Catholic Junior College

JC2 Preliminary Examinations

Higher 1

CANDIDATE NAME	
CLASS	**2T**

CHEMISTRY

Paper 2 Structured Questions

8873/02
29 August 2025
2 hours

Candidates answer on the Question Paper.
Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work you hand in.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Section A
Answer **all** the questions**.**

Section B
Answer **one** question.

The use of an approved scientific calculator is expected where appropriate.
You are reminded of the need for good English and clear presentation in your answers.
A Data Booklet is provided.

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

Section A	**Q1**	**/ 5**
	Q2	**/ 6**
	Q3	**/ 15**
	Q4	**/ 16**
	Q5	**/ 6**
	Q6	**/ 12**
Section B	**Q7**	**/ 20**
	Q8	**/ 20**
Paper 2 (67%)		**/ 80**
Paper 1 (33%)		**/ 30**
Percentage		
Grade		

Section A

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

1(a) The hydrogen carbonate ion, HCO_3^-, has both acidic and basic properties.
State the conjugate acid and conjugate base of HCO_3^-.

Conjugate acid: H_2CO_3

Conjugate base: CO_3^{2-} [1]

(b) In the human body, it is important for blood to be maintained at a pH between 7.35 and 7.45. The main buffering agent in blood plasma is the $H_2CO_3(aq)$ / $HCO_3^-(aq)$ system. During a vigorous physical workout, the muscles will produce an acid which will be transported by the blood to the liver to be broken down.

(i) Define the term *buffer solution*.

A buffer solution is one that can maintain a fairly constant pH when small amount of acid or base is added to it. [1]

(ii) Briefly explain the effect physical workout will have on the pH of blood if there is no buffer present.

Blood will become more acidic due to production of acid, resulting in the pH of blood falling below 7.35. [2]

(iii) Write an equation to explain how the $H_2CO_3(aq)$ / $HCO_3^-(aq)$ buffer system helps to maintain the pH of blood during a physical workout.

When blood becomes more acidic,

$HCO_3^- + H^+ \rightarrow CO_2 + H_2O$ [1]

[Total: 5]

2 A student used the apparatus shown in Fig. 2.1 to find the enthalpy change of combustion of butan-1-ol, ΔH_c(butan-1-ol).

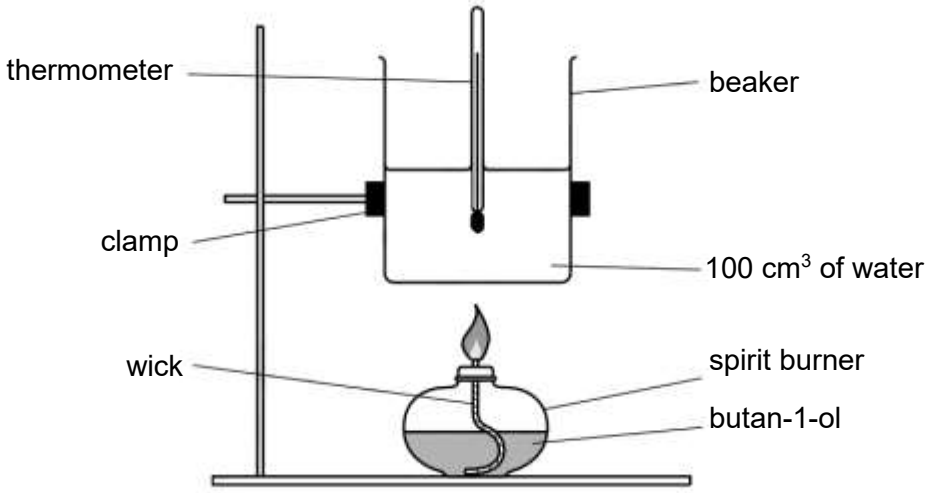


Fig. 2.1

temperature of water before heating = 25.0 °C
temperature of water after heating = 83.7 °C
mass of spirit burner and butan-1-ol before heating = 80.44 g
mass of spirit burner and butan-1-ol after heating = 79.70 g

The specific heat capacity of water is 4.18 J g^{-1} K^{-1}.

$CH_3CH_2CH_2CH_2OH(l) + 6O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$ ΔH_c(butan-1-ol).

(a) From the data provided above, calculate the number of moles of butan-1-ol that reacted and hence determine the enthalpy change of combustion of butan-1-ol.

mass of butan-1-ol reacted = 80.44 – 79.70 = 0.74 g
No. of moles of butan-1-ol reacted = 0.74 / 74.0 = 0.0100 mol

amount of heat absorbed by water = mcΔT
= 100 x 4.18 x (83.7 – 25.0) **or (100 x 4.18 x 58.7)**
= 24.54 kJ

enthalpy change of combustion of butan-1-ol = –24.54/ 0.0100
= –2450 kJ mol^{-1} (3sf)

[3]

(b) $CH_3CH_2CH_2CH_2OH(l) + 6O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$ ΔH_c(butan-1-ol).

