Victoria Junior College
2021 H1 Chemistry Prelim Exam 8873/2
Suggested Answers

Section A

Answer **all** the questions in this section in the spaces provided.

1 **(a)** The ***n*^th^** (n = 1, 2, 3, 4 or 5) ionisation energies of consecutive elements **Q** to **Z**, with atomic number below 20, are shown in **Fig. 1.1**.

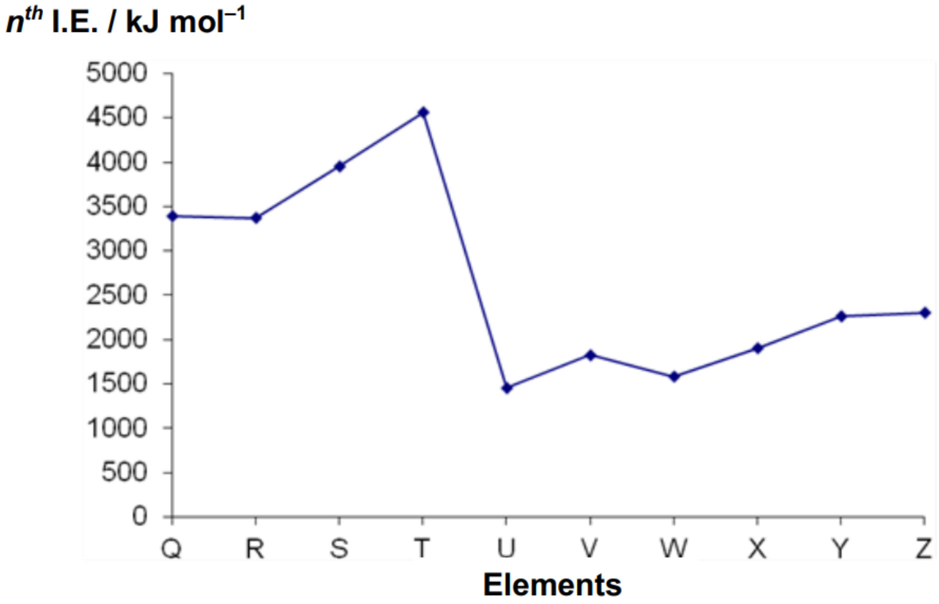


Fig. 1.1

(i) Define the $\boldsymbol{n^{th}}$ ionisation energy of element **T**.

The n^{th} ionisation energy of T is the amount of energy required to remove one mole of electrons from one mole of $T^{(n-1)+}$ gaseous ions, producing one mole of T^{n+} gaseous ions.
$T^{(n-1)+}(g) \rightarrow T^{n+}(g) + e^{-}$

[1]

(ii) Element **U** is identified as A*l*. State the value of ***n***.

n = 3 or 3rd ionisation energy

[Since U is a Group 13 element and T is a Group 2. There is a large decrease from T to U indicating that electrons is removed from a higher principle quantum shell in U^{2+}.]

[1]

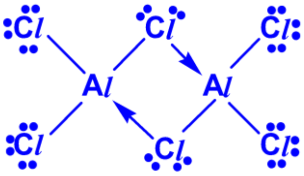
(b) Aluminium chloride has a wide number of uses in the chemical industry. Anhydrous $AlCl_3$ adopts different structures depending on the temperature and the state it is in. In the liquid state, it exists as the dimer Al_2Cl_6 while a mixture of monomer and dimer can be found in the gaseous phase.

(i) State the type of interactions between two molecules of $AlCl_3$.

instantaneous dipole–induced dipole interactions

[1]

(ii) Draw a diagram to show the bonding in an Al_2Cl_6 dimer, and state the bond angle about the Al atom.



Bond angle: 109.5°

[2]

(c) Beryllium chloride, $BeCl_2$, has properties similar to those of $AlCl_3$.

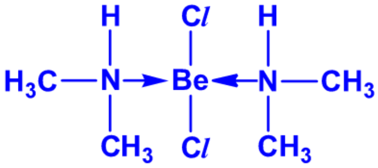
(i) Explain why $BeCl_2$ behaves similarly to $AlCl_3$.

Both $BeCl_2$ and $AlCl_3$ are Lewis acids, i.e. they are electron deficient and act as an electron pair acceptor.
[OR Both are covalent compounds due to similar charge to size ratio.]

[1]

(ii) $BeCl_2$ and dimethylamine, $(CH_3)_2NH$ reacts in the molar ratio 1:2. By considering the number of bond pairs and lone pairs around the central atoms of each molecule, explain the molar ratio and draw a diagram to show the bonding in the product.

$BeCl_2$: 2 bond pairs, 0 lone pair
$(CH_3)_2NH$: 3 bond pairs, 1 lone pair
$BeCl_2$ can accept 1 lone pair of electrons from 2 molecules of $(CH_3)_2NH$ to achieve octet configuration.



[2]

[Total: 8]

2 **(a)** **Fig. 2.1** shows the trend in melting points of some Period 3 elements:

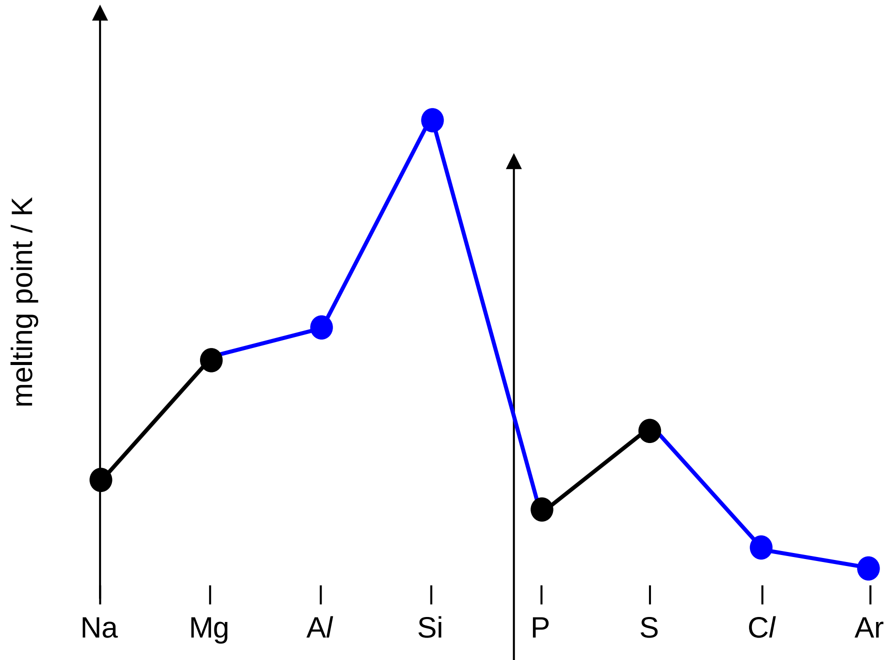


Fig. 2.1

(i) Complete the trend in melting point of the Period 3 elements for aluminium, silicon, chlorine and argon on **Fig 2.1**.

