

CATHOLIC JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATIONS
Higher 1

Answers

CANDIDATE
NAME

CLASS

CHEMISTRY

Paper 2

8872/02

Monday 1 September 2014
2 hours

Candidates answer Section A on the Question Paper

Additional Materials: Answer Paper

Data Booklet

Graph Paper (2 sheets)

READ THESE INSTRUCTIONS FIRST

Write your name and HT group on all the work you hand in.

Write in dark blue or black pen.

You may use a soft pencil for any diagrams, graphs or rough working.

Do not use staples, paper clips, highlighters, glue or correction fluid.

Section A

Answer **all** the questions

Section B

Answer **two** questions on separate answer paper.

You are advised to spend not more than 1 hour for Section B.

You are advised to show all working in calculations.

You may use a calculator.

The number of marks is given in brackets [] at the end of each question or part question.

For Examiner's Use	
Paper 1	30
Section A	40
A1	/13
A2	/14
A3	/13
Section B	40
B4	/20
B5	/20
B6	/20
TOTAL	110

This document consists of **12** printed pages and **0** blank page.

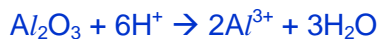
[Turn over

Section A

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

- 1 (a) Aluminium oxide, Al_2O_3 , is significant in its use as a refractory material due to its high melting point.

- (i) Aluminium oxide is said to be *amphoteric*. Write equations to illustrate this fact.



- (ii) Write balanced equations, if any, to illustrate how oxides of elements on either side of aluminium in the third period differ in their behaviour when reacted with

I acids/bases



II water



SiO_2 is insoluble in water

[6]

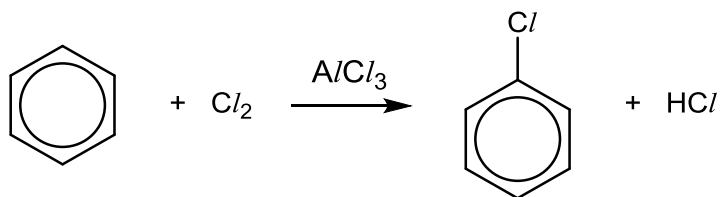
- (b) Unlike aluminium oxide, aluminium chloride cannot be used as a refractory material due to its low melting point.

- (i) By considering structure and bonding, explain the difference in melting point between aluminium oxide and aluminium chloride.

Al_2O_3 is a giant ionic compound held together by strong electrostatic forces of attraction between oppositely charged ions while AlCl_3 is a simple covalent molecule held together by weak van der Waal's forces of attraction.

Thus, more energy is required to break the strong ionic bonding in Al_2O_3 than the weak van der Waal's forces of attraction in AlCl_3 . This results in a much higher melting point in Al_2O_3 than AlCl_3 .

Aluminium chloride is often used as a catalyst in electrophilic substitution reactions. The chlorination of benzene is represented by the following overall equation.



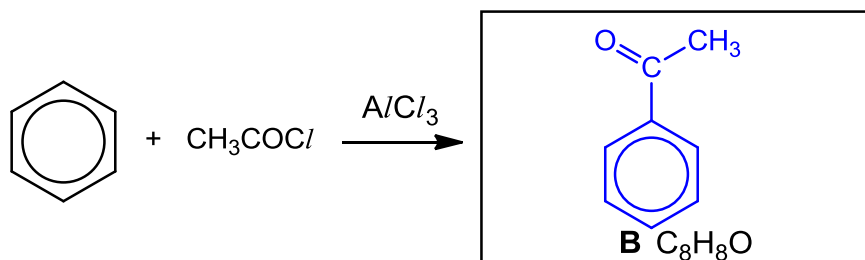
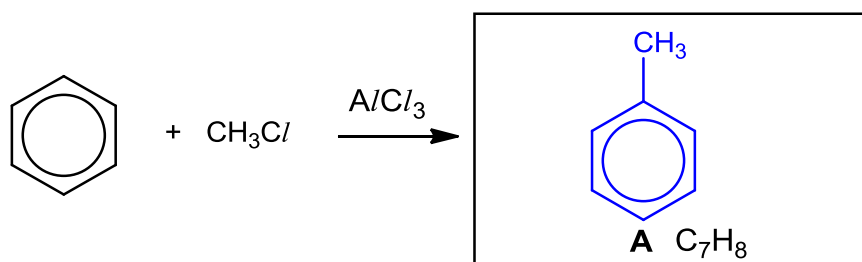
The reaction occurs in two steps.

Step 1: The reaction between Cl_2 and AlCl_3 generates the Cl^+ electrophile.

