – **(c)** – This answer is based on the following calculations: $\frac{Final\ pH}{Initial\ pH} - 1 = \frac{10^{-9.2}}{10^{-9.1}} - 1 = 10^{-0.1} - 1 = -21\% \quad \therefore$ there has been a **21% decrease** **(1)**

18. Answer – **(d)** – Nylon form strong hydrogen bonds between its chains giving it its high tensile strength

19. Answer – **(d)** – a decrease in pressure or temperature, as well as increase in volume will decrease the reaction rate, and this graph shows an increase. The addition of a catalyst will increase the reaction rate of both the forward and reverse reactions equally.

20. Answer – **(a)** – only (iii), (iv) and (v) will produce a positive standard reduction potential and involve one of the reactants oxidizing and the other reducing.

21. Answer – **(a)** – as the temperature decreases, the K_w decreases and thus the concentration of products decreases. This means the reverse reaction is favoured when temperature is decreased, meaning the reverse reaction is exothermic. Thus the forward reaction is endothermic.

22. Answer – **(c)** – This answer is based on the following calculations: $[H_3O^+] = \sqrt{K_w} = \sqrt{0.38 \times 10^{-14}} = 6.164 \times 10^{-8}$ ==> $pH = -log[H_3O^+] = -log[6.164 \times 10^{-8}] = 7.21$

23. Answer – **(c)** – Since a strong acid and weak base have been used, the equivalence point will be around pH 3-5 (i.e. acidic). Phenolphathlein's end point is at a pH of 8-10 (i.e. basic), so the end point will occur before the equivalence point since ammonia is in the conical flask as we are going from a basic to acidic pH. Since less titrant needs to be added to reach the end point, so the calculated ammonia concentration will be lower.

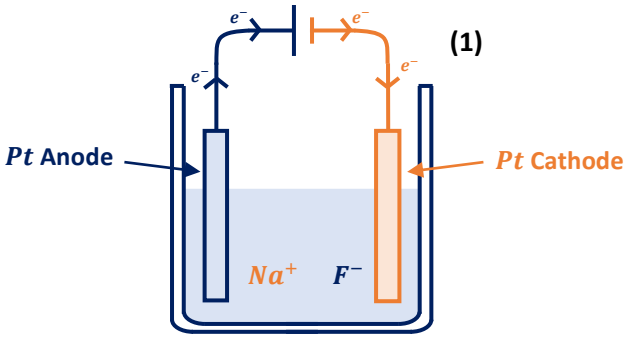
24. Answer – **(a)** – Using the wrong indicator is a systematic error because it creates a constant bias in the results that will occur in every trial. Using different glassware and viewing the meniscus from different levels will give results below and above the theoretical value meaning it is random. Rinsing a conical flask with water is the correct procedure.

25. Answer – **(b)** – Oxidizing an aldehyde produces a carboxylic acid. Oxidizing a secondary alcohol produces a ketone. An alcohol and carboxylic acid produce an ester. An alkene and hydrogen gas produce an alkane.

Section 2: Short Answer **35% (68 marks)**

26. **[9 marks]**

(a)



Marking Criteria	Marks Allocated
• Electron flow drawn from anode to cathode	1
Total	**1**

(b)

Oxidation half-equation	$2H_2O_{(l)} \rightleftharpoons O_{2\,(g)} + 4H^+_{(aq)} + 4e^-$ **(1)**
Reduction half-equation	$2H_2O_{(l)} + 2e^- \rightleftharpoons H_{2\,(g)} + 2OH^-_{(aq)}$ **(1)**

Marking Criteria	Marks Allocated
• Correct oxidation half-equation • Correct reduction half-equation	$1-2$
Total	**2**

Points to note: Water is oxidized and reduced because it has higher oxidation and reduction potential than fluorine and sodium ions. Always remember to consider the oxidation and reduction potentials of water in aqueous electrolytic cells.

(c)

$$(-1.23) + (-0.83) = -2.06\ V$$

$\therefore$ a voltage of $2.06\ V$ is required **(1)**

Marking Criteria	Marks Allocated
• States a positive voltage of $2.06V$ is required	1
Total	**1**

(d) It would be observed that a **colourless**, **odourless gas** is produced at the **anode** **(1)**, and a **colourless**, **odourless gas** is produced at the **cathode** **(1)**.

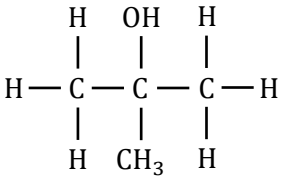
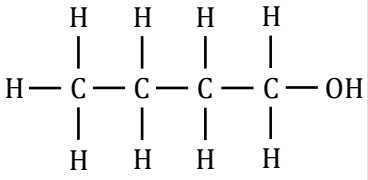
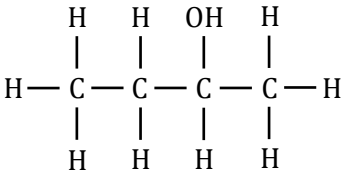
Marking Criteria	Marks Allocated
• A colourless odourless gas is produced at the anode • A colourless odourless gas is produced at the cathode	$1-2$
Total	**2**

(e) The E^0 for the **oxidation** of **fluorine ions** is $-2.89V$ and the E^0 for the **reduction** of **sodium ions** is $-2.71V$, which are **much lower** than **water's oxidation** and **reduction** potentials of $-1.23V$ and $-0.83V$ respectively **(1)**. Therefore, in an aqueous electrolytic cell, water will be oxidized and reduced in **preference** to sodium and fluorine **(1)**. As a result, sodium fluoride undergoes electrolysis in its **molten form** so that there is **no water present** to prevent its oxidation and reduction from occurring **(1)**.