[1]

(ii) Explain, with reference to structure and bonding, why magnesium has a higher melting point than sodium.

Both Na and Mg have giant metallic structures.
Both Na and Mg have strong electrostatic forces of attraction between the cations and sea of delocalised electrons (i.e. metallic bonds).
Mg has more delocalised electrons than Na, leading to stronger metallic bonds for Mg compared to Na.
More energy is required to overcome the stronger metallic bonds of Mg.
Thus, Mg has a higher melting point than Na.

[2]

(iii) Explain, with reference to structure and bonding, why sulfur has a higher melting point than phosphorus.

P_4 and S_8 have simple molecular structures.
Both P_4 and S_8 have weak instantaneous dipole-induced dipole interactions (id-id) between their molecules.
However, S_8 has a larger and more polarisable electron cloud due to greater number of electrons present, leading to stronger id-id interactions between their molecules compared to P_4.
More energy is required to overcome the stronger id-id attractions in S_8.
Thus, S_8 has a higher melting point than P_4.

[2]

(b) Serpentine has the formula $Mg_3Si_2O_5(OH)_x$.

There is currently a lot of interest in the use of serpentine as a “green” cement as it chemically absorbs carbon dioxide, a major constituent of greenhouse gases.

(i) Deduce the value of ***x*** in $Mg_3Si_2O_5(OH)_x$.

$3(+2) + 2(+4) + 5(-2) + x(-1) = 0$

$x = 4$

[1]

(ii) Serpentine reacts with carbon dioxide to form water, silicon(IV) oxide and one other product. Write a balanced equation for this reaction.

$Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow 2H_2O + 2SiO_2 + 3MgCO_3$

[1]

(c) Dolomite has the formula Mg**Y**$(CO_3)_2$, where **Y** is a metal element.

Dolomite is insoluble in water but dissolves in aqueous acid due to the reaction between the carbonate ions and hydrogen ions.

$$CO_3^{2-} + 2H^+ \rightarrow CO_2 + H_2O$$

A 4.50 g sample of dolomite is dissolved in 25.0 cm^3 of 5.00 mol dm^{-3} hydrochloric acid, in excess.

The resulting solution is made up to 100 cm^3 in a volumetric flask using distilled water and labelled solution **A**. 10.0 cm^3 of solution **A** is titrated against a 0.100 cm^3 solution of sodium hydroxide. An average titre of 27.30 cm^3 is obtained.

(i) Calculate the amount of hydrochloric acid in 100 cm^3 of solution **A**.

Amount of NaOH in titration $= \frac{27.30}{1000} \times 0.100$

= 0.00273 mol

Amount of excess HC*l* (10.0 cm^3) **= 0.00273 mol**

Amount of excess HC*l* (100 cm^3) $= \frac{100}{10.0} \times 0.00273$

= 0.0273 mol

[2]

(ii) Hence, calculate the amount of hydrochloric acid that reacted with the 4.50 g sample of dolomite.

Amount of added HC*l* $= \frac{25.0}{1000} \times 5.00$

= 0.125 mol

Amount of reacted HC*l* **= 0.125 – 0.0273**
= 0.0977 mol

[1]

(iii) Determine the mole ratio of Mg**Y**$(CO_3)_2$: CO_3^{2-} : H^+.

$MgY(CO_3)_2 : CO_3^{2-} : H^+ = 1 : 2 : 4$

[1]

(iv) Hence, calculate the molar mass of **Y** and suggest its identity.

Amount of dolomite in 4.50 g $= \frac{0.0977}{4}$
= 0.0244 mol

Molar mass of dolomite $= \frac{4.50}{0.0244}$
= 184.4 g mol^{-1}

Molar mass of Y ion **= 184.4 – 24.3 – 2[12.0 + 3(16.0)]**
= 40.1 g mol^{-1}

Y is Ca.

[2]

[Total: 13]

3 This question involves the study of the kinetics of decomposition of hydrogen peroxide, H_2O_2 in the presence of iron(III) nitrate, $Fe(NO_3)_3$.

$$H_2O_2(aq) \rightarrow H_2O(l) + \tfrac{1}{2}O_2(g)$$

A small amount of $Fe(NO_3)_3$ was added to 100 cm^3 of 0.200 mol dm^{-3} H_2O_2 and the stopwatch was started.

At various time intervals, 10 cm^3 samples of the reaction mixture was extracted into a conical flask. 50 cm^3 of 0.200 mol dm^{-3} H_2SO_4 was added into a sample and titrated against 0.0200 mol dm^{-3} $KMnO_4$.

$$2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \rightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 5O_2(g)$$

Based on the titration results, the concentration of H_2O_2 in each 10 cm^3 sample was calculated. A graph of concentration of H_2O_2 against time was obtained as show in Fig 3.1.

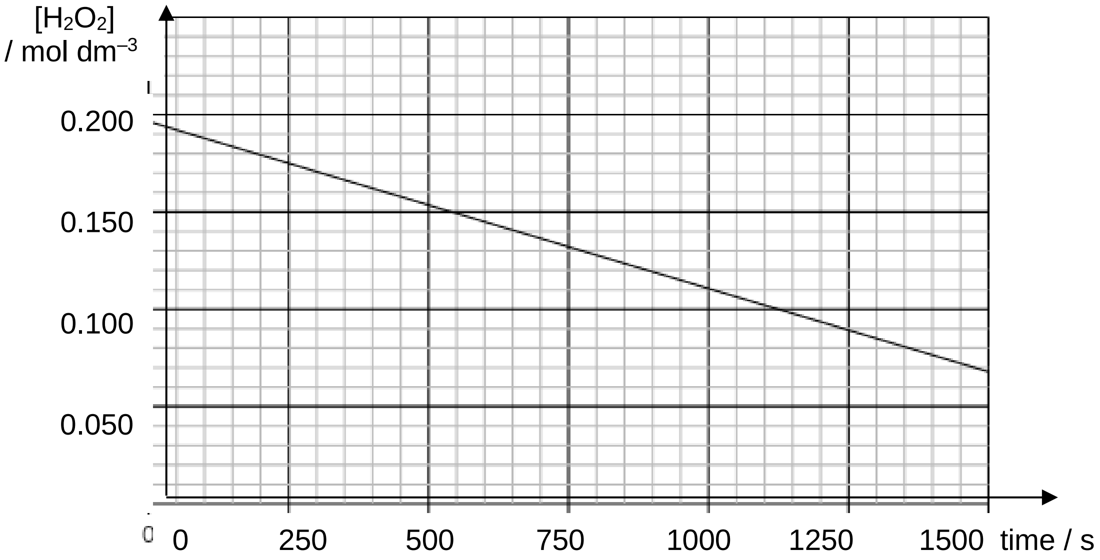


Fig. 3.1

(a) **(i)** It was observed that the concentration of $Fe(NO_3)_3$ in the reaction mixture remained constant throughout the whole experiment.