Step 2: The benzene ring is then attacked by the electrophile to form the final product.

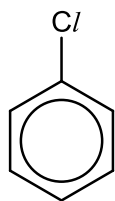
AlCl_3 reacts in a similar way with halogenoalkanes (e.g. CH_3Cl) and acyl chlorides (e.g. CH_3COCl), producing an electrophile that can then attack the benzene ring.

(ii) Predict the structure of the organic products **A** and **B** of each of the following reactions.

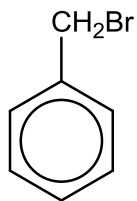


[5]

- (c) Suggest the reagents and conditions for a simple chemical test that could be used to distinguish between chlorobenzene and (bromomethyl)benzene.



chlorobenzene

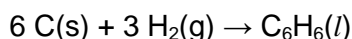


(bromomethyl)benzene

.....
.....
.....[2]

[Total: 13]

2 Benzene can be formed via the reaction between carbon and hydrogen as shown below.

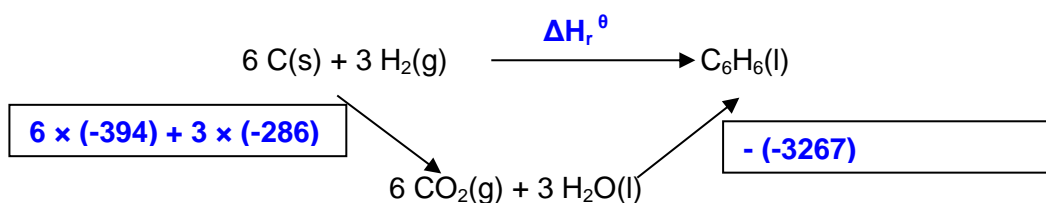


Standard enthalpy change of combustion of carbon	- 394 kJ mol ⁻¹
Standard enthalpy change of combustion of hydrogen	- 286 kJ mol ⁻¹
Standard enthalpy change of combustion of benzene	- 3267 kJ mol ⁻¹

(a) (i) Explain what is meant by *standard enthalpy change of combustion*.

It is the enthalpy change when one mole of a compound is completely burnt in oxygen under standard conditions of 298K and 1 atm.

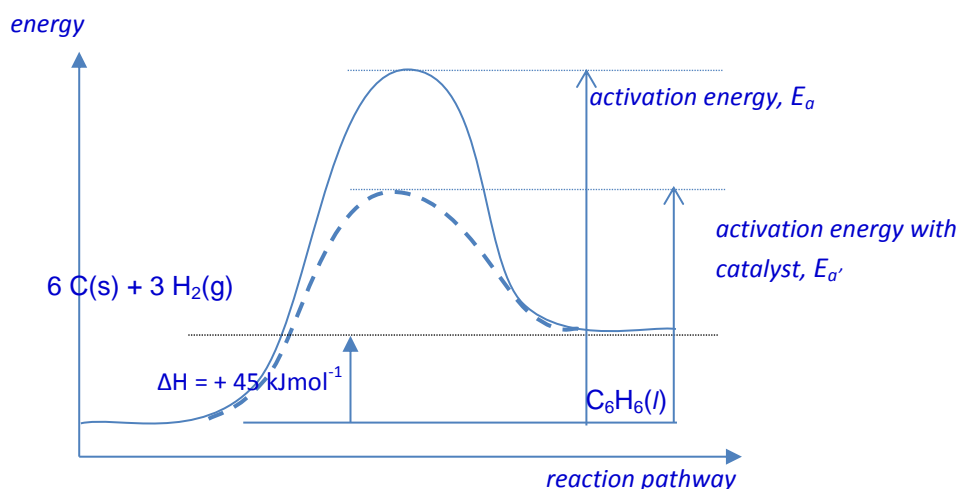
(ii) Given the following energy cycle, fill in the correct enthalpy changes in the boxes and hence calculate the enthalpy change of the above reaction.



$$\Delta H_r^\theta = 6 \times (-394) + 3 \times (-286) + 3267 = \underline{+ 45 \text{ kJ mol}^{-1}}$$

*Recall: $\Delta H_r^\theta = \Sigma (\Delta H_c^\theta \text{ of reactants}) - (\Delta H_c^\theta \text{ of products})$

