Suggested Answers

VCE Chemistry 2015 Year 12 Trial Exam Units 3/4

SECTION A – Multiple Choice Answers

Q1. **A** The chemical formulae and K_a values of the acids are in ***Table 12 of the Data Book.***

The acids ionise in aqueous solution according to

$C_6H_5COOH(aq) + H_2O(l) \rightleftharpoons C_6H_5COO^-(aq) + H_3O^+(aq)$; $K_a = 6.4\times10^{-5}$

$HC_3H_5O_3 + H_2O(l) \rightleftharpoons C_3H_5O_3^-(aq) + H_3O^+(aq)$; $K_a = 1.4\times10^{-4}$

At equal concentrations, the weaker acid, benzoic acid C_6H_5COOH, the one with the smaller K_a, is less ionised in aqueous solution and so has the lower $[H_3O^+]$ and higher pH.

Consider the alternatives:

A. On dilution, the extent of ionisation of weak acids increases as the equilibrium shifts to the right, so **the number of H_3O^+ ions present increases**. However the increase in the number of H_3O^+ ions does not fully compensate for the volume increase during dilution and so the $[H_3O^+]$ decreases and the **pH increases**.

B. **Benzoic acid** (C_6H_5COOH) has the lower K_a value and so, for equal concentrations of both acids, it is less ionised in aqueous solution and so has the **lower $[H_3O^+]$** and higher pH.

C. The amount of strong base, NaOH(aq), required to neutralise an acid depends on acid concentration not acid strength. Continued addition of the strong base to a weak acid pushes the ionisation of the acid further to the right until all the available $H^+(aq)$ has been released. Hence the **same amount of 0.10 M NaOH(aq) would be required** for both acids.

D. **Lactic acid** ($HC_3H_5O_3$) has the higher K_a value and so, for equal concentrations of both acids, it is more ionised and so has the higher $[H_3O^+]$ and **lower pH.**

Q2. **C** Identification of an organic compound commonly involves the following techniques.

Mass Spectroscopy – to obtain the relative molecular mass and the relative mass of molecule fragments.

IR Spectroscopy – to identify bonds and functional groups present.

^{1}H NMR and ^{13}C NMR spectroscopy – to identify carbon and hydrogen molecules in the molecules.

Q3. **B** For the ratio of O_3 to O_2 to increase the equilibrium $2O_3(g) \rightleftharpoons 3O_2(g)$ must shift to the left. This would be the result of:
- temperature increase: the forward reaction is exothermic and favoured by low temperatures.
- pressure increase: system moves to side with fewer particles to partially compensate.

Lightning releases energy into the atmosphere and so **favours the reverse endothermic reaction.**

Q4. **A** $K = [O_2]^3/[O_3]^2$

The forward reaction is exothermic. The forward reaction is favoured, and the equilibrium constant increases as the temperature decreases. Alternatively as temperature increases, the equilibrium constant decreases.
The relationship $K = [O_2]^3/[O_3]^2 = \{[O_2]/[O_3]\}^{1.5}$ shows that the increase in the value of K is not linear.
Assuming Y represents K and X represents T, alternative A best represents the relationship for this equilibrium – as X (T) increases, Y (K) decreases.

Q5. **D** The only change that leads to a change in the value of the equilibrium constant for a specific equilibrium is a change in temperature. So a **change in pressure at constant temperature has no effect** on the K value. This is best represented by alternative D where Y (K) stays constant as X (pressure) increases.

Q6. **B** The reactions occurring are:

$\mathbf{2}Mg + \mathbf{O_2} \rightarrow 2MgO$
$MgO + \mathbf{H_2O} \rightarrow Mg(OH)_2$
$Mg(OH)_2 + \mathbf{CO_2} \rightarrow MgCO_3 + H_2O$
$MgCO_3 + \mathbf{2HCl} \rightarrow MgCl_2 + H_2O$
$MgCl_2 \rightarrow Mg + Cl_2$ **Electrolysis**
Four other reactants required: O_2, H_2O, CO_2, HCl

Q7. **B** Assume that all the energy absorbed by the water is the energy ‘lost’ from the heated metal sample.

Energy into water $= 4.18\ J\ g^{-1}\ °C^{-1} \times 200\ g \times (29.0\text{-}22.6)$
$= 5.35x10^3\ J$
Energy lost from metal $= SHC \times 100\ g \times (100 - 29.0)\ °C$
$5.35x10^{-3} = SHC \times 7100$
$SHC = 5.35x10^3 / 7100$
$= \mathbf{0.754}\ J\ g^{-1}\ °C^{-1}$

Q8. C Atoms or molecules absorb visible and ultraviolet light if the wavelengths correspond to exact difference between electronic energy levels. Both visible and ultraviolet light contain wavelengths suitable for iodine but only ultraviolet radiation contains wavelengths suitable for nitrogen.
Transitions between vibrational energy levels require wavelengths present in infrared radiation.
Transitions between nuclear spin energy levels require wavelengths present in radiowave radiation.
It is true that breaking the triple bond between N atoms in nitrogen molecules requires more energy than the single bond between I atoms in iodine molecules but that is not the reason for different visible light absorption behaviour.

Q9. B The change at t_1 causes an immediate increase in the concentration of both species present in the equilibrium mixture. The most likely cause of such a change is a **decrease in the volume of the container.** For a gaseous system, this will also cause the pressure to increase and the system will move to compensate by favouring the side with fewer particles, i.e. $2O_3$. So the top graph would be the $[O_2]$ and the bottom graph the $[O_3]$. As the system returns to equilibrium the $[O_2]$ decreases, but not back to its original value, whilst the $[O_3]$ increases.

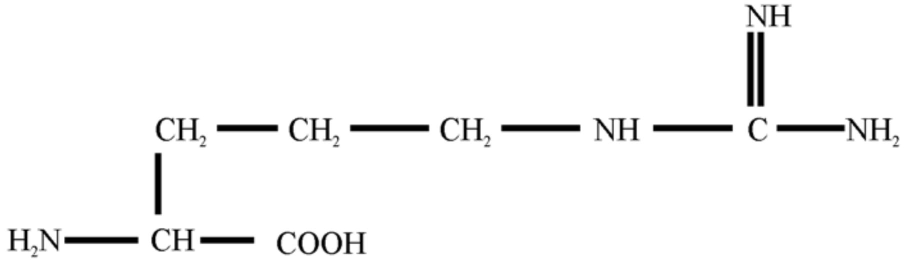
Q10. A The reaction between potassium and water can be deduced from the electrochemical series.
$2\mathbf{H_2O}(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ -0.83 V
$K^+(aq) + e^- \rightarrow \mathbf{K}(s)$ -2.93 V
Hence the reaction occurring is
$2K(s) + 2H_2O(l) \rightarrow 2K^+(aq) + H_2(g) + 2OH^-$
The skimming and spinning of the potassium can be attributed to the production of $H_2(g)$ at the potassium-water interface. Heat generated in the exothermic reaction is sufficient to initiate combustion of $H_2(g)$. This in turn generates enough energy to excite the potassium atoms which release energy as lilac light as electrons return to lower energy levels.
Consider the alternatives

A. **Best alternative**: the flame is due to the combustion of H_2; $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
B. **Incorrect**, the lilac flame colour is characteristic of potassium, but is due to the excited electrons dropping back to lower energy levels.
C. **Incorrect**, since $OH^-(aq)$ is produced, the pH increases.
D. Potassium is, according to the electrochemical series, a stronger reductant **than** water – however in the reaction water is the oxidant - but this is not an adequate full explanation of the observations.