Complete the table 2.1 below by using the bond energies given in the Data Booklet to calculate another value for the standard enthalpy change of combustion of butan-1-ol.

Table 2.1

Bonds broken:			**Bonds formed**:	
3 C-C	3 x 350		8 C=O	8 x 805
9 C-H	9 x 410		10 O-H	10 (460)
1 C-O	1 x 360			
1 O-H	1 x 460			
6 O=O	6 x 496			

Energy required to break bonds
= (3 x 350) + (9 x 410) + (1 x 360) + (1 x 460) + (6 x 496) = 8536 kJ

Energy released from bonds formed = (8 x 805) + 10 x 460 = 11 040 kJ

$\Delta H_c^{\ominus}$ of butan-1-ol = -11040 + 8536 = –2500 kJ mol^{-1} 3sf

[2]

(c) Suggest a reason for the discrepancy between the two values calculated in **(a)** and **(b)**.

Heat loss to the surrounding hence the temperature rise was lower.

OR The bond energies given in the data booklet are only averages and would not apply to the exact compounds in the reaction. [1]

Or

The $\Delta H_c^{\ominus}$ calculated applies for the reactants and products in the gaseous phase but the standard enthalpy change of combustion is defined in terms of the formation of liquid H_2O rather than gaseous H_2O.

[Total: 6]

3(a) Propanone reacts with iodine in an aqueous solution of sulfuric acid as shown below.

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + H^+ + I^-(aq)$$

The rate of this reaction was investigated by withdrawing samples from the reaction mixture, 'quenching' by adding the sample to a large volume of ice-cold water, then measuring the amount of iodine in the sample.

(i) Why is it necessary to quench the sample before measuring the amount of iodine?

To **slow down the reaction significantly** by lowering concentration and temperature of the reaction, such that the **reaction is considered to have stopped at that instant**. This allows the reaction to be studied kinetically. [1]

Separate experiments were carried out to determine the initial rates of reaction and the results obtained are given in the table below.

The rate equation for the reaction is

$$\text{Rate} = k[CH_3COCH_3][H_2SO_4]^n$$

(ii) The volumes of each reagent is proportional to its concentration. Complete the table below with appropriate values.

Expt	Volume of CH_3COCH_3 / cm^3	Volume of H_2SO_4 / cm^3	Volume of I_2 / cm^3	Volume of H_2O / cm^3	Relative initial reaction rate
1	40	20	20	70	4
2	20	20	20	**90**	2
3	40	20	10	**80**	**4**
4	40	40	20	50	8

[1]

(iii) Determine the order of reaction, *n*, with respect to H_2SO_4. Use data in the table to support your answers.

Using experiments 1 and 4, When volumes of CH_3COCH_3 and I_2 remain constant, and **volume of H_2SO_4 doubles** (from 20 to 40 cm^3), the relative initial reactionn **rate also doubles from 4 to 8.** Hence order of reaction with respect to H_2SO_4 is **1**. [2]

(b) The rate of hydration of ethanal was studied by dissolving ethanal in 625 cm^3 of water.

The concentration of ethanal is measured every 2 minutes. The results of the experiment are shown below.

time /min	[ethanal] /mol dm^{-3}
0	0.80
2	0.56
4	0.42
6	0.31
8	0.23
10	0.16
12	0.12
14	0.09
16	0.08

(i) Using the information given in the question, calculate the mass of ethanal used in this reaction. (M_r of ethanal = 44.0)