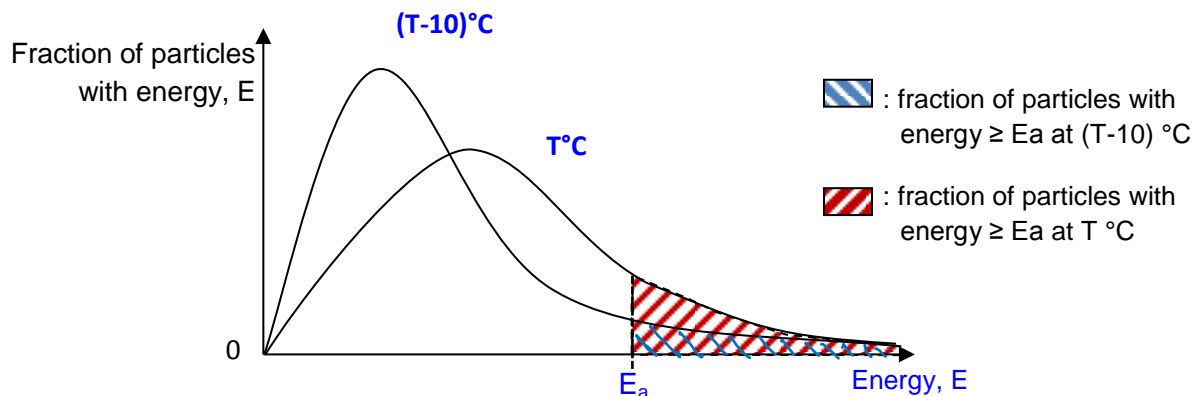
(iii) In the space below, draw a fully labelled energy profile diagram for the reaction in (a).



(iv) On the same axes, draw another energy profile diagram, with labels, when the same reaction is catalysed. [6]

- (b) When the reaction in part (a) was performed at a lower temperature, it was found that the reaction rate changed.

With reference to the Maxwell-Boltzmann distribution curve, explain how this decrease in temperature affected the reaction rate. Label the curves clearly. [4]



When temperature decreases, the fraction of particles with energy $\geq E_a$ decreases, causing the frequency of effective collisions to also decrease. Thus rate of reaction decrease.

- (c) 1.17 g of benzene was burnt to heat up 250 g of water in a beaker. The initial temperature of the water was 27.6°C .

- (i) Find the amount, in moles, of benzene used.

$$\text{Amount of benzene} = 1.17 / (12.0 \times 6 + 1.0 \times 6) = \underline{0.0150 \text{ mol}}$$

- (ii) Using the information given at the beginning of the question, calculate the total amount of heat evolved.

$$\text{Total amount of heat evolved} = 0.0150 \times (-3267) = \underline{-49.01 \text{ kJ}}$$

- (iii) Assuming that there is 20% heat loss to the surrounding, calculate the highest temperature reached by the water.

[Specific heat capacity of water is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$.] [4]

Amount of heat absorbed by the water = $0.80 \times 49.005 = 39.20 \text{ kJ}$

Heat absorbed by water = $mc\Delta T$

$$39.20 \times 10^3 = 250 \times 4.18 \times \Delta T$$

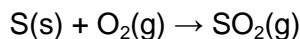
$$\Delta T = 37.5^\circ\text{C}$$

Highest temperature reached = $27.6 + 37.5 = 65.1^\circ\text{C}$

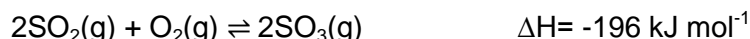
[Total: 14]

- 3 Sulfuric acid which is widely used in the manufacturing of fertilisers, explosives and the purification of petroleum, is produced via the Contact process.

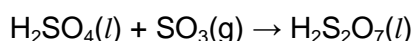
In the first step of the Contact Process, sulfur solid is first burnt in excess oxygen to form sulfur dioxide gas.



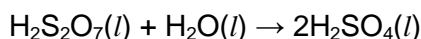
The sulfur dioxide gas formed then reacts with excess oxygen at 450°C and 1 atm, in the presence of vanadium(V) oxide catalyst, to form sulfur trioxide gas according the following equilibrium.



To prevent formation of a fog of sulfuric acid, sulfur trioxide formed is not directly dissolved in water. Instead, it is dissolved in concentrated sulfuric acid to form oleum, $\text{H}_2\text{S}_2\text{O}_7$.



Following which, the oleum that is produce can then be reacted safely with water to produce concentrated acid.



Sulfuric acid is colourless thick oily liquid without any odour at room temperature. It has to be stored in dry containers.

- (a) With the aid of Le Chatelier's Principle, explain why a moderate temperature of 450°C is used in the formation of sulfur trioxide gas.

Since the formation of sulfur trioxide is exothermic, according to Le Chatelier's principle, a low temperature will cause the position of equilibrium to shift to the right to produce more heat and thus producing more SO_3 . However, the rate of reaction will be slow at low temperature; therefore, to increase the rate of reaction, a moderate temperature of 450°C is used. [2]

- (b) Given that 3 moles of SO_2 and 2 moles of O_2 are allowed to reach dynamic equilibrium in a 2 dm³ vessel. It is found that the total number of moles of gases present in the vessel at equilibrium is 4.