Marking Criteria	Marks Allocated
• Compares the E^0 values of fluorine and sodium ions with water • Explains why water is oxidised and reduced in preference to sodium and fluorine ions • Sodium fluoride undergoes electrolysis in its molten form because there is no water present	$1-3$
Total	**3**

27. **[7 marks]**

(a)

	Beaker A	Beaker B	Beaker C
Compound name	Methylpropan-2-ol **(1)**	Butan-1-ol **(1)**	Butan-2-ol **(1)**
Structural formula	 **(1)**	 **(1)**	 **(1)**

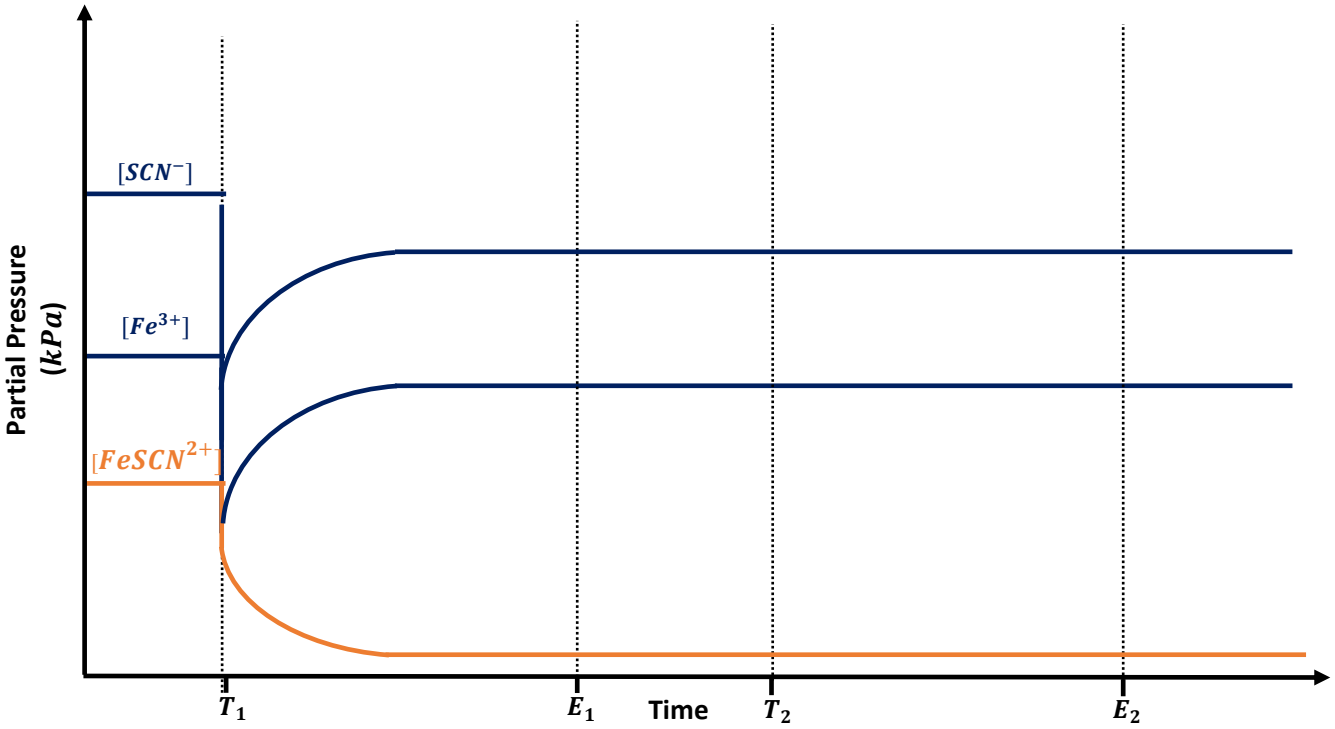
Marking Criteria	Marks Allocated
• States correct compound name	$1-3$
• Draws correct compound structure based on name	$1-3$
Total	**6**

(b) **Butyl ethanoate (1)**

Marking Criteria	Marks Allocated
• Butyl ethanoate	1
Total	**1**

28. **[8 marks]**

(a)



Marking Criteria	Marks Allocated
From T_1 to E_1: • Instantaneous drop in all concentration curves at T_1 to half their concentrations • Correct curvature and orientation for all curves to reach equilibrium at E_1	$1-2$
From T_2 to E_2: • Continue equilibrium lines	1
• Equilibrium lines from E_1 to T_2, E_2 to T_3 and E_3 onwards	1
Total	**4**

Points to note: At T_2 the pressure change has no effect because this is an aqueous system, so the concentrations remain unaffected.

(b)

Time	Predicted Colour
T_1	Very pale brown **(1)**
E_1	Pale brown **(1)**
T_2	Pale brown **(1)**
E_2	Pale brown **(1)**

Marking Criteria	Marks Allocated
• States correct predicted colour based off their concentration graph drawn in part (a)	$1-4$
Total	**4**

29. **[5 marks]**

The boiling point of a substance is dependent upon the **sum** of the strength of its **intermolecular forces** **(1)**. **Pentane**, **pentanal** and **pentanoic acid** all exhibit **dispersion forces** due to the presence of electrons, and these are of a **similar strength** as the molecules all have similar molar masses **(1)**. Both **pentanal** and **pentanoic acid** are **polar molecules** and therefore exhibit **dipole-dipole forces**, giving them a higher boiling point than **pentane** **(1)**. Only **pentanoic acid** has an ***OH* group** that can form **hydrogen bonds** with the lone pair electrons on another pentanoic acid molecule **(1)**. As a result, **pentanoic acid** has the **highest boiling point** because it has the **strongest sum** of **intermolecular forces** **(1)**.

