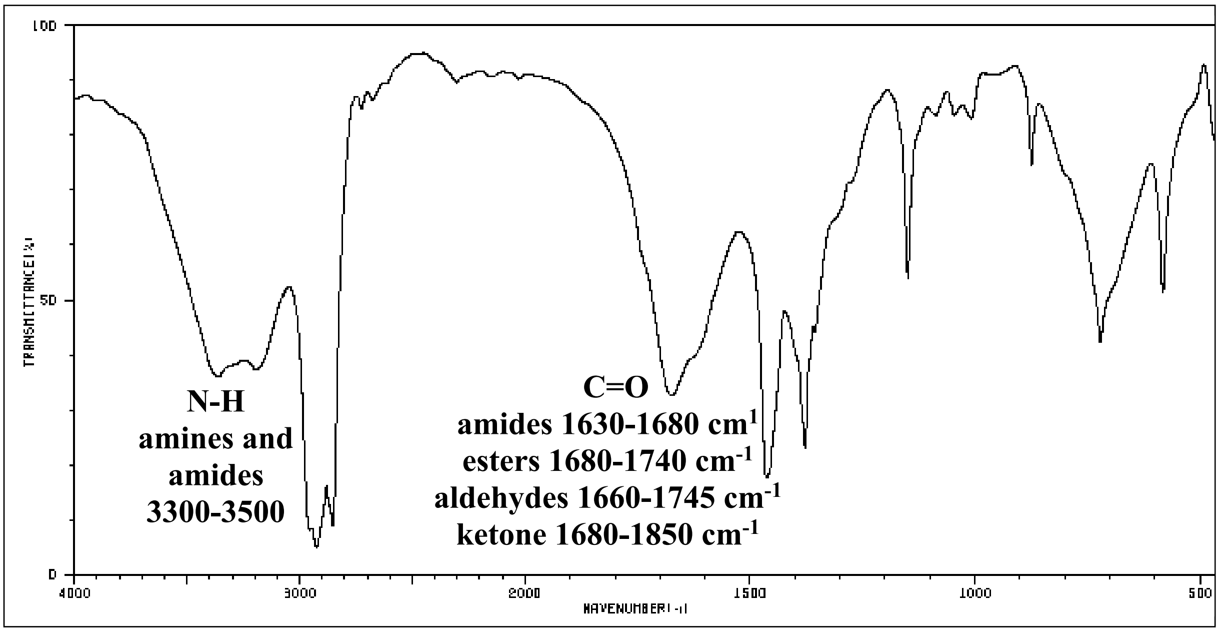
Suggested Answers

VCE Chemistry 2017 Year 12 Trial Exam Unit 3/4

SECTION A – Multiple Choice Answers

Q1. B Need to use the data to calculate the reaction quotient (concentration fraction), *Q*, (*CF*).
$Q = [NO]^2 / [N_2][O_2]$
$= (4.2 \times 10^{-3})^2 / \{0.50 \times 0.25\}$
$= 1.41 \times 10^{-4}$
$Q < K$ (1.7×10^{-3}), so system is not at equilibrium and moves to increase *Q* to get there. The **forward reaction is favoured and proceeds faster than the reverse reaction** as the position of equilibrium shifts to the right.

Q2. C



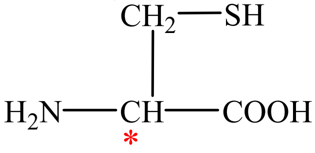
The two significant peaks on the spectrum are at about 1680 cm^{-1} and 3300 cm^{-1}.
The carbonyl group at **1680 cm^{-1}**, could be part of an amide, an ester or an aldehyde (ketone is less likely according to its absorption band).
At **3300 cm^{-1}** the lack of a broad band overlapping C-H (2850-3900 cm^{-1}) rules out O-H acid (2500-3300 cm^{-1}).

Q3. **D** Some ‘garbage’ in landfill that provides a source of methane is from food waste and garden waste. On this basis, the methane can be classified as biogas and renewable. The methane in coal seam gas is not renewable because of its relationship with fossil-fuels. So, depending on the source, methane may be classified as **both renewable and non-renewable**.

Q4. **B** Since only spirit burners containing methanol, not the required ethanol, were supplied, a **systematic error** has occurred. This was not a random selection of the incorrect fuel by the student.
Because methanol (22.7 kJ g^{-1}) has a lower heat of combustion than ethanol (29.6 kJ g^{-1}), **more ethanol will need to react** to provide the energy needed to increase the temperature of the water by 20°C.

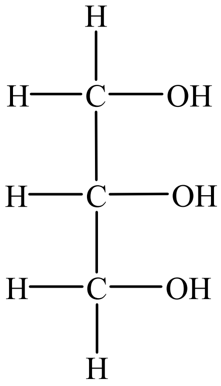
Q5. **C** Chiral molecules have enantiomers, optical isomers which are non-superimposable images. To be chiral a molecule must have a chiral centre, indicated with an asterisk * on the structures below, which has a C atom attached to four different atoms or groups of atoms.
Glycerol is not chiral because **none of the C atoms is attached to four different atoms / groups of atoms**.

Cysteine

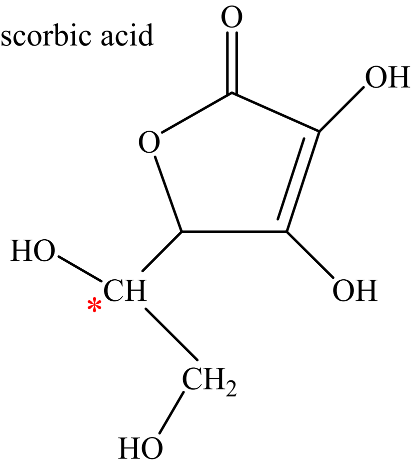


$$H_2N-\overset{CH_2-SH}{\underset{*}{CH}}-COOH$$

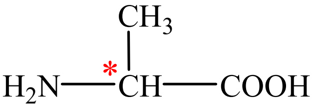
Glycerol



Ascorbic acid



Alanine



$$H_2N-\overset{CH_3}{\overset{*}{CH}}-COOH$$

Q6. **C** Since $d = m / V$

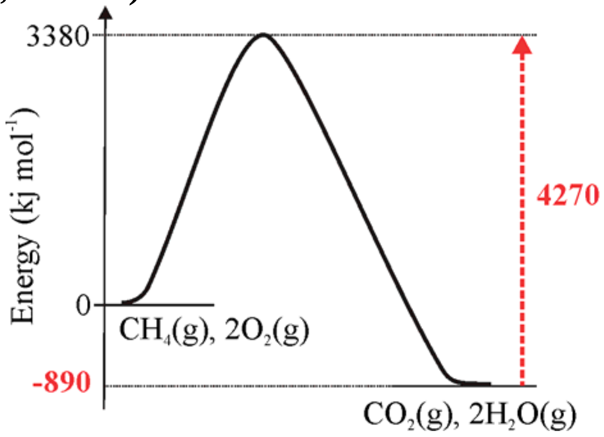
$m(C_{16}H_{34}) = d \times V$
$= 0.775 \text{ g mL}^{-1} \times 20.0 \times 10^3 \text{ mL}$
$= 1.55 \times 10^4 \text{ g}$

$n(C_{16}H_{34})$ reacting $= 1.55 \times 10^4 / 226.0$
$= 68.6 \text{ mol}$

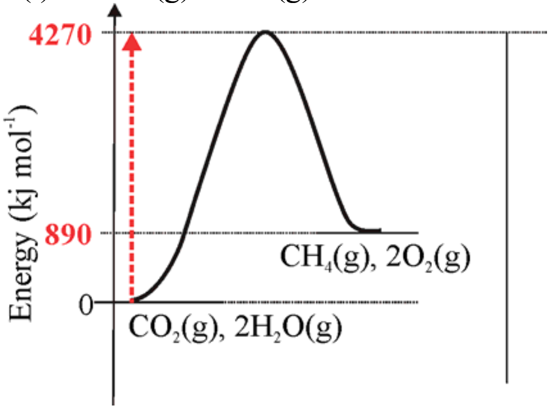
$n(CO_2)$ produced $= 16 \times n(C_{16}H_{34})$
$= 16 \times 68.6$
$= 1.10 \times 10^3 \text{ mol}$

$V(CO_2) = 1.10 \times 10^3 \text{ mol} \times 24.8 \text{ L mol}^{-1}$
$= 2.72 \times 10^4 \text{ L}$
$=$ **27.2 ML**

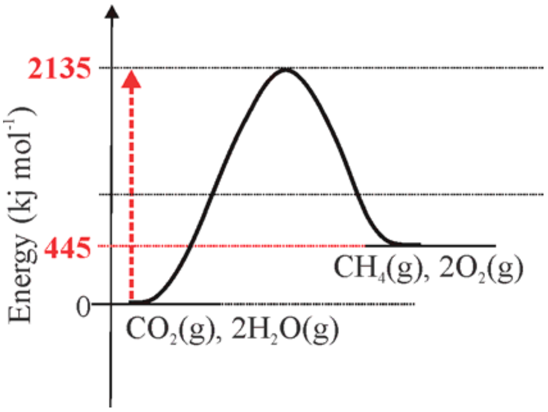
Q7. **B** $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$; $\Delta H = -889$ kJ mol^{-1}.
(Data Book, Table 10).



