# Suggested answers to multiple-choice questions

Q1   **D**   Since a chiral carbon is bonded to four different atoms or groups of atoms, the arrangement of connecting atoms around the chiral centre will be tetrahedral.

Q2   **A**   Data precision is judged from the closeness of multiple measurements to each other. Student A's data with a range of 0.2 mL was more precise than Student B's data with a range of 0.4 mL.

Accuracy was reflected in how close the concentration of ethanoic acid in the vinegar was to the actual value.

Since $CH_3COOH(aq)$ was titrated with $NaOH(aq)$, the pH increases during titration. At the equivalence point of the reaction, the species present in the solution were $Na^+(aq)$ and $CH_3COO^-(aq)$. Since $CH_3COO^-(aq)$ will be weakly basic, the pH at the equivalence point will be greater than 7. So, the indicator chosen should show the endpoint at a pH > 7.

Methyl orange, pH range 3.1-4.4 *(Table 7 Chemistry Data Book)* will change colour at a lower titre than phenolphthalein, pH range 8.3-10.0.

The $V(NaOH)$ from which the $c(CH_3COOH)$ in the vinegar is calculated by Student A will be too low compared to the $V(NaOH)$ used by Student B.

The $c(CH_3COOH)$ calculated by Student B will be closer to the true value and so more accurate.

Q3   **C**   All undergo addition reactions with water.

Both *cis*-but-2-ene and *trans*-but-2-ene produce only 2-butanol, $CH_3CH_2CHOHCH_3$, which, being a secondary alcohol, is oxidised to butanone, $CH_3CH_2COCH_3$.

1-butene reacts to give two products, 1-butanol, $CH_3CH_2CH_2CH_2OH$, and the more abundant 2-butanol, $CH_3CH_2CHOHCH_3$.

1-butanol can be oxidised to butanal, $CH_3CH_2CH_2CHO$, and butanoic acid, $CH_3CH_2CH_2COOH$, both of which show 4 signals on their ^{13}C NMR spectra. 2-butanol is oxidised to butanone, $CH_3CH_2COCH_3$, which also has 4 signals on its ^{13}C NMR spectrum.

2-methylprop-1-ene reacts to give two products, 2-methylpropan-1-ol, $(CH_3)_2CHCH_2OH$, and the more abundant 2,2-dimethylpropan-2-ol, $(CH_3)_3OH$. 2-methylpropan-1-ol, $(CH_3)_2CHCH_2OH$, can be oxidised to 2-methylpropanal, $(CH_3)_2CHCHO$, and 2-methylpropanoic acid, $(CH_3)_2CHCOOH$, both of which have 3 signals on their ^{13}C NMR. 2,2-dimethylpropan-2-ol, $(CH_3)_3COH$, is a tertiary alcohol so does not react with acidified dichromate.

cis-but-2-ene

trans-but-2-ene

but-l-ene

2-methyprop-l-ene
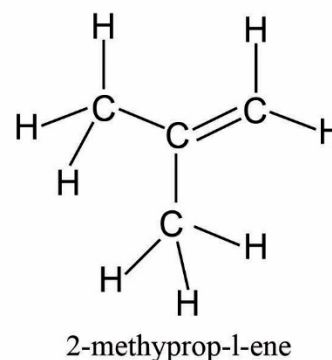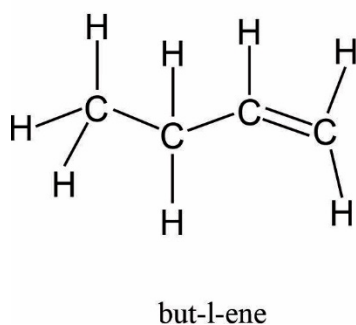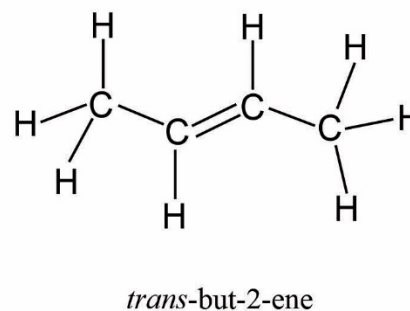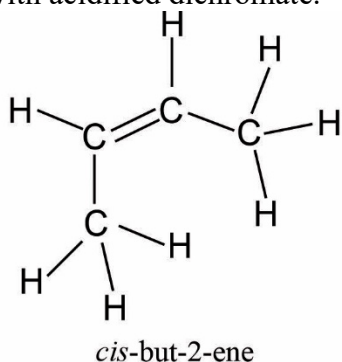
Q4   **C** $n(\text{gas}) = pV / RT = 102 \times 3.42 / [8.31 \times (77 + 273)]$
$$= 0.12 \text{ mol}$$

$M(\text{hydrocarbon}) = m / n = 5.25 / 0.12$
$$= 43.8 \text{ g mol}^{-1}$$

The hydrocarbon was propane, $C_3H_8 - M = 44.0 \text{ g mol}^{-1}$

Since $n(CO_2) = 3 \times n(C_3H_8)$, then at the same temperature and pressure
$V(CO_2) = 8 \times V(C_3H_8) = 3 \times 3.42 \text{ L}$
$$= 10.3 \text{ L}$$

Q5 **C** The increased rates of both the forward and reverse reactions at t suggest the imposed change was a decrease in volume with associated concentration increases. As the system adjusts to the imposed change and moves to compensate for the increased concentrations, the side of the equilibrium with fewer particles is favoured, so the equilibrium equation must have fewer particles on one side than the other.

Both $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ and $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ fit the criteria, but given the relative extents of the rate changes as the system returns to equilibrium,

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$ is the more likely option.

Q6 **B** Vitamin D_2 is ergocalciferol *(Chemistry Data Book Table 10)* which has the higher boiling point, suggesting stronger intermolecular attraction. Consequently, it may be assumed that ergocalciferol will have the stronger attraction to the stationary phase and the higher retention time. Ergocalciferol molecules each contain one more C atom than cholecalciferol molecules, but the relative molecular masses are so large it is reasonable to treat the ratio of the relative peak areas as a good approximation to the ratio of the masses of vitamin D_2 and vitamin D_3 in the mixture.

m(vitamin D_2) : m(vitamin D_3) = 325 / 275

% by mass vitamin D_2 = [325 / (325 + 275)] × 100
                        = 54 %

Q7 **B** Energy added to water = 4.18 J g^{-1} °C^{-1} × m(H_2O) × ΔT(water)
                        = 4.18 × 200 × (28.4 – 24.5)
                        = $3.26 × 10^3$ J

Energy lost by aluminium = $3.26 × 10^3$ J

$3.26 × 10^3$ = 0.921 × m(Al) × ΔT(aluminium)
             = 0.921 × m(Al) × (95.4 – 28.4)

m(Al) = $3.26 × 10^3$ / (0.921 × 67)

m(Al) = 52.8 g

Q8 **B** The glycaemic index is a ranking of carbohydrates based on hydrolysis of starch and the relative amounts of amylose – straight chain and slow release of glucose, hence lower GI – and amylopectin – branched chain and more rapid release of glucose, hence higher GI.