Marking Criteria	Marks Allocated
• Boiling point is dependent upon the sum of the strength of the intermolecular forces • Pentane, pentanal and pentanoic acid all exhibit dispersion forces • Pentanal and pentanoic acid exhibit dipole-dipole forces, giving them higher boiling points than pentane • Only pentanoic acid exhibits hydrogen bonding • The sum of intermolecular forces is greatest for pentanoic acid, giving it the highest boiling point	$1-5$
Total	**5**

30. **[6 marks]**

(a)

Salt	NaF	NH_4Cl	$LiOH$	NaH_2PO_4	$KHSO_4$	$MgCO_3$
Nature	**Basic**	**Acidic**	**Basic**	**Acidic**	**Acidic**	**Basic**

Marking Criteria	**Marks Allocated**
• States correct nature of each salt (1/2 mark for each correct answer)	$1-3$
Total	**3**

(b) $KHSO_4$ is an **amphiprotic substance** because it is **capable** of both **donating** and **accepting** a **proton** **(1)**. For instance, in water $KHSO_4$ can either **donate** a proton (acting as an acid): $\boldsymbol{HSO_{4\,(aq)}^-} + H_2O_{(l)} \rightleftharpoons SO_{4\,(aq)}^{2-} + H_3O_{(aq)}^+$ **(1)** or **accept** a proton (acting as a base) $\boldsymbol{HSO_{4\,(aq)}^-} + H_2O_{(l)} \rightleftharpoons H_2SO_{4\,(aq)} + OH_{(aq)}^-$ **(1)**.

Marking Criteria	**Marks Allocated**
• An amphiprotic substance can both donate and accept a proton • States an equation of HSO_4^- donating a proton • States an equation of HSO_4^- accepting a proton	$1-3$
Total	**3**

31. **[9 marks]**

(a)

$$\boldsymbol{n(Ba(OH)_2)} = n(OH) \times \frac{\mathbf{1}}{\mathbf{2}}$$
$$= 0.0230 \times \frac{1}{2}$$
$$= \mathbf{0.0115\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{[Ba(OH)_2]} = \frac{n}{V}$$
$$= \frac{0.0115}{0.025}$$
$$= \mathbf{0.46\ mol\ L^{-1}} \quad \textbf{(1)}$$

(b)

$$\boldsymbol{n(HNO_3)} = cV$$
$$= 0.402 \times 0.08$$
$$= \mathbf{0.03216\ mol}$$

$$\boldsymbol{n(Ba(OH)_2)} = cV$$
$$= 0.46 \times 0.04$$
$$= \mathbf{0.0184\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{n(H_3O^+)} = n(HNO_3)$$
$$= \mathbf{0.03216\ mol}$$

$$\boldsymbol{n(OH^-)} = n(Ba(OH_2)) \times 2$$
$$= 0.0184 \times 2$$
$$= \mathbf{0.0368\ mol} \quad \textbf{(1)}$$

$$H_3O^+_{(aq)} + OH^-_{(aq)} \rightarrow 2H_2O_{(l)} \quad \textbf{(1)}$$

$$\therefore\ n(OH^-)_{in\ excess} = 0.0368 - 0.03216$$
$$= 0.00464\ mol \quad \textbf{(1)}$$

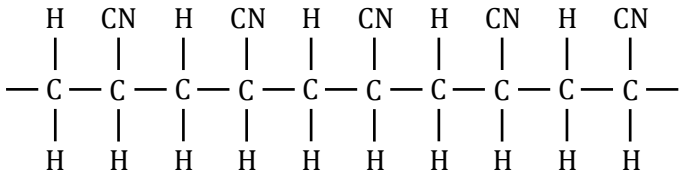
$$[OH^-] = \frac{n(OH^-)_{in\ excess}}{V_a + V_b}$$
$$= \frac{0.00464}{0.08+0.04}$$
$$= 0.03867\ mol\ L^{-1} \quad \textbf{(1)}$$

$$[H_3O^+] = \frac{1\times10^{-14}}{[OH^-]}$$
$$= \frac{1\times10^{-14}}{0.03867}$$
$$= 2.586 \times 10^{-13}\ mol\ L^{-1} \quad \textbf{(1)}$$

$$pH = -log\ [H_3O^+]$$
$$= -log\ [2.586 \times 10^{-13}]$$
$$= 12.6 \quad \textbf{(1)}$$

32. **[12 marks]**

(a)



(2)

Marking Criteria	Marks Allocated
• Draws correct repeating monomer structure • Draws five repeating units	1 – 2
Total	**2**

(b)

	Low density polyethene (LDPE)	High density polyethene (HDPE)	Ultra-High molecular weight polyethene (UHMWE)
Properties	Low melting point **(1)**	Moderate strength **(1)**	Very high hardness **(1)**
Applications	Soft plastic bottles **(1)**	Rigid plastic bottles **(1)**	Bullet proof vest panels **(1)**

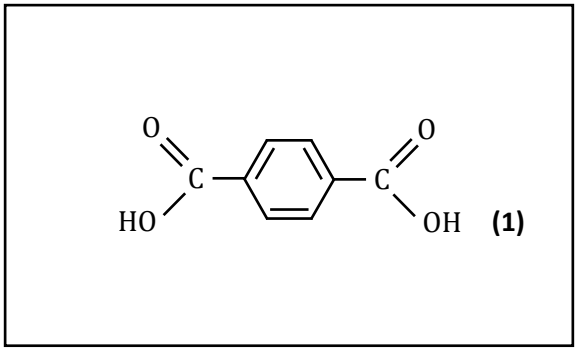
Marking Criteria	Marks Allocated
• States correct property for each type of polyethene	$1-3$
• States correct application for each type of polyethene	$1-3$
Total	**6**

(c) **Condensation polymerisation** is different to addition polymerization because it is the joining two **different monomer units** which each contain **two reactive functional groups** instead of the joining of the same monomer unit by breaking a double bond **(1)**. Examples of the types of reactants that can be used are those containing **carboxylic acid** or **amine functional groups** or **one of each (1)**.