Q11. B Total peak area = 32.4 + 47.1 + 40.6 + 27.3
= 147.4
% Norgestrel = [(Peak Area of Norgestrel) / Total Peak Area] × 100
= [40.6 / 147.4] × 100
= **27.5 %**

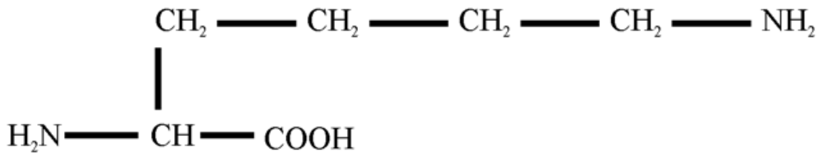
Q12. **D** The structures of the amino acids are given in ***Table 8 of the Data Book***.

Arginine



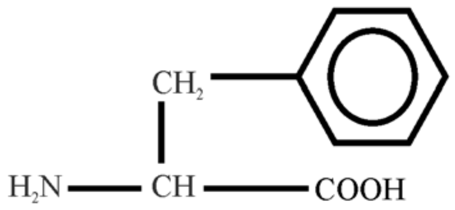
$H_2N-CH(COOH)-CH_2-CH_2-CH_2-NH-C(=NH)-NH_2$

Lysine



$H_2N-CH(COOH)-CH_2-CH_2-CH_2-CH_2-NH_2$

Phenylalanine



Since all molecules are amino acids, the determining factor in their separation will be the relative polarity of the side chains. Phenylalanine, the least polar, will be most strongly attracted to the non-polar (hydrophobic) stationary phase and will have the highest retention time. Arginine, the most polar, will be most strongly attracted to the polar (hydrophilic) mobile phase and will have the lowest retention time.
The order of elution will be **arginine**, followed by **lysine**, followed by **phenylalanine**.

Q13. **C** Absorbance 0.260 → $c(Pb^{2+})$ = 0.400 ppb
= 0.400 $\mu g\ L^{-1}$
All the Pb^{2+} from 2.5 g milk powder ends up in 200 mL of solution
$m(Pb^{2+})$ in 2.5 g milk powder = $m(Pb^{2+})$ in 200 mL
= $(0.400 / 1000) \times 200$
= 0.080 μg
$m(Pb^{2+})$ in 1 g milk powder = 0.080 / 2.5
= 0.032 μg
Data Book Table 4 → 1 μg = 1000 ng
$c(Pb^{2+})$ in milk powder = $0.032\ \mu g\ g^{-1} \times 1000\ ng\ \mu g^{-1}$
= **32 ng g^{-1}**
Hence the correct alternative is C since 32 is closest to 30.

Q14. B Investigations A and B produce twice as much CO_2 as C and D. Since the $MgCO_3$ is in excess and volume of HNO_3 used is the same in all four, the $c(HNO_3)$ must have been higher – twice as high in fact – for investigations A and B.

The fact that investigation A and C occur at faster initial rates than investigations C and D respectively could be due to

- the use of catalysts in investigations A and C.
- the use of smaller $MgCO_3$ particles in A and C.
- the use of higher temperatures in A and C.

All three of these would increase the proportion – catalyst and higher temperature, or number – smaller particles, of successful collisions and so produce a faster reaction rate.

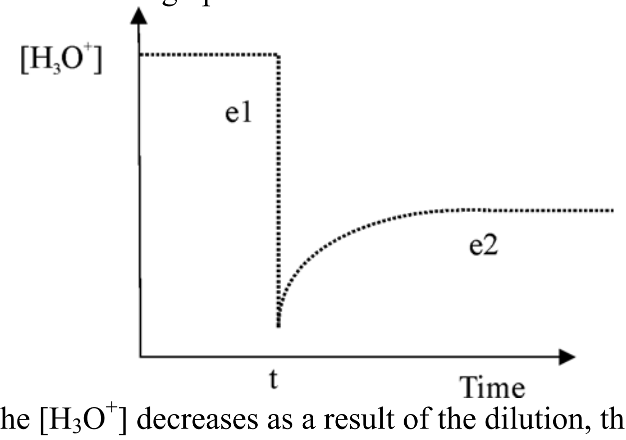
Q15. A Propanoic acid is a weak acid and in aqueous solution, is partially ionised according to the equilibrium.

$CH_3CH_2COOH(aq) + H_2O(l) \rightleftharpoons CH_3CH_2COO^-(aq) + H_3O^+(aq)$; $K_a = 1.3\times10^{-5}$

When 20 mL of **0.10 M $CH_3CH_2COOH(aq)$** is **diluted to 100 mL**, the overall concentration decreases and the **position of equilibrium shifts to the right to produce more particles in the larger volume.**

The **number of H_3O^+ increases** as the system shifts to the right.

Initially the **$[H_3O^+]$ decreases** due to the volume increase, then increases as the forward reaction is favoured. However when equilibrium is re-established, the **$[H_3O^+]$ is still lower than before the dilution.** This is represented in the concentration-time graph.



Since the $[H_3O^+]$ decreases as a result of the dilution, the **pH increases**. As the system shifts right to compensate for the volume increase, the **percentage ionisation increases**.

Q16. D The components of the half-cell indicate it is an $Sn^{4+}(aq)$ / $Sn^{2+}(aq)$ half-cell, so the electrode material must be a conducting element which does not react with either $Sn^{4+}(aq)$ or $Sn^{2+}(aq)$, C (graphite) and Pt are elements commonly used where inert electrodes are required.

According to the electrochemical series half-equations

$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$ +0.80 V

$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$ +0.15 V

$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$ -0.14 V

silver could be used because being a reductant higher on the electrochemical series, it will not react with the oxidant $Sn^{4+}(aq)$ in the half-cell.