Suggest and explain the role of $Fe(NO_3)_3$ in the decomposition of H_2O_2.

FA 1 serves as a catalyst, that provides an alternative pathway with lower activation energy.

[1]

(ii) Hence, suggest and explain how the shape of the graph in **Fig. 3.1** would change if $Fe(NO_3)_3$ was **not** added to the reaction mixture.

The graph will have a more gentle gradient, implying a lower rate of reaction when a catalyst is not added.
Fewer particles have energy higher than activation energy, frequency of effective collisions decreases, hence rate decreases.

[2]

(b) **(i)** Calculate the **initial** number of moles of H_2O_2 in a 10.0 cm^3 sample of the reaction mixture.

Number of moles of H_2O_2 = 10.0 / 1000 x 0.200 = 2.00×10^{-3} mol

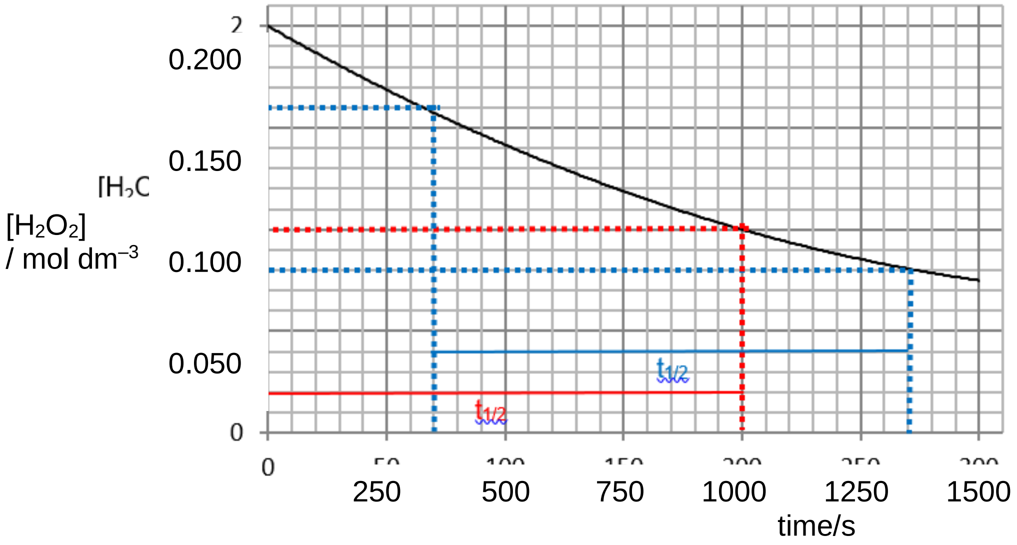
[1]

(ii) Hence, calculate the volume of $KMnO_4$ that is needed for the titration.

Number of moles of FA 2 = 2/5 x 2.00×10^{-3} = 8.00×10^{-4} mol
Volume of FA 2 = 8.00×10^{-4} / 0.02 = 0.040 dm^3
= 40.0 cm^3

[2]

(c) **(i)** By drawing relevant construction lines on the above graph in **Fig. 3.1**, determine the order of reaction with respect to H_2O_2. Explain your answer.



Time taken for [H_2O_2] to fall from 0.200 mol dm^{-3} to 0.100 mol dm^{-3} 1000 s.
Time taken for [H_2O_2] to fall from 0.160 mol dm^{-3} to 0.080 mol dm^{-3} is 1000 s.
(Show two consistent half lives on above graph)
Since half life is approximately constant at 1000 s, hence it is first order with respect to H_2O_2.

[2]

(ii) Given that the initial rate of the reaction is 1.4 × 10^{-4} mol dm^{-3} s^{-1}. Calculate the rate constant of the reaction, stating its units.

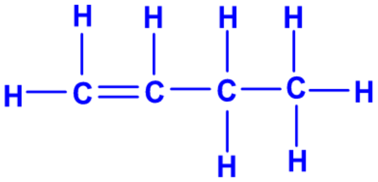
Rate = k[H_2O_2]
$1.4 \times 10^{-4} = k \times (0.200)$
$k = 7.00 \times 10^{-4}$ s^{-1}

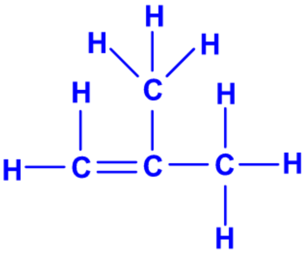
[1]

[Total: 9]

4 **(a)** Two alkenes with the molecular formula C_4H_8 **cannot** show cis-trans isomerism.

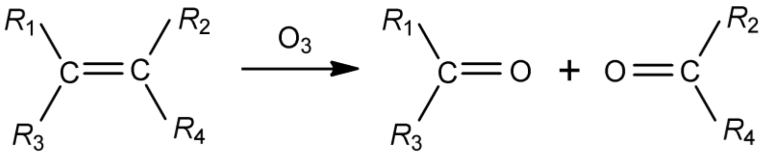
Draw the **displayed** formulae of these two alkenes.





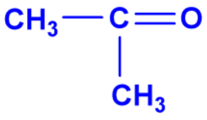
[2]

(b) Ozonolysis is a reaction where the unsaturated bonds of alkenes are cleaved with ozone, forming carbonyl compounds.

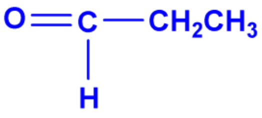


R_1, R_2, R_3 and R_4 can represent either alkyl groups or hydrogen atoms.