The energy profile for the reverse reaction
$CO_2(g) + 2H_2O(l) \rightarrow CH_4(g) + 2O_2(g)$ is



The energy profile for the reverse reaction
$\frac{1}{2}CO_2(g) + H_2O(l) \rightarrow \frac{1}{2}CH_4(g) + O_2(g)$ is



This shows the activation energy to be 2135 kJ mol^{-1}.

Q8. B The **$c(CH_3COOH)$ values**, as calculated from the five investigations are **quite consistent** and so reflect **low random error** effect.
However, all the values are **below the true value**, suggesting a **significant systematic error**, such as the use of an incorrectly calibrated pipette, incorrectly calibrated burette or even incorrect indicator
In combination, the results show **low random error** and **high systematic error.**

Q9. A $Br_2(aq) + 2OH^-(aq) \rightleftharpoons Br^-(aq) + OBr^-(aq) + H_2O(l)$, $\Delta H = 15$ kJ mol^{-1}
Assigning oxidation numbers, as per standard rules.

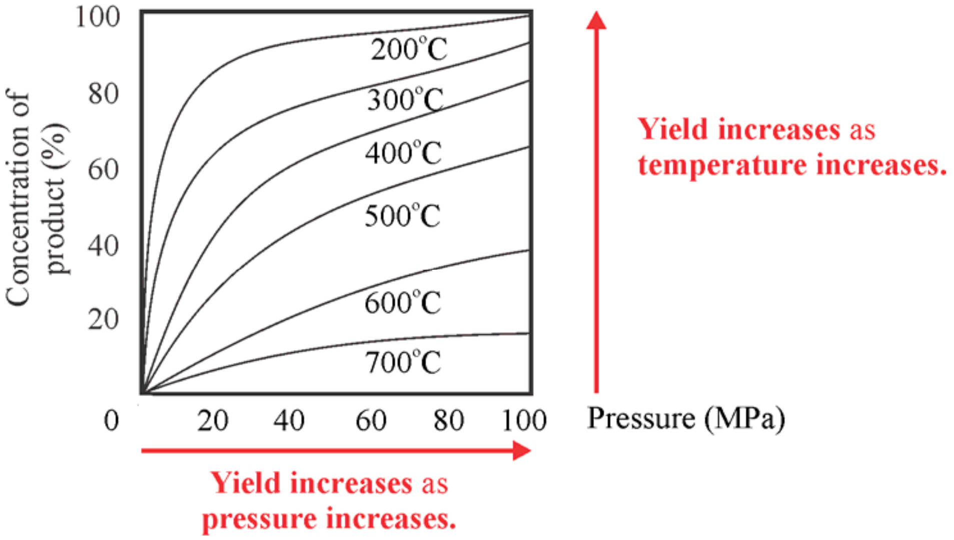
$$\overset{0}{Br_2}(aq) + 2\overset{-2+1}{OH^-}(aq) \rightleftharpoons \overset{-1}{Br^-}(aq) + \overset{-2+1}{OBr^-}(aq) + \overset{+1\ -2}{H_2O}(l),$$

Since the forward reaction is endothermic, when temperature of the equilibrium solution is decreased, the **reverse** exothermic **reaction is favoured**. Therefore

- the **number of atoms with oxidation number +1 decreases**; there are three atoms on the right (Br in BrO^- and 2H in H_2O) but only two - 2H atoms - on the left (in the $2OH^-$).
- the number of atoms with oxidation number -2 does not change; there are two atoms on the right and two atoms on the left (in the $2OH^-$).
- the number of atoms with oxidation number -1 decreases from one (Br^-) to zero.
- the number of atoms with oxidation number zero increases from zero to one (Br_2).

Q10. A. From the electrochemical series $E°$ ($Fe^{2+}(aq)/Fe(s)$) = -0.44 V.
The cell voltage of 1.21 V is the difference between the $E°$ values of the two half cells, so half-cell one must contain a redox pair with $E°$ either 1.21 V higher or 1.21 V lower than $E°(Fe^{2+}(aq)/Fe(s))$.
$E°$(half-cell 1) = -0.44 + 1.21 = +0.77 V
or
$E°$(half-cell 1) = -0.44 - 1.21 = -1.65 V
According to the electrochemical series
$E°$ ($Fe^{3+}(aq)/Fe^{2+}(aq)$) = +0.77 V
$E°$ ($Al^{3+}(aq)/Al(s)$) = -1.66 V
It is a close call, but $Fe^{3+}(aq)/Fe^{2+}(aq)$ is the more accurate option.
In the $Fe^{3+}(aq)/Fe^{2+}(aq)$, the electrode must be non-reactive, so it cannot be Fe since it could react with $Fe^{2+}(aq)$. So, either a **platinum (Pt) or graphite (C)** electrode would be used.
Half-cell reactions would be
Half-cell 1: $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$
Half-cell 2: $Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$

Q11. A



Yield increases as temperature increases.

Yield increases as pressure increases.

Since the yield increases as the temperature decreases, the **forward reaction** is favoured by low temperature, i.e. is **exothermic**.
Since the yield is increasing as the pressure increases, and the equilibrium system responds to partially oppose the pressure increase by moving to **reduce the number of particles** in the system, the **product** must **on the side** of the equilibrium **with fewer particles.**
This behaviour is consistent with the equilibrium involved in ammonia production, i.e.
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g),\ \Delta H = -92\ kJ\ mol^{-1}$

Q12. D The reactions represented by **1.** are all **hydrolysis** (hydrolytic) reactions which occur during the digestion of the major food groups. Proteins are broken down into amino acids, fats into fatty acids and glycerol, and carbohydrates into monosaccharides.
The reaction represented by **2.** is **respiration** where energy required for the effective functioning of the body is released via the reaction
$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$
The reactions represented by **3.** are all **condensation** reactions that occur as proteins, fats and glycogen are formed in cells of the body.

Q13. A To answer this question it is necessary to first deduce that **X** represents amino acids, **Z** represents proteins, **Q** represents glycerol and **Y** represents glycogen.

Q – formula $CH_2OHCHOHCH_2OH$ or $C_3H_8O_3$

1 mol (92.0 g) $C_3H_8O_3$ contains 3 × 16.0 = 48.0 g of O atoms

% O = (48.0 / 92.0) × 100

= **52.2 %**

X – general amino acid formula is $NH_2CH(Z)COOH$

Consider glycine NH_2CH_2COOH, the amino acid with the lowest molar mass

1 mol (75.0 g) NH_2CH_2COOH contains 2 × 16.0 = 32.0 g of O atoms

% O = (32.0 / 75.0) × 100

= 42.7 %

Aspartic acid $NH_2CH(CH_2COOH)COOH$, the amino acid with the largest mass of oxygen, has 64.0 g of O atoms in 1 mole (133 g)

% O = (64.0 / 133) x 100

= 48.1 %

Z – since proteins are formed from amino acids, and oxygen is released as water in the condensation process, the percentage, by mass, of oxygen in protein is going to be less than 48.1 %.

Y – glycogen is formed from the condensation polymerisation of glucose and can be represented by $nC_6H_{12}O_6 \rightarrow -(C_6H_{10}O_5)_n- + n\text{-}1\ H_2O$, where *n* is a very large number.

So, the percentage, by mass, of O in glycogen is effectively the same as the % in $C_6H_{10}O_5$

1 mol (162 g) $C_6H_{10}O_5$ contains 5× 16.0 = 80.0 g O atoms

% O = (80.0 / 162) × 100

= 49.4 %

Q14. D Since NiOOH (nickel oxide hydroxide) is reduced, it must be the oxidant. This suggests that H_2 must be the reductant.

As the **reductant, H_2** causes the reduction of NiOOH to $Ni(OH)_2$ and is itself **oxidised**.

Since the electrolyte is alkaline, i.e. contains $OH^-(aq)$, the oxidation half-equation must contain $OH^-(aq)$ ions and may be obtained from the electrochemical series in the ***Data Book***.