- (i) Write a K_c expression for the equilibrium in the formation of sulfur trioxide.

$$K_c = \frac{[\text{SO}_3]^2}{[\text{O}_2][\text{SO}_2]^2}$$

- (ii) Calculate the number of moles of each gas at equilibrium, showing your workings clearly.



Let the number of moles of SO_3 formed be x

	SO_2	O_2	SO_3
Initial no. of moles / mol	3	2	0
Change in no. of moles / mol	- x	- $0.5x$	+ x
Equilibrium no. of moles / mol	$3-x$	$2-0.5x$	x

Given that the total number of moles of gases at equilibrium is 4,

$$3-x + 2-0.5x + x = 4$$

Solving for x , $x = 2$

At equilibrium, there is 1 mole of SO_2 , 1 mole of O_2 and 2 moles of SO_3 .

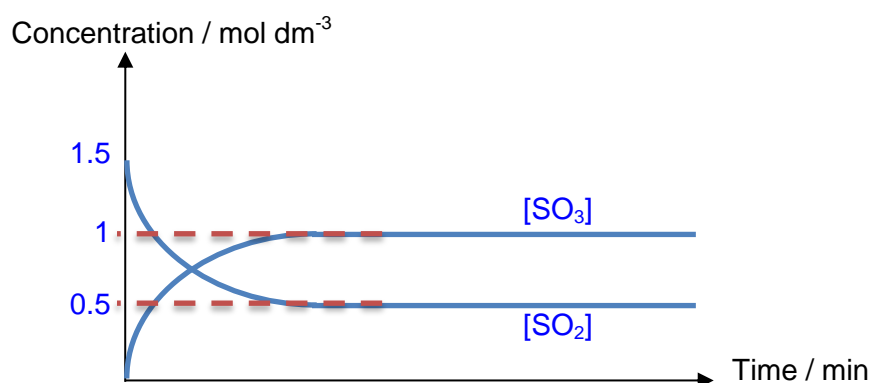
[1 for 3 correct final answers]

- (iii) Hence, calculate the equilibrium constant and state its units.

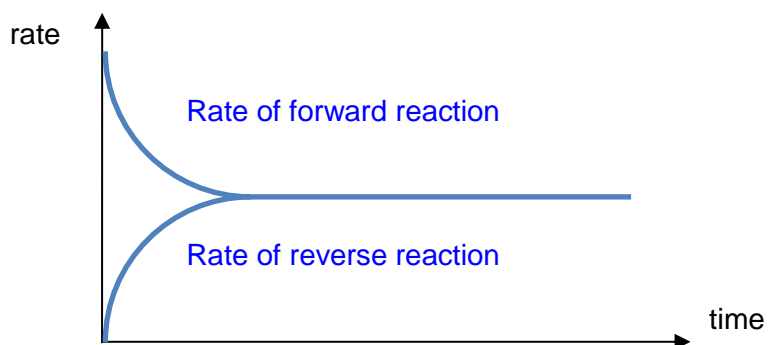
$$K_c = \frac{[2/2]^2}{[1/2][1/2]^2}$$

$$= 8.00 \text{ mol}^{-1} \text{ dm}^3$$

- (iv) Using your answer in (b)(i), sketch, on the axes below, the **concentrations** of SO_2 and SO_3 against time for the above equilibrium. Label your graphs clearly.



- (v) Sketch, on the axes below, the **rates** of the forward and reverse reactions against time for the above equilibrium. Label your graphs clearly.



[8]

- (c) Calculate the mass of oleum required to produce 3 kg of sulfuric acid..



No. of moles of $\text{H}_2\text{SO}_4 = 3000/98 = 30.61$

No. of moles of $\text{H}_2\text{S}_2\text{O}_7$ required = $30.61/2 = 15.3$

Mass of $\text{H}_2\text{S}_2\text{O}_7$ required = $15.3 \times 178 = 2724 \text{ g}$

[2]

- (d) Suggest why sulfuric acid has to be stored in dry containers.

Sulfuric acid reacts violently with water/ dilution of sulfuric acid releases a huge amount of heat which is dangerous.

[1]

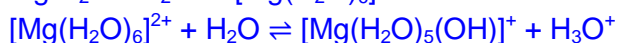
[Total: 13]

Section B

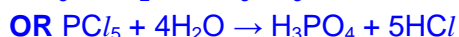
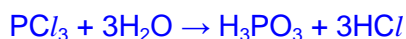
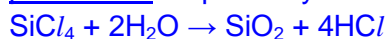
Answer **two** questions from this section on separate answer sheet.