Tin could not be used because, as a reductant lower on the electrochemical series, it could react with the oxidant $Sn^{4+}(aq)$ according to

$Sn(s) + Sn^{4+}(aq) \rightarrow 2Sn^{2+}(aq)$

Q17. B According to the electrochemical series, the only half-cell that can be combined with $Sn^{4+}(aq)/Sn^{2+}(aq)$ to provide a potential difference of 1.53 V is $Au^+(aq)$ / $Au(s)$

$\mathbf{Au^+}(aq) + e^- \rightleftharpoons Au(s)$ +1.68 V

$Sn^{4+}(aq) + 2e^- \rightleftharpoons \mathbf{Sn^{2+}}(aq)$ +0.15 V

$E_{cell} = 1.68 - 0.15$

$= 1.53$ V

The reactions occurring at the electrodes are

X: $Sn^{2+}(aq) \rightarrow Sn^{4+}(aq) + 2e^-$ ... Anode (-)

Z: $Au^+(aq) + e^- \rightarrow Au(s)$ .... Cathode (+)

Consider the alternatives

A. Incorrect, reduction is occurring at Z
B. **Correct**, cations move towards the cathode
C. Incorrect, X is the anode, Z is the cathode
D. Incorrect, $Sn^{2+}(aq) \rightarrow Sn^{4+}(aq) + 2e^-$

Q18. B $n(CH_4)$ produced $= 2.45\text{x}10^5$ L / 24.5 L mol^{-1}

$= 1.00\text{x}10^4$ mol

Table 13 Data Book → $\Delta H_c(CH_4) = -889$ kJ mol^{-1}

Energy available from methane $= 1.00 \times 10^4$ mol $\times$ 889 kJ mol^{-1}

$= 8.89 \times 10^6$ kJ

$= 8.89 \times 10^3$ MJ

Volume of heating oil saved = Energy from methane/ Energy per L oil

$= 8.89 \times 10^3$ MJ / 38.5 MJ L^{-1}

= **231 L**

Q19. A The calorimeter constant is the energy needed to raise the temperature of the entire calorimeter contents (water and hardware) by 1°C (1 K).

Specific heat capacity of water = 4.18 J g^{-1} °C^{-1}

Energy to raise 600 mL water by 1 °C = 4.18 J g^{-1} °C^{-1} × 600 g × 1 °C

= 2508 J

Energy needed to raise hardware by 1 °C = 785 J

Calorimeter constant = 2508 + 785

$= 3.29 \times 10^3$ J °C^{-1}

= **3.29 kJ °C^{-1}**

Q20. C Use the data to determine the molar mass of M and use ***Table 1 Data Book***.

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

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

$= 2.50 \times 35.0x60 / 96500$

$= 0.0544$ mol

$n(M) = ½ \times n(e^-)$

$= ½ \times 0.0544$

$= 0.0272$ mol

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

$= 3.06 / 0.0272$

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

Cadmium - Cd

Q21. B Since the ester groups form from condensation reactions between the hydroxyl, -OH, and carboxyl, -COOH functional groups, the reactants, identifiable from ***Tables 9 and 10 in the Data Book***, were

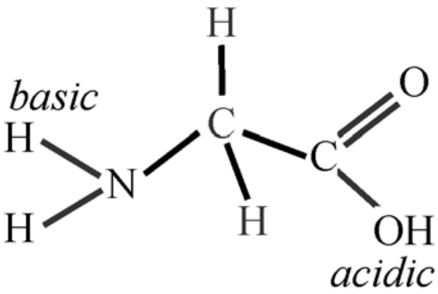
$CH_2OHCHOHCH_2OH$ – glycerol

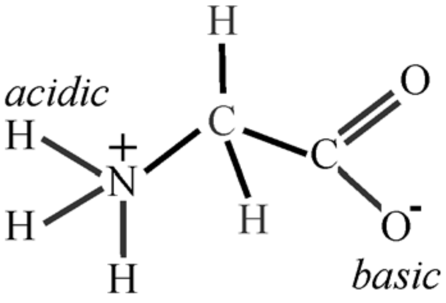
$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$, i.e. $C_{17}H_{33}COOH$ – oleic acid

$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH\ (CH_2)_7COOH$ – linoleic acid.

Stearic acid, $C_{17}H_{35}COOH$ was not one of the reactants. It is a saturated fatty acid.

Q22. C





In zwitterion formation from amino acid molecules, the acid –COOH group is converted to its conjugate base the $–COO^-$ group and the basic $–NH_2$ group is converted to its conjugate acid $–NH_3^+$.

Q23. B Titrated with $H_2SO_4(aq)$ implies $Ba(OH)_2(aq)$ was in the titration flask and $H_2SO_4(aq)$ was added from the burette.

Beyond the equivalence point – 30 mL – **$H_2SO_4(aq)$ was in excess**.

Equation for reaction is $Ba(OH)_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) + 2H_2O(l)$ so $Ba^{2+}(aq)$ ions do not remain in solution but are precipitated out as $BaSO_4$.

$V(H_2SO_4)$ added at equivalence point = 30 mL

$n(H_2SO_4)$ added $= 0.10 \times 30 \text{x} 10^{-3}$

$= 3.0 \text{x} 10^{-3}$ mol

$n(Ba(OH)_2) = n(H_2SO_4) = 3.0 \text{x} 10^{-3}$ mol

$c(Ba(OH)_2) = 3.0 \text{x} 10^{-3}$ mol / $25.0 \text{x} 10^{-3}$

= **0.12 M**

$[OH^-] = 2 \times [Ba(OH)_2] = 0.24$ M

$[H_3O^+] = 10^{-14} / 0.24$

$= 4.2 \times 10^{-14}$

$pH = -\log(4.2 \times 10^{-14})$

$= 13.4$

Q24. A The equation for the titration reaction is

$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COO^-(aq) + Na^+(aq) + H_2O(l)$

The equivalence point is where exactly the same $n(NaOH)$ has been added as the $n(CH_3COOH)$ in the titration flask. So the only species, other than H_2O, present in significant quantity in the reaction flask are $CH_3COO^-(aq)$ and $Na^+(aq)$. Since **$CH_3COO^-(aq)$** is the conjugate base of the weak acid CH_3COOH, it is a **weak base** and **makes the pH of the solution at the equivalence point greater than 7.**

