Name: ( )	Class: 25S0_____

H

RAFFLES INSTITUTION
2024 YEAR 5 PROMOTION EXAMINATION

Higher 2

CHEMISTRY

9729

24 September 2024

2 hours 30 minutes

Additional Materials: Multiple Choice Answer (OMR) Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, 6-digit exam index number and class in the spaces provided on the OMR sheet and the cover sheets on **pages 1 and 19**. Shade your 6-digit exam index number on the OMR sheet.

This paper consists of three sections, **A**, **B** and **C**.

Section A (15 marks) consists of 15 multiple-choice questions.
Answer this section first. The OMR sheet will be collected after the **first 30 minutes**.
For each question there are four possible answers **A**, **B**, **C** and **D**. Choose the **one** you consider correct and record your choice in **soft pencil** on the OMR sheet. Each correct answer will score one mark. A mark will not be deducted for a wrong answer. Any rough working should be done in the question paper.

Section B (35 marks) consists of 3 structured questions.
Answer **all** questions in the spaces provided in the question paper. If additional space is required, you should use the page at the end of the booklet for Section B (page 18). The question number must be clearly shown.

Section C (40 marks) consists of 3 free-response questions.
Answer **all** questions in the spaces provided in the question paper. If additional space is required, you should use the pages at the end of the booklet for Section C (pages 31 – 32). The question number must be clearly shown.

Write in dark blue or black pen. You may use a HB pencil for any diagrams or graphs.

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

The use of an approved scientific calculator is expected, where appropriate.

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

For Examiner's Use Only	
B1	**/ 14**
B2	**/ 13**
B3	**/ 8**

This document consists of **32** printed pages.

Section A (15 marks)

For each question, there are four possible answers, **A**, **B**, **C**, and **D**. Choose the **one** you consider to be correct.

1 A sample of neon gas was found to contain a mix of three different isotopes, ^{20}Ne, ^{21}Ne and ^{22}Ne. The information in the table was obtained by analysis of the sample.

species	^{20}Ne	^{21}Ne	^{22}Ne
% abundance	60.9	1.2	37.9

Which A_r value for neon is given by these figures?

A 20.2 **B** 20.5 **C** 20.8 **D** 21.0

2 When a sample of hydrocarbon, C_xH_y, was combusted in an excess of oxygen, 0.06 mol of carbon dioxide and 0.04 mol of water were obtained.

What could be the values of *x* and *y*?

	x	*y*
A	3	6
B	6	10
C	6	12
D	9	12

3 *Use of the Data Booklet is relevant to this question.*

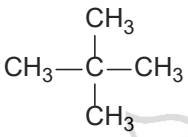
W, X and Y are isotopes of three different elements. An isotope of strontium, a Group 2 element, has a nucleon number of 84 and the same number of neutrons in the nucleus as each of the isotopes W, X and Y.

The species Sr^{2+}, W, X^- and Y^{2-} all contain the same number of electrons.

What are the nucleon numbers of W, X and Y?

	W	X	Y
A	80	81	82
B	82	81	80
C	82	83	84
D	84	83	82

4 In which pair of substances is the boiling point of the first substance higher than that of the second substance?

	first substance	second substance
A	K	Na
B	CO_2	SiO_2
C		
D		$CH_3CH_2CH_2CH_2CH_3$

5 Which statement is correct about the ethanoate ion, CH_3COO^-?

A It is a planar ion.

B The π electrons are delocalised over all atoms.

C The two carbon−oxygen bonds have different bond lengths.

D The H−C−H bond angle is smaller than the C−C−O bond angle.

6 The standard enthalpy change of combustion of methane is −890 kJ mol^{-1}.

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$$

Values of the relevant average bond energies are given in the table.

	average bond energy / kJ mol^{-1}
C−H	410
C=O	805
O−H	460
O=O	496

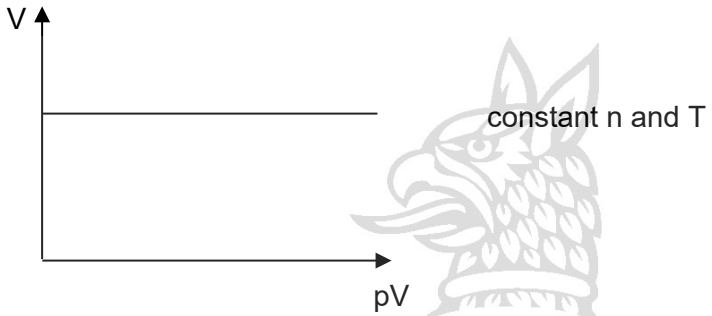
What is the value for the standard enthalpy change of vaporisation of water?

$$H_2O(l) \longrightarrow H_2O(g)$$

A −72 kJ mol^{-1} **B** −36 kJ mol^{-1} **C** +36 kJ mol^{-1} **D** +72 kJ mol^{-1}