- 4 (a) (i) Using the chlorides of magnesium, silicon and phosphorus as examples, describe the reactions of the chlorides of the third period of the Periodic Table with water. Include in your answer, the pH of the resultant solutions. Write equations where appropriate.

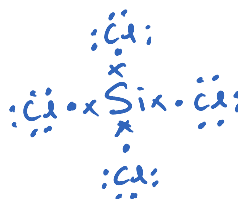
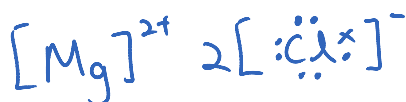
MgCl_2 hydrolyses partially in water to produce a slightly acidic solution of pH 6.5.



SiCl_4 and $\text{PCl}_3/\text{PCl}_5$ both hydrolyse completely in water to give acidic solutions of pH 2 and 1 respectively.

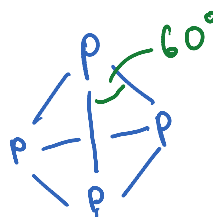
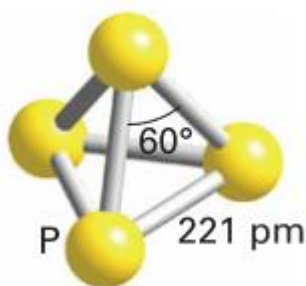


- (ii) Draw the dot-and-cross diagrams of the chlorides of magnesium and silicon. [7]



- (b) White phosphorus, P_4 , is a highly reactive allotrope of phosphorus with a simple molecular structure where each atom is trivalently bonded.

- (i) Draw the structure of a molecule of white phosphorus and state the shape about each P atom.



shape: trigonal pyramidal

- (ii) By considering the **structure** of white phosphorus, suggest the bond angle.

60°

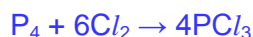
- (iii) Hence, suggest why white phosphorus is highly reactive.

[4]

P_4 has a trigonal pyramidal shape should have an angle of about 107° , however, P_4 has an angle of 60° . Thus the bond angle is highly strained leading to high reactivity.

(c) Phosphorus trichloride is prepared industrially by heating white phosphorus with chlorine gas.

- (i) Given that 3.50 tonnes of phosphorus trichloride is produced when 1 tonne of white phosphorus is reacted with excess chlorine, calculate the percentage yield of phosphorus trichloride. (1 tonne = 1×10^6 g)



$$\text{no of mol of } P_4 = \frac{1 \times 10^6}{31 \times 4} = 8.06 \times 10^3 \text{ mol}$$

$$\text{no of mol of } PCl_3 = 8.06 \times 10^3 \times 4 = 3.23 \times 10^4 \text{ mol}$$

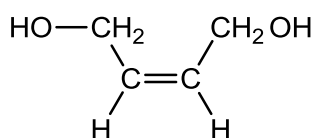
$$\begin{aligned} \text{theoretical mass of } PCl_3 &= 3.23 \times 10^4 \times (31 + 35.5 \times 3) \\ &= 4.43 \text{ tonnes} \end{aligned}$$

$$\% \text{ yield of } PCl_3 = \frac{3.50}{4.43} \times 100\% = 78.9\%$$

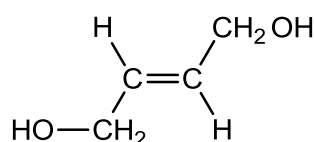
- (ii) Identify one potential safety hazard and state how you would minimise it. [3]

PCl_3 is corrosive, thus wear safety gloves when handling PCl_3 .

- (d) (i) It was observed that the boiling point of cis-but-2-ene-1,4-diol is lower than that of the trans isomer. Suggest a reason for this observation.

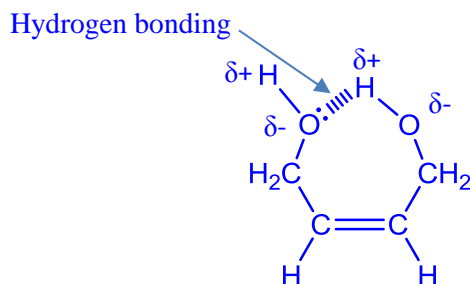


cis-but-2-ene-1,4-diol



trans-but-2-ene-1,4-diol

Both compounds are held together by intermolecular hydrogen bonding. However, due to the presence of intramolecular hydrogen bonding in cis-but-2-ene-1,4-diol, intermolecular hydrogen bonding between the cis isomers is less extensive. Thus, less energy is required to break the hydrogen bonding between cis-but-2-ene-1,4-diol than trans-but-2-ene-1,4-diol.