Q25. D Electrical energy = *VIt*

$V = 2.75$ V

$I = 85.6\ \mu A = 85.6 \times 10^{-6}$ A

$t = 10.0$ years

$= 10.0 \times 365 \times 24 \times 60 \times 60$ seconds

$= 3.15 \times 10^{8}$ s

Electrical energy $= 2.75 \times 85.6 \times 10^{-6} \times 3.15 \times 10^{8}$

$= 7.42 \times 10^{4}$ J

$= 74.2$ kJ

Q26. C The titration curve is characteristic of the titration of a strong acid by a strong base with the equivalence point at pH 7.0 Sulfuric acid, $H_2SO_4(aq)$, hydrochloric acid, $HCl(aq)$ and nitric acid, $HNO_3(aq)$ are all strong acids. Sulfuric acid is diprotic whilst the other two are monoprotic. Ethanoic acid is a weak acid. The pH of the solution in the titration flask prior to the addition of the base was, according to the titration curve, 1.5

$[H_3O^+] = 10^{-pH} = 10^{-1.5}$

$= 0.032$ M

Hence the solution in the flask was most likely **0.030 M $HNO_3(aq)$.**

Q27. C

$Na_2CO_3(aq) \rightarrow 2Na^+(aq) + CO_3^{2-}(aq)$
$n(Na^{2+})$ present in 3.00 L $= 0.0430 \times 3.00$
$= 0.129$ mol
$n(Na_2CO_3)$ required $= \frac{1}{2} \times n(Na^+)$
$= \frac{1}{2} \times 0.129$
$= 0.0645$ mol
$m(Na_2CO_3)$ used $= 0.0645 \times 106.0$
= **6.84 g**

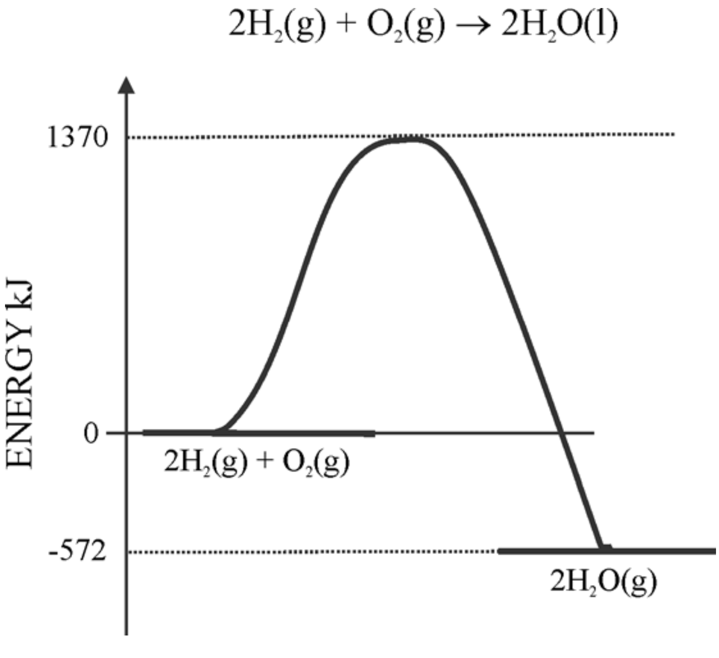
Q28. B

Reaction Quotient (Concentration Fraction) $= [NO_2]^2 / \{[NO]^2 \times [O_2]\}$
$= 0.10^2 / (0.10^2 \times 0.010)$
= 100

Since CF (100) < K_c ($3x10^6$), the system is not at equilibrium and forward reaction (left to right) will be favoured until equilibrium is established.
As the system moves to equilibrium, the rate of the forward reaction will be greater than the rate of reverse reaction.

Q29. D

The energy profile shown does not include the enthalpy change for the reaction. This can be determined from $\Delta H_c(H_2)$ given in
Table 13 of the Data Book.
$\Delta H_c(H_2) = -286$ kJ mol^{-1}.
From this it can be deduced that for
$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$, $\Delta H = -286$ kJ mol^{-1}
and consequently for
$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$, $\Delta H = -572$ kJ mol^{-1}
This can be incorporated in energy profile for the combustion of 2 mol H_2.



Energy released when bonds in 2 mol of H_2O molecules form
$= 1370 - (-572)$
= **1942 kJ**

Q30. A

Methane is produced in landfill by bacterial (microbial) decomposition of plant and other biomaterial in the garbage in the landfill. Hence it is, in this context, classified as a biofuel.

SECTION B - Short Answer (Answers)

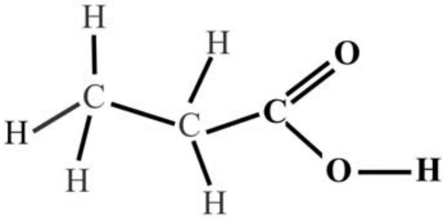
Question 1 (17 marks)

a. Molar mass / relative molecular mass – from the peak with the highest *m*/*z* ratio.
M(F) = 74 g mol^{-1} *or* M_r(F) = 74❶

b. There are **three different signals** – **one for each hydrogen environment**. ❶
The **doublet**, at $\delta = 1.2$ ppm, is for hydrogens on the molecule which have **one neighbouring hydrogen**, i.e. **only one hydrogen bonded to an adjacent carbon**. ❶
(This single hydrogen splits the signal for its neighbouring hydrogens into n+1, i.e. 2 peaks).

c. The **absorption** centred around **3350 cm^{-1}** indicates the presence of the hydroxyl, **O-H (alcohol)** functional group – absorption band 3200 – 3550 cm^{-1};
Table 7 of the Data Book. ❶
The absorptions around 2950 cm-1 (C-H) and 1100 cm-1 (C-O) would also be expected to be seen on the spectrum of an alcohol.

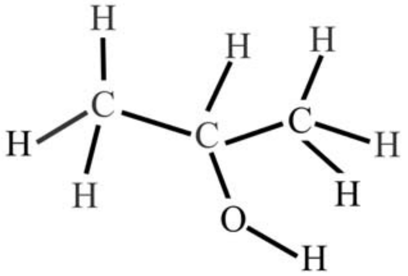
d. Compound F must be an acid as it reacts with sodium carbonate to produce CO_2.
The carboxylic acid with molar mass of 74 is propanoic acid CH_3CH_2COOH.



❶

e. Compound E is converted to compound F in the pathway, hence compound E is a primary alcohol with three C atoms, i.e. 1-propanol

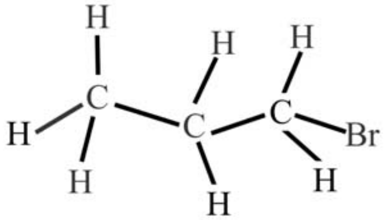
- **i.** **$CH_3CH_2CH_2OH$** ❶
- **ii.** Since compounds B and E are structural isomers with the same functional group, **B is 2-propanol**, i.e.