$\mathbf{H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-}$.

Q15. C Green diesel will exhibit similar properties to petrodiesel and so, compared to FAME biofuel will

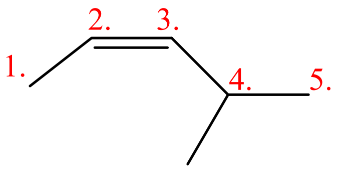
- have higher energy content per gram due to lack of oxygen in the molecules.
- be less viscous due to weaker intermolecular attraction.
- **have better cold flow properties** – determined by weaker intermolecular attraction.
- be less likely to absorb water because it lacks the polar sites present on ester groups in FAME biodiesel.

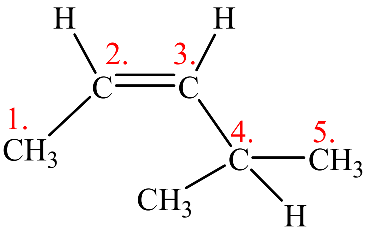
Q16. B When all gases are measured at the same temperature, the ratios by volume of the reactants and products are the same as the ratio by mole amount as indicated in the balanced equation.
V(methane) reacting = 0.80 × 2.0 = 1.6 L
The balanced equation for the combustion of methane is

	$CH_4(g)$ +	$2O_2(g)$ →	$CO_2(g)$ +	$2H_2O(g)$
mole ratio	*1 mol*	*2 mol*	*1 mol*	*2 mol*
volume ratio	*1 L*	*2 L*	*1 L*	*2 L*
volumes	**1.6 L**	**3.2 L**	**1.6 L**	**3.2 L**

Greenhouse gases
Initially – 1.6 L $CH_4(g)$
Finally – 1.6 L $CO_2(g)$ and 3.2 L of $H_2O(g)$ = **4.8 L**
Change in volume of greenhouse gases = 4.8 – 1.6
= **3.2 L**

Q17. B The C atoms on the structure are numbered so the alkene C=C double bond starts on the lowest possible numbered C atom.





pent-2-ene	five C atoms with C=C between C2 and C3
4-methylpent-2-ene	methyl group attached to C4
***cis*-4-methylpent-2-ene**	the C atoms attached to the C=C double bond are on the same side of the C=C double bond.

Q18. D The species $Cu^{2+}(aq)$ and $H_2O(l)$ appear on the electrochemical series (***Data Book***) according to

$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2\underline{\mathbf{H_2O}}(l)$ +1.77 V

$\underline{\mathbf{Cu^{2+}}}(aq) + 2e^- \rightleftharpoons Cu(s)$ +0.34 V

$2\underline{\mathbf{H_2O}}(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$ -0.83 V

The electrolysis involves the strongest oxidant, $Cu^{2+}(aq)$, and strongest reductant, $H_2O(l)$. The half-equations for the reactions at the electrodes are

Anode (+) $2H_2O(l) \rightarrow O_2 + 4H^+(aq) + 4e^-$

Cathode (-) $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

Consider the four statements

1. Incorrect, the **ions are present in solution** prior to the passing of the electric current.
2. Incorrect, Cu is deposited on the cathode, which is the **(-) electrode** in electrolysis.
3. Incorrect, whilst $H^+(aq)$ ions are produced at the anode, **no O^2(aq) ions** are formed.
4. **Correct**, **O_2(g) is produced in the oxidation of H_2O(l)** at the anode.

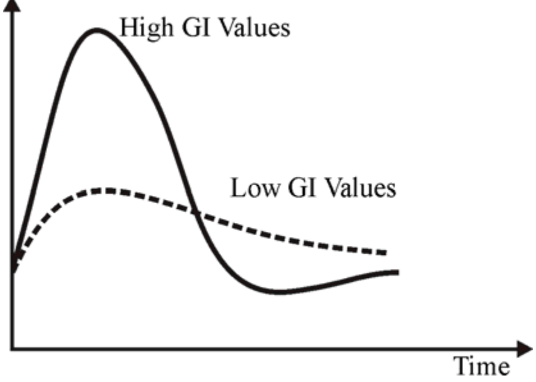
Q19. D The rate of a chemical reaction is determined by the **proportion of reactant molecule collisions that have energy greater than the activation energy for the reaction**.
This proportion is reflected, on a Maxwell-Boltzmann kinetic energy distribution curve, as the **area under the curve to the right of the activation energy**.
This area, and hence the **rate of reaction, increases in order** of
Reaction 3 < Reaction 1 < Reaction 2 < Reaction 4

Q20. A The two main models of enzyme function are the lock-and-key model and the induced fit model.
In the lock and key model, the shape of the enzyme active site (the lock) is such that only a specifically shaped substrate (the key) fits.
In the **induced fit model**, the shape of the **active site** is **temporarily modified** as it interacts with the substrate molecules to provide a better fit for the substrate. The active site resumes its normal shape as the product of the reaction leaves.
The **shape of the active site is unique to each enzyme**.
Coenzymes are not enzymes, rather they are a cofactor (metal ion or non-protein organic compound) which enable some enzymes to catalyse reactions; without the coenzyme, the catalysis would not occur. However, a **coenzyme in isolation does not have catalytic properties** and, in isolation, does not affect reaction rate.
Enzyme activity occurs in a narrow pH range and is **significantly decreased by any change to a pH outside that range**. Some enzymes are active in alkaline solutions – higher pH, whilst others are active in acidic solutions – lower pH.

Q21. C Ascorbic acid, also known as Vitamin C, is an **antioxidant**, thus it reduces the impact of free radicals by donating electrons in its role as a water soluble free radical scavenger. A key chemical property of antioxidants is they act as **reductants**. Reductants are oxidised (donate electrons) in chemical reactions.

Q22. C In conjunction with the information supplied in Tables 14, 15 and 16 of the ***VCE Chemistry Data Book:***
The IR spectrum provides evidence of the **presence of** the carbonyl (**C=O**) functional group.
C=O (**aldehydes**); absorption band 1670-1745 cm^{-1}, *or* **C=O** (**ketones**); absorption band 1680-1850 cm^{-1}
lack of O-H acids, no broad absorption band in absorption band 2500-3500 cm^{-1}
lack of O-H alcohols no characteristic absorption in absorption band 3200-3600 cm^{-1}
The ^{1}H NMR spectrum provides evidence of
H attached to a carbonyl group as in RC**H**O, peak at **9.8 ppm** (in the range 9.4-10.0 ppm),
H in a CH_3 attached to a carbonyl group as in $RCOC\mathbf{H}_3$, peak at 2.2 ppm **(**in the range 2.1-2.7).
This evidence suggests the **most likely compound** was the **aldehyde CH_3CHO** (ethanal). This is further supported by the ^{13}C NMR spectrum which provides evidence of **H** attached to a carbonyl group as in RC**H**O, peak at **200 ppm** (in the range 205-220 ppm).

Q23 B The graphs **best represent the digestion of high GI and low GI carbohydrates**.

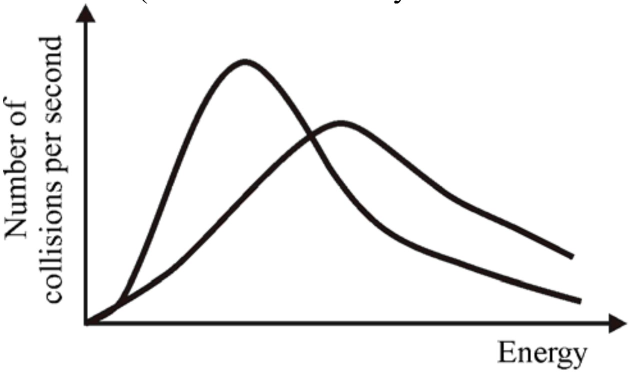


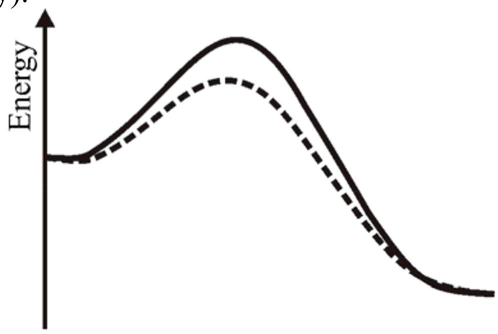
High GI carbohydrates contain a **greater proportion of amylopectin**, the more digestible branched component of starch, and **so release glucose more rapidly** than low **GI carbohydrates**, which contain a **greater proportion of amylose,** the less branched component. The graphs represent the change in blood glucose levels after digestion.