(i) Give the structures and names of the products formed from the ozonolysis of 2–methylpent–2–ene.


$\mathrm{CH_3-\underset{\underset{CH_3}{|}}{C}=O}$

propanone


$\mathrm{O=\underset{\underset{H}{|}}{C}-CH_2CH_3}$

propanal

[2]

(ii) Describe a test to distinguish between the two products formed in **(i)**. State the reagents and conditions required, as well as the observation for each compound.

$KMnO_4$(aq) / H_2SO_4(aq), heat
Propanal decolorises purple solution but propanone does not.
[OR aqueous $K_2Cr_2O_7$(aq) / H_2SO_4(aq), heat
Propanal turns orange solution green but propanone does not.]

[2]

(c) Consider the following synthesis pathway starting from an alkene:

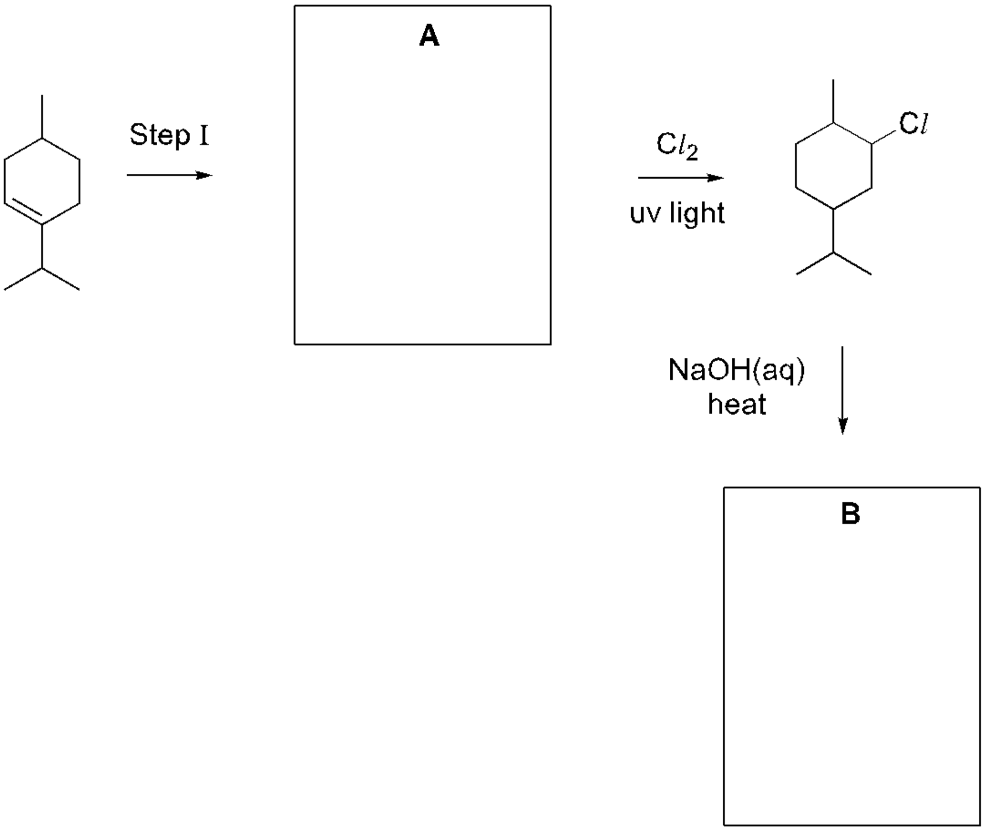
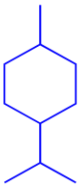
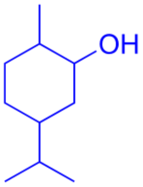


Fig. 4.1

(i) Draw the structures of **A** and **B** in the boxes in **Fig. 4.1**.



A



B

[2]

(ii) State the reagents and conditions required for Step **I**.

H_2 and Ni catalyst, heat
[OR Pt catalyst, room temperature]

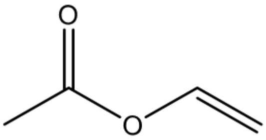
[1]

[Total: 9]

S5 The usage of the wood materials has improved considerably with the development of the industry and consequently the demand for wood adhesives has also increased accordingly. Today, there are several types of adhesives commonly used in woodworks. The use of each of these varies based on the properties such as curing time, strength, viscosity and water resistance.

(a) Polyvinyl acetate (PVAc) glue is the common type of glue with advantages that include high initial bonding strength and ease of use. The disadvantage includes rapid deterioration of bonding strength when exposed to moisture and higher temperature and not waterproof.

It is made from the monomer shown.



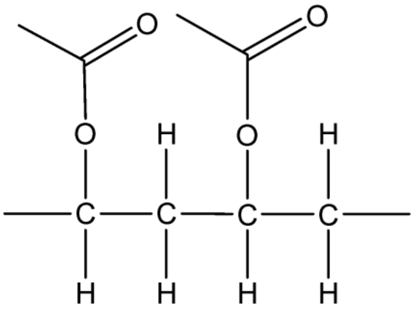
vinyl acetate

(i) State the type of polymerisation that produces PVAc.

Addition polymerisation

[1]

(ii) Draw the structure of PVAc, showing **two** repeat units.



[1]

(iii) Dried PVAc glue on any surface can be easily removed using vinegar or soap.

Explain why this is so.

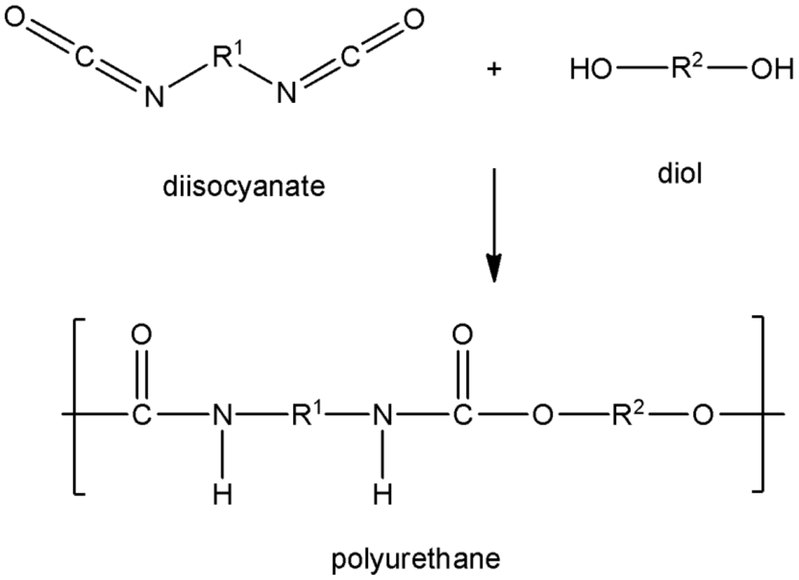
The presence of vinegar (acid) or soap (base) <u>hydrolyses ester linkages</u> and breaks down PVAc thereby allowing it to be more easily removed.