Concentration of ethanal = $\frac{\text{amt in moles}}{0.625}$ = 0.8 mol dm^{-3}

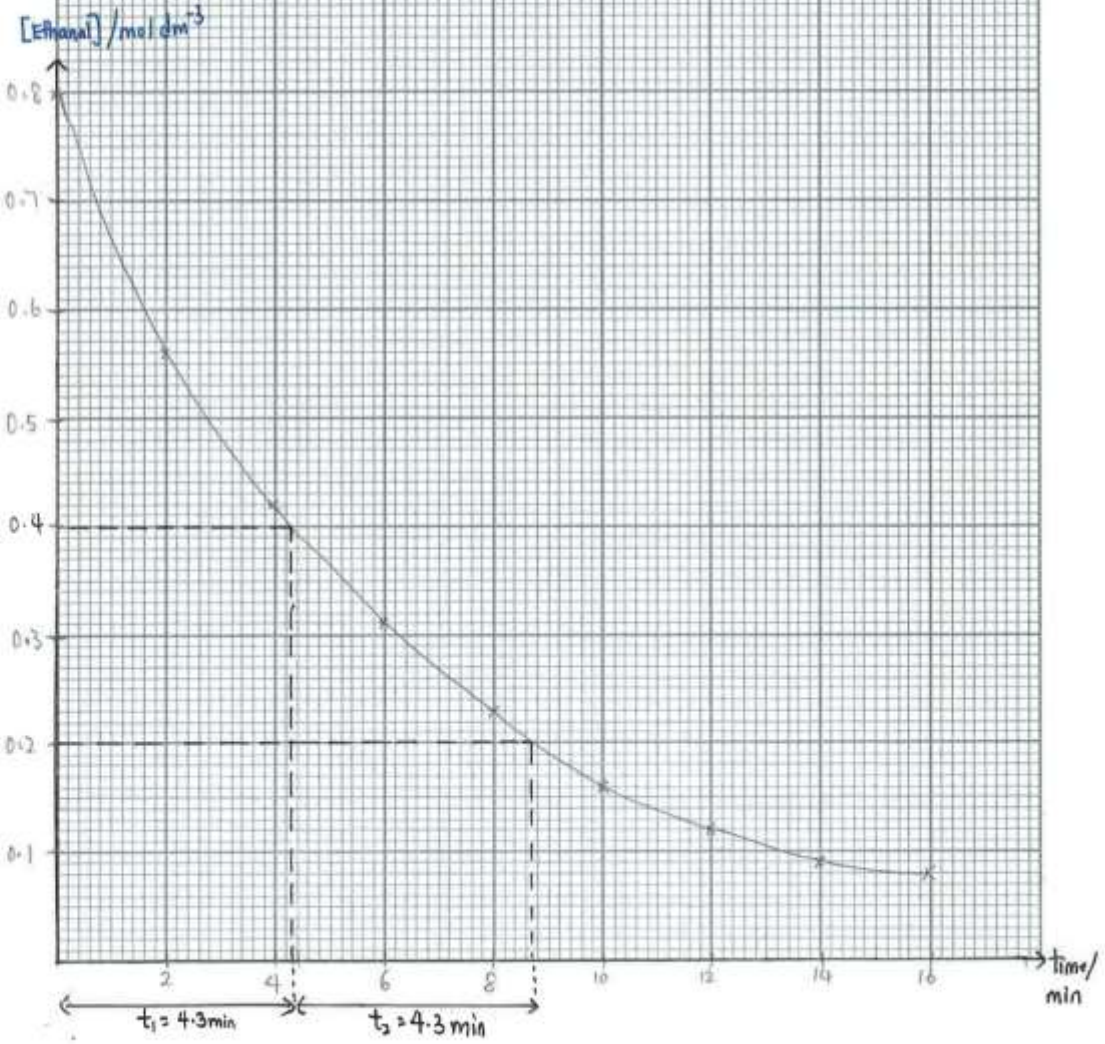
Amount in moles = 0.500 mol

Mass of ethanal = 0.500 x 44.0 = 22.0 g

[1]

(ii) On the grid provided below, plot a graph of the results. [3]

- axes correctly labelled
- appropriate scales (plotted pts cover at least ½ of each axis) with no odd scale
- points – all correctly plotted (to within ½ small square) with smooth best



(iii) Use your graph to show that the reaction is first order with respect to ethanal. Justify your answer by showing appropriate construction lines on your graph.

There is a constant half-life of 4.3 min.

[2]

(iv) Write the rate equation for the reaction.

Rate = k [ethanal]

[1]

(v) The rate of reaction was measured to be 0.18 mol dm^{-3} min^{-1} at t = 0 min. Determine the rate constant for the reaction and state its units.

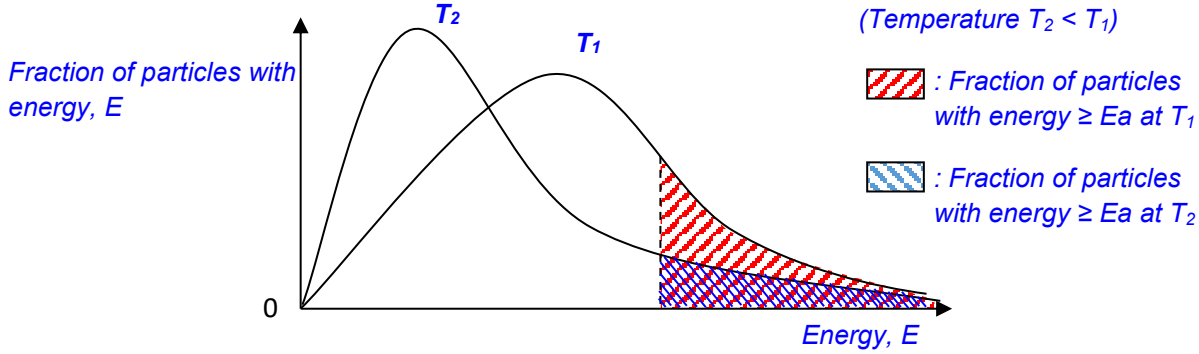
Rate = k[ethanal]

0.18 = k (0.8)

k = 0.225 min^{-1}

[1]

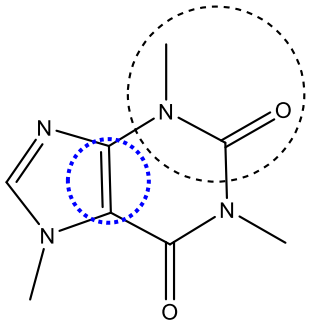
(c) Explain how the rate of the reaction will be affected when the experiment is conducted at a lower temperature. Illustrate your answer with the aid of an energy distribution diagram.