Lactose intolerance refers to the inability to digest lactose due to the absence of the enzyme lactase. This is **not** associated with starch digestion.

The amount of amylose present in starch is linked to GI levels. High amylose levels mean low amylopectin levels and slower hydrolysis to glucose.

Glucose, a reactant in respiration, is produced from the hydrolysis of starch.

SECTION A - Suggested Answers
TURNOVER

Q9 **D** Each hour of the reaction, the reactant concentration will drop to 90 per cent of its value at the end of the previous hour. Assuming the initial concentration is Y mol L^{-1}

After 1 hour, c = 0.90 Y

After two hours c = 0.90 × 0.90 Y = 0.81 Y

After three hours c = 0.90 × 0.81 Y = 0.73 Y

After four hours c = 0.90 × 0.73 Y = 0.66 Y

After five hours c = 0.90 × 0.66 Y = 0.59 Y

After six hours c = 0.90 × 0.59 Y = 0.53 Y

After seven hours c = 0.90 × 0.53 Y = 0.48 Y

So, the 50 per cent consumption will have been reached in the hour during which *c* = 0.50 Y. This will happen during the **seventh** hour.

Q10 **D** Lowering the reactant concentration can lower the reaction rate but is not a factor in enzyme activity.

Since the active site of an enzyme is generally chiral – amino acids other than glycine have at least one chiral carbon – chiral substrates will fit the complementary active site.

Removal of product has no impact on enzyme activity.

The main factors that reduce enzyme activity are changes in temperature and pH, since both can cause the enzyme to become denatured.

Q11 **A** The conversion of salicin to salicyl alcohol is an hydrolysis reaction wherein H_2O reacts across the ether –O– link to produce two hydroxyl groups, one on salicyl alcohol and one on glucose.

The -CH_2OH group on salicyl alcohol is then oxidised to -COOH, by $Cr_2O_7^{2-}$(aq)/H^+(aq) which is reduced to Cr^{3+}(aq)

Q12   A $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$
In experiment 1, getting to equilibrium
0.050 mol HI $\rightarrow 0.025$ mol $H_2 + 0.025$ mol I_2.
In experiment 2, getting to equilibrium
0.020 mol $I_2 + 0.020$ mol $H_2 \rightarrow 0.040$ mol HI.

Experiment	Equilibrium amount - mol		
	HI	I_2	H_2
1	0.020	0.025	0.025
2	0.040	0.005	0.020

$K = [H_2][I_2] / [HI]^2$
$K_1 = 0.025 \times 0.025 / 0.020^2 = 1.56$
$K_2 = 0.020 \times 0.005 / 0.040^2 = 0.0625$
Since the forward reaction is endothermic, the K value increases as the temperature increases. Hence Equilibrium 1 was at the higher temperature.

Q13   B   In aqueous solutions of NaCl(aq), the reducing agents present are $Cl^-(aq)$ and $H_2O(l)$, which are very close together on the electrochemical series.
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$ 1.36 V
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$ 1.23 V
Since these E^0 values are for 1 M solutions, the higher the $c(Cl^-)$ the greater is its impact on the oxidation process, with $Cl_2(g)$ being the more likely product.
For 1 M NaCl(aq), O_2 is produced at the anode
$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$
For 10 M NaCl(aq), Cl_2 is produced at the anode
$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$
For 4 M NaCl(aq), both $Cl_2(aq)$ and $O_2(aq)$ are produced at the anode.
Given that all electrolyses proceed for the same length of time, the order of $[H_3O^+]$ in solution will be:
1 M NaCl(aq) > 4 M NaCl(aq) > 10 M NaCl(aq)
Hence the order of pH will be:
1 M NaCl(aq) < 4 M NaCl(aq) < 10 M NaCl(aq) and the correct graph order will be C (1 M NaCl) B (4M NaCl) A 10 M (NaCl)

Q14   **B**   Graph B indicates that after modifying the conditions, the rate of reaction is higher (the graph has a steeper gradient), and the amount of calcium carbonate reacted is greater (there's a greater decrease in mass during the reaction). Since $CaCO_3$ was the limiting reagent in the original reaction, the larger decrease in mass with the changed conditions suggests more $CaCO_3$ was present. This is also consistent with the higher starting mass of the beaker with the changed conditions.
However, a larger mass of the same size particles with the same acid would not impact the rate but powdered $CaCO_3$ would provide a larger surface area and hence a faster reaction.
Whilst higher temperature and higher concentration would increase the reaction rate, they would not affect the change in mass for the same amount of limestone.

Q15   **B**   Molecules of the trans isomer – fumaric acid – are symmetrical and hence non-polar (similar to CO_2). However, the polarity of hydroxyl groups at either end of the molecule allows for extensive intermolecular hydrogen bonding. In maleic acid (the *cis* isomer) molecules are polar and the shape of the molecule and the relative positions of the carboxyl groups effectively allows for intramolecular hydrogen bonding and less intermolecular hydrogen bonding. Because there is less attraction between maleic acid molecules, they form hydrogen bonds with water more readily, making maleic acid more soluble than fumaric acid.

Q16   **B**   According to the semi-structural formulae in **Table 9**:

Stearic acid, $C_{17}H_{35}COOH$, is saturated.

Oleic acid, $C_{17}H_{33}COOH$, is monounsaturated with one C=C in each molecule.

Linoleic acid, $C_{17}H_{31}COOH$, is polyunsaturated with two C=C in each molecule.

Linolenic acid, $C_{17}H_{29}COOH$, is polyunsaturated with three C=C in each molecule.

Since all four acids have similar molar masses, the intermolecular dispersion attraction forces will effectively be the same for all four molecules.

So, the impact of C=C double bonds on intermolecular attraction is the main consideration. The greater the number of C=C present in each molecule, the more extensive the kinking in the hydrocarbon chains, the more difficult it is for the molecules to pack together, the weaker the attraction and hence the lower the melting temperature.

Hence linolenic acid should have the lowest melting temperature and be the first to liquefy as the mixture is heated and it will be the last to solidify as the mixture is cooled.