Marking Criteria	Marks Allocated
• Condensation poylmerisation is between two different monomer units with each containing two reactive functional groups • Reactants can be those that contain carboxylic acid or amine functional groups	$1-2$
Total	**2**

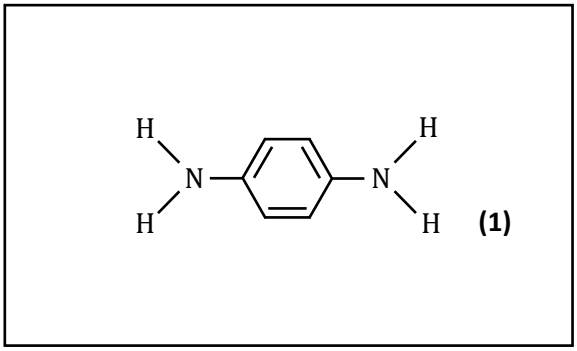
(d)

Monomer 1



(1)

Monomer 2



(1)

Marking Criteria	Marks Allocated
• Draws monomer 1 (benzenedioic acid) • Draws monomer 2 (benzene-1,4-diamine)	$1-2$
Total	**2**

33. **[5 marks]**

Of the three options, **cresolphthalein** would be the **most suitable indicator (1)**. When ethanoic acid and potassium hydroxide react under the following reaction: $KOH_{(aq)} + CH_3COOH_{(aq)} \rightarrow KCH_3COO_{(aq)} + H_2O_{(aq)}$ **(1)** they form the **basic salt** KCH_3COO. As shown in this equation: $CH_3COO^- + H_2O_{(l)} \rightarrow CH_3COOH_{(aq)} + OH^-_{(aq)}$ **(1)** the KCH_3COO salt is **basic** and will therefore cause the **equivalence point** of the titration to be **basic (1)**. As a result **cresolphthalein** should be used because it has a **basic end point range (1)**.

Marking Criteria	Marks Allocated
• Cresolphthalein is the most suitable indicator • Salt produced is KCH_3COO: $KOH_{(aq)} + CH_3COOH_{(aq)} \rightarrow KCH_3COO_{(aq)} + H_2O_{(aq)}$ • KCH_3COO is basic: $KCH_3COO_{(aq)} + H_2O_{(l)} \rightarrow CH_3COOH_{(aq)} + OH^-_{(aq)}$ • A basic salt will cause the equivalence point to be basic • Cresolphthalein should be used because it has a basic end point range	$1-5$
Total	**5**

34. **[7 marks]**

(a)

Oxidation half-equation	$H_{2(g)} + 2OH^-_{(aq)} \rightleftharpoons 2H_2O_{(l)} + 2e^-$ **(1)**
Reduction half-equation	$O_{2(g)} + 2H_2O_{(l)} + 4e^- \rightleftharpoons 4OH^-_{(aq)}$ **(1)**

Marking Criteria	Marks Allocated
• Correct oxidation half-equation • Correct reduction half-equation	$1-2$
Total	**2**

(b)

$$E^0 = 0.40 + 0.83$$
$$= 1.23\,V \quad \textbf{(1)}$$

Marking Criteria	Marks Allocated
• Calculates E^0 of $1.23V$	1
Total	**1**

(c) The IPHE was established to encourage the research and development of the hydrogen fuel cell and to develop codes and standards around their development and use **(1)**. Some barriers to the widespread use of the hydrogen fuel cell are:

- Storage is difficult because hydrogen gas is highly explosive and oxygen gas is highly flammable **(1)**
- Hydrogen fuel cells are currently expensive to produce **(1).**
- Hydrogen gas is currently sourced from steam reforming which uses fossil fuels **(1).**

Marking Criteria	Marks Allocated
• Provides a brief statement about the purpose of the IPHE	1
• States three appropriate issues with the widespread use hydrogen fuel cells	$1-3$
Total	**4**

Section 3: Extended Answer **40% (93 marks)**

35. **[19 marks]**

(a)

Equation 1 $\times 3$ $12NH_{3\,(g)} + 15O_{2\,(g)} \rightarrow 12NO_{(g)} + 18H_2O_{(g)}$

Equation 2 $\times 6$ $12NO_{(g)} + 6O_{2\,(g)} \rightarrow 12NO_{2\,(g)}$

Equation 3 $\times 4$ $12NO_{2\,(g)} + 4H_2O_{(l)} \rightarrow 8HNO_{3\,(aq)} + 4NO_{(g)}$ **(1)**

$$12NH_{3\,(g)} + \overset{21}{\cancel{15}}O_{2\,(g)} \rightarrow \cancel{12NO_{(g)}} + \overset{14}{\cancel{18}}H_2O_{(g)}$$

$$\cancel{12NO_{(g)}} + \cancel{6O_{2\,(g)}} \rightarrow \cancel{12NO_{2\,(g)}}$$

$$\cancel{12NO_{2\,(g)}} + \cancel{4H_2O_{(l)}} \rightarrow 8HNO_{3\,(aq)} + 4NO_{(g)} \quad \textbf{(1)}$$

$$12NH_{3\,(aq)} + 21O_{2\,(g)} \rightarrow 14H_2O_{(l)} + 8HNO_{3\,(aq)} + 4NO_{(g)} \quad \textbf{(1)}$$

Marking Criteria	Marks Allocated
• Balances each of the equations correctly • Cancels out correct reactants and products • Provides correct overall equation	$1-3$
Total	**3**

(b) The third step of the Ostwald process is **highly exothermic** with an enthalpy of $-348kJ$ **(1)**. If there were no cooling circuits the reaction chamber would **heat up** and the nitric acid would become a **gaseous state** **(1)**. This would make it **much more difficult** to **collect**, as it is much harder to collect nitric acid in its **gaseous form** than in its **aqueous form** **(1)**.

Marking Criteria	Marks Allocated
• The third step is highly exothermic • Without cooling circuits the reaction chamber will heat up and the nitric acid will be in a gaseous state • Nitric acid in a gaseous state is much more difficult to collect than in a liquid state	$1-3$
Total	**3**

(c)

$$\boldsymbol{n(NH_3)} = \frac{10\times10^3}{14.01+3\times1.008}$$
$$= \boldsymbol{587.1\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{n(HNO_3)_{theoretical}} = \boldsymbol{n(NH_3)} \times \frac{8}{12}$$
$$= 587.1 \times \frac{8}{12}$$
$$= \boldsymbol{391.4\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{n(HNO_3)_{actual}} = cV$$
$$= 7.00 \times 50$$
$$= \boldsymbol{350\ mol} \quad \textbf{(1)}$$

$$Efficiency = \frac{\boldsymbol{n(HNO_3)_{actual}}}{\boldsymbol{n(HNO_3)_{theoretical}}} \times 100$$
$$= \frac{350}{391.4} \times 100$$
$$= \boldsymbol{89.4\%} \quad \textbf{(2)}$$