When **temperature decreases** from T_1 to T_2, the **number of molecules with energy greater than** or equal to **the activation energy / E_a decreases**. Hence **frequency of effective collisions** between molecules with energy greater than or equal to activation energy **decreases** and **rate** of reaction **decreases**. [3]

[Total: 15]

4 This question explores four of the many hundreds of compounds present in a cup of coffee. The first and most well-known compound is caffeine.
The structure of caffeine is shown below:



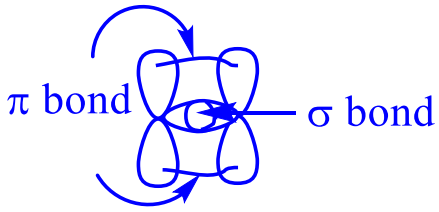
caffeine

(a) State the functional group that is circled in the molecule of caffeine.

(tertiary) amide ..... [1]

(b) (i) In the above structure, circle the alkene functional group. [1]

(ii) Describe, in terms of orbital overlap, the bonding of the two carbon atoms of the C=C bond in caffeine. A clearly labelled diagram may clarify your answer.



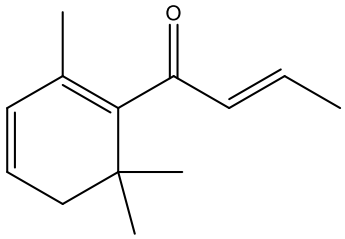
[correct drawing and label, 1]

Sigma bond: head on overlap of (sp^2) orbitals.

Pi bond: sideway overlap of p orbitals.

[3]

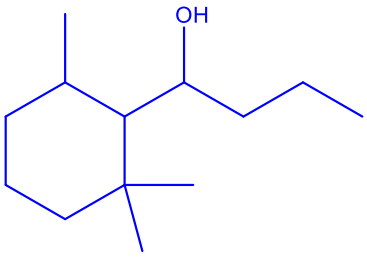
(c) The second compound in coffee is damascenone and it has the following structure shown below.



Damascenone

Draw the products formed when damascone is reacted with the following reagents and conditions:

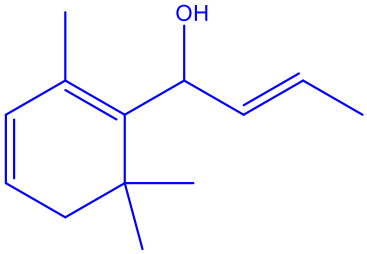
(i) H_2 with nickel catalyst in the presence of heat



[1] alcohol group
[1] all alkene groups reacted

[2]

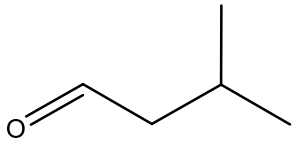
(ii) $NaBH_4$ in methanol



[1] Alcohol group shown and the rest of the molecule does not react

[1]

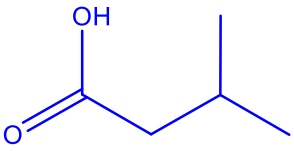
(d) The third compound in coffee is the aldehyde shown below.



(i) Give the IUPAC name of the aldehyde.

3-methylbutanal ..... [1]

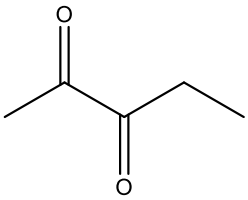
(ii) Draw the product formed when the aldehyde is reacted with hot acidified potassium manganate (VII), $KMnO_4$.



[1]

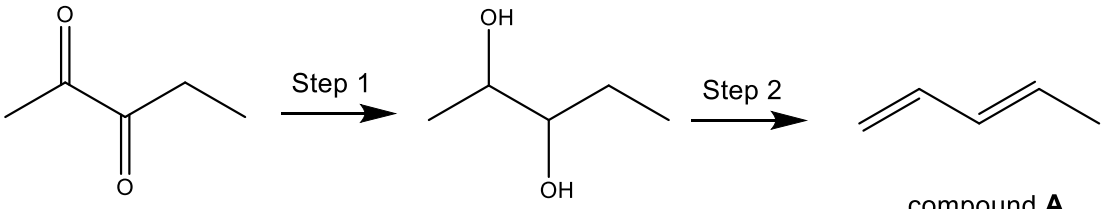
[1]

(e) The fourth compound, 2,3-pentanedione is present in coffee.



2,3-pentanedione

2,3-pentanedione can be reacted in the following sequence:



2,3-pentanedione

compound **A**

(i) State the type of reaction that occurred in step 1.

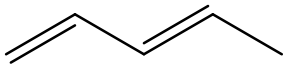
reduction [1]

(ii) State the reagents and conditions required in step 2.

Excess concentrated H_2SO_4 with heat; OR Hot Al_2O_3 catalyst [1]

(iii) Compound **A** can be used to form polymers. Define the term polymer.