❶

- **iii.** Compound E, 1-propanol, is oxidised to compound F, propanoic acid. This requires reaction with an oxidant that is reduced. Acidified dichromate solution ($Cr_2O_7^{2-}$(aq)/H^+) is commonly used.
  In the redox reaction $CH_3CH_2CH_2OH$ is oxidised to CH_3CH_2COOH and $Cr_2O_7^{2-}$(aq) is reduced to Cr^{3+}(aq). The half-equations are
  Oxidation: **$CH_3CH_2CH_2OH(l) + H_2O(l) \rightarrow CH_3CH_2COOH(l) + 4H^+(aq) + 4e^-$** ❶
  Reduction: **$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$** ❶
- **iv.** Only primary alcohols, those with the hydroxyl (-OH) group bonded to C-1, can be oxidised to acids.
  2-propanol has the hydroxyl (-OH) group bonded to C-2. ❶

f. **i.**

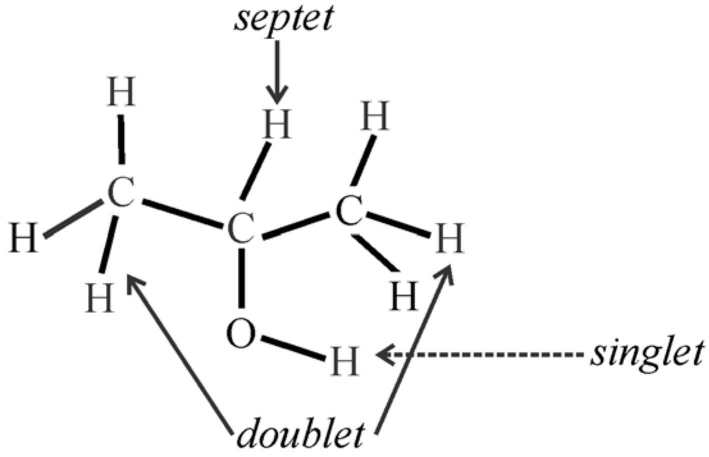


❶

The **three peaks** on the ^{13}C NMR spectrum are reflective of the **three different carbon environments** in each molecule. ❶

ii. **$CH_3CH_2CH_3(g)+Br_2(g) \rightarrow CH_3CH_2CH_2Br(g)+HBr(g)$** ❶

g. **Propene** ❶ – different number of carbon atoms to compound C which is propane.
$CH_3CH{=}CH_2(g) + H_2O(l) \rightarrow CH_3CHOHCH_3(l)$ ❶
This is also consistent with the ^{1}H NMR spectrum of compound B.



h. **i.** **ethyl propanoate** ❶

Carboxylic acids and esters with the same number of C atoms are structural isomers and so have the same molar mass. Since pentanoic acid has 5 C atoms, compound G must have 5 C atoms. Since F is propanoic acid, CH_3CH_2COOH, compound G must be an alcohol with 2 C atoms, i.e. ethanol. Acids and alcohols react to produce esters, in this case ethyl propanoate.

ii. **$CH_3CH_2COOH(l) + CH_3CH_2OH(l) \rightarrow CH_3CH_2COOCH_2CH_3(l) + H_2O(l)$** ❶

Question 2 (9 marks)

a. **$C(s) + O_2(g) \rightarrow CO_2(g)$, $\Delta H = -394\ kJ\ mol^{-1}$** ❶ **….** *molar enthalpy of combustion from* ***Table 13 of Data Book***.

b. **$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$, $\Delta H = -10928\ kJ\ mol^{-1}$** *or*
$C_8H_{18}(l) + 12.5O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$, $\Delta H = -5464\ kJ\ mol^{-1}$ ❶

c. Requires manipulation of
$2C(s) + O_2(g) \rightarrow 2CO(g)$ $\Delta H = -221\ kJ\ mol^{-1}$ ……..**A**
$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -394\ kJ\ mol^{-1}$ ……..**B**
$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$, $\Delta H = -10928\ kJ\ mol^{-1}$ …..…**C**
to establish $\underline{2C_8H_{18}(l) + 17O_2(g) \rightarrow 16CO(g) + 18H_2O(l),\ \Delta H = ?}$
This requires using equations **A** and **B** to introduce CO into and remove CO_2 from equation **C.** This can be achieved by combining **C** with **16 times** the **reverse** of **B** and **8 times A**, i.e.

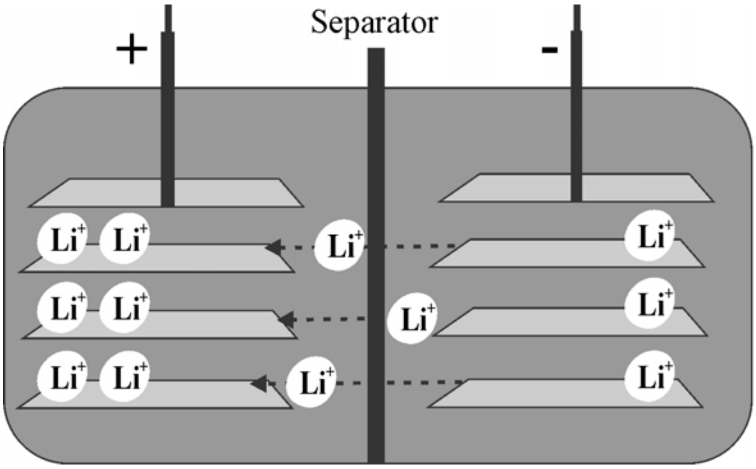
$2C_8H_{18}(l) + 25O_2(g) \rightarrow \underline{16CO_2}(g) + 18H_2O(l)$, $\Delta H = -\ 10928\ kJ\ mol^{-1}$**…………..C**
$\underline{16CO_2}(g) \rightarrow \mathit{16C(s)} + 16O_2(g)$, $\Delta H = 16 \times +394 = 6304\ kJ\ mol^{-1}$**…..Reverse** of **B×16** ❶
$\mathit{16C(s)} + 8O_2(g) \rightarrow 16CO(g)$ $\Delta H = 8 \times -221 = -1768\ kJ\ mol^{-1}$ **…..Multiply A×8** ❶
Add these three thermochemical equations together.
$2C_8H_{18}(l) + 25O_2(g) + \underline{16CO_2}(g) + \mathit{16C(s)} + 8O_2(g) \rightarrow \underline{16CO_2}(g) + 18H_2O(l) + \mathit{16C(s)} + 16O_2(g) + 16CO(g)$
$\Delta H = (-10928\ kJ\ mol^{-1}) + (+6304\ kJ\ mol^{-1}) + (-1768\ kJ\ mol^{-1})$