As a matter of interest, the melting temperatures are:

Stearic acid – no C=C: 69 °C

Oleic acid – one C=C: 13 °C

Linoleic acid – two C=C: -5 °C

Linolenic acid – three C=C: -11 °C

Q17   **A**   The equilibrium $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ ΔH = -192 kJ mol^{-1}

- forward reaction is exothermic, so is favoured by lower temperatures and (at constant pressure) the yield of SO_3 increases as the temperature decreases, as shown in A and B.
- has fewer particles on the product side so the forward reaction is favoured by higher pressure as the system will respond by favouring the side with fewer particles and (at constant temperature) the yield increases as pressure increases, as shown in A and C.
- The yield of SO_3 will increase with decreasing temperature and increasing pressure, as shown in A.

Q18   **A**   The equilibrium is described by the equation $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$.
For the original equilibrium $K = 1$ M^{-1}
For more SO_3 to be present in a different equilibrium mixture, the concentration fraction (reaction quotient, Q) must be less than 1.
$Q = [SO_3]^2 / ([SO_2]^2[O_2])$
Mixture 1: $Q = 1^2 / (1.2^2 \times 0.8)$ $= 0.86$
Mixture 2: $Q = 1^2 / (1.1^2 \times 0.9)$ $= 0.91$
Mixture 3: $Q = 1^2 / (0.9^2 \times 1.1)$ $= 1.12$
Mixture 4: $Q = 1^2 / (0.8^2 \times 1.2)$ $= 1.30$
As the reaction moves to equilibrium the amount of SO_3 present will increase in systems where $Q < 1$ and decrease in systems where $Q > 1$.
The lower the values of Q, the more the forward reaction will proceed, producing more SO_3.

Q19   **C**   The carbohydrates represented by the structures are:
 1. Amylose   2. Amylopectin   3. Glycogen   4. Cellulose
Glycogen is the most branched and soluble of these carbohydrates and is formed when glucose released from the digestion of ingested carbohydrates, but not needed immediately for energy, undergoes glycogenesis. Glycogen is stored in the liver and muscles.

Q20   **A**   In the DHHPFC, N_2H_4 will be oxidised, so $NH_3(g)$ cannot be a product. In the cell the half-equations are
$N_2H_4(l) + 4OH^-(aq) \rightarrow N_2(g) + 4H_2O(l) + 4e^-$ at the (-) electrode
$H_2O_2(l) + 2H^+(aq) + 2e^- \rightarrow 2H_2O(l)$ at the (+) electrode
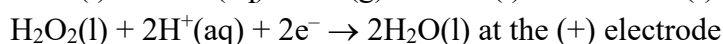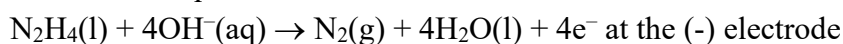
Unused NaOH, unused H_2SO_4 and H^+, as well as H_2O will be present in the respective outlet streams, as will the oxidation product N_2 and, because of migration of Na^+ ions through the cation exchange membrane, Na_2SO_4. The outlet streams are shown in **Figure 8**.
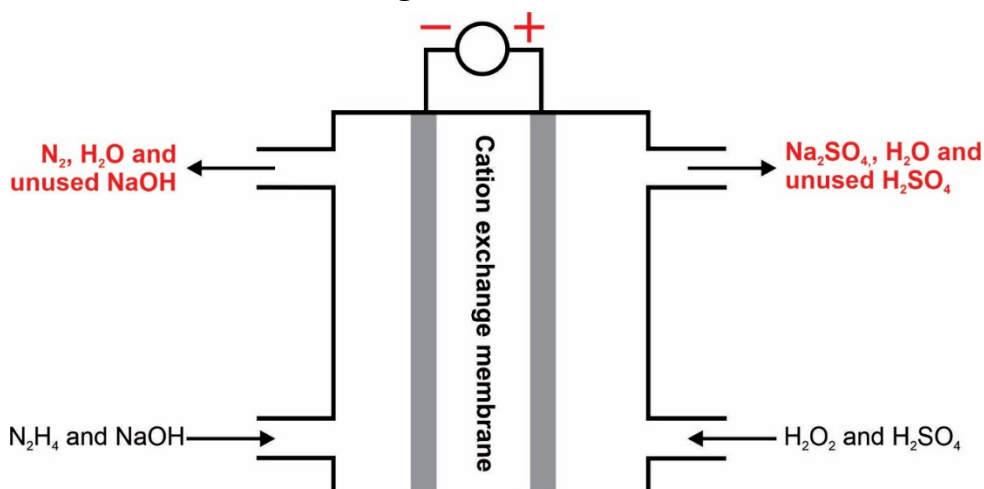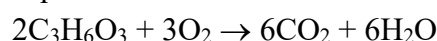
Q21 B The structure of lactic acid indicates that the molecular formula is $C_3H_6O_3$.
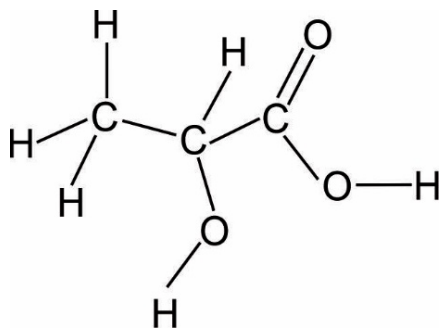
$m(C_3H_6O_3)$ consumed to give 100 kJ $= (1 / 15 \times 100)$
                                                                        $= 6.67$ g

Equation for combustion of lactic acid

$2C_3H_6O_3 + 3O_2 \rightarrow 6CO_2 + 6H_2O$

$n(C_3H_6O_3) = 6.67$ g $/ 90.0$ g mol$^{-1} = 0.0741$ mol

$n(CO_2)$ $= 3 \times 0.0741 = n(H_2O)$
                      $= 0.222$ mol

$m(CO_2) = 0.222 \times 44.0 = 9.78$ g

$m(H_2O) = 0.222 \times 18.0 = 4.0$ g

Total mass products $= 13.8$ g i.e. approximately 15 g

Q22 C The ΔH in the efficiency relationship is based on the understanding that the overall reaction occurring in the fuel cell is the same as the combustion of ethanol to produce CO_2, and so is the value of the heat of combustion, i.e., 1360 kJ mol^{-1} *(Chemistry Data Book Table 11)*.
The $n(e^-)$ is referenced to the oxidation half-equation, i.e.