[1]

(b) Another adhesive, Polyurethane (PU) glue can be used to bond almost any material to wood as it provides very good adhesion and is waterproof. However, dealing with dried polyurethane glue can be problematic for finishes.

Polyurethanes are polymers made up of organic units joined by urethane links.

The reaction of a diisocyanate with a diol to form polyurethanes is as shown. R^1 and R^2 are hydrocarbon groups.



(i) State the functional group(s) present in polyurethane.

Amide and ester

[1]

(ii) Suggest and explain the type of R^1 and R^2 groups that polyurethane can have in order for the polymer to exhibit possible electrical conducting behaviour.

R^1 and R^2 groups can be electron rich functional groups such as alkenes or aromatic rings (e.g. benzene) so that there is presence of delocalised electrons to acts as mobile charge carriers to conduct electricity.

[1]

(iii) A derivative of polyurethane can be formed by replacing the diol with glycerol, $CH_2OHCH(OH)CH_2OH$. The new polymer is found to be harder and stronger.

Suggest whether the new polymer formed is a thermosetting or thermoplastic polymer. Explain your answer using your knowledge of the structure and bonding in polymers.

Thermosetting.
The additional –OH group allows cross links between polymer chains to be formed via hydrogen bonds which causes the new polymer to be more rigid.

[2]

(c) A compound of molecular formula, $C_4H_8O_2$, has several possible **functional group isomers**, compound **A** to **C**.

The observations of the three tests carried out on compound **A** to **C** are given in **Table 5.1**.

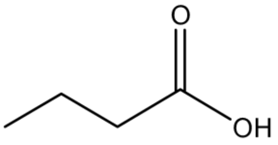
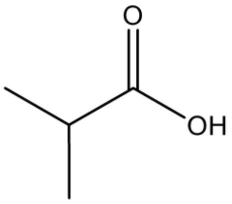
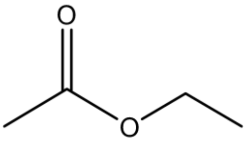
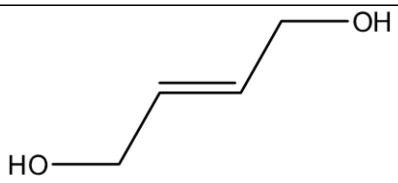
Table 5.1

test	chemical reagent and conditions	compound **A**	compound **B**	compound **C**
1	Br_2 in CCl_4 at room temperature	no observable change	no observable change	decolourisation of yellow solution
2	heat with acidified $K_2Cr_2O_7$(aq)	no observable change	solution turns from orange to green with only one organic product formed	solution turns from orange to green with only one organic product formed
3	NaOH(aq) at room temperature	compound **A** dissolves to form a colourless solution	no observable change	no observable change

Complete **Table 5.2** with the identities of compound **A** to **C**. Give evidence from the observations in **Table 5.1** by stating the **type of reaction** that occurred to support your conclusions.

Further information that may help with the identification of the compounds are as shown:
1. None of the compounds have the same functional group.
2. Compound **A** can exist as two constitutional (structural) isomers.
3. Compound **B** is a sweet-smelling compound.
4. There is no net-dipole moment for compound **C**.

Table 5.2

	structure	evidence
compound A	 or 	**Compound A undergoes neutralisation (or acid-base) reaction with NaOH(aq) at room temperature. Hence A is a carboxylic acid.**
compound B		**Compound B undergoes acid hydrolysis to form carboxylic acid (CH_3CO_2H) and alcohol (CH_3CH_2OH). The alcohol is oxidised to give the same carboxylic acid. Hence B is an ester.**
compound C		**Compound C undergoes addition with bromine in CCl_4. Hence C contains an alkene functional group. There is no net-dipole moment for C which means it is a trans isomer with same group attached on opposite sides of the alkene ring. C can be oxidised and therefore it contains an alcohol functional group.**

[6]

[Total: 13]

6 Phosgene, $COCl_2$, is very poisonous and was used as a chemical weapon during World War I, It can decompose to gaseous chlorine and carbon monoxide under suitable conditions as shown in the equation below.

$$COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g)$$

At the start of the reaction, 3 mol of phosgene were introduced into a 10.0 dm^3 vessel at 300 °C. When equilibrium was established, it was found that 30% of the phosgene was left.

(i) Define the term *dynamic equilibrium*.

Dynamic equilibrium is reached when the rate of the forward reaction is equal to the rate of the backward reaction in a reversible reaction and the concentrations of both reactants and products are constant.

[1]

(ii) Calculate the equilibrium concentrations of the three gases.

	$COCl_2(g)$ ⇌	**$CO(g)$ +**	**$Cl_2(g)$**
Initial amt / mol	**3**	**0**	**0**
Change in amt / mol	**–2.1**	**+2.1**	**+2.1**
Eqm amt / mol	**0.9**	**2.1**	**2.1**
Eqm conc. / mol dm^{-3}	**0.9/10 = 0.09**	**2.1/10.0 = 0.21**	**2.1/10.0 = 0.21**

[2]

(iii) Determine the equilibrium constant, K_c, for this reaction at 300 °C, stating its units.

$$K_c = [Cl_2][CO]/[COCl_2]$$
$$= 0.21 \times 0.21 / 0.09$$
$$= 0.49 \text{ mol dm}^{-3}$$

[2]

(iv) When the temperature was increased to 400 °C, it was found that only 20% of phosgene was left. Hence, deduce whether the reaction is endothermic or exothermic.

When the temperature increases, lesser phosgene is present means that the position of equilibrium shifts to the right. Hence, forward reaction is endothermic since endothermic reaction is favoured by an increase in temperature.

[1]

(v) It is known that 340 parts per million (ppm) of phosgene in a gas mixture is enough to kill a rat within 30 min. (1 ppm of phosgene = 1 molecule of phosgene in 10^6 molecules of gas mixture)

Calculate the concentration, in ppm, of 0.150 g of phosgene in 64.0 dm^3 vessel at room temperature and pressure. Hence, determine if this concentration is enough to kill a rat, placed in the same vessel, in 30 min.