(d)

$$\boldsymbol{6NO_{(g)} + 4NH_{3(g)} \rightarrow 6H_2O_{(g)} + 5N_{2(g)}} \quad \textbf{(1)}$$

(e)

$$\boldsymbol{n(NO)_{per\ minute}} = \frac{\boldsymbol{PV_{per\ min}}}{RT} \times purity$$
$$= \frac{200\times20}{8.314\times(100+273.15)} \times 0.012$$
$$= \boldsymbol{0.01547\ mol\ per\ min} \quad \textbf{(3)}$$

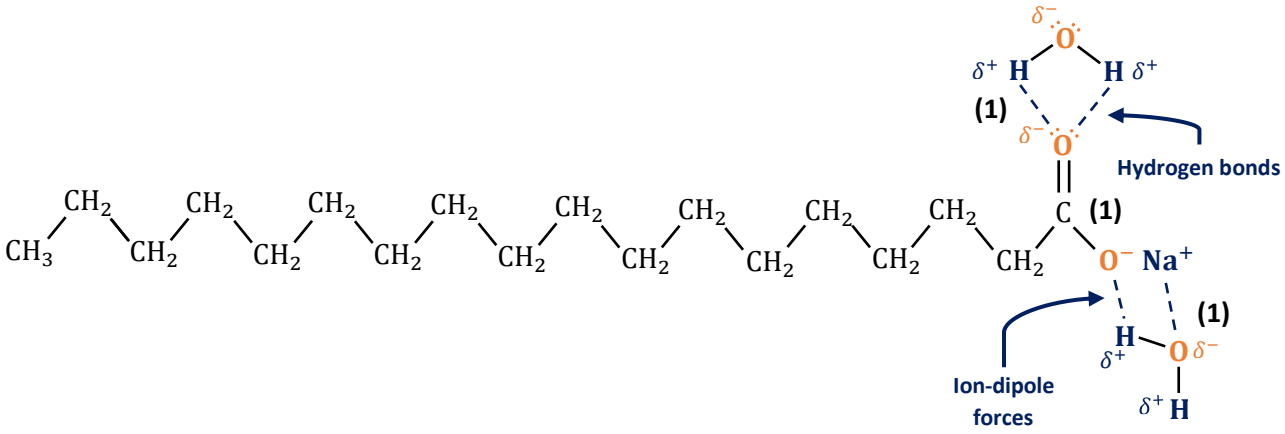
$$\boldsymbol{n(NO)_{8\ hours}} = n(NO)_{per\ min} \times 60 \times 8$$
$$= 0.01547 \times 60 \times 8$$
$$= \boldsymbol{7.4256\ mol} \quad \textbf{(2)}$$

$$\boldsymbol{n(NH_3)_{8\ hours}} = n(NO)_{8\ hours} \times \frac{4}{6}$$
$$= 7.4256 \times \frac{4}{6}$$
$$= \boldsymbol{4.950\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{V(NH_3)} = n(NH_3) \times 22.71$$
$$= 4.950 \times 22.71$$
$$= \boldsymbol{112.4L} \quad \textbf{(1)}$$

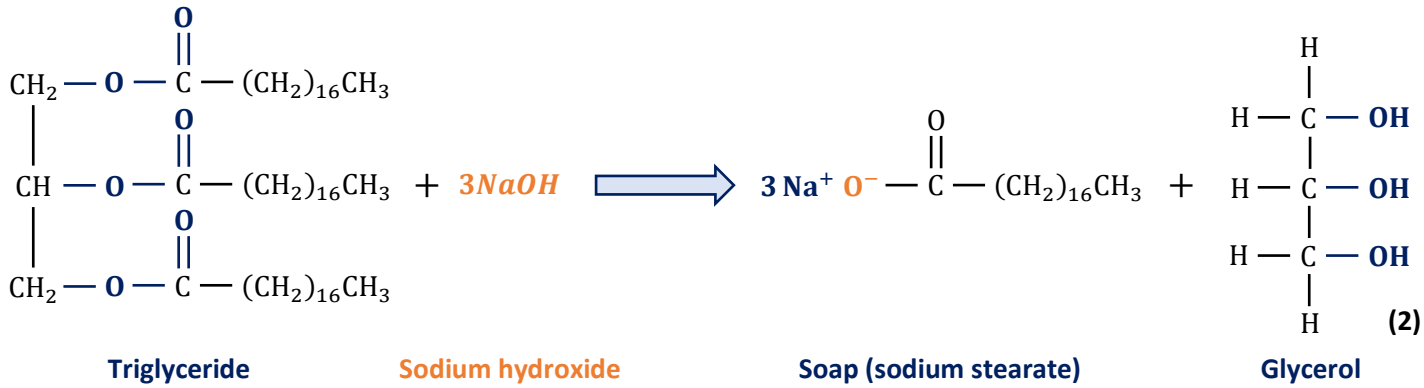
36. **[13 marks]**

(a)



Marking Criteria	Marks Allocated
• Draws $COO^{-}Na^{+}$ polar head of soap • Draws water molecule forming hydrogen bond • Draws water molecule forming ion-dipole forces	1 – 3
Total	**3**

(b)



Marking Criteria	Marks Allocated
• Writes correct reactants and products • Balances equation correctly	1 – 2
Total	**2**

Points to note: You can write the equation in its condensed structural formula or even in its worded form (as long as it is correctly balanced) and still receive the marks.