The "0" hour on the horizontal axis represents the time at which one eats. The unbroken curve shows the rise in blood sugar following a high glycemic index meal. Rapid blood glucose rise in the first hour causes a high insulin output to lower blood glucose. Since cell requirements are not this great in the first hour, much of that glucose is sent to the liver and converted to triglyceride for fat storage. This happens aggressively in the presence of high insulin, resulting in the blood glucose dropping rapidly by about 2 hours after digestion. This can stimulate hunger and further intake of food. The dashed curve represents the digestion of a low GI index meal.

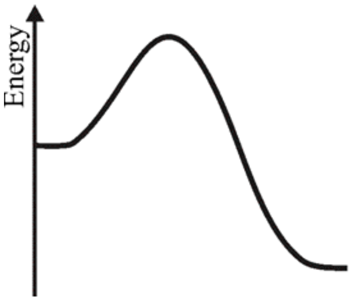
This was the only alternative for which 'Time' was a valid axis. The Boltzmann distribution curve showing the effect of temperature on particle collision has 'Energy' as the horizontal axis. Energy profiles do not need horizontal axes.

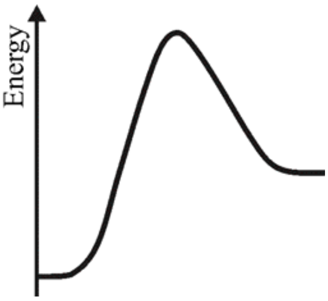
The diagrams below represent **A** (the effect of temperature on particle collision) and **C** (the effect of a catalyst on activation energy).





The diagrams below represent **D** (energy profiles for exothermic and endothermic reactions).





Q24. C Energy released $= 1600 \times 1000 \text{ kJ s}^{-1} \times (60 \times 60) \text{ s}$

$= 5.76 \times 10^9 \text{ kJ}$

$n(CH_4)$ $= 5.76\times 10^9 \text{ kJ} / 890 \text{ kJ mol}^{-1}$

$= 6.48\times 10^6 \text{ mol}$

$V(CH_4)$ $= nRT/PV$

$= 6.48\times 10^6 \times 8.31 \times 303 / 150$

$= 1.08\times 10^8 \text{ L}$

However, since the energy conversion is only 60 per cent efficient,

$1.08 \times 10^8 \text{ L} = 0.60 \times V(CH_4)$ needed

$V(CH_4)$ needed $= 1.08\times 10^8 / 0.60$

$= 1.81\times 10^8 \text{ L}$

$= 1.81\times 10^5 \text{ kL}$

$\mathbf{= 1.81\times 10^2 \text{ ML}}$

Alternatively:

$E = 1600 \times 1000 \times 3600$

$= 5.76\times10^9 \text{ kJ}$

60 % efficiency

E required $= 5.76 \times 10^9 /(60/100)$

$= 9.6 \times 10^9 \text{ kJ}$

$\Delta H_c(CH_4) = -890 \text{ kJ mol}^{-1}$

$n(CH_4) = 9.6\times10^9 / 890 = 1.08\times10^7 \text{ mol}$

$V= nRT/P$

$= 1.08\times10^7 \times 8.31 \times 303 / 150$

$= 1.81\times108 \text{ L}$

$= \mathbf{1.81\times10^2 \text{ ML}}$

Q25. D Proteins, enzymes and polypeptides must retain secondary, tertiary and, in many cases quaternary structures to maintain their activity. So, anything that will disrupt the structure of these species in the toxin will reduce the impact of the jellyfish sting.

Inorganic ions, acid and **hot water** can all **denature protein structures**.

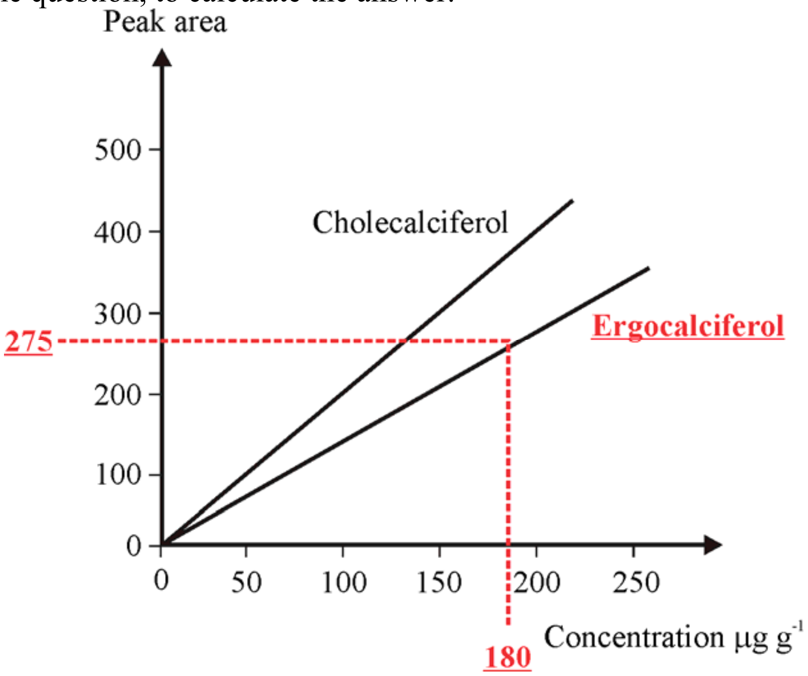
Solution of **inorganic ions will disrupt ion-ion interactions** in the tertiary structure.

Treating with **acidic solution will decrease the pH** and so disrupt tertiary structure.

The **higher temperature** of hot water **will disrupt secondary, tertiary and quaternary structures.**

The treatment least likely to impact on protein structure is cold water.

Q26. C **Vitamin D_3** (cholecalciferol) has the **higher retention time**.
So the peak area of vitamin D_2 (ergocalciferol) was 275.
Use the calibration graph for ergocalciferol, i.e. the one unlabelled on the diagram in the question, to calculate the answer.



c(ergocalciferol) = 180 µg g^{-1}
So, m(vitamin D_2) in 50 g sample = 50 × 180
= 9000 µg
= **9 mg**

Q27. B The semi-structural formula of **Levulinic acid** is $CH_3COCH_2CH_2COOH$, so its molecular formula is **$C_5H_8O_3$**.
Fructose is structural isomer of glucose and so its molecular formula is **$C_6H_{12}O_6$**
Atom economy = (mass of desired product / mass of reactants) × 100
= [$M(C_5H_8O_3)$ / $M(C_6H_{12}O_6)$] × 100
= (116 / 180) × 100
= **64 %**

Alternatively:
A simple atom balance indicates compound X must be CH_2O_2 (actually methanoic acid – HCOOH)
Equation: $C_6H_{12}O_6 \rightarrow C_5H_8O_3 + HCOOH + 2H_2O$
Atom economy = (mass of desired product / total mass of products) × 100
= [$M(C_5H_8O_3)$ / [$M(C_6H_{12}O_6)$ + $M(HCOOH)$ + $M(H_2O)$]] × 100
= (116 / [116 + 46 + 18]) × 100
= 64 %

Q28. B Since lactic acid, $C_3H_6O_3$, is a carbohydrate, the energy released during the combustion of the lactic acid may be estimated.

Energy from 5.865 g lactic acid = 5.865 × 15
= 88.0 kJ

<u>Lactic acid</u> combustion: ΔT = 39.2 – 28.7
= 10.5°C

Energy released = Calorimeter constant × ΔT

Calorimeter constant = 88.0 kJ / 10.5°C
= 8.38 kJ°C^{-1}

<u>Ethanol</u> combustion: ΔT = 35.4 – 23.1
= 12.3°C

Energy released during ethanol combustion = 8.38 kJ °C^{-1} × 12.3°C
= 103 kJ.

<u>Heat of combustion of ethanol = 29.6 kJ g^{-1}</u> – ***Data Book Table 11***.

m(ethanol) used= 103 kJ / 29.6 kJ g^{-1}
= **3.5 g**

<u>Alternatively</u>:

The ratio of the energies released by ethanol and lactic acid is equal to the ratio of the temperature changes.

Energy from CH_3CH_2OH / 88.0 = 12.3 / 10.5
= (12.3 / 10.5) × 88.0
= 103 kJ

m(CH_3CH_2OH) = 103 / 29.6
= **3.5 g**

Q29. A In discharging reactions, which convert chemical energy to electrical energy, electrons move from the (-) electrode to the (+) electrode. Electrons always move from the site of oxidation (anode) to the site of reduction (cathode).

(-) – anode $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$

(+) - cathode $PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$

So, recharging reactions occurring at these electrodes are the reverse of the discharging reactions.