(iii) Suggest a simple chemical test which can be used to distinguish the following.

I $(\text{CH}_3)_3\text{COH}$ and $(\text{CH}_3\text{CH}_2)_2\text{CO}$

II $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$ and $\text{CH}_3\text{CH}_2\text{OCOCH}_2\text{CH}_3$

State clearly the reagents used and the observations made.

[6]

I $(\text{CH}_3)_3\text{COH}$ and $(\text{CH}_3\text{CH}_2)_2\text{CO}$

Test 1

To two separate test tubes containing $(\text{CH}_3)_3\text{COH}$ and $(\text{CH}_3\text{CH}_2)_2\text{CO}$, add anhydrous $\text{PCl}_5(\text{s})$ at rtp **OR** SOCl_2 and heat.

In the test tube containing $(\text{CH}_3)_3\text{COH}$, there will be steamy white fumes of HCl observed.

In the test tube containing $(\text{CH}_3\text{CH}_2)_2\text{CO}$, there will not be any steamy white fumes of HCl observed.

Test 2

To two separate test tubes containing $(\text{CH}_3)_3\text{COH}$ and $(\text{CH}_3\text{CH}_2)_2\text{CO}$, add 2,4-dinitrophenylhydrazine and heat.

In the test tube containing $(\text{CH}_3\text{CH}_2)_2\text{CO}$, there will be orange precipitate / crystals observed.

In the test tube containing $(\text{CH}_3)_3\text{COH}$, no such precipitation / orange crystals observed

II $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$ and $\text{CH}_3\text{CH}_2\text{OCOCH}_3$

Test 1

To two separate test tubes containing $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$ and $\text{CH}_3\text{CH}_2\text{OCOCH}_3$, add I_2 in $\text{NaOH}(\text{aq})$ and heat.

In the test tube containing $\text{CH}_3\text{CH}_2\text{OCOCH}_3$, there will be yellow precipitate of CHI_3 observed.

In the test tube containing $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$, no such precipitation of CHI_3 observed.

Test 2

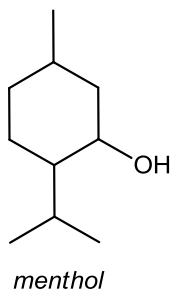
To two separate test tubes containing $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$ and $\text{CH}_3\text{CH}_2\text{OCOCH}_3$, add acidified $\text{KMnO}_4(\text{aq})$ and heat.

For $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$, purple KMnO_4 decolourises and effervescence which produces white precipitate when passed through limewater is observed.

For $\text{CH}_3\text{CH}_2\text{OCOCH}_3$, purple KMnO_4 decolourises but no effervescence is observed.

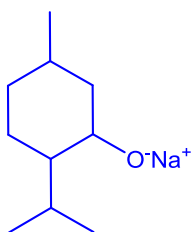
[Total: 20]

- 5 Menthol, $C_{10}H_{20}O$, which can be found in peppermint leaves is widely used in the production of medications, candies and beauty products. The skeletal structure of menthol is shown below:

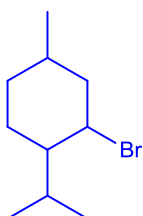


- (a) Draw the structures of all the possible organic products formed when a molecule of menthol is reacted with the following.

- (i) Na(s)

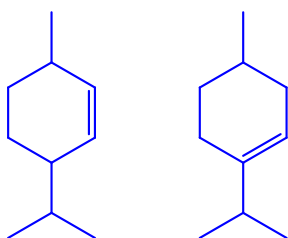


- (ii) NaBr with concentrated H_2SO_4 with heat



- (ii) hot Al_2O_3

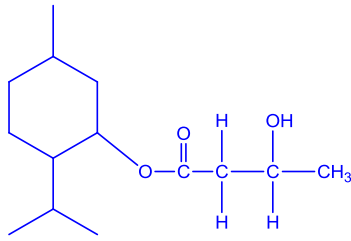
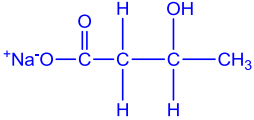
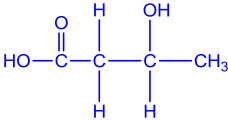
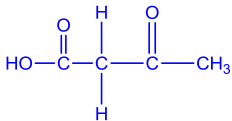
[4]

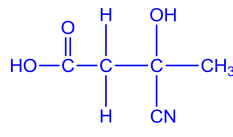


- (b) Compound **A**, $C_{14}H_{26}O_3$, produces menthol and compound **B** upon heating with $NaOH(aq)$. Acidification of compound **B** produces compound **C**, $C_4H_8O_3$, which gives effervescence with Na_2CO_3 . Compound **C** gives compound **D** when reacted with hot acidified $KMnO_4$. Compound **D** gives yellow crystals with aqueous alkaline iodine but does not produce brick-red precipitate when reacted with Fehling's solution. Upon reacting compound **D** with $HCN(aq)$ in the presence of KCN , compound **E**, $C_5H_7O_3N$, is formed.