$2C_8H_{18}(l) + 17O_2(g) \rightarrow 16CO(g) + 18H_2O(l)$; **$\underline{\Delta H = -6392\ kJ\ mol^{-1}}$** ❶

d. $n(CO)$ collected $= pV / RT$ $= 102.3 \times 100 / (8.31 \times 308)$
$= 4.00$ mol ❶
$n(C_8H_{18})$ reacting $= n(CO) / 8 = 4.00 / 8$
$= 0.500$ mol
$m(C_8H_{18})$ reacting $= 0.500 \times 114.0$
$= 57.0$ g ❶
$V(C_8H_{18})$ reacting $= m(C_8H_{18}) / d(C_8H_{18})$
$= 57.0\ g / 0.703\ g\ mL^{-1}$
$= 81.1$ mL ❶
% C_8H_{18} reacting $= [V(C_8H_{18})$ reacting $/ V(C_8H_{18})$ in sample$] \times 100$
$= (81.1 / 200) \times 100$
= 40.5 % ❶

Question 3 (18 marks)

a. **i.** ❶



Cations move towards the cathode which is discharging the positive electrode.

ii. ANODE: $Li_xC_6(s) \rightarrow C_6(s) + xLi^+(aq) + xe^-$ ❶

CATHODE: $Li_{1-x}MnO_2(s) + xLi^+(aq) + xe^- \rightarrow LiMnO_2(s)$ ❶

iii. $C_6(s) + xLi^+(aq) + xe^- \rightarrow Li_xC_6(s)$ ❶

b. **i.** Energy produced = 7.0×3.6

= 25.2 MJ ❶

$\Delta H_c(C) = -394$ kJ mol^{-1}

n(C) required = Energy produced / Energy per mol C

= 25.2×10^3 / 394

= 64 mol ❶

Since the power station is only 35 per cent efficient 64 mol is only 35 % of the amount of carbon actually used.

64 = 0.35 × n(C) used → n(C) used = 64 / 0.35

= 183 mol ❶

m(coal used) = m(C) used = 183 × 12.0

= 2.2×10^3 g

= **2.2 kg**. ❶

ii. **Cheaper electricity** since less coal would need to be used to supply the required energy. ❶

Lowered **environmental impact** because less CO_2 would be produced. ❶

c. No need to pay for electricity used in recharging ❶

No significant environmental impact since energy is not obtained from a coal fired power station.

Effective energy storage at night and in times of limited sunlight.

d. **i.** $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ ❶

ii. $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ ❶

e. **i.** $\mathbf{C_{13}H_{11}N_3}$ ❶

ii. Each nucleotide in the **primary structure of DNA** contains **one** of the four **nitrogen bases** (G, C, A, T) **bonded to deoxyribose through a C-N covalent bond**. ❶

The secondary structure of DNA is maintained by **hydrogen bonds between nitrogen bases** on adjacent strands of the double helix. ❶ The bases pairs formed **are guanine-cytosine (G-C)** with **three sites at which hydrogen bonding occurs** and **adenine-thymine (A-T)** with **two sites at which hydrogen bonding occurs**. ❶

iii. The presence of the **amino (NH_2) groups** means that the **H atoms in those groups** can from **hydrogen bonds with available lone pairs on accessible N and O atoms on the nitrogen bases**. ❶

Question 4 (24 marks)

a. m(I) in 500g iodised salt =(0.0055 / 100) × 500
= 0.0275 g
n(I in 500 g iodised salt) = 0.0275 g / 126.9 g mol^{-1}
= 2.17×10^{-4} mol ❶
$n(KIO_3)$ in 500 g iodised salt = 2.17×10^{-4} mol ❶
$m(KIO_3)$ in 500 g iodised salt = $2.17 \times 10^{-4} \times 214.0$
= 4.6×10^{-2} g
= **46 mg** ❶

b. **i.** $Pb^{2+}(aq) + 2I^{-}(aq) \rightarrow PbI_2(s)$ ❶

ii. The precipitate is dried, by gentle heating, until all water has been evaporated as indicated by **mass not changing after further drying**.
If the mass of precipitate was based on the first drying it would be higher than its true value and the **iodide content would be calculated to be higher than its true value.** ❶

iii. $m(PbI_2)$ produced = 1.698 – 1.462
= 0.236 g
$n(PbI_2)$ produced = 0.236 / 461.0
= $5.12\text{x}10^{-4}$ mol ❶
All the iodine (present as I^-) in the 0.425 g tablet was precipitated as PbI_2
n(I) = 2 × $n(PbI_2)$
= $2 \times 5.12 \times 10^{-4}$
= $1.02\text{x}10^{-3}$ mol
m(I) = $1.02\text{x}10^{-3} \times 126.9$
= 0.130 g ❶
% iodine in tablet = [m(I) / m(tablet)] × 100
= (0.130 / 0.425) × 100
= **30.6 %** ❶

c. **i.** Starch, glycogen and ‘simple carbohydrates’ all have **differences in** their **structures**, with **starch and glycogen both condensation polymers** of glucose. The observations suggest that components of **Lugol’s solution interact with complex carbohydrates such as starch and glycogen but not simple carbohydrates**, e.g. monosaccharides and disaccharides. ❶

ii. **Hydrolysis of starch** during digestion **produces glucose**. ❶ Most of this **glucose is converted to glycogen by condensation polymerisation.** ❶

iii. To maintain a steady supply of energy for body process, stored **glycogen is converted to glucose by hydrolysis**. Glucose is then oxidised, and energy released, during respiration. ❶
The thermochemical equation for respiration is
$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$, $\Delta H = -2816$ kJ mol^{-1}
(ΔH, ***Data Book Table 13).*** ❶

d. **i.** Oxidation: **$3I^-(aq) \rightarrow I_3^-(aq) + 2e^-$** ❶

Reduction: **$3IO_3^-(aq) + 18H^+(aq) + 16e^- \rightarrow I_3^-(aq) + 9H_2O(l)$** ❶

Equalise *electrons by multiplying oxidation half-equation by 8*

Oxidation: $24I^-(aq) \rightarrow 8\ I_3^-(aq) + 16e^-$ then *add it to the reduction half-equation to produce the overall equation for the reaction.*

Overall: $24I^-(aq) + 3IO_3^-(aq) + 18H^+(aq) \rightarrow 9I_3^-(aq) + 9H_2O(l)$ which simplifies to

$8I^-(aq) + IO_3^-(aq) + 6H^+(aq) \rightarrow 3I_3^-(aq) + 3H_2O(l)$ ❶

ii. $2S_2O_3^{2-}(aq) + I_3^-(aq) \rightarrow S_4O_6^{2-}(aq) + 3I^-(aq)$

Assume all the IO_3^- had been reduced to $I_3^-(aq)$ by the excess I^-.