You may assume that phosgene does not undergo decomposition at room temperature and pressure and that the vessel is filled with gaseous air particles.

No. of phosgene molecules in the vessel
= $0.150 \div (12.0 + 16.0 + 35.5 \times 2) \times 6.02 \times 10^{23}$
= 9.12×10^{20}

No. of gaseous molecules in the vessel
= $64 \div 24 \times 6.02 \times 10^{23}$
= 1.61×10^{24}

Concentration of phosgene in the equilibrium mixture in ppm
= $(9.12 \times 10^{20} / 1.61 \times 10^{24}) \times 10^{6}$
= 566 ppm

Since there is 566 ppm of phosgene in the equilibrium mixture, which is <u>higher than the 340 ppm, it is enough to kill</u> the rate in 30 min.

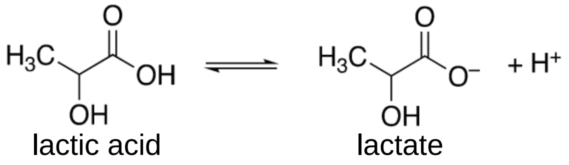
[2]

[Total: 8]

Section B

Answer **one** question from this section in the spaces provided.

7 Lactic acid, $CH_3CH(OH)COOH$, is a *weak acid* commonly found in sour milk products such as yogurt and cottage cheese.



The graph below shows the pH changes during the titration of 20.0 cm^3 of 0.1 mol dm^{-3} lactic acid with barium hydroxide. During this titration, barium hydroxide is added gradually, from a burette, until a total volume of 20.00 cm^3 has been added to the acid.

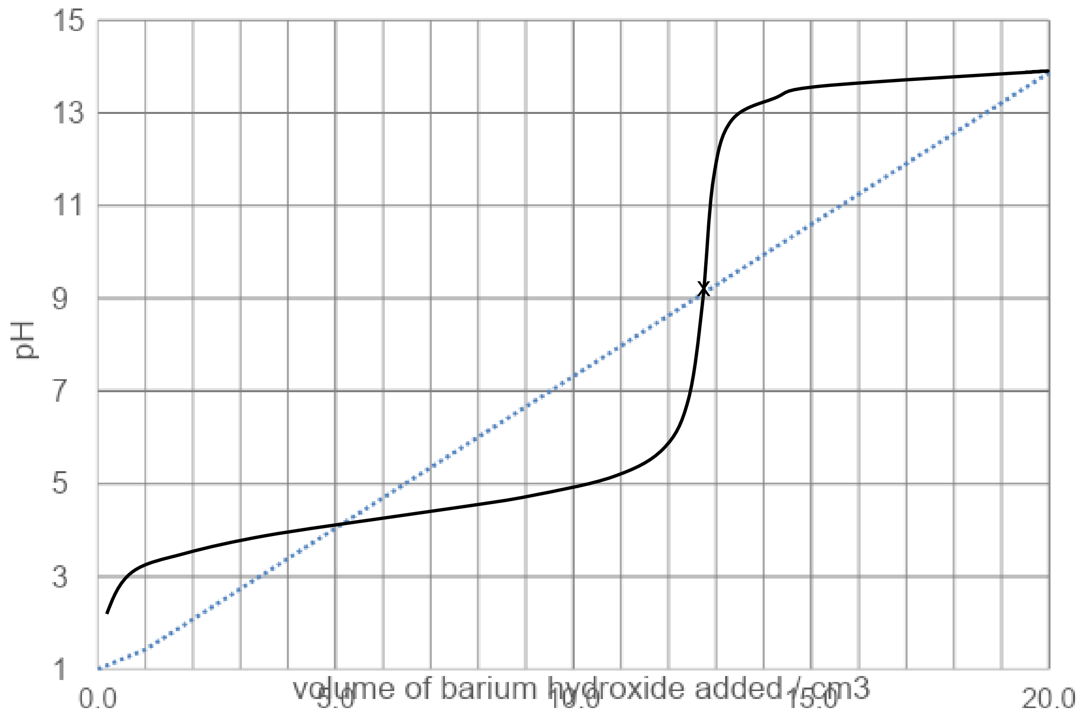


Fig. 7.1

(a) **(i)** Using the Bronsted-Lowry theory of acid, explain the meaning of the term *weak acid* with respect to lactic acid. Use information from **Fig. 7.1** to support your explanation.

An acid is a proton donor.
Lactic acid is a weak acid which undergoes partial dissociation in water to give H^+ ions.

[lactic acid] = 0.100 mol dm^{-3}

From graph, initial pH ≈ 2.0

$[H^+] = 10^{-2.0} = 0.0100$ mol dm^{-3} < [lactic acid] = 0.100 mol dm^{-3}
Therefore, it is a weak acid with partial dissociation.

[2]

(ii) Lactic acid has an acid dissociation constant, K_a of 8.3 × 10^{-4} mol dm^{-3}.

Write the expression for the acid dissociation constant of lactic acid and state its units. You may represent lactic acid with RCO_2H.

$K_a = \frac{[RCO_2^-][H^+]}{[RCO_2H]}$ **mol dm^{-3}**

[1]

(b) (i) Write a balanced equation for the reaction between lactic acid and barium hydroxide.

$2CH_3CH(OH)COOH + Ba(OH)_2 \rightarrow (CH_3CH(OH)COO)_2Ba + 2H_2O$

[1]

(ii) Given that '**x**' in **Fig. 7.1** is the end point of the titration, calculate the concentration of barium hydroxide.

From graph, V ≈ 12.5 cm^3
$n(CH_3CH(OH)COOH) = 20 \div 1000 \times 0.100 = 2.00 \times 10^{-3}$ mol
$n(Ba(OH)_2) = \underline{\frac{1}{2}} \times 2.00 \times 10^{-3} = 1.0 \times 10^{-3}$ mol
$[Ba(OH)_2] = 1.0 \times 10^{-3} / (12.5 \times 10^{-3}) = \underline{0.0800 \text{ mol dm}^{-3}}$

[1]

(iii) Using the information from **Fig. 7.1**, suggest which of the following indicators in **Table 7.1** should be used for the titration.

Table 7.1

indicator	colour in acid	colour in alkali	pH range over which colour change occurs
chlorophenol red	yellow	violet	4.8–6.7
phenolphthalein	colourless	pink	8.2–10.0
alizarin yellow	yellow	orange	10.1–13.0

phenolphthalein since the pH range for colour change coincides with the end point pH ≈ 8.5.