(-) - cathode $PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$

(+) - anode $PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^-$

Checking the four alternatives

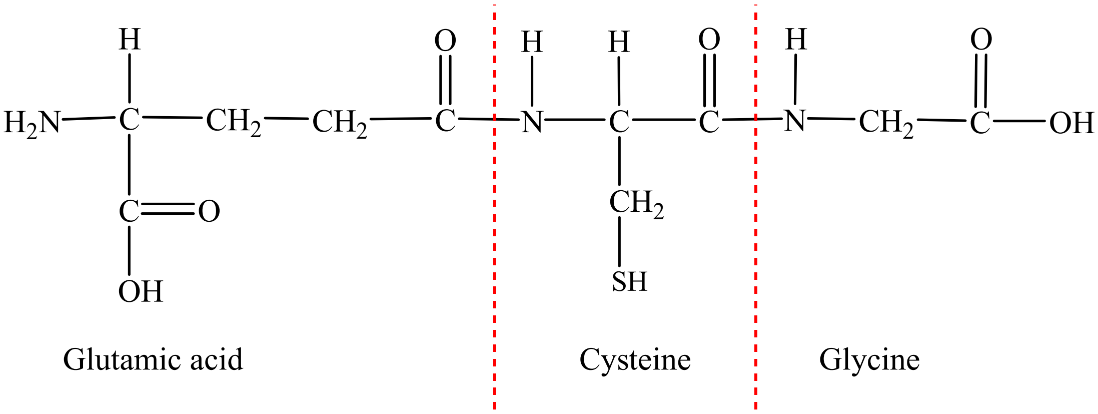
A. **<u>Pb is produced at the (-) electrode</u>.**

B. pH will **decrease** as H^+ ions are produced **at (+) electrode.**

C. **$PbSO_4$** is consumed **NOT produced.**

D. Oxidation numbers of Pb change from **+2 to +4 at the anode**, and +**2 to 0 at the cathode.**

Q30. D. The expanded structure of **glutathione** shown below may be used to show that **three 2-amino acids** may be identified (using ***Table 17 in the Data Book***) as contributing to the structure.



Hence alternative **D** is **incorrect**.
As a free radical scavenger, **glutathione is an antioxidant**.
Glutathione is a tripeptide, because it contains three amino acid residues.
The **four functional groups** present are -NH_2 (amino), -COOH (carboxyl), -CONH- (peptide), -SH(thiol).

SECTION B – Short Answer (Answers)

Question 1 (11 marks)

a. $2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(l)$; $\Delta H = -1452$ kJ mol^{-1} ❶ *or*

$CH_3OH(l) + 1.5O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$; $\Delta H = -726$ kJ mol^{-1}

b. **i.** Energy added to water $= 4.18\ J\ g^{-1}\ °C^{-1} \times m(H_2O) \times \Delta T$

$= 4.18 \times 200 \times (54.7-23.5)$

$= 4.18 \times 200 \times 31.2$

$= 2.61 \times 10^4$ J

= **26.1 kJ** ❶

$m(CH_3OH)$ used $= 125.62 – 121.56$

$= 4.06$ g

Energy released by CH_3OH $= m(CH_3OH) \times$ Energy released per gram CH_3OH

According to the ***Data Book***, Heat of combustion = 22.7 kJ g^{-1}

$= 4.06\ g \times 22.7\ kJ\ g^{-1}$

= **92.2 kJ** ❶

% energy transferred to water = (energy added to water / energy released by CH_3OH) × 100

= (26.1 / 92.2) × 100

= **28.3 %** ❶

Alternatively – for the second mark:

$n(CH_3OH)$ used $= 4.06 / 32.0$

$= 0.127$ mol

Energy released by CH_3OH $= n(CH_3OH) \times$ Energy released per mole CH_3OH

According to the ***Data Book***, *1 mol* $CH_3OH \rightarrow$ *726 kJ*

$= 0.127\ mol \times 726\ kJ\ mol^{-1}$

= **92.1 kJ**

ii. *Possible answers include*:

1. Put a lid on the can – this reduces heat escaping from the water to the atmosphere.
2. Move the flame closer to the can – this reduces heat loss to the surrounding atmosphere.
3. Place a reflective shield around the burner and flame – this reduces heat loss to the atmosphere and the impact of air currents on the flame.

❶ mark for an appropriate answer.

c. **i.** (-) electrode

The fuel, CH_3OH, is oxidised to CO_2

$CH_3OH(l) \rightarrow CO_2(g)$

$\mathbf{CH_3OH(l) + H_2O(l) \rightarrow CO_2(g) + 6H^+(aq) + 6e^-}$ ❶

(+) electrode

Oxygen is reduced, since the electrolyte is acid, the reduction half-equation is obtained from the electrochemical series by looking for O_2 – the oxidant – in a half-equation with $H^+(aq)$

$\mathbf{O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)}$ ❶

ii. Porous electrodes **allow for better contact between the fuel and the electrolyte**, and with oxygen and the electrolyte thereby **increasing the reaction rate**. ❶ They can also be impregnated with catalyst.
Electrodes in a fuel cell must:
- **conduct electricity**.
- **not react** with the fuel, oxygen or electrolyte.

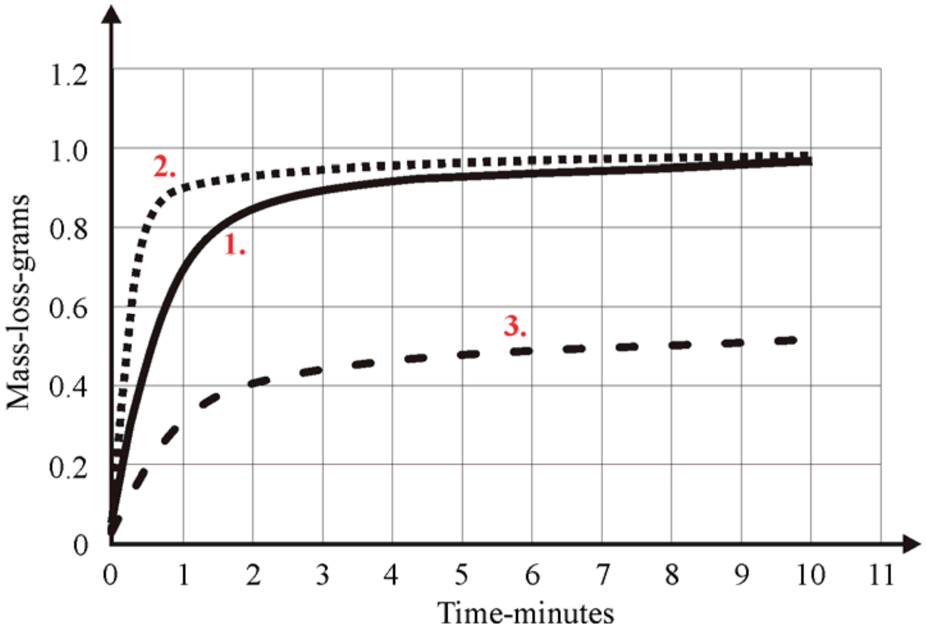
d. i. Both steps involve equilibria with exothermic reactions. To **maximise yield**, **low** temperatures **should be used**. However, the **reaction rate decreases at lower temperatures**. ❶ Using a **catalyst means that both a good yield and a good reaction rate can be achieved**. ❶

ii. The **much smaller bioDME molecules have less intermolecular attraction**, so bioDME is less viscous than methyl stearate. The **low viscosity means the bioDME is a poor lubricant**. ❶

Question 2 (8 marks)

a. $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$ ❶ *or*
$CaCO_3(s) + 2H^+(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

b.



i. Since the **gradients of all three graphs decrease**, **reaction rate decreases** ❶ as the reaction proceeds (time increases).

ii. As the reaction proceeds**, reactant concentration** – in this case ***c*****(HCl(aq)) – decreases**. This **reduces the number of collisions, and the number of successful collisions.** ❶

c. i. **Increase in surface area.**
The initial reaction rate is higher. This could be caused by a temperature increase, higher c(HCl), addition of a catalyst, or increased surface area. Since it was **clearly stated the starting temperature was the same and no catalyst was used for all three investigations, either the surface area was larger** – smaller marble chips used **or a higher *c*(HCl) was used**. ❶ However, **since the $CaCO_3$ was in excess (HCl was the limiting reactant), a higher *c*(HCl) would produce a greater overall mass loss**. ❶

ii. Lower *c*(HCl)
The **initial reaction rate is lower** and the overall **mass loss in investigation 3 is half of that for investigation 1** both observations are **consistent with using a lower *c*(HCl)** – most likely half the *c*(HCl) used in investigation 1. ❶

d.