$n(IO_3^-) = n(KIO_3) = 0.0120 \times 25.00x10^{-3}$
$= 3.00x10^{-4}$ mol

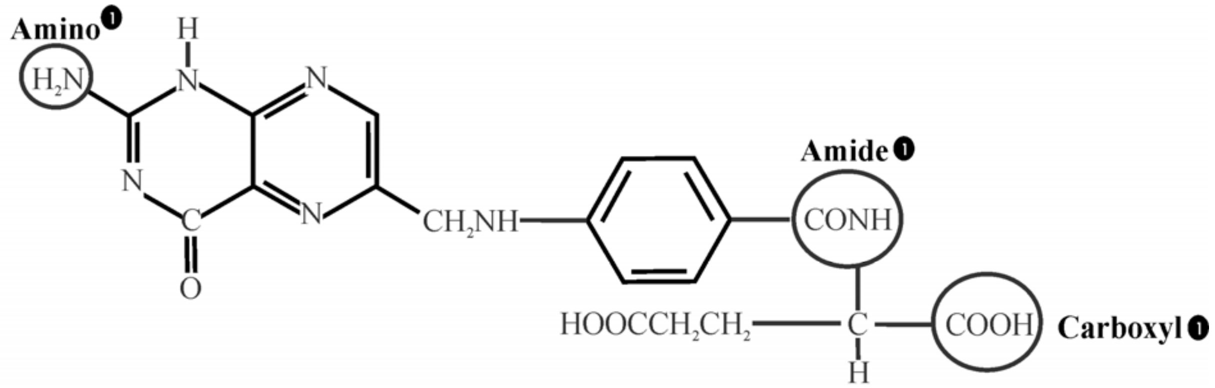
$n(I_3^-) = 3 \times n(IO_3^-)$
$= 3 \times 3.00x10^{-4}$
$= 9.00x10^{-4}$ mol ❶

$n(S_2O_3^{2-}) = 2 \times n(I_3^-)$
$= 2 \times 9.00x10^{-4}$
$= 1.80 \times 10^{-3}$ mol ❶

$c(S_2O_3^{2-}) = 1.80 \times 10^{-3} / 35.40x10^{-3}$
$= 0.0508$ M

Since $n(Na_2S_2O_3) = n(S_2O_3^{2-})$ then **$c(Na_2S_2O_3)$ = 0.0508 M** ❶

e. **i.**



ii. ***$C_{19}H_{19}N_7O_6$***

The structure of the folic acid molecule **shows multiple sites (NH_2, NH, CONH, COOH and others) where hydrogen bonds can form with water** suggesting it should be quite soluble. However this is balanced against the **large size** of the molecules. ❶

In 1.0 M NaOH(aq), the carboxyl groups**, -COOH become deprotonated to –COO⁻** (folic acid is converted to folate). This allows for ion-dipole bonding with water molecules. Since this **ion-dipole bonding is stronger than hydrogen bonding this leads to increased solubility.** ❶

Question 5 (18 marks)

a. In **both processes** there are more moles of products (particles) than reactants so the **yield will be higher at lower pressure**. This is because lowering the pressure will cause the system to partially oppose this change by **favouring the side with more moles (particles**). ❶
From a temperature viewpoint, since **SMR is endothermic,** the **yield of syngas** will **increase as temperature increases** whereas since **CPOX is exothermic** the yield of syngas will **increase as temperature decreases. ❶**
However in the CPOX method, **low temperature** will **lower reaction rate** so the **conditions used** will be those that provide an **economic balance between yield and reaction rate**. ❶

b. **Catalysts speed up the rate of reaction** and so **allow the system to get to equilibrium more quickly** but **do not affect equilibrium yield**. ❶However in the **exothermic CPOX system,** there is a **rate-yield conflict** where the use of **low temperatures decreases the rate of reaction**. Using a **catalyst enables a good reaction rate to be maintained at the lower temperatures used to increase syngas yield**. ❶ *NB It is the lower temperature that is the cause of the increased yield NOT the catalyst.*

c. The **honeycomb structure increases the surface area of the catalyst**. Since the **catalytic effect depends on contact between the reactants and the catalyst surface**, ❶ there will be **more collisions between reactants and the catalyst surface, lowering the activation energy so increasing the proportion of successful collisions** ❶ (those with energy greater than the activation energy) and **giving a faster rate of reaction**.

d. **i.** $K_c = \{[CO]^3[H_2]^3[H_2O]\}/\{[CH_4]^2[O_2][CO_2]\}$. ❶

ii. Syngas contains CO and H_2;
the mass of syngas produced = $m(CO)$ produced + $m(H_2)$ produced
According to the equation $n(CO) = n(H_2)$
According to the equation production of 3 mol CO →releases 31 kJ energy
Total energy released is 310 MJ, so
3 mol CO → 31 kJ
'×' mol CO → $310 \text{x} 10^3$ kJ
'×' / 3 = $310 \times 10^3 / 31$
'×' = $3 \times (310 \times 10^3 / 31)$
= 3.0×10^4 mol
$n(CO)$ produced = 3.0×10^4 mol ❶
$n(H_2)$ produced = 3.0×10^4 mol
$m(\text{syngas}) = m(CO) + m(H_2)$ ❶
= $(3.0 \times 10^4 \times 28.0) + (3.0 \times 10^4 \times 2.0)$
= $8.4 \times 10^5 + 6.0 \times 10^4$
= 9.0×10^5 g
= $9.0 \times 10^5 / 10^6$
= 0.90 tonne ❶