[1]

(c) (i) Using the pH from **Fig. 7.1**, calculate the concentration of hydrogen ions, in mol dm^{-3}, in the solution when 8.00 cm^3 of barium hydroxide is added.

pH = 4.5
$[H^+] = 10^{-4.5} = 3.16 \times 10^{-5}$ mol dm^{-3}

[1]

(ii) The solution formed when 8.00 cm^3 of barium hydroxide is added acts as a buffer.

Explain, with the aid of relevant equations, how the solution can act as a buffer.

When a small amount of acid is added,

$$CH_3CH(OH)COO^- + H^+ \rightarrow CH_3CH(OH)COOH$$

A large reservoir of $CH_3CH(OH)COO^-$ removes excess H^+, hence pH remains relatively constant.

When a small amount of base is added,

$$CH_3CH(OH)COOH + OH^- \rightarrow CH_3CH(OH)COO^- + H_2O$$

A large reservoir of $CH_3CH(OH)COOH$ removes excess OH^-, thus pH remains relatively constant.

[3]

(d) The *enthalpy change of neutralisation* for the reaction between 1.00 mol dm^{-3} lactic acid and 1.00 mol dm^{-3} barium hydroxide can be determined experimentally by measuring the change in temperature when the two solutions are mixed together.

The following data was obtained:

Table 7.2

volume of lactic acid used / cm^3	30.0
volume of barium hydroxide used / cm^3	20.0
initial temperature of lactic acid solution / ºC	32.1
initial temperature of barium hydroxide solution / ºC	30.0
highest temperature after mixing / ºC	39.2

(i) Define the term *standard enthalpy change of neutralisation*.

The heat released when 1 mole of water is formed when an acid neutralizes a base and is carried out in an infinitely dilute aqueous solution under standard conditions of 298K and 1 bar.

[1]

(ii) When the initial temperatures of two solutions are different, the weighted average initial temperature is calculated as follows:

$$\text{weighted average initial temperature} = \left(\frac{V_1}{V_1 + V_2} \times T_1\right) + \left(\frac{V_2}{V_1 + V_2} \times T_2\right)$$

where V_1 and V_2 are the volumes of solutions 1 and 2 respectively,
T_1 and T_2 are the initial temperatures of solutions 1 and 2 respectively.

Calculate the weighted average initial temperature of the reaction.

Weighted average initial temperature = 30/50 × 32.1 + 20/50 × 30
= 31.3 ªC

[1]

(iii) Using your answer in **(d)(ii)** and the information provided, calculate the enthalpy change of neutralisation of lactic acid with barium hydroxide.

You should assume that the specific heat capacity of the reaction mixture is 4.18 J g^{-1} K^{-1} and the density of each solution is 1.00 g cm^{-3}.

$2CH_3CH(OH)COOH + Ba(OH)_2 \rightarrow (CH_3CH(OH)COO)_2Ba + 2H_2O$

n(lactic acid) = 30/1000 × 1.00 = 0.0300 mol
n($Ba(OH)_2$) = 20/1000 × 1.00 = 0.0200 mol
$Ba(OH)_2$ is in excess.

$Q = mc\Delta T = 50 \times 4.18 \times (39.2 - 31.3) = 1659$ J
n(H_2O) = n(lactic acid) = 0.0300 mol
$\Delta H = -1659 \div 0.0300 = -55.3$ kJ mol^{-1}

[2]

(iv) The K_a of ethanoic acid is 1.8×10^{-5} mol dm^{-3}.

With reference to the data given in **(a)(ii)**, suggest how the magnitude of the enthalpy change of neutralization of ethanoic acid with barium hydroxide would differ from that of lactic acid with barium hydroxide.

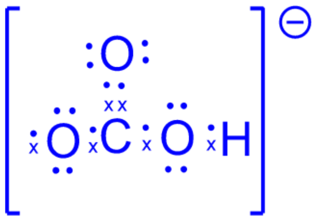
The magnitude of then enthalpy change of neutralization of ethanoic acid with barium hydroxide would be smaller than that of lactic acid. The K_a of ethanoic acid is smaller than lactic acid. It is dissociated to a smaller extent. More energy is absorbed to break the O–H bond in ethanoic acid, leading to a less exothermic reaction.

[2]

(e) Anaerobic metabolism and lactic acid accumulation often lead to metabolic acidosis.

Metabolic acidosis is associated with the loss of the bicarbonate ions, HCO_3^-.

(i) The HCO_3^- ion consists of two central atoms, C and O. Draw a dot and cross diagram of HCO_3^-.



[2]

(ii) State the shapes and bond angles about both central atoms.

shape and bond angle about C: **120º, trigonal planar**

shape and bond angle about O: **104.5º, bent**

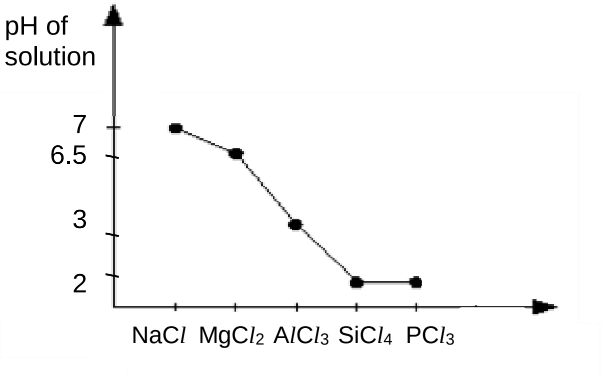
[2]

[Total: 20]

8 This question is about the chemistry of some Group 17 elements.

(a) Period 3 elements react with chlorine to form chlorides having different chemical structures.

(i) Sketch a graph to show the trend in pH of the resultant solutions when chlorides of Period 3 elements, Na to P, are dissolved in water.



Show correct trends
Indicate pH = 7 for NaC*l*

[1]

(ii) With the aid of two equations, explain the two reactions occurring when a zinc metal strip is added to the resultant solution obtained from the reaction of $SiCl_4$ with water.

$SiCl_4$ undergoes complete hydrolysis in water to give a strongly acidic solution.

$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$

Acid-metal reaction between HC*l* and Zn takes place.

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

[3]

(iii) Explain, why there is no reaction observed when zinc metal strip is added to the resultant solution obtained from the reaction of CCl_4 with water.

CCl_4 cannot undergo hydrolysis in water, due to the absence of energetically accessible vacant 3d orbitals on carbon in CCl_4 to accommodate lone pair of electrons from oxygen atoms of water.