Investigations	Independent variables	Dependent variables	Controlled variables
1 and 2 ❶	Surface area (particle size) of CaCO3	m(CO2) / mass loss / reaction rate	Temperature V(HCl) c(HCl)
1 and 3 ❶	Concentration of HCl(aq)	m(CO2) / mass loss / reaction rate	Temperature V(HCl) Surface area CaCO3

Question 3 (7 marks)

a. **Cathode.** There are **4 oxidants** present in the cell – Cu^{2+}(aq), Ag^{+}(aq), K^{+}(aq) and H_2O(l), but **only 1 reductant** – H_2O(l), so **multiple products are only possible at the cathode** (where oxidants are reduced). ❶

b. Referring to the relevant half-reactions on the electrochemical series.

$O_2(g) + 4H^{+}(aq) + 4e^{-}$	$\rightleftharpoons$	$2\underline{H_2O}(l)$	+1.77 V
$\underline{Ag^{+}}(aq) + e^{-}$	$\rightleftharpoons$	$Ag(s)$	+0.80 V
$\underline{Cu^{2+}}(aq) + 2e^{-}$	$\rightleftharpoons$	$Cu(s)$	+0.34 V
$2\underline{H_2O}(l) + 2e^{-}$	$\rightleftharpoons$	$H_2(g) + 2OH^{-}(aq)$	-0.83 V
$\underline{K^{+}}(aq) + e^{-}$	$\rightleftharpoons$	$K(s)$	-2.93 V

i. **Ag, silver** – the **strongest oxidant, Ag^{+}(aq)** is the **first** to be **reduced.** ❶

ii. **Cu, copper** – as the *c*(Ag^{2+}) decreases, a point will be reached where the **next strongest oxidant, Cu^{2+}(aq)** will be **reduced** at the cathode. ❶

iii. **$2H_2O(l) + 2e^{-} \rightarrow H_2(g) + 2OH^{-}(aq)$** ❶
H_2*, hydrogen** *is the third substance formed – as the c(Cu^{2+}) decreases, a point will be reached where the* ***next strongest oxidant, H_2O(l) *will be* ***reduced*** *at the cathode.*
NB*. K(s) will not be produced because H_2O(l) is a much stronger oxidant and is reduced preferentially to K^{+}(aq).*

c. The **layers of Ag and Cu deposited would be far more irregular** and we are **assuming that the behaviour predicted by standard conditions, 1 M solutions, 25°C and 100 kPa will be followed.** ❶ *or*
There may be **areas – depending on concentration - where both Ag(s) and Cu(s) or Cu(s) and H_2(g) are produced simultaneously**.

d. **$2H_2O(l) \rightarrow O_2(g) + 4H^{+}(aq) + 4e^{-}$** ❶

e. Total cation concentration is **increased**.
Cations consumed as Ag^{+}(aq) and Cu^{2+}(aq) are reduced and **replaced by H^{+}(aq) ions from the oxidation half-equation $2H_2O(l) \rightarrow O_2(g) + 4H^{+}(aq) + 4e^{-}$.**
Each Ag^{+} is replaced by one H^{+},
$4Ag^{+}(aq) + 2H_2O(e) \rightarrow O_2(g) + 4H^{+}(aq)$.
Each Cu^{2+} is replaced by $2H^{+}$,
$2Cu^{2+}(aq) + 2H_2O(l) \rightarrow 2Cu(s) + 4H^{+}(aq) + O_2(g)$. ❶
Overall, the number of cations increases.

Question 4 (7 marks)

a. **Incomplete combustion of carbon containing fuels**. ❶
Any **balanced combustion equation of a fuel showing CO** as a product, e.g. ❶
$\mathbf{2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(g)}$

b. **Haemoglobin has a greater affinity for CO(g) than O_2(g),** so in the presence of CO the equilibrium
$Hb(aq) + 4CO(aq) \rightleftharpoons Hb(CO)_4(aq)$ is established. ❶ This impacts on the haemoglobin-oxygen equilibrium as **the decrease in [Hb] causes the equilibrium $Hb(aq) + 4O_2(aq) \rightleftharpoons Hb(O_2)_4(aq)$ to shift to the left** ❶ to compensate. Consequently, **CO is carried round the body rather than O_2.**

c. The presence of CO in the air effectively establishes the equilibrium
$Hb(O_2)_4(aq) + 4CO(g) \rightleftharpoons Hb(CO)_4(aq) + 4O_2(g)$
This **equilibrium lies far to the right and so treatment of CO poisoning must involve intervention that will push the equilibrium to the left to allow more $Hb(O_2)_4$ to form**. Since **O_2(g) is a product in this equilibrium, pure oxygen therapy will achieve this goal as the system moves to compensate for the increased oxygen concentration.** ❶

d. Haemoglobin has a quaternary structure, i.e. contains **two or more protein (polypeptide) chains clustered into a specific shape**. ❶ Haemoglobin has **four heme units** each containing an Fe^{2+} ion (a cofactor) and **each haemoglobin molecule can carry four O_2 molecules.**

e. **Low blood pH is due to the $[H_3O^+]$ being too high**. The system compensates by using up some of the H_3O^+(aq) thereby **pushing all the linked equilibria to the left**. ❶ **This increases the amount of CO_2(g) released in the lungs** to be exhaled.

Question 5 (8 marks)

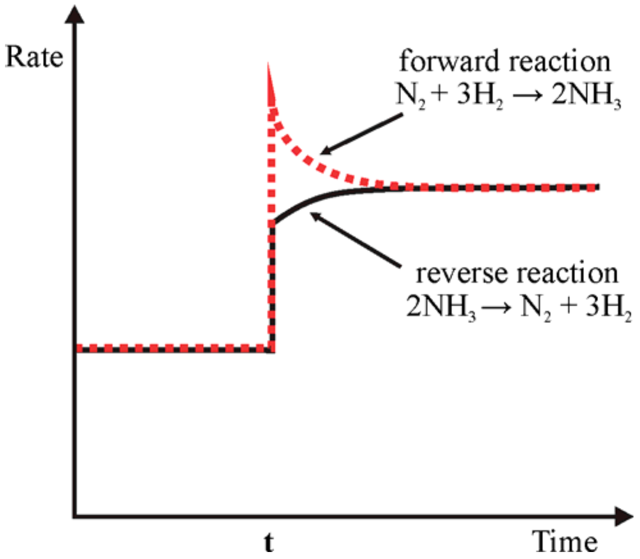
a. The data show that, at constant temperature, the **yield of NH_3 increases as the pressure increases**. ❶ This is consistent with Le Chatelier's principle which suggests that the **system strives to partially oppose a pressure increase by favouring the side of the reaction with fewer particles** and so **favours the NH_3 producing a forward reaction**. ❶

b. **$K_c = [NH_3]^2 / \{[N_2]\ [H_2]^3\}\ M^{-2}$** ❶

c. **Exothermic.**
The data show that at constant pressure (2.00×10^5 kPa), the **yield of NH_3 decreases as the temperature increases**. ❶

d. **No effect.** A catalyst would increase the rate of production of NH_3 but since it **would not change the position of equilibrium**, it would **not affect** the **equilibrium yield**. ❶

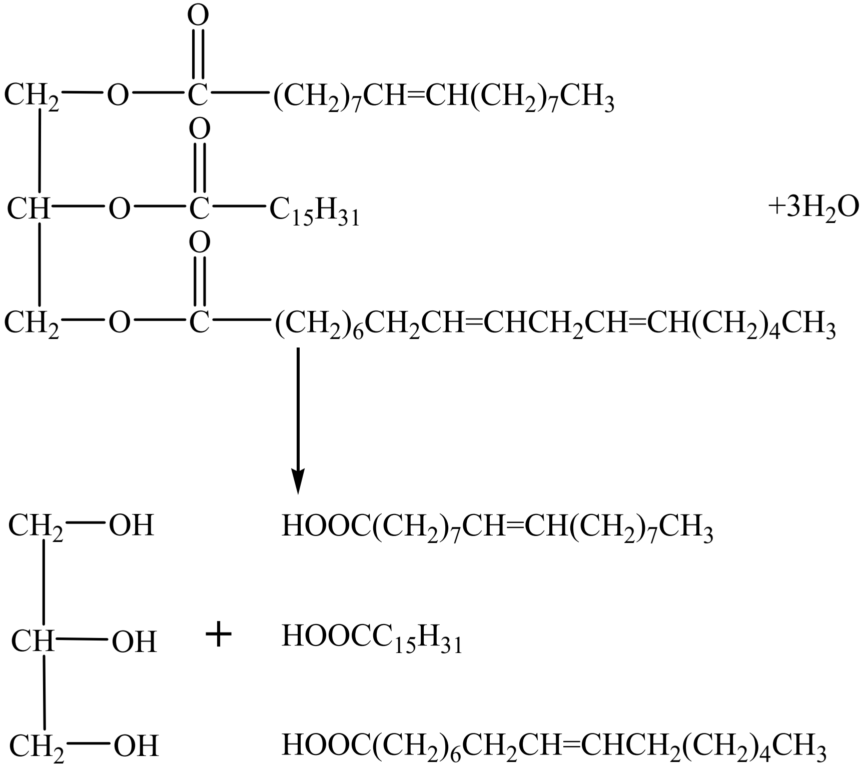
e.