Suggest the identities for the compounds **A**, **B**, **C**, **D**, **E** and explain the chemistry of the reactions. [10]

Answer:

Observation / information	Type of reaction	Functional group present	structure
Compound A , $C_{14}H_{26}O_3$, produces a molecule of menthol and compound B upon heating with $NaOH(aq)$.	Base-catalysed hydrolysis of ester	Ester functional group $\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{O}- \end{array}$ present in A	A is  $A \ C_{14}H_{26}O_3$
Acidification of compound B produces compound C , $C_4H_8O_3$, which gives effervescence with Na_2CO_3 .	<u>acid-base reaction</u>	$-\text{CO}_2\text{H}$ group present in C	B is  $B \ C_4H_7O_3Na$
Compound D is produced when compound C reacts with hot acidified $KMnO_4$.	C undergoes <u>oxidation</u> to form D	<u>Secondary</u> alcohol functional group present in C	C is  $C \ C_4H_8O_3$
Yellow crystals are observed when compound D reacts with aqueous alkaline iodine	D undergoes <u>oxidation</u>	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{CH}_3 \end{array}$ present in D	D is  $D \ C_4H_6O_3$
Compound D does not produce brick-red precipitate when reacted with Fehling's solution.	D does not contain aldehyde functional group, thus ketone is present	Ketone present in D	

Upon reacting with compound D with HCN(aq) in the presence of KCN, compound E , $C_5H_7O_3N$, is formed.	D undergoes <u>addition with HCN to form a hydroxynitrile, E</u> .		 <p>E is $C_5H_7O_3N$</p>
---	---	--	--

- (c) (i) Define, with the aid of an equation, the term second ionisation energy with reference to sulfur.



It is the enthalpy change when one mole of electrons is removed from one mole of $S^+(g)$ to form one mole of $S^{2+}(g)$.

- (ii) Describe qualitatively the general trend of second ionisation energy across period 3.

The second ionisation energy generally increases across the period.

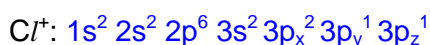
The increase in shielding effect is minimal, nuclear charge increases and ionic size decreases significantly.

OR

The increase in nuclear charge outweighs the increase in shielding effect.

Thus, electrons are more strongly attracted to the nucleus, and so more energy is required to remove them.

- (iii) Write the full electronic configuration of S^+ and Cl^+ , and hence explain why the second ionisation energy of chlorine does not follow the general trend across the period. [6]



Due to inter-electronic repulsion between paired electrons in $3p_x$ orbitals for Cl^+ , less energy is required to remove the second electron.

[Total: 20]

- 6 In 1669, the German alchemist, Hennig Brand, discovered phosphorus, which has several allotropes. The one of the most common allotropes of elemental phosphorus is white phosphorus, P_4 .

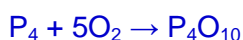
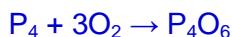
- (a) Sulfur, like phosphorus, is an element in period 3 of the periodic table. State whether phosphorus or sulfur has a higher boiling point in their elemental state. Explain your answer. [3]

Sulfur has a higher boiling point than phosphorus.

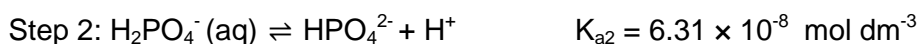
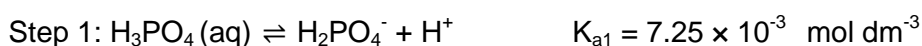
Elemental sulfur exists as S_8 while elemental phosphorus exists as P_4 . Thus S_8 has more electrons than P_4 . The results in a larger electron cloud in S_8 than P_4 . Thus S_8 has more extensive van der Waal's forces of attraction between its molecules compared to P_4 .

Elemental phosphorus can be used to produce phosphorus-containing acid by first heating phosphorus to form two different phosphorus oxides. These oxides are subsequently dissolved in water to form phosphoric(III) acid and phosphoric(V) acid respectively.