Polymers are macromolecules with an average molecular mass of at least 1000 or at least 100 repeat units. [1]

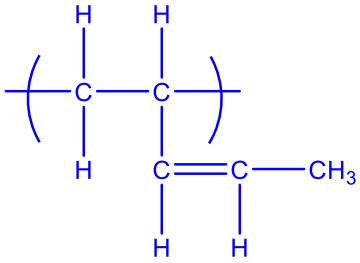


compound **A**

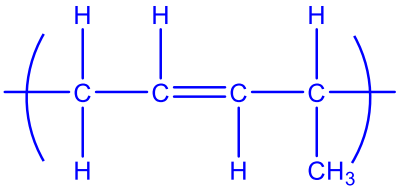
(iv) State the type of polymerisation that compound **A** can undergo.

Addition ..... [1]

(v) Draw a repeat unit of a polymer that compound **A** can form.



OR



[1]

[1]

(vi) Explain why the monomer drawn in part **(v)** can potentially form thermoset polymers.

The alkene group in the monomer can form covalent cross links

between monomer chains to form thermoset polymers. ..... [1]

[Total: 16]

5(a) Explain the decreasing trend in volatility down Group 17.

Down the group, number of electrons in the molecule increases.

Hence, the strength of instantaneous dipole-induced dipole attraction between X_2 molecules increases. Energy needed to overcome the stronger intermolecular forces increases.

Hence, volatility (ease of becoming gaseous form) decreases.

[2]

(b) Explain the decreasing thermal stability of the hydrides of Group 17.
Include data from the *Data Booklet* in your answer.

Bond energies / kJ mol^{-1}: H–Cl (431); H–Br (366); H–I (299).

Bond energy of H–X decreases, hence thermal stability decreases down the group.

[2]

(c) Write an ionic equation for the reaction when chlorine gas is bubbled into a solution of potassium iodide. State the colour change observed in the solution of potassium iodide.

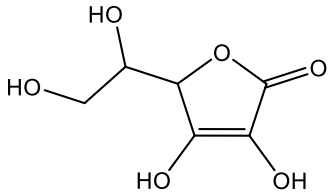
$Cl_2(g) + 2I^-(aq) \rightarrow 2Cl^-(aq) + I_2(aq)$

From colourless to brown

[2]

[Total: 6]

6 Vitamin C, also known as ascorbic acid, has the following structure:

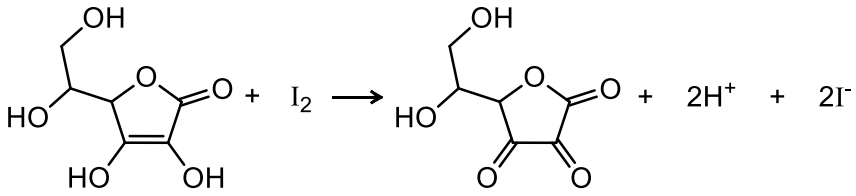


ascorbic acid

To determine the concentration of ascorbic acid in a typical Vitamin C tablet, an experiment known as *iodometric titration* is used. Firstly, ascorbic acid is reacted with a known amount of iodine that is present in excess. Ascorbic acid will reduce the brown iodine present to colourless iodide. Secondly, unreacted excess iodine is then titrated against a standard solution of sodium thiosulfate. Once the amount of sodium thiosulfate used is known, the amount of ascorbic acid present originally can then be determined.

To prepare a solution of ascorbic acid for the experiment, one 500 mg Vitamin C tablet is dissolved in sulfuric acid and diluted with deionised water up to 250 cm^3 mark in a standard flask. 25.0 cm^3 of this ascorbic acid solution is pipetted into a conical flask containing 3.00×10^{-4} mol of iodine solution (excess). Lastly, the resulting solution in the conical flask is immediately titrated with a standard sodium thiosulfate solution using a suitable indicator.

Reaction 1:
Iodine will oxidise ascorbic acid, $C_6H_8O_6$, to form dehydroascorbic acid:



ascorbic acid dehydroascorbic acid

Reaction 2:

The excess iodine will react with a standardised sodium thiosulfate solution.

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

It was found 12 cm^3 of 0.005 mol dm^{-3} sodium thiosulfate is required to react with iodine.

(a) With reference to the molecular structure of ascorbic acid, explain why ascorbic acid dissolves in water.

The presence of hydroxy(-OH) groups allows the formation of hydrogen-bonds between ascorbic acid molecules and water molecules. [1]

(b) Explain why **Reaction 2** is a redox reaction. Include oxidation numbers in your answer.

S is oxidised as the oxidation number increases from +2 in $S_2O_3^{2-}$ to +2.5 in $S_4O_6^{2-}$.

I is also reduced as the oxidation number decreases from 0 in iodine to -1 in I^-.

[2]

(c) (i) Calculate the amount of iodine that reacted with sodium thiosulfate.