(c) When there are **grease stain**, the **soap/detergent micelle positions itself around** the **grease stain** **(1)**. The **ionic polar head** remains on the outside, being **dissolved** in the **water** from **forming strong hydrogen bonds** **(1)** and **ion-dipole forces** **(1)**. The non-polar tail dissolves in the grease stain because they are both **large hydrocarbons** with **similar sized dispersion forces** **(1)**. Vigorous **agitation** of the mixture allows the micelles to be **released** from the object **(1)**. Once released, the grease particles are in a **stable micelle arrangement**, allowing them to be **suspended** in the **water** and can be **washed away** **(1)**. Hard water contains Ca^{2+} and Mg^{2+} **ions** in **high concentrations**, and the soap will form **precipitate** with these ions (e.g. $Ca^{2+}_{(aq)} + 2CH_3(CH_2)_{16}COO^-_{(aq)} \rightarrow Ca(CH_3(CH_2)_{16}COO)_{2\,(s)}$) **(1).** This **scum** means that the soap is **wasted** and **does not clean** as **effectively** **(1).**

Marking Criteria	Marks Allocated
• Soap forms a micelle arrangement around the grease stain • The ionic polar head forms strong hydrogen bonds with water (allowing it to dissolve) • The ionic polar head also forms ion-dipole forces with water (allowing it to dissolve) • The non-polar tail forms dispersion forces with the grease stain (allowing it to dissolve) • Agitation releases the mixture from the object • The grease and soap are in a micelle arrangement, allowing it to be suspended in water and washed away	$1-6$
• Soap precipitates with the Ca^{2+} and Mg^{2+} ions in hard water • The scum formed means soap is wasted and it doesn't clean as effectively	$1-2$
Total	**8**

37. **[17 marks]**

$$n(CO_2) = \frac{18.493}{44.01} = 0.4202\ mol$$

$$n(C) = n(CO_2) = 0.4202\ mol$$

$$m(C) = nM = 0.4202 \times 12.01 = 5.047\ g \quad (1)$$

$$\%\,(C) = \frac{5.047}{10.20} \times 100 = 49.48\% \quad (1)$$

$$n(H_2O) = \frac{4.731}{18.016} = 0.2626\ mol$$

$$n(H) = n(H_2O) \times 2 = 0.2626 \times 2 = 0.5252\ mol \quad (1)$$

$$m(H) = nM = 0.5252 \times 1.008 = 0.5294\ g \quad (1)$$

$$\%(H) = \frac{0.5294}{10.20} \times 100 = 5.19\% \quad (1)$$

$$NH_{3\,(aq)} + HCl_{(aq)} \rightarrow NH_4Cl_{(aq)}$$

$$n(HCl) = cV = 2.00 \times 0.01762 = 0.03524\ mol \quad (1)$$

$$n(NH_3)_{25mL} = n(HCl)$$
$$= \mathbf{0.03524\ mol}$$

$$n(NH_3)_{100mL} = n(NH_3)_{25mL} \times \frac{100}{25}$$
$$= 0.03524 \times 4$$
$$= \mathbf{0.1410\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{n(N)} = n(NH_3)$$
$$= \mathbf{0.1410\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{m(N)} = nM$$
$$= 0.1410 \times 14.01$$
$$= \mathbf{1.975g}$$

$$\%\ \boldsymbol{(N)} = \frac{1.975}{6.843} \times 100$$
$$= \mathbf{28.86\%} \quad \textbf{(1)}$$

$$\%(\boldsymbol{O}) = 100 - \%(C) - \%(H) - \%(N)$$
$$= 100 - 49.48 - 5.19 - 28.86$$
$$= \mathbf{16.47\%} \quad \textbf{(1)}$$

	C	H	N	O	
Mass in $100g$	$49.48g$	$5.19g$	$28.86g$	$16.47g$	
Moles	$\frac{49.48}{12.01} = 4.120\ mol$	$\frac{5.19}{1.008} = 5.149\ mol$	$\frac{28.86}{14.01} = 2.06\ mol$	$\frac{16.47}{16.00} = 1.029\ mol$	**(1)**
Simple Ratio	$\frac{4.120}{1.029} = 4.004$	$\frac{5.149}{1.029} = 5.004$	$\frac{2.06}{1.029} = 2.002$	$\frac{1.029}{1.029} = 1$	
Whole Ratio	4	5	2	1	**(1)**

∴ the empirical formula is $\boldsymbol{C_4H_5N_2O}$ **(1)**

$$\boldsymbol{n(Compound)} = \frac{PV}{RT}$$
$$= \frac{110 \times 11.824}{8.314 \times (63 + 273.15)}$$
$$= \mathbf{0.4654\ mol} \quad \textbf{(1)}$$

$$\boldsymbol{M(Compound)} = \frac{m}{n}$$
$$= \frac{90.38}{0.4654}$$
$$= \mathbf{194.2g\ mol^{-1}} \quad \textbf{(1)}$$

$$\boldsymbol{Ratio} = \frac{\boldsymbol{M(Compound)}}{\boldsymbol{M(Empirical)}}$$
$$= \frac{194.2}{12.01 \times 4 + 1.008 \times 5 + 14.01 \times 2 + 16}$$
$$= \mathbf{2} \quad \textbf{(1)}$$

$$\boldsymbol{Molecular} = \boldsymbol{Empirical} \times \mathbf{2}$$
$$= \boldsymbol{C_4H_5N_2O} \times \mathbf{2}$$
$$= \boldsymbol{C_8H_{10}N_4O_2} \quad \textbf{(1)}$$

38. **[14 marks]**

(a)

$$C_6H_8O_{7(aq)} + H_2O_{(l)} \rightleftharpoons C_6H_7O_7^-{}_{(aq)} + H_3O^+{}_{(aq)} \quad \textbf{(2)}$$

Marking Criteria	Marks Allocated
• Writes correct reactants and products • Has ⇌ to show it is an equilibrium system	$1-2$
Total	**2**

(b)

$$K_c = \frac{[C_6H_7O_7^-][H_3O^+]}{[C_6H_8]} \quad \textbf{(2)}$$

Marking Criteria	Marks Allocated
• Writes correct equilibrium constant • Does not include water in constant	$1-2$
Total	**2**

(c) H_2O and H_3O^+ which are the **conjugate base** and **conjugate acid** respectively **(1)**.

Marking Criteria	Marks Allocated
• H_2O and H_3O^+	1
Total	**1**

(d) When the concentration of H_3O^+ **increases**, the **pH** will **decrease** **(1).** According to Le Chatelier's principle, the system will act to partially oppose this change by favouring the **reverse reaction** to **consume** some of the of H_3O^+ **ions (1).** This will mean that the **pH** will **not change significantly** **(1)**, so the jam will not become sour until all of the $C_6H_7O_7^-$ has been consumed **(1)**.