e. **i.** $CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$ ❶

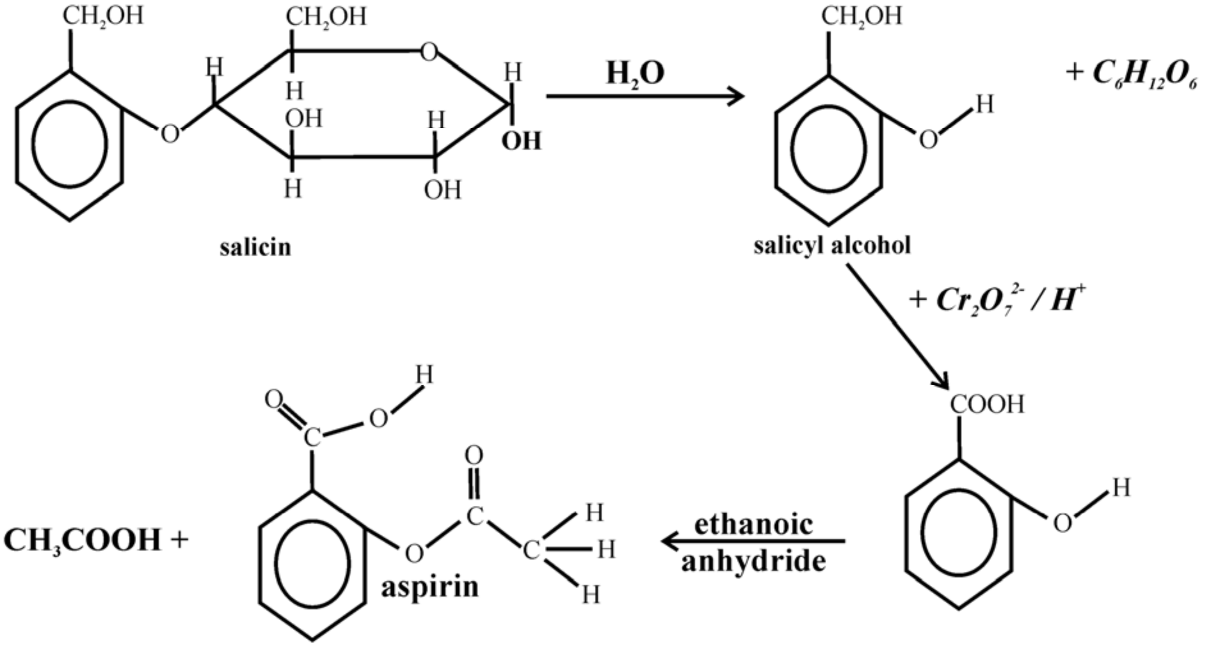
ii. **CPOX** in which the syngas produced has **CO and H_2 in the ratio 1:2,** i.e. the ratio **needed for methanol production.** ❶

iii. ***Table 13. Of the Data Book*** gives molar enthalpies of combustion of H_2 (-286 kJ mol^{-1}) and CH_3OH (-725 kJ mol^{-1})
If the **reactants (1 mol CO and 2 mol H_2) undergo combustion**:
Total **energy released** $= 293.5 + (2 \times 286)$
$=$ **865.5 kJ**. ❶
Energy released in the combustion of **1 mol CH_3OH** = **725 kJ**. ❶
Difference in energies released $= 865.5 - 725$
$= 140.5$ **kJ** ❶
On combustion, 1 mol CH_3OH releases 140.5 kJ less than is released from the combustion of 2 mol H_2 and 1 mol CO, hence the production of CH_3OH syngas must be **exothermic** with **$\Delta H = -141$ kJ mol^{-1}**.
The thermochemical equation for the reaction is
$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$, **$\Delta H = -142$ kJ mol^{-1}**

iv. $\Delta H_c(CH_3OH) = -725$ kJ mol^{-1} (***Table 13 of Data Book***).
$CH_3OH(l) + 1.5O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$; $\Delta H = -725$ kJ mol^{-1} ❶ *or*
$2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(l)$; $\Delta H = 2 \times -725 = -1450$ kJ mol^{-1}

v. In a fuel cell, oxidation occurs at the negative electrode.
$CH_3OH(l) + H_2O(l) \rightarrow CO_2(g) + 6H^+(aq) + 6e^-$ ❶

Question 6 (10 marks)



a. **Aspirin** ❶
b. A – **H_2O**, B – **$C_6H_{12}O_6$** ❶❶
c. **$Cr_2O_7^{2-}$**(aq) / **H^+**(aq) ❶
d. **Ethanoic anhydride** ❶
e. **Hydrolysis, oxidation (redox), condensation (esterification)** ❶
f. Molecular formula of F (aspirin) is $C_9H_8O_4$.
$M(C_9H_8O_4) = 180.0 \text{ g mol}^{-1}$
n(aspirin) produced $= 2.15 / 180.0$
$= 1.19 \times 10^{-2}$ mol
n(salicin) converted to aspirin $= n$(aspirin)
$= 1.19 \times 10^{-2}$ mol ❶
This is 43 % of the total n(salicin) used.
$1.19\text{x}10^{-2} = 0.43 \times n$(salicin) used
n(salicin) used $= 1.19 \times 10^{-2} / 0.43$
$= 2.78 \times 10^{-2}$ mol ❶
Molecular formula of salicin is $C_{13}H_{18}O_7$
$M(C_{13}H_{18}O_7) = 286.0 \text{ g mol}^{-1}$ ❶
m(salicin) used $= 2.78 \times 10^{-2} \times 286.0$
= **7.94 g** ❶

Question 7 (7 marks)

The products of the electrolysis of water and 1 M LiCl(aq)can be deduced from the electrochemical series

$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	*1.36 V*
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	*1.23 V*
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	*-0.83 V*
$Li^+(aq) + e^- \rightarrow Li(s)$	*-3.02 V*

utilising the strongest oxidant reacts with strongest reductant principle.
In Li *Cl(l) the only possible reactions are the reduction of* Li $^+$*(l) at the cathode and the oxidation of* Cl^-*(l) at the anode.*
In electrolysis, oxidation occurs at the (+) electrode and reduction at the (-)

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

ii. $\mathbf{Li^+(l) + e^- \rightarrow Li(l)}$ ❶

iii. **Cathode** (-) $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$.
pH increases as $[OH^-]$ increases ❶

b. In **1 M LiCl(aq) water is oxidised and reduced** because in both cases it is the strongest reductant and the strongest oxidant; the products are $\mathbf{O_2(g)}$ – anode, and $\mathbf{H_2(g)}$ - cathode.
In molten LiCl, the products are $\mathbf{Cl_2(g)}$ – anode, and **Li(l)** – cathode.
In **8 M LiCl(aq)** the high concentration means that **predictions based on the electrochemical series (1 M solutions, 25°C and 101.3 kPa) are less accurate**. ❶
Because **Cl^-(aq): 1.36 V, and H_2O(l): 1.23) are similar in reducing strength,** the **higher** the **concentration of Cl^-(aq**) the **greater** the **likelihood of Cl_2(g) being produced at the anode instead of O_2(g),** ❶ i.e. the products are $\mathbf{Cl_2(g)}$ - anode, and $\mathbf{H_2(g)}$ - cathode
Anode (+) half-equations:
1 M LiCl(aq): $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$
8 M LiCl(aq): $2Cl^-(aq) \rightarrow \mathbf{Cl_2}(g) + 2e^-$ ❶
LiCl(l): $2Cl^-(l) \rightarrow \mathbf{Cl_2}(g) + 2e^-$ ❶

End of Suggested Answers