Amount of thiosulfate reacted = (0.012)(0.005) = 6.00×10^{-5} mol

Amount of iodine reacted = ½ (6.00×10^{-5}) = 3.00×10^{-5} mol

[2]

(ii) Calculate the amount of iodine that reacted with 25 cm^3 of ascorbic acid solution.

Amount of iodine reacted with ascorbic acid

= $3.00 \times 10^{-4} - 3.00 \times 10^{-5}$

= 2.70×10^{-4} mol

[1]

(iii) Calculate the amount of ascorbic acid in the 250 cm^3 standard solution.

Amount of iodine reacted with ascorbic acid

= $2.70 \times 10^{-4} \times (250/25)$

= 2.70×10^{-3} mol

[1]

(iv) Determine the mass percentage of ascorbic acid in a 500 mg Vitamin C tablet (M_r of ascorbic acid is 176).

Mass of ascorbic acid = $(2.70 \times 10^{-3})(176) = 0.475$g

Mass % of ascorbic acid in Vitamin C tablet

= (0.475 / 0.500)*100

= 95.0%

[1]

(d) Suggest a reason why the resulting solution is *immediately* titrated and not allowed to stand for too long before titration.

The (excess) iodine is volatile and may easily vapourise on standing.

(This will result in a lower than expected titre value.) [1]

(e) Patients who have undergone surgery have been given vitamin C to promote wound healing. Concurrently, external medications with silver ions can also be applied to help prevent inflammation in their post-surgical wounds. Scientists studied the influence of silver nanoparticles on post-surgical wound healing and found that silver nanoparticles exhibited a much more positive effect on wound healing compared to conventional silver preparations.

(i) A silver cation, Ag^+, has an ionic **radius** of 1.29×10^{-10} m. Assume that the ions are placed side by side to form the diameter of the smallest spherical silver nanoparticle, calculate the minimum number of Ag^+ ions needed to form the nanoparticle.

Diameter of the smallest silver nanoparticle = 1×10^{-9} m

Diameter of $Ag^+ = 2(1.29 \times 10^{-10})$

No. of Ag^+ needed = $\frac{1 \times 10^{-9}}{2(1.29 \times 10^{-10})}$ = 3.88 = 4 ions

[1]

(ii) With reference to the surface to volume ratio, suggest why silver nanoparticles exhibit a much more positive effect on wound healing compared to conventional silver preparations.

Silver nanoparticles have **high surface to volume ratio.**

The **greater surface area of contact** releases **more silver ions** into the wound to bind to bacterial tissues and destroy them which leads to **faster wound healing**. [2]

[Total:12]

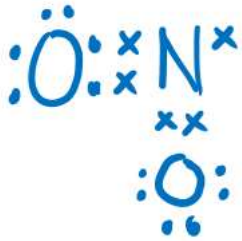
Section B

Answer **one** question in the spaces provided.

7 Dinitrogen tetroxide, N_2O_4 is a brownish yellow liquid which vaporises easily to form a pale yellow gas. It is one of the most important rocket propellants ever developed. N_2O_4 forms an equilibrium mixture with nitrogen dioxide, NO_2, a brown gas, according to the following equation.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \textbf{Equilibrium I}$$

(a) (i) Draw a dot-and-cross diagram to show the bonding in a molecule of NO_2. The molecule contains a dative covalent bond. The central atom is nitrogen which has a single non-bonded valence electron. Distinguish carefully between electrons originating from the central atom and those from the two outermost atoms.



[1]

(ii) State the shape of the NO_2 molecule.

Bent ..... [1]

(b) Calculate a value for the enthalpy change for the forward reaction in **Equilibrium I**. Relevant enthalpy changes are given in table 7.1 below.

Table 7.1

Thermochemical Equation	Enthalpy change / kJ mol^{-1}
½ $N_2(g)$ + $O_2(g)$ → $NO_2(g)$	+33.85
$N_2(g)$ + 2 $O_2(g)$ → $N_2O_4(g)$	+9.66

$\Delta H_r = \Sigma\Delta H_f$(products) - $\Sigma\Delta H_f$(reactants)
= (2 x 33.85) – (9.66)
= + 58.0 kJ mol^{-1}

[2]

(c) In an experiment, 0.5 mol of N_2O_4 was allowed to reach equilibrium in a reaction vessel at 50 °C at a pressure of 1 atm. When equilibrium was established, it was found that there were 0.35 mol of N_2O_4.

(i) Calculate the number of moles of NO_2 at equilibrium, showing your working clearly.