Marking Criteria	Marks Allocated
• When the H_3O^+ concentration increases, the pH will decrease • According to LCP the reverse reaction will be favoured • A favoured reverse reaction will mean the H_3O^+ concentration/pH will not change significantly • The jam will not become sour until the buffering capacity is reached	$1-4$
Total	**4**

(e) When the concentration of **atmospheric CO_2 increases**, the system $CO_{2\,(g)} \rightleftharpoons CO_{2\,(aq)}$ will have a favoured **forward reaction**, increasing the amount of **dissolved CO_2 (1)**. An increased amount of dissolved CO_2 will increase the amount of carbonic acid in our oceans from favouring the forward reaction of: $CO_{2\,(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3\,(aq)}$ **(1)**. More carbonic acid produces more hydronium ions which favours the reverse reaction of the second ionisation of H_2CO_3: $HCO_{3\,(aq)}^- + H_2O_{(l)} \rightleftharpoons H_3O_{(aq)}^+ + CO_{3\,(aq)}^{2-}$ **decreasing** the concentration of CO_3^{2-} **(1)**. This will favour the **forward reaction** of the system: $CaCO_{3\,(s)} \rightleftharpoons Ca_{(aq)}^{2+} + CO_{3\,(aq)}^{2-}$ consuming **calcium carbonate (1)**. With **less** $CaCO_3$ in our oceans, it becomes **progressively more difficult** for reefs and marine organisms to produce and maintain structures/shells **(1)**.

Marking Criteria	Marks Allocated
• Dissolved CO_2 concentration increases: $CO_{2\,(g)} \rightleftharpoons CO_{2\,(aq)}$ • Carbonic acid concentration increases $CO_{2\,(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3\,(aq)}$ • Carbonate ion concentration decreases $HCO_{3\,(aq)}^- + H_2O_{(l)} \rightleftharpoons H_3O_{(aq)}^+ + CO_{3\,(aq)}^{2-}$ • Amount of calcium carbonate in oceans decreases $CaCO_{3\,(s)} \rightleftharpoons Ca_{(aq)}^{2+} + CO_{3\,(aq)}^{2-}$ • Less calcium carbonate means it is more difficult for reefs/marine organisms to form their structures/shells	$1-5$
Total	**5**

Points to note: To write a concise answer focus mainly on the equations as this is where the marks mostly come from.

39. **[18 marks]**

(a)

$$\textbf{\textit{Average titre}} = \frac{22.50 + 22.45 + 22.55}{3}$$
$$= \mathbf{22.50\ mL}\ \textbf{(2)}$$

Marking Criteria	Marks Allocated
• Determines correct average titre • Does not include trial 1	$1-2$
Total	**2**

(b)

Titration: $2KOH_{(aq)} + H_2SO_{4\,(aq)} \rightarrow K_2SO_{4\,(aq)} + 2H_2O_{(l)}$ **(1)**

$$\begin{aligned} n(H_2SO_4) &= cV \\ &= 0.04 \times 0.02250 \\ &= 9.00 \times 10^{-4}\ mol \end{aligned}$$ **(1)**

$$\begin{aligned} n(KOH)_{aliquot} &= n(H_2SO_4) \times 2 \\ &= 9.00 \times 10^{-4} \times 2 \\ &= 1.8 \times 10^{-3}\ mol \end{aligned}$$ **(1)**

$$\begin{aligned} \therefore n(KOH)_{in\ excess} &= n(KOH)_{aliquot} \times \frac{250}{25} \\ &= 1.8 \times 10^{-3} \times 10 \\ &= 0.018\ mol \end{aligned}$$ **(1)**

Dissolving of aspirin: $C_9H_8O_{4\,(s)} + KOH_{(aq)} \rightarrow KC_9H_7O_{4\,(aq)} + H_2O_{(l)}$ **(1)**

$$\begin{aligned} \therefore n(KOH)_{total} &= cV \\ &= 0.180 \times 0.150 \\ &= 0.027\ mol \end{aligned}$$ **(1)**

$$\begin{aligned} n(KOH)_{initially\ reacted} &= n(KOH)_{total} - n(KOH)_{in\ excess} \\ &= 0.027 - 0.018 \\ &= 0.009\ mol \end{aligned}$$ **(1)**

$$\begin{aligned} n(C_9H_8O_4) &= n(KOH)_{initially\ reacted} \\ &= 0.009\ mol \end{aligned}$$ **(1)**

(c)

$$\begin{aligned} M(C_9H_8O_4) &= 9 \times 12.01 + 8 \times 1.008 + 4 \times 16 \\ &= 180.154\ g\ mol^{-1} \end{aligned}$$ **(1)**

If $0.009\ mol$ is used:

$$\begin{aligned} m(C_9H_8O_4) &= nM \\ &= 0.009 \times 180.154 \\ &= 1.621\ g \end{aligned}$$ **(1)**

$$\begin{aligned} Percentage\ by\ Mass &= \frac{m(C_9H_8O_4)}{m(Aspirin)} \times 100 \\ &= \frac{1.621}{1.70} \times 100 \\ &= 95.4\% \end{aligned}$$ **(1)**

If $0.0085\ mol$ is used:

$$\begin{aligned} m(C_9H_8O_4) &= nM \\ &= 0.0085 \times 180.154 \\ &= 1.531\ g \end{aligned}$$ **(1)**

$$\begin{aligned} Percentage\ by\ Mass &= \frac{m(C_9H_8O_4)}{m(Aspirin)} \times 100 \\ &= \frac{1.531}{1.70} \times 100 \\ &= 90.05\% \end{aligned}$$ **(1)**

(d) Drug X **will not** be approved **(1)**.