$C_2H_6O(l) + 3H_2O(l) \rightarrow 2CO_2(g) + 12H^+(aq) + 12e^-$

For 1 mol C_2H_6O, $n(e^-) = 12$

Electrical energy $= QV = n(e^-) \times F \times V$
                                        $= 12 \times 96500 \times 0.576$
                                        $= 6.67 \times 10^5$ J
                                        $= 667$ kJ

Efficiency $= 667 / 1360 = 0.490$
                              $= 49 \%$

Q23   D   Energy released from the chips increases the temperature of the water and the reaction bomb.

Energy added to **water** $= 4.18$ **J g**$^{-1}$ **K**$^{-1}$

$= 4.18 \times 1.5\text{x}10^3 \times 0.997 \times (52.7 - 22.1)$

$= 1.91 \times 10^5$ J $= 191$ **kJ**

Energy added to the **reaction bomb** $= 0.500 \times (52.7 - 22.1)$

$= 15.3$ **kJ**

Total energy from 10 g chips $= 191 + 15.3 = 206.3$ **kJ**

Energy content $= 206.3 / 10.0$

$= 21$ **kJ g**$^{-1}$

NB since a temperature change is used it is the same in °C as it in K.

Q24   D   The acids ionise in aqueous solution according to the general equilibrium

$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$; $K_a = 1.7 \times 10^{-5}$ M

$HCOOH(aq) \rightleftharpoons HCOO^-(aq) + H^+(aq)$; $K_a = 1.8 \times 10^{-4}$ M

Since the K_a value is lower for $CH_3COOH(aq)$ it is the weaker acid and will be less ionised at equilibrium. Consequently, it will have the lower $c(H^+)$ and the higher pH.

Q25   D   Number the longest chain of C atoms in such a way that side groups have the lowest possible numbers.
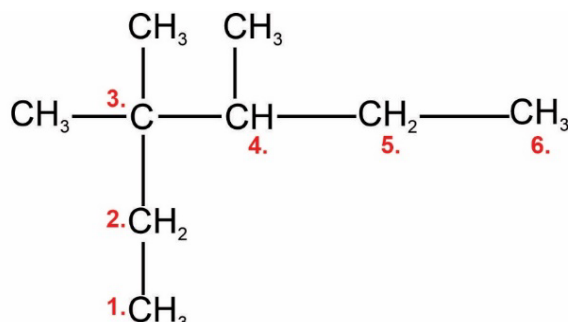
6 C in longest chain – hexane

3 CH_3 side groups, hence trimethyl, 2 methyl groups on C3 and 1 methyl group on C4

The systematic name is 3,3,4-trimethylhexane.

Q26 **C** The amount of energy released by each fuel = 4.18 J g^{-1} °C^{-1} × 200 g × 20 °C
$$= 1.67 × 10^4 \text{ J}$$
$$= 16.7 \text{ kJ}$$

The heats of combustion provided in the *(Chemistry Data Book Table 11)* for methanol (22.7 kJ g^{-1}) and ethanol (29.6 kJ g^{-1}) suggest that in the homologous series of alcohols, the heat of combustion increases with molecular size. Hence propan-1-ol will have the highest heat of combustion of the three alcohols and hence require the smallest mass of fuel.

Heat of combustion of propan-1-ol = 16.7 kJ / 0.585 g
$$= 29 \text{ kJ } g^{-1}.$$

The calculated heats of combustion would be lower than the true values because the transfer of energy to the water was not 100 per cent efficient.

Q27 **B** The relationships indicate an enzyme dependent reaction which slows down after 40 °C because the enzyme is denatured.
Ethanol in alcoholic beverages produced by fermentation depends on the presence of the enzymes present in yeast.
Ester production usually involves concentrated H_2SO_4 as a catalyst.
Ethane and ethene productions generally depend on crude oil and heat.

Q28 **D** The strength of Ag^+(aq) as an oxidising agent increases with concentration and when the only difference between the two half-cells is the $c(Ag^+)$, the system will try to equalise the $c(Ag^+)$, eventually reaching equilibrium. This means that Ag(s) will be oxidised in half-cell X and Ag^+(aq) will be reduced in half-cell Y.
Y electrode is the cathode: half-equation Ag^+(aq) + e^- → Ag(s)
X electrode is the anode: half-equation Ag(s) → Ag^+(aq) + e^-
So, cations move into half-cell Y.
There is no change in total m(Ag) nor total $n(Ag^+)$ across the two half-cells, hence total $c(Ag^+)$ is unaffected.
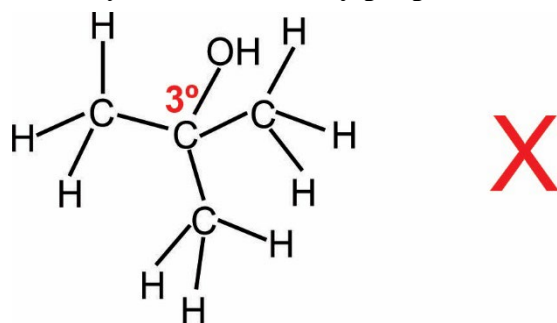
Q29   D   In the presence of acidified dichromate,
- primary alcohols – **propan-1-ol** and **methylpropan-1-ol** –are oxidised to aldehydes and carboxylic acids
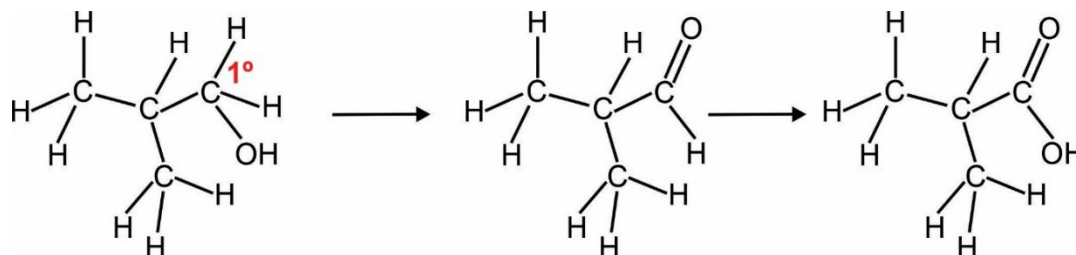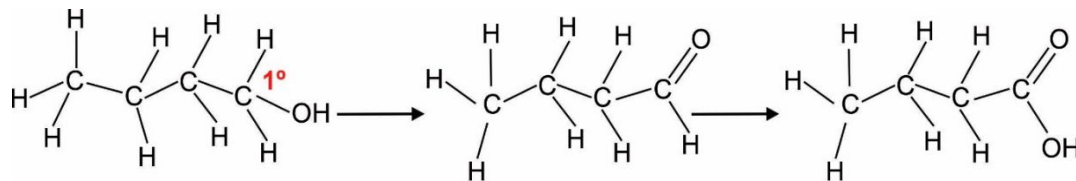
- secondary alcohols – **propanol-2-ol** – are oxidised to ketones
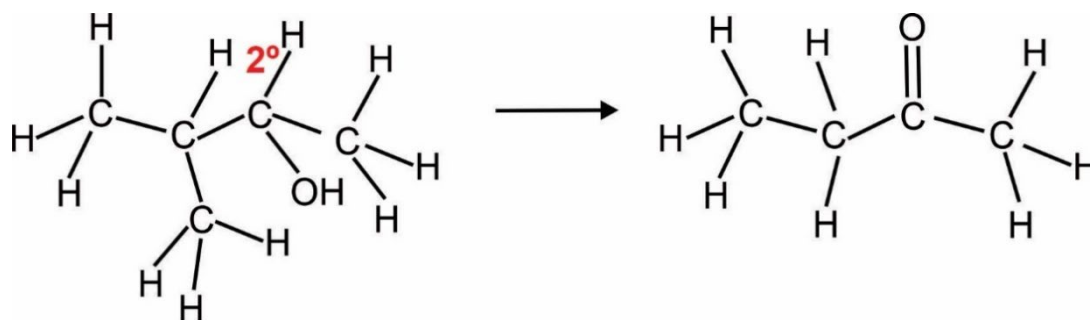
- tertiary alcohols – **methylpropane-2-ol** – are not oxidised