	$N_2O_4(g)$	⇌	$2\ NO_2(g)$
Initial /mol	**0.5**		**0**
Change / mol	**–0.15**		**+2(0.15)**
Eqm / mol	**0.35**		**0.3**

[2]

(ii) Given that the reaction was carried out in a vessel that was 2 dm^3, determine the equilibrium concentrations of N_2O_4 and NO_2. [1]

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$ **Equilibrium I**

(iii) Write the K_c expression for **Equilibrium I**.

$$K_c = \frac{[NO_2]^2}{[N_2O_4]}$$

[1]

(iv) Using the expression in **(iii)** and your answers in **(ii)** determine the value of K_c for this reaction at 50 °C. Show your working clearly.

$$K_c = \frac{[NO_2]^2}{[N_2O_4]}$$

$$= \frac{(\frac{0.3}{2})^2}{(\frac{0.35}{2})}$$ **[1, ecf]**

= 0.129 mol dm^{-3}

[1]

(v) The initial experiment in **(c)** was repeated at a higher pressure of 2 atm and 50 °C.

I Using Le Chatelier's Principle, predict the effect, if any, on the **equilibrium constant** and **equilibrium composition** of **Equilibrium I**; and

II State any observations made in terms of colour changes.

There is no change in the equilibrium constant because the temperature remains unchanged.

When the pressure is increased, the system will respond by decreasing the number/amount of gas molecules. Hence, the equilibrium position will shift to the left and there will be more N_2O_4 produced and less NO_2 formed.

The mixture becomes paler/turns from brown to yellow.

[4]

(d) NO_2 reacts with oxygen and water to produce nitric acid, HNO_3, according to the following equation:

$$2NO_2(g) + ½O_2(g) + H_2O(l) \rightarrow 2HNO_3(aq)$$

(i) Nitric acid is a strong acid. Define the term *strong acid*.

A proton donor that completely dissociates in water. [1]

(ii) Calculate the pH value of a 0.0250 mol dm^{-3} solution of dilute nitric acid.

$[H^+] = 0.0250$ mol dm^{-3}
pH = –lg (0.0250) = 1.60

[2]

(iii) A student suggests that "a 0.0250 mol dm^{-3} solution of both dilute sulfuric (VI) acid, H_2SO_4, and nitric acid, HNO_3, will give the same pH value, because both are strong acids".

Justify, with relevant calculations of pH, if the student is correct to make that statement.

The student is incorrect to make that statement.
For H_2SO_4, $[H^+] = 2 \times 0.0250 = 0.0500$ mol dm^{-3}
pH = –lg (0.0500) = 1.30

[2]

(iv) State and explain which indicator would be suitable for the neutralisation of nitric acid and aqueous ammonia.

Methyl orange Indicator gives a distinct colour change in the pH range that coincides with the range of rapid pH change of the titration. [2]

[Total: 20]

8(a) (i) Phosphorus compounds are commonly used in commercial products. One example is calcium phosphide, Ca_3P_2, which is used in fireworks.

With reference to structure and bonding, explain the difference in melting point between Ca_3P_2 and elemental phosphorus, P.

Ca_3P_2 has a giant ionic structure with strong electrostatic forces of attraction between oppositely charged ions.

P (or P_4) has a simple molecular structure with weak instantaneous dipole – induced dipole forces of attraction between molecules.

Ca_3P_2 has a higher melting point since more energy is needed to break the strong ionic bonds compared to the weaker instantaneous dipole – induced dipole forces of attraction.

[3]

(ii) When beams of Ca^{2+} and P^{3-} are travelling at the same speed, through an electric field of constant strength, the angle of deflection is proportional to their charge/mass ratio.

Given that Ca^{2+} deflects at an angle of $+x^o$ (where the positive sign indicates the direction of deflection), calculate the angle at which P^{3-} deflects.
Your answer must be in terms of x and have the appropriate sign to indicate the direction of deflection.

Angle of deflection of $Ca^{2+} = +k\left(\frac{2}{40.1}\right) = +x$

Which means, the constant k = $\left(\frac{40.1}{2}\right)x$

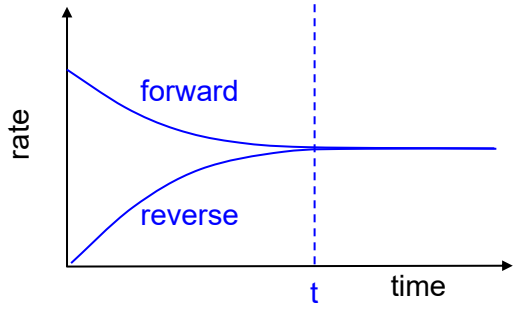
Angle of deflection of $P^{3-} = -k\left(\frac{3}{31.0}\right) = -\left[\left(\frac{40.1}{2}\right)x\right]\left(\frac{3}{31.0}\right) = -1.94x$

[1]

(b) (i) When gaseous PCl_5 is heated in a closed container, the following equilibrium is established.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

Sketch, on the same axis below, two graphs that show how the rate of forward and reverse reactions vary over time. Label your graphs clearly and indicate *t*, the time when equilibrium was established.



[1]

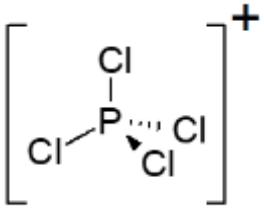
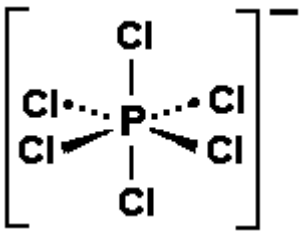
(ii) Describe the reaction of PCl_5 with water.
Include a balanced equation in your answer.