[2]

(b) *Use of the Data Booklet is relevant to this question.*

X$_2$, **Y**$_2$ and **Z**$_2$ are Cl_2, Br_2 and I_2 but are not necessarily in the given order.

The table below recorded observations when these halogens are separately added to aqueous solutions containing the halide ions followed by the addition of an organic solvent, CCl_4.

experiment	reactants	observation after shaking with CCl_4
1	$\mathbf{X}_2$ (aq) + $\mathbf{Y}^-$ (aq)	violet organic layer seen
2	$\mathbf{Z}_2$ (aq) + $\mathbf{X}^-$ (aq)	orange-red organic layer seen

(i) Deduce with reasoning, the oxidising strength of **X**$_2$, **Y**$_2$ and **Z**$_2$ in decreasing order. Hence, identify **X**$_2$, **Y**$_2$ and **Z**$_2$.

From expt 1, Y^- is oxidised to Y_2 by X_2. With Y_2 appearing as violet in organic layer, Y_2 is I_2 and oxidising strength: $X_2 > Y_2$.

From expt 2, X^- is oxidised to X_2 by Z_2. With X_2 appearing as orange-red in organic layer, X_2 is Br_2 and oxidising strength: $Z_2 > X_2$.

Hence, oxidising strength: $Z_2 > X_2 > Y_2$

Z_2 is Cl_2.

[3]

(ii) By quoting relevant values from the *Data Booklet*, explain with reasons, the relative magnitude of the K_a values of H**Y** and H**Z**.

K_a value of HY is larger than that of HZ.
Bond energy of H–Y = 299 kJ mol^{-1}
Bond energy of H–Z = 431 kJ mol^{-1}

H−Y bond is weaker than H−Z bond. Less energy is needed to overcome H−Y bond to dissociate HY into H$^+$ and Y$^-$. HY is a stronger acid than HZ, hence HY has a larger K_a value.

[2]

(c) E300, $C_6H_8O_6$, is an oxidant used in white wines. The maximum concentration of E300 allowed in drinks is 8.52×10^{-4} mol dm^{-3}.

To find out if a 250.0 cm^3 sample of a drink containing E300 was within this limit, the following redox titration procedure is carried out.

An I_2 solution was first prepared by reacting 25.0 cm^3 of 0.00500 mol dm^{-3} KIO_3(aq) with excess KI(aq) under acidified conditions.

reaction 1 $IO_3^-(aq) + 5I^-(aq) + 6H^+(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$

The resultant I_2 solution was then reacted with the E300 in the 250.0 cm^3 sample of the drink as follow.

reaction 2 $C_6H_8O_6 + I_2 \rightarrow C_6H_6O_6 + 2H^+ + 2I^-$

The amount of unreacted I_2 reacted with 20.40 cm^3 of 0.00500 mol dm^{-3} $Na_2S_2O_3$(aq) in the titration as follow.

reaction 3 $I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$

(i) Calculate the amount, in moles, of iodine, I_2, formed in the reaction in **(c)**.

n_{KIO3} = 0.00500 x 25.0 x 10^{-3}
= 1.25 x 10^{-4} mol

n_{I2} = $\underline{3}$ x 1.25 x 10^{-4}
= 3.75 x 10^{-4} mol

[1]

(ii) Calculate the amount, in moles, of iodine, I_2, remaining after the E300 had reacted.

n_{S2O32-} = 0.00500 x 20.40 x 10^{-3}
= 1.02 x 10^{-4} mol

n_{I2} = $\underline{1/2}$ x 1.02 x 10^{-4}
= 5.10 x 10^{-5} mol

[1]

(iii) Determine the concentration of the E300 in the 250.0 cm^3 sample of the drink.

Hence, deduce whether the drink is within the limit allowed.

n_{E300} = $\overset{(c)(i)}{n_{I2} \text{ produced}}$ – $\overset{(c)(ii)}{n_{I2} \text{ reacted with } S_2O_3^{2-}}$
= 3.75 x 10^{-4} – 5.10 x 10^{-5}
= 3.24 x 10^{-4} mol

Concentration of E300 = 3.24 x 10^{-4} / 250.0 x 10^{-3}
= 1.30 x 10^{-3} mol dm^{-3}

Since the concentration is $\underline{> 8.52 \text{ x } 10^{-4} \text{ mol dm}^{-3}}$, the drink is $\underline{\text{not within the allowed limit for E300}}$.

[2]

(d) **(i)** Define *the standard enthalpy change of formation*.

Standard enthalpy change of formation is the heat change when one mole of a substance is formed from its constituent elements under standard conditions of 298 K and 1 bar.

[1]

(ii) Titanium tetrachloride, $TiCl_4$ is an important intermediate in the production of titanium metal and the pigment titanium dioxide.

Use the data given below, calculate the enthalpy change of the following reaction involving $TiCl_4$.

$$TiCl_4(g) + 2H_2O(g) \rightarrow TiO_2(s) + 4HCl(g)$$

$Ti(s) + 2Cl_2(g) \rightarrow TiCl_4(g)$ $\Delta H_1 = -763$ kJ mol^{-1}

$Ti(s) + O_2(g) \rightarrow TiO_2(s)$ $\Delta H_2 = -945$ kJ mol^{-1}

$H_2(g) + Cl_2(g)$ □ $2HCl(g)$ $\Delta H_3 = -185$ kJ mol^{-1}

$H_2(g) + ½ O_2(g)$ □ $H_2O(g)$ $\Delta H_4 = -242$ kJ mol^{-1}

$\Delta H_{rxn}{}^{o} = [\Delta H_f{}^{o}(TiO_2) + 4\Delta H_f{}^{o}(HCl)] - [\Delta H_f{}^{o}(TiCl_4) + 2\Delta H_f{}^{o}(H_2O)]$
$= [-945 + 4(-185/2)] - [-763 + 2(-242)]$
$= -68.0$ kJ mol^{-1}

[2]

(iii) The standard enthalpy of formation of $F_2O(g)$ is +24.5 kJ mol^{-1}.

Given that F_2O is made up of two F–O bonds, use data from the *Data Booklet* to calculate the bond energy of F–O bond.

$2F_2(g) + O_2(g) \rightarrow 2F_2O(g)$

+2(24.5) = 2BE(F–F) + BE(O=O) – 4BE(F–O)
+2(24.5) = 2(158) + (496) – 4BE(F–O)
BE(F–O) = +191 kJ mol^{-1}

[2]

[Total: 20]