Hence methylpropan-2-ol is least likely to react with acidified dichromate.

Q30 **B** Biodiesel requires less oxygen to complete combustion because it contains oxygen, i.e., is partially oxidised compared to petrodiesel.

Stronger intermolecular attraction between polar biodiesel molecules, due to the presence of ester groups, causes higher viscosity, so the lower the temperature, the less easily the biodiesel will flow in fuel lines.

Whilst the chemistry of the production and use of biodiesel suggest carbon neutrality – the same amount of CO_2 released in combustion as absorbed during photosynthesis during plant formations – it is not fully carbon neutral because of emissions during production and transport.

Because biodiesel molecules are partially oxidised (contain oxygen) compared to petrodiesel, it has a lower energy content than petrodiesel. (Biodiesel = 33 MJ L^{-1}, Petrodiesel – 37 MJ L^{-1})

Suggested answers to short-answer questions

Question 1 (14 marks)

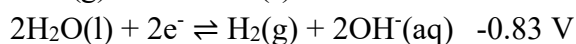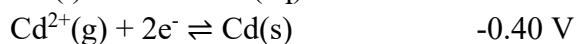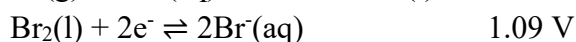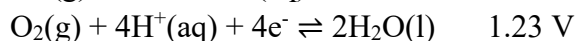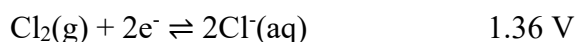**a.**   Heat of combustion of ethanol = 29.6 kJ g^{-1} *(Table 11 Chemistry Data Book)*
Energy released from ethanol combustion = 1.253 g × 29.6 g mol^{-1} = 37.1 kJ

Change in T = 24.87 – 22.30 = 2.57 °C ❶

Calibration Factor = 37.1 / 2.57 = 14.4 kJ °C^{-1} ❶

b.   Peanut butter X
ΔT = 25.47 – 23.15 = 2.32 °C
Energy from 1.53 g X = 2.32 °C × 14.4 kJ °C^{-1}
                  = 33.4 kJ ❶
Energy per 100 g   = 100 × (33.4 / 1.53)
                  = 2.18 × 10^3 kJ ❶

c.   Peanut butter Y
ΔT = 27.09 – 24.83 = 2.26 °C
Energy from 1.25 g X = 2.26 °C × 14.4 kJ °C^{-1}
                  = 32.5 kJ
Energy per 100 g = 100 × (32.5 / 1.25)
                  = 2.60 × 10^3 kJ ❶

d.   **i.**   Whilst different masses of the different peanut butters are used, the fact that the outcome is the determination of energy per 100 g for each of the brands, the independent variable may be considered to be the brand of peanut butter used. ❶

  ii.   Yes. The change in temperature during reaction of the peanut butter is dependent on both the brand of peanut butter and the sample mass. ❶

e.   **i.**   Compared to 100 g of peanut butter Y, 100 g of peanut butter X contains 3.3 g more protein but 8.9 g less fat and 8 g less carbohydrate. Given the relative energy contents of proteins (17 kJ g^{-1}), fats (37 kJ g^{-1}) and carbohydrates (16 kJ g^{-1}), peanut butter X will have the lower energy content. ❶

  ii.   Reasons peanut butter X may be considered the healthier option, consistent with the relative protein, fat and carbohydrate levels:
-   Higher protein content
-   Lower saturated fat levels
-   Lower sugar levels

❶ for any **two** relevant properties

f. **i.** The three fatty acids *(identified from Table 9 of the Chemistry Data Book)* are

$CH_3(CH_2)_{14}COOH$ – **palmitic acid**; a **saturated** fatty acid. ❶

$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$ – **oleic acid**; a **monounsaturated** fatty acid. ❶

$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$ – **linoleic acid**; a **polyunsaturated** fatty acid. ❶ The structure is shown in the B *(Chemistry Data Book)* as $CH_3(CH_2)_4CH=CHCH_2(CH=CHCH_2)_2(CH_2)_6COOH$

Also, oleic acid is an omega-9 acid and linoleic acid is an omega-6 acid.

ii. The **C=C double bond** and the **-OH groups** ❶ are consistent with **resveratrol** acting as an **antioxidant** ❶ and protecting the unsaturated fats in peanut butter.