PCl_5 dissolves vigorously in water and is **hydrolysed completely** to give acidic solution (pH 2) with the evolution of HCl gas.

$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$

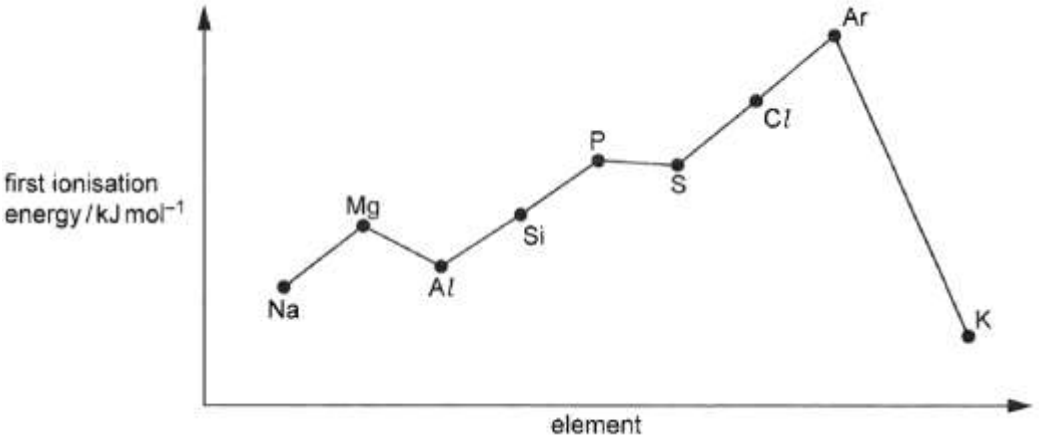
[2]

(iii) PCl_5 dissolves in some polar solvents without reacting with them. Such solutions conduct electricity. This is due to the presence of the two ions $[PCl_4]^+$ and $[PCl_6]^-$. Draw the structures and suggest the shapes of **each** of these ions.

Structure of $[PCl_4]^+$	Structure of $[PCl_6]^-$
	
Shape of ion: Tetrahedral	Shape of ion: octahedral

[4]

(c) The first ionisation energies for the elements sodium to potassium are shown in the graph below:



(i) Write an equation to represent the first ionisation energy of phosphorus.

P(g) → P+(g) + e⁻

..... [1]

(ii) Explain why the first ionisation energy of phosphorus is higher than that of

- silicon

P has a higher nuclear charge and smaller atomic size than Si. Since outer electrons in phosphorus are more strongly attracted to the positive nucleus, more energy is required to remove the electron and the first ionisation energy is higher for phosphorus as compared to silicon.

..... [2]

- sulfur. (Give suitable electronic configurations to support your answer.)

P: $1s^2\ 2s^2 2p^6\ 3s^2 3p_x^1 3p_y^1 3p_z^1$ S: $1s^2\ 2s^2 2p^6\ 3s^2 3p_x^2 3p_y^1 3p_z^1$

There are two electrons in S which occupies the $3p_x$ orbital / paired electrons in S which gives rise to inter-electron repulsion. Therefore, less energy is required to remove an electron from the paired 3p electrons in S as compared to P.

..... [2]

(d) (i) Calculate the pH of 1.50 x 10^{-3} mol dm^{-3} phosphoric acid, H_3PO_4 (aq). Assume phosphoric acid behaves as a strong tribasic (triprotic) acid.

H_3PO_4 → $3H^+ + PO_4^{3-}$

Amt of H^+ present = 3 x 1.50 x 10^{-3} = 4.50 x 10^{-3}

pH = –lg(4.50 x 10^{-3}) = 2.34 [2]

In reality, phosphoric acid is a weak tribasic acid. It dissociates into PO_4^{3-} in the three steps shown below.

Step 1: H_3PO_4 (aq) ⇌ $H_2PO_4^-$ + H^+ K_{a1} = 7.25 × 10^{-3} mol dm^{-3}

Step 2: $H_2PO_4^-$ (aq) ⇌ HPO_4^{2-} + H^+ K_{a2} = 6.31 × 10^{-8} mol dm^{-3}

Step 3: HPO_4^{2-} (aq) ⇌ PO_4^{3-} + H^+ K_{a3} = 4.80 × 10^{-13} mol dm^{-3}

(ii) Write an expression for the first acid dissociation constant of phosphoric acid, K_{a1}.

$$K_{a1} = \frac{[H_2PO_4^-][H^+]}{[H_3PO_4]}$$ [1]

(iii) From the information given above in the three steps, state the weakest acid.

The weakest acid is HPO_4^{2-}. (since K_{a3} is the smallest, showing that the position of equilibrium for dissociation of HPO_4^{2-} lies more on the left hand side. Hence it is the poorest proton donor.) [1]

[Total: 20]