Initially the system is at equilibrium and the rates of forward and reverse reactions are equal. The **volume decrease instantaneously increases reactant and product concentrations** and so the **rates of the forward and reverse reactions increase**. ➊ The forward rate increases more because of the greater number of reactant particles in the equation. As **the system moves to counteract the volume decrease** (concentration increase), the reactant that produces **fewer particles** is favoured, i.e. the forward reaction. ➊ As the **forward reaction** proceeds, its **rate drops** as [N_2] and [H_2] (reactants) decrease, and the **rate of the reverse reaction increases** as the [NH_3] (product) increases. Eventually **equilibrium is established again** and the **rates of the forward and reverse reactions are again equal**. ➊

Question 6 (17 marks)

a. **i.** The key process in triglyceride digestion is **lipase catalysed hydrolysis, in which water acts across the ester groups each of which is thus converted to a carboxyl and a hydroxyl group**. However, since **fats are effectively insoluble in water and lipase is a water-soluble protein, bile is used to emulsify the triglyceride**. ❶❶
The overall hydrolysis reaction is



ii. Two ❶❶ of the following:
Oleic acid [$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$] – **monounsaturated** fatty acid.
Palmitic acid [$C_{15}H_{31}COOH$] – **saturated** fatty acid.
Linoleic acid [$CH_3(CH_2)_4CH=CHCH_2CH=CHCH_2(CH_2)_6COOH$ – **polyunsaturated** fatty acid.

iii. An **omega-6 unsaturated fatty acid** has its **first C=C double bond beginning with the sixth carbon** from the beginning of the hydrocarbon chain. **Linoleic acid,** ❶ $CH_3CH_2CH_2CH_2CH_2\mathbf{C}H=CHCH_2CH=CHCH_2(CH_2)_6COOH$, is an omega-6 fatty acid.

iv. Linolenic **acid,**
$\mathbf{CH_3(CH_2)_4CH=CHCH_2CH=CHCH_2CH=CHCH_2(CH_2)_6COOH}$ ❶

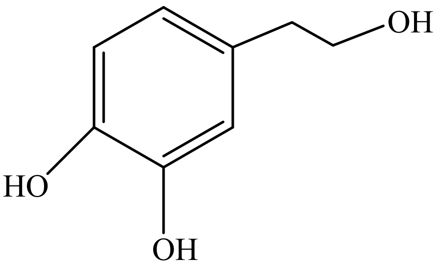
b. The molecular formula of the triglyceride is $\mathbf{C_{52}H_{98}O_6}$

1. Skeleton equation $C_{55}H_{100}O_6(l) + \_\_\_O_2(g) \rightarrow \_\_\_CO_2(g) + \_\_\_H_2O(g)$
2. Balance C atoms $C_{55}H_{100}O_6(l) + \_\_\_O_2(g) \rightarrow 55CO_2(g) + \_\_\_H_2O(g)$
3. Balance H atoms $C_{55}H_{100}O_6(l) + \_\_\_O_2(g) \rightarrow 55CO_2(g) + 50H_2O(g)$
4. Balance O atoms, 110 + 50 = 160 on right, 6 on left, need 154 O, i.e.$77O_2$ on left.

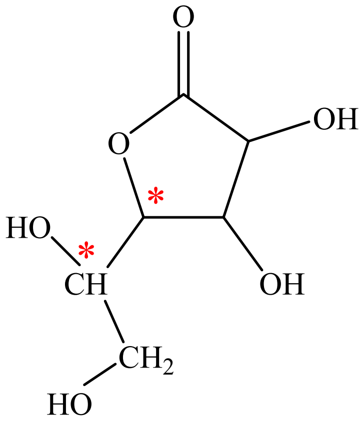
$$\mathbf{C_{55}H_{100}O_6(l) + 77O_2(g) \rightarrow 55CO_2(g) + 50H_2O(g)}$$ ❶❶

c. **i.** The presence of **C=C bonds in unsaturated fatty acids in olive oil are very reactive**. ❶ Oxidative rancidity is associated with **autoxidation of fats** from which **foul smelling short chain aldehydes and ketones** can result. **Antioxidants** prevent this happening by **inhibiting the propagation of free radicals** ❶ associated with autoxidation.

ii.



Hydroxytyrosol



Ascorbic acid (from ***Data Book***)

To have enantiomers, a **molecule must be chiral**, i.e. have a chiral centre. **Carbon atoms making single bonds to four different atoms or groups are chiral centres.** ❶

Hydroxytyrosol has no chiral centre, whereas ascorbic acid has two chiral centres, ❶ indicated by the asterisks (*).

d. Energy released by oil $= (517 / 15) \times 7.5$

$= 258.5$ kJ

Energy transferred to water $= 0.40 \times 258.5$

$= 103.4$ kJ ❶

$103.4 \times 10^3\text{ J} = 4.18\text{ J g}^{-1}\ {}^\circ\text{C}^{-1} \times 500\text{ g} \times \Delta T$ ❶ assume $d(H_2O) = 1\text{ g mL}^{-1}$

$\Delta T = 103.4 \times 10^3 / (4.18 \times 500)$

$= \mathbf{49.5^\circ C}$ ❶

e. According to ***Data Book, Table 13***.

Energy content of fats and oils = 37 kJ g^{-1}

15 mL olive oil → 517 kJ

m(olive oil) for 517 kJ $= 517 / 37$

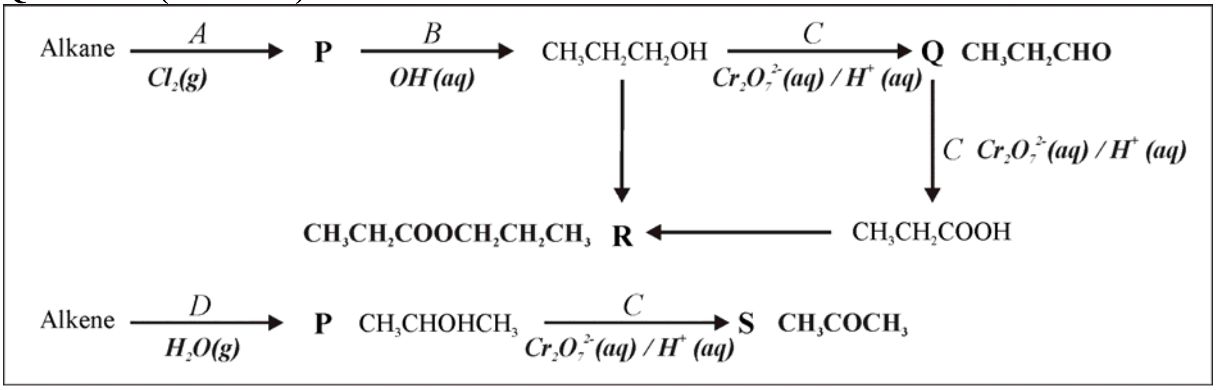
$= 14$ g ❶

So, 14 g olive oil is equivalent to 15 mL olive oil

***d*(olive oil)** = 14 g / 15 mL

= **0.93 g** $\mathbf{mL^{-1}}$ ❶

Question 7 (10 marks)



a. **Q – CH_3CH_2CHO ❶**
R – $CH_3CH_2COOCH_2CH_3$ ❶
S – CH_3COCH_3 ❶

b. **B – $OH^-(aq)$ / NaOH(aq) ❶**
C – $Cr_2O_7^{2-}(aq)$ / $H^+(aq)$ ❶
D – $H_2O(g)$ ❶

c. Oxidation: **$CH_3CHOHCH_3(aq) \rightarrow CH_3COCH_3(l) + 2H^+(aq) + 2e^-$ ❶**
Reduction: **$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$ ❶**

d. Compound R is propylpropanoate produced via the equilibrium
$CH_3CH_2COOH(l) + CH_3CH_2CH_2OH(l) \rightleftharpoons CH_3CH_2COOCH_2CH_2CH_3(l) + H_2O(l)$
Because equal chemical amounts of each reactant were used, the initial amount may be assumed to be, say 0.50 mol, of which 75 %, i.e. 0.375 mol (0.75 × 0.50) reacts as the system gets to equilibrium