Question 2 (10 marks)

a. $Q = It$

$\quad = 2.50 \times 35.0 \times 60$

$\quad = 5.25 \times 10^3$ C

$n(e^-) = Q / F$

$\quad = 5.25 \times 10^3 / 96500$

$\quad = 0.0544$ mol ❶

Reduction half-equation: $M^{2+}(aq) + 2e^- \rightarrow M(s)$

$n(M) = \frac{1}{2} \times n(e^-)$

$\quad = \frac{1}{2} \times 0.0544$

$\quad = 0.0272$ mol ❶

Molar mass M $= m(M) / n(M)$

$\quad\quad = 3.06 / 0.0272$

$\quad\quad = 112.5$ g mol^{-1}

Element is cadmium, Cd ❶

b. **i.** Relative atomic mass 63.5 → Cu

$E(cell) = E^0(Cu^{2+}/Cu) - E^0(Cd^{2+}/Cd)$

$\quad = 0.34 - (-0.40)$

$\quad = 0.74$ V ❶

If conditions are not standard, i.e., the solutions are less than 1 M, or the temperature is less than 25 °C, the generated voltage could be less than 0.80 V ❶

ii. KNO_3

$NO_3^-(aq)$ ions flow from the salt bridge to counteract the buildup of positive charge in the solution around the anode due to the oxidation half-equation $Cd(s) \rightarrow Cd^{2+}(aq) + 2e^-$, ❶ and so maintain the half-cell solution neutrality essential for effective operation of the galvanic cell. ❶

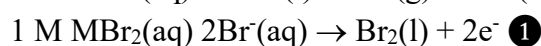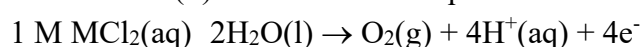**c.**   Consider the relevant information from the electrochemical series

$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$ 1.36 V

$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$ 1.23 V

$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$ 1.09 V

$Cd^{2+}(g) + 2e^- \rightleftharpoons Cd(s)$ -0.40 V

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

In both cells, the stronger oxidising agent is $Cd^{2+}(aq)$. However, the stronger reducing agents are $H_2O(l)$ in $MCl_2(aq)$ and $Br^-(aq)$ in $MBr_2(aq)$.

Cd is the product at the (-) electrode (cathode) in both cells. ❶

(-) $Cd^{2+}(g) + 2e^- \rightarrow Cd(s)$
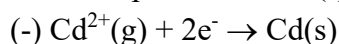
The products at the (+) electrode (anode) are $O_2(g)$ in $MCl_2(aq)$ and $Br_2(l)$ in $MBr_2(aq)$. ❶

Reduction – (+) electrode - half-equations

1 M $MCl_2(aq)$ $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$

1 M $MBr_2(aq)$ $2Br^-(aq) \rightarrow Br_2(l) + 2e^-$ ❶

Question 3 (12 marks)

a.   Using data from *(Table 14 of the Chemistry Data Book)* the IR spectrum shows a peak around 3300-3500 cm⁻¹ consistent with **N-H** bonds in amides and amines and a peak around 1600-1700 cm⁻¹ consistent with **C=O** bonds ❶ suggesting the **final product is an amide.** ❶ The peak around 2900 cm⁻¹ is due to C-H bonds.

b.   The molecular mass of 78.5 suggests that Cl – relative atomic mass 35.5 - is present in the starting compound. The mass spectrum shows **parent ions** at **m/z = 78** and **m/z = 80** consistent with the presence of Cl-35 and Cl-37 isotopes. ❶

The **base peak is at m/z = 43**. Since this is the starting compound of an organic reaction pathway, that peak is consistent with **C₃H₇⁺** ❶ and, since the molecular mass is 78.5, the molecular formula of the starting compound, W, must be **C₃H₇Cl.** ❶

c.   **i**.   Four signals indicate the presence of **4 H environments**. ❶

The signals for the H atoms bonded to the C atoms are split by H atoms on neighbouring C atoms consistent with the presence of 2 triplets ($\delta = 0.9$ ppm and 3.6 ppm) indicating the presence of 2 C atoms, with H atoms, next to a CH_2 group.

Since there are three carbons and four hydrogen environments, the fourth hydrogen must be bonded to a different element. Based on the chemical shift this is most probably an oxygen, therefore this would be the hydrogen for an hydroxyl group, -OH.

Figure 17 is a ¹³C NMR spectrum with 3 signals consistent with **3 C environments.** ❶ Also the signal with a chemical shift of 64 ppm would be consistent with that for an alkanol, R-CH_2-OH.

ii. Since compound X is produced directly from the starting compound, C_3H_7Cl, and is then oxidised in the pathway it should be an **alcohol** with, according to the ^1H and ^{13}NMR spectra, 3 C environments and 4 H environments.
Compound is propan-1-ol $CH_3CH_2CH_2OH$ with structural formula

 (1)
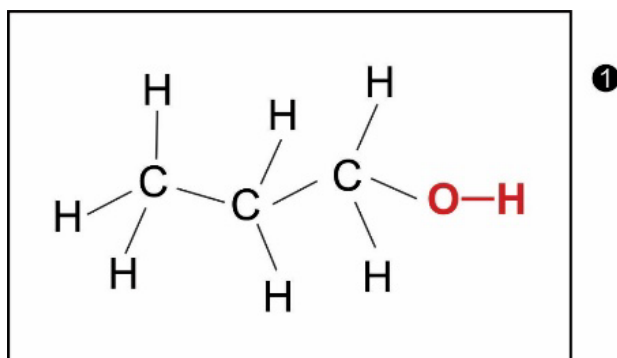
d.   **i.** The IR spectrum is consistent with a carboxylic acid – propanoic acid since it is produced from propan-1-ol.
CH_3CH_2COOH **(1)**

     ii. $CH_3CH_2CH_2OH + H_2O \rightarrow CH_3CH_2COOH + 4H^+ + 4e^-$ **(1)**

     iii. $CH_3CH_2COOH + NH_3 \rightarrow CH_3CH_2CONH_2 + H_2O$ **(1)**

     iv. Propanamide. **(1)**

Question 4 (13 marks)

a. $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$ **(1)**

b. To get the overall thermochemical equation, add the two half-equations and ΔH values together.
     $CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g);$ $\Delta H = +165$ kJ mol^{-1} **(1)**
The production of hydrogen is favoured by high temperatures since the forward reaction is endothermic **(1)** and low pressures since the forward reaction will be favoured as the system compensates because there are a greater number of particles on the product side. **(1)**

c. To be classified as green ammonia, the source of hydrogen must be renewable and produced using renewable energy.
The electrolysis of water using solar energy produces renewable H_2. **(1)**

d. The major components of air are O_2 and N_2, both of which are non-polar. Since N_2 molecules are lighter than O_2 molecules, the intermolecular forces are weaker, and when liquefied air is heated gently, N_2 will vaporise first. **(1)**

e. The data show that the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ is exothermic and the lower the temperature, the higher the yield. The temperature used will be influenced by the fact that lower temperatures mean a lower rate of reaction despite the higher yield. **(1)**
A compromise of a moderate temperature in conjunction with a catalyst is used.