Marking Criteria	Marks Allocated
• Drug X will not be approved	1
Total	**1**

(e)

	Effect on sulfuric acid average titre volume	Effect on % by mass of aspirin calculated
The top of the meniscus on the burette was read consistently instead of the bottom	**No effect (1)**	**No effect (1)**
Thymolthalein indicator (pH range 8.8 – 10) was used instead of bromothymol blue (pH range 6.0 – 7.6)	**Decrease (1)**	**Increase (1)**

Marking Criteria	Marks Allocated
• Correctly states increase, decrease or no effect	$1-4$
Total	**4**

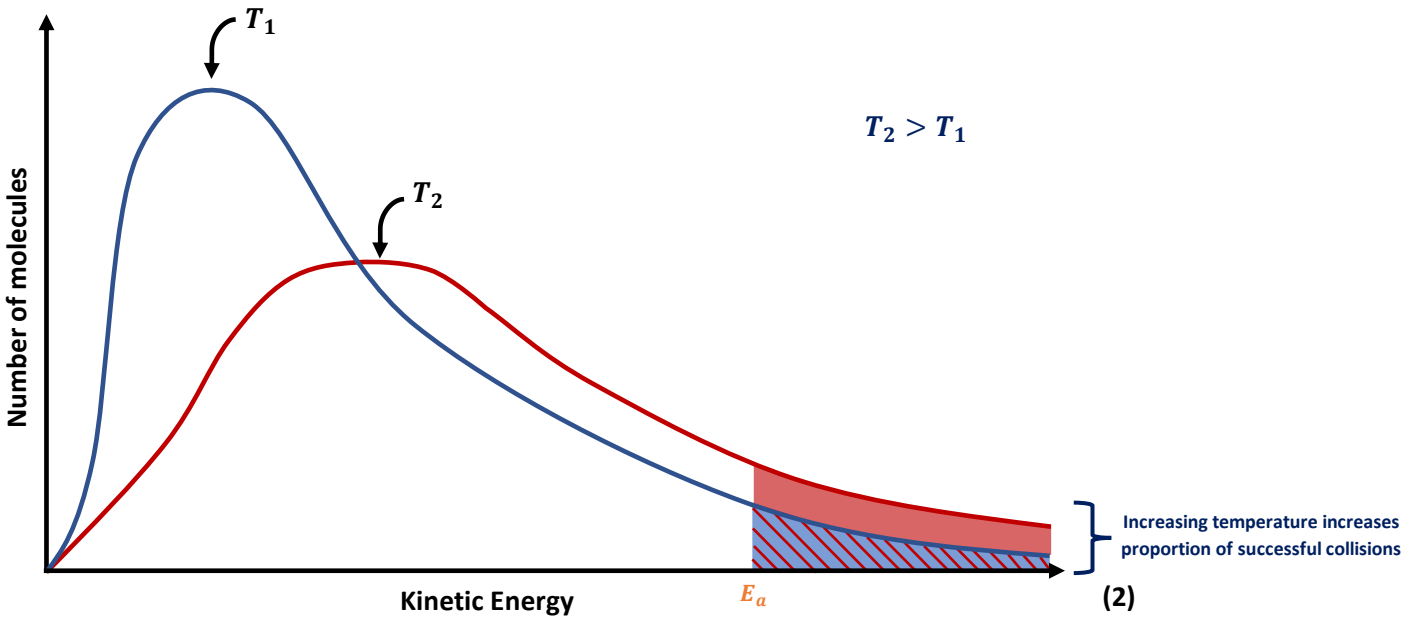
Points to note: If you consistently read from the same point on a meniscus when starting and finishing a titration, the titre volume will be the same irrespective of whether you read from the top or bottom (so this change has no effect). The thymolthalein indicator has a basic pH range and the equivalence point is neutral. As KOH is in the conical flask we start at a basic pH and move towards an acidic pH, so the end point will be reached before the equivalence point (giving a smaller H_2SO_4 titre volume). With a smaller H_2SO_4 volume, it appears that there is less excess KOH. This means that it appears that more KOH was required to react with the aspirin, thus giving the aspirin a higher percentage by mass.

40. **[12 marks]**

(a) When the pressure of the system is **increased**, according to Le Chatelier's Principle, the system will act to partially oppose this by favouring the **forward reaction** due to a **4 : 2 molar ratio (1)**. With a favoured **forward reaction** the **yield** will **increase** from more ammonia being produced **(1)**. Also, a **higher pressure** will also **increase** the **reaction rate** due to an **increase** in the **collision frequency (1)**. As a result a **very high pressure** is used because it **optimizes** both the **reaction rate** and **yield** of the reaction **(1)**.

Marking Criteria	Marks Allocated
• From an increase in pressure, system will favour forward reaction due to $4:2$ **molar ratio** • A favoured forward reaction will increase the reaction yield • A higher pressure will also increase the reaction rate from an increase in collision frequency • A very high pressure is used because it optimises both reaction rate and yield	$1-4$
Total	**4**

(b)



(2)

When the **temperature** is **increased**, the **average kinetic energy** of the particles **increases (1)**. A higher average kinetic energy means particles will **move faster** and therefore have a **higher collision frequency (1)**. As shown on the Maxwell Botlzmann curve, a higher average kinetic energy also means the **proportion of successful collisions** will **increase (1)**, thus **increasing** the **reaction rate** for the **forward** and **reverse** reactions **(1)**. However, **t**here will be a **greater increase** in the **proportion of successful collisions** for the **endothermic reverse reaction (1)**, thus creating a **net reverse reaction** which **decreases** the **yield (1)**. As a result, a **compromise** is made between the reaction rate and yield thus a **moderate temperature** of $350-550℃$ is selected **(1).**

Marking Criteria	Marks Allocated
• A temperature increase will increase the average kinetic energy of the particles • The collision frequency will increase from an increase in average kinetic energy	$1-6$

• The proportion of successful collisions will increase from an increase in average kinetic energy • The proportion of successful collisions will increase more for the endothermic reverse reaction • A net reverse reaction decreases the yield • A moderate temperature is used to find a compromise between reaction rate and yield	
• Appropriate Maxwell Boltzmann curve drawn • Maxwell Boltzmann curve is appropriately labelled	$1-2$
Total	**8**