	$CH_3CH_2COOH(l)$ +	$CH_3CH_2CH_2OH(l)$ $\rightleftharpoons$	$CH_3CH_2COOCH_2CH_2CH_3(l)$ +	$H_2O(l)$
Initially (mol)	0.50	0.50	-	-
*Reacting (*mol*)*	0.375	0.375	0.375	0.375
Equilibrium	**0.125**	**0.125**	**0.375**	**0.375**❶

Because there are the same number of mol on both sides of the balanced equation, volume is not a significant issue in the calculation; it may be assumed to be 1 L

$K_c = [CH_3CH_2COOCH_2CH_2CH_3][H_2O] / [CH_3CH_2COOH][CH_3CH_2CH_2OH]$
$= (0.375 \times 0.375) / (0.125 \times 0.125)$
$= \mathbf{9.0}$ ❶

Alternatively:
Since 75 % percent of each of the reactants were consumed in getting to equilibrium, and equal mole amounts of reactants were initially present, the ratio of each of the products to each of the reactants at equilibrium will be 3 : 1.
Hence, for **this** equilibrium, $K = 3 \times 3 / 1 \times 1 =$ **9.0**

Question 8 (11 marks)

a. **i. $C_2H_2O_4$(aq) + 2NaOH(aq) → $C_2H_2O_4^{2-}$(aq) + 2H_2O(l)** ❶

ii. $C_7H_8O_7$(aq) + 3NaOH(aq) → $C_7H_5O_7^{3-}$(aq) + 3H_2O(l) ❶

b. The **data in the third column (*V*(NaOH) required to react with citric acid in the fruit juice) should have been presented separately** to avoid confusion; these data are not linked to the individual amounts of oxalic used. ❶

c. **Oxalic acid is a primary standard.** ❶ Sodium hydroxide absorbs water from the atmosphere and reacts with atmospheric CO_2, hence the samples used are unlikely to be pure and the accurate concentration of the solution will not be 1.00 M.

By reacting the NaOH(aq) with oxalic acid, the accurate *c*(NaOH) can be determined.

d. Average $m(C_2H_4O_4)$ used = (1.25 + 1.23 + 1.26) / 3

= 1.247 g

Average *V*(NaOH) used = (27.6 + 27.1 + 27.4) / 3

= 27.37 mL ❶

$n(C_2H_4O_4)$ reacting = 1.247 / 90

= 0.0139 mol ❶

n(NaOH) required = 2 × $n(C_2H_4O_4)$

= 2× 0.0139

= 0.0277 mol

c(NaOH) = 0.0277 mol / 0.0237 L

= **1.012 mol L^{-1}** ❶

e. Average *V*(NaOH) used in titrating citric acid in fruit juice = (33.6 + 33.4 + 33.9)

= 33.63 mL

n(NaOH) reacting with citric acid in juice sample = 1.012 mol L^{-1} × 33.63× 10^{-3} L

= 0.0340 mol ❶

$n(C_7H_8O_7)$ reacting = *n*(NaOH) / 3

= 0.0340 / 3

= 0.0113 mol ❶

$m(C_7H_8O_6)$ in 50.0 sample of juice = 0.0113 mol × 204.0 g mol^{-1}

= 2.32 g

$m(C_7H_8O_6)$ in one L of juice = (2.32 / 50) × 1000

= **46.3 g L^{-1}** ❶

f. The **calculated concentration of citric acid will be higher than the true value** because the total ***V*(NaOH) added includes some that will have reacted with malic acid**. ❶

Question 9 (11 marks)

a. Parent-ion peak at *m*/z = 88, indicating that the **relative molecular mass** of the compound is **88**. ❶
Reference peak at *m*/z = 43, indicating that the **relative mass of the most abundant fragment** is **43**. ❶

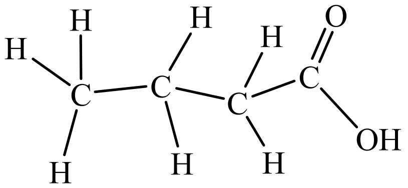
b. The compound has **4** different **carbon environments**. ❶

c. The compound has **3** different **hydrogen environments**. ❶
The presence of a **quartet** and a **triplet** indicates the presence of a **CH_3CH_2-** group. ❶
The singlet at δ **= 2.0 ppm** is consistent with **H on a carbon which is bonded to the carbon of an ester or amide** group, i.e. CH_3COOR, or $CH_3COONHR$. [***Data Book, Table 16***] ❶

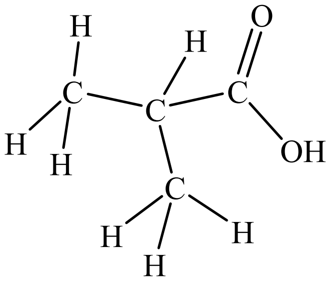
d. All the information deduced so far indicates that the **compound could be either $CH_3COOCH_2CH_3$ or $CH_3CONHCH_2CH_3$**. ❶
$M_r(CH_3COOCH_2CH_3) = 88.0$
$M_r(CH_3CONHCH_2CH_3) = 79.0$
Compound is **$CH_3COOCH_2CH_3$** ❶ – ethyl ethanoate.

e. **1720-1840 cm^{-1} C=O esters** *and*
2850-3090 cm^{-1} C-H ❶

f. **Carboxylic acids are structural isomers of esters with the same number of C atoms.**
There are two 4 C carboxylic acids.



Butanoic acid



Methylpropanoic acid

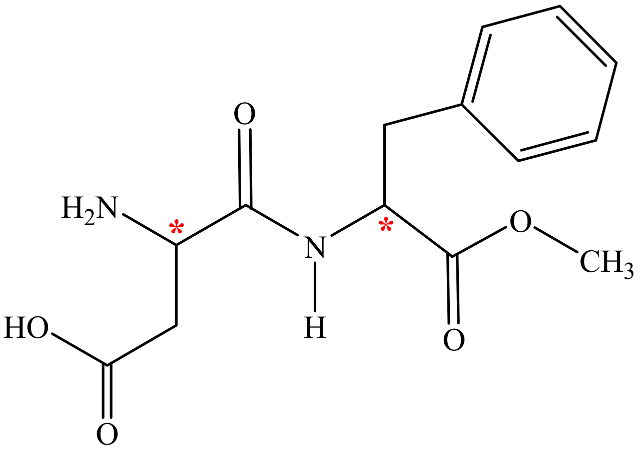
Differences in ^1H NMR spectra, from the spectrum for the compound would be
Butanoic acid ❶ -**Peak at δ = 9.0-13.0 for H in the carboxyl group** -COOH ❶ *or*
Four hydrogen environments rather than three.
or
Methyl propanoic acid - Peak at δ = 9.0-13.0 for H in the carboxyl group -COOH *or*
Singlet, doublet and septet, rather than singlet, triplet and quartet on its high resolution spectrum.

End of Suggested Answers

Question 10 (13 marks) BONUS QUESTION

a. **Two. ❶**

The structure of aspartame was supplied in Table 10 in the ***Data Book***. This is shown below with the two chiral carbons (those bonded to four different groups) indicated by an asterisk (*).



b. At **pH 10**, the **carboxyl group (-COOH) is deprotonated to COO$^-$**, as aspartame acts as an acid in the alkaline solution and the **molecules are negatively charged**. ❶

At **pH 4**, the **amino (-NH_2) group is protonated to $^+NH_3$**, as aspartame acts as a base in the acidic solution and the **molecules are positively charged**. ❶ (**Also, NH in the amide group could be protonated to $^+NH_2$).**

c. The fact that we taste L-aspartame but not D-aspartame indicates that **only the chiral molecules interact with our taste buds.** ❶

d. **i.** Aspartame: **peptide (amide) → carboxyl + amino** ❶

Sucrose: **ether (glycoside) → hydroxyl** ❶

ii. **Aspartic acid ❶, phenylalanine ❶** – (from ***Table 17 in the Data Book***)

iii. **Glucose ❶, Fructose ❶**

iv. The **glycaemic index ranks carbohydrate-intense foods based on their effect on blood-sugar (glucose) levels** ❶ (over a 2-hour period). Glucose is released during the hydrolysis of starch but **the rate at which glucose is released into the blood depends on the relative amounts of amylose and amylopectin** ❶ (polymers of glucose) present in the starch. Straight chain **amylose is more difficult** to digest **than** branched chain **amylopectin**, so a **more rapid higher peak** in **blood glucose levels** indicate a **greater proportion of amylopectin in the starch.** ❶

End of Suggested Answers (Bonus Question)