f.   Equation $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
        Energy required to break bonds:
        $N \equiv N$; 945 kJ
        3H-H; $3 \times 435 = 1305$ kJ
        Total energy required = 945 + 1305
                            = 2250 kJ ❶
        Energy released when a bond is formed is equivalent to the energy needed to break that bond.
        Energy released when bonds form in $NH_3 = 2 \times 3 \times$ N-H $= 6 \times 390$
                            = 2340 kJ ❶

        2340 – 2250 = 90 kJ more energy is released when bonds in the products are formed than is consumed when the reactant bonds are broken, so the reaction is exothermic.
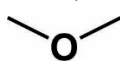   Equation $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$; ΔH = -90 kJ mol^{-1} ❶

g. NH_3 molecules are polar and have intermolecular hydrogen bonding compared to the dispersion force attraction for N_2 and H_2 molecules, which are both non-polar. ❶
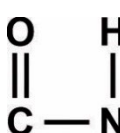
h.   **i.** $2NH_3 + 3O^{2-} \rightarrow N_2 + 3H_2O + 6e^-$ ❶
        ii.   Ammonia is less expensive to store and transport. It can be stored and transported as a liquid, whereas hydrogen must be stored at low temperature and high pressure which is far more costly. ❶

Question 5 (11 marks)

a.   Carbohydrates – provide the body with glucose, the main energy source in the body. ❶

             Fats – act as an energy source and support cell function. ❶

             Proteins – a source of amino acids, particularly essential amino acids, used to produce enzymes to control reactions and build and repair muscle. ❶

b.   For all three nutrients, digestion involves hydrolysis reactions.
   Carbohydrates - water reacts across the glycosidic links, converting them to hydroxyl -OH groups as monosaccharides are produced. ❶
        Proteins – water reacts across the peptide links, converting them to amino -NH_2 and carboxyl -COOH groups as amino acids are produced. ❶
        Fats – water reacts across the ester links, converting them to hydroxyl and carboxyl groups as glycerol and fatty acids are produced. ❶
        Post digestion, the products of digestion become available for the production of different carbohydrates, fats and proteins in cells. These processes involve condensation reactions wherein water is produced as the functional group changes are the reverse of those in digestion. ❶

c. The major product of carbohydrate digestion is glucose, some of which has immediate use as an energy source via respiration.

$$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g/aq) + 6H_2O(l)$$ ❶
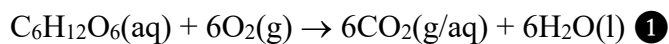
Glucose also undergoes condensation polymerisation to produce glycogen, which is stored in the liver and muscles and gradually converted back to glucose for respiration. ❶

d. The digestion of proteins releases amino acids which may be used in the production of enzymes which are used to control chemical reactions in the body. ❶

The active sites of different enzymes used in digestion are uniquely complementary to carbohydrates, fats and proteins.

Some proteins which may act as enzymes can only do so in the presence of coenzymes, many of which are linked to essential vitamins which must be in the diet. ❶

A summary of the functional group changes associated with digestion is shown in the diagram below.
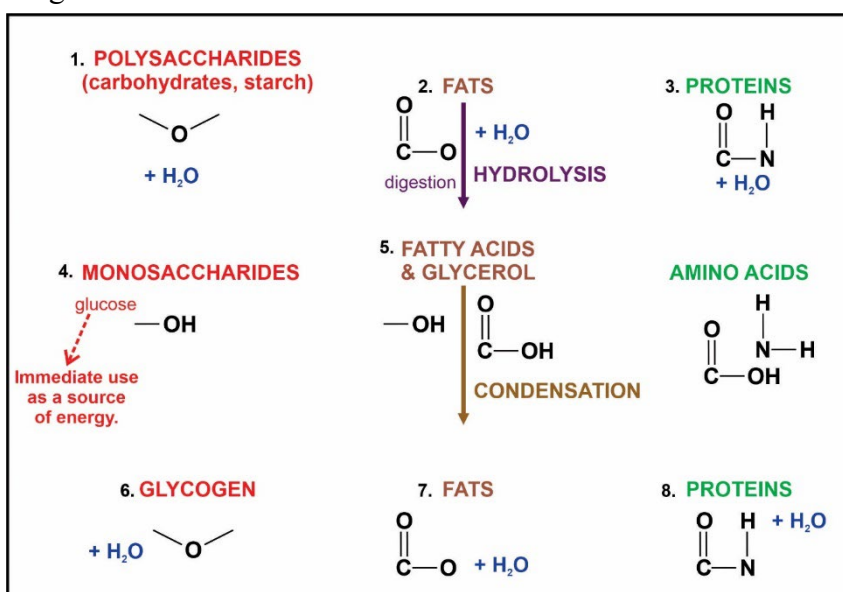
Question 6 (11 marks)

a.   Since cations and electrons are released and both travel to the cathode, the reaction is at the anode.

$LiC_6 \rightarrow C_6 + Li^+ + e^-$ **❶**

b. $CoO_2 + Li^+ + e^- \rightarrow LiCoO_2$ **❶**

Oxidation number of Co changes from + 4 to +3 **❶**

c.   If temperatures are too low, such as 0 °C, there may be a loss of capacity due to the chemical reactions inside the battery slowing down. **❶**

If conditions are too hot, side reactions may occur as well as potential hazards such as fire and explosion. **❶**

d.   **i.**   20 kWh = 20 × 3.6 = 72 MJ

$= 7.2 \times 10^4$ kJ per 100 km **❶**

ii. $n(C_8H_{18})$ = 7.2×10^4 kJ / 5460 kJ mol^{-1} *(Chemistry Data Book Table 11)*

= 13.19 mol

$m(C_8H_{18})$ = 13.19 × 114 g mol^{-1}

= 1503 g **❶**

$V(C_8H_{18})$ = 1503 g / 750 g L^{-1}

= 2.0 L **❶**

iii.   The internal combustion engine has low efficiency – with only 20 % of released energy used in driving the car, and most energy being lost as heat. So, the actual volume of petrol needed to travel 100 km would be approximately 10 L. **❶**

e.   Low yield ores mean extensive mining is needed to extract a viable amount of the metal. This can cause extensive environmental damage with respect to land and water. **❶**

f. H_2 is oxidised in an alkaline solution.

$H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-$ **❶**

Question 7 (10 marks)

a.   HPLC would be most suitable ❶, as the temperature needed to maintain a gaseous mobile phase in GC may impact on the molecular structures of aspirin and caffeine ❶.

b.   The molecules would interact with a non-polar stationary phase by dispersion force attraction.