- (b) Write equations to illustrate all reactions stated above. [2]



Phosphoric(V) acid is a weak tribasic acid, and it dissociates into PO_4^{3-} in the three steps shown below.



- (c) (i) Write an expression for the first acid dissociation, K_{a1} .

$$K_{a1} = \frac{[H_2PO_4^-][H^+]}{[H_3PO_4]}$$

- (ii) By considering the K_a values given above, identify the strongest conjugate base. Using Le Chatelier's Principle, explain your answer. [3]

The strongest conjugate base is PO_4^{3-} since K_{a3} is the smallest, showing that the position of equilibrium for dissociation of HPO_4^{2-} lies more to the left. This means that PO_4^{3-} has the highest tendency to recombine with H^+ , thus acting as the strongest conjugate base.

- (d) A student performed a titration by adding $0.200 \text{ mol dm}^{-3} \text{H}_3\text{PO}_4(\text{aq})$ to a conical flask containing 20 cm^3 of $0.100 \text{ mol dm}^{-3} \text{NaOH}(\text{aq})$. You may assume that $\text{H}_3\text{PO}_4(\text{aq})$ behaves as a dibasic acid.

- (i) Calculate the pH of solution in the conical flask at the start of the titration.

$$\begin{aligned} \text{no. of mol of NaOH} &= \text{no. of mol of OH}^- \\ &= 0.100 \text{ mol} \end{aligned}$$

$$\begin{aligned} \text{pH} &= 14 - \text{pOH} = 14 - (-\lg[\text{OH}^-]) \\ &= 14 - 1 = 13.0 \end{aligned}$$

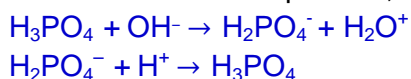
- (ii) Suggest a value for the equivalence point of the above titration.

Any value $8 \leq \text{pH} \leq 11$

- (iii) Define acidic buffer.

An acidic buffer is a solution is of weak acid and the salt of the weak acid and it is able to maintain a fairly constant pH when a small amount of acid or base is added.

- (iv) With the aid of two equations, show how the above mixture acts as a buffer.

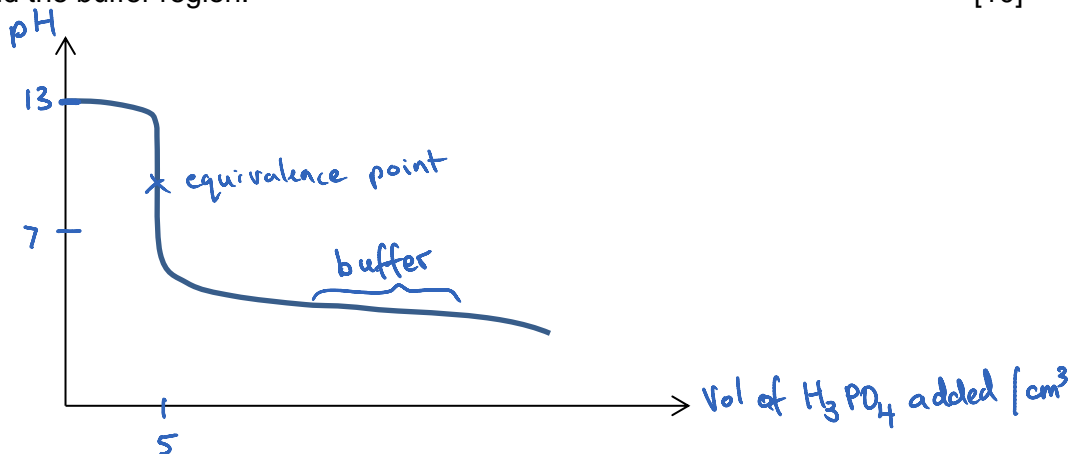


- (iv) Using answers from (i) and (ii), predict if an acidic buffer is formed before or after equivalence point. Explain your answer.

Buffer will form after equivalence point

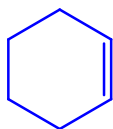
After equivalence point, when all strong base (NaOH) has been neutralised, the solution will contain salt of weak acid and weak acid.

- (v) Using the answers in part (d), sketch the titration curve of the above reaction. In your sketch, indicate clearly the starting pH of the solution, the equivalence point and the buffer region. [10]

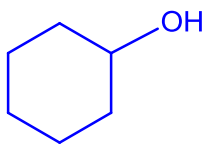


- (e) H_3PO_4 , heated at $300\text{ }^\circ\text{C}$ and 70 atm in the presence of C_6H_{10} and steam, will form only one organic compound, **W**. Draw the structural formula of C_6H_{10} and compound **W**. [2]

[Total: 20]



C_6H_{10}



W