The molecular formulae and relative molecular masses are:

Aspirin:

$C_9H_8O_4$ - $M_r(C_9H_8O_4) = 9 \times 12.0 + 8 \times 1.0 + 4 \times 6.0 = 180$

Caffeine:

$C_8H_{10}N_4O_2$ – $M_r(C_8H_{10}N_4O_2) = 8 \times 12.0 + 10 \times 0 + 4 \times 14.0 + 2 \times 16.0 = 194$ ❶

Based on the relative molecular masses, caffeine molecules would have stronger attraction to a non-polar stationary phase and hence a higher retention time. ❶

c.   ❶ for relative location of peaks – caffeine has higher retention time

❶ for relative peak areas – caffeine has smaller peak area

d.   Relative molecular mass of phenacetin is 179. So, the dispersion force attraction to the column will be only slightly less than aspirin. So, with an expected retention time just below that of aspirin, the peak for phenacetin would be just to the left of that for aspirin, most likely overlapping to some extent. ❶
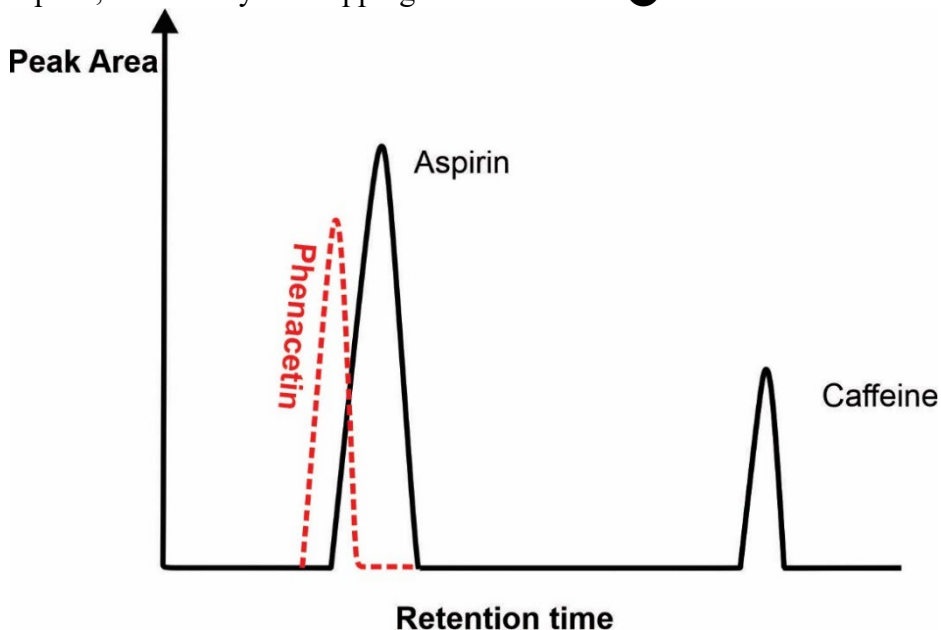
e.   **i.** $C_9H_8O_4(aq) + NaOH(aq) \rightarrow C_9H_7O_4Na(aq) + H_2O(l)$ ❶

ii. $(C_9H_8O_4)$ present $= 325 \times 10^{-3}$ g / 180 g mol^{-1}

$= 1.81 \times 10^{-3}$ mol

According to the equation n(NaOH) required $= n(C_9H_8O_4)$ reacting

$= 1.81 \times 10^{-3}$ mol ❶

Since $n = cV$ then V(NaOH) required $= n$(NaOH) / c(NaOH)

$= 1.81 \times 10^{-3}$ mol / 0.120 mol L^{-1}

$= 0.0150$ L

$= \textbf{15.0 mL}$ ❶

Question 8 (9 marks)

a.   **20 seconds ❶** - the concentrations stop changing at 20 seconds and the graphs are horizontal.

b.   **i.**

	Initial concentration	Equilibrium concentration	How the concentration changes as the system moves to equilibrium	
X	1.0 mol L^{-1}	4.0 mol L^{-1}	Increases by 3.0 mol L^{-1}	❶
Y	2.0 mol L^{-1}	3.0 mol L^{-1}	Increases by 1.0 mol L^{-1}	❶
Z	4.0 mol L^{-1}	2.0 mol L^{-1}	Decreases by 2.0 mol L^{-1}	❶

    ii. The concentrations of X and Y increase so more of both is being made as the system moves to equilibrium and Z is being consumed.

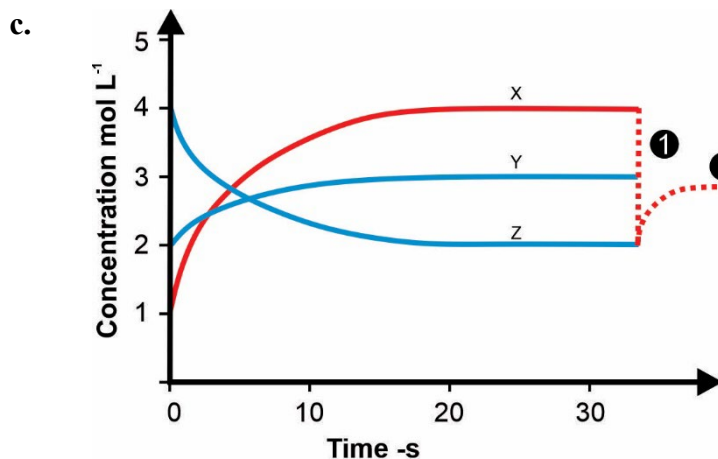Since it is a one L vessel, 2 mol of Z has reacted to produce 3 mol of X and 1 mol of Y. ❶

Hence the equilibrium equation would be

$2Z(g) \rightleftharpoons 3X(g) + Y(g)$ ❶   *or* $3X(g) + Y(g) \rightleftharpoons 2Z(g)$
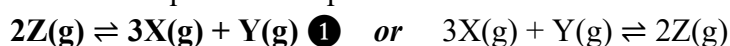
$K = [X]^3[Y] / [Z]^2$ *or* $K = [Z]^2 / [X]^3[Y]$

    $= 4.0^3 \times 3.0 / 2.0^2$ $= 2.0^2 / (4.0^3 \times 3.0)$

    $= 48 \text{ M}^{-2}$ ❶ $= 0.021 \text{ M}^{-2}$

c.

[X] would halve from 4 mol L^{-1} to 2 mol L^{-1} if the volume was doubled. [X] would increase as the system moves to the side with more particles to compensate for the pressure decrease (produce more particles in the larger volume), but would be lower than the original figure when equilibrium was reestablished.