7 Which graph about the behaviour of an ideal gas is correct?

A



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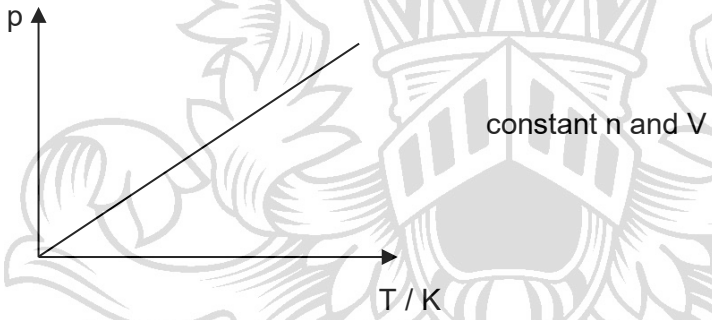

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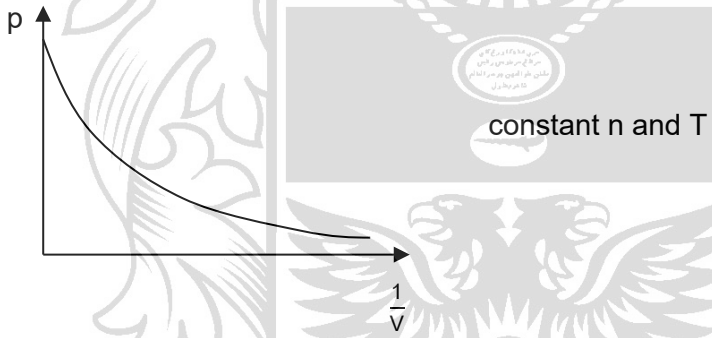
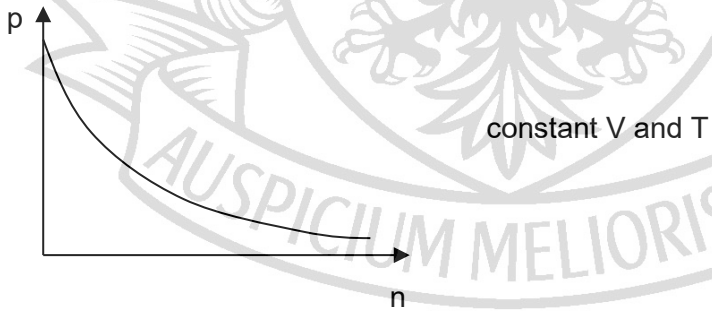


D



8 Which equation correctly represents the lattice energy of sodium oxide?

A $2Na(s) + \frac{1}{2}O_2(g) \longrightarrow Na_2O(s)$

B $2Na^+(g) + O^{2-}(g) \longrightarrow Na_2O(s)$

C $Na_2O(s) \longrightarrow 2Na^+(g) + O^{2-}(g)$

D $Na_2O(s) \longrightarrow 2Na(g) + O(g)$

9 The equation below shows the decomposition of magnesium carbonate.

$$MgCO_3(s) \longrightarrow MgO(s) + CO_2(g) \qquad \Delta H^{\ominus} = +118 \text{ kJ mol}^{-1}$$

Which statement is correct for this reaction?

A The reaction is only spontaneous at high temperatures.

B The reaction is only spontaneous at low temperatures.

C The reaction is not spontaneous at all temperatures.

D The reaction is spontaneous at all temperatures.

10 The kinetics of the reaction between I^- and $S_2O_8^{2-}$ ions can be investigated by varying the volume of the reactants used. The two reactants are mixed in the presence of $Na_2S_2O_3$ and starch solution.

$$S_2O_8^{2-}(aq) + 2I^-(aq) \longrightarrow 2SO_4^{2-}(aq) + I_2(aq)$$

When all the $Na_2S_2O_3$ has reacted with the I_2 produced, an intense blue colour will be observed. The time taken for the blue colour to appear is recorded.

experiment	volume used / cm^3				time / s
	1.0 mol dm^{-3} I^-	0.080 mol dm^{-3} $S_2O_8^{2-}$	1.0 mol dm^{-3} $S_2O_3^{2-}$	H_2O	
1	10.0	5.0	2.0	23.0	85.0
2	20.0	5.0	2.0	13.0	42.5
3	10.0	15.0	2.0	13.0	28.5
4	40.0	20.0	4.0	16.0	?

What is the time taken, in seconds, for the intense blue colour to be observed for experiment 4?

A 5.3 **B** 10.6 **C** 21.3 **D** 42.5

11 Phosgene can be synthesised via the following reaction.

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

The proposed mechanism for the reaction is given below.

step 1	$Cl_2 \rightleftharpoons 2Cl$	(fast)
step 2	$CO + Cl \longrightarrow COCl$	(slow)
step 3	$COCl + Cl \longrightarrow COCl_2$	(fast)

Which conclusions can be drawn from this information?

1 Overall order of reaction is 1.5.

2 An increase in the partial pressure of Cl_2 will decrease the reaction rate.

3 The units for the rate constant of the reaction is the same as the units of the equilibrium constant of step 1.

A 1 only **B** 1 and 2 **C** 1 and 3 **D** 2 and 3

12 When an equimolar mixture of $H_2(g)$ and $I_2(g)$ react, the mole fraction of HI(g) in the final mixture is $2x$.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

What is the equilibrium constant, K_p, for the reaction?

A $\dfrac{4x^2}{(1-x)^2}$ **B** $\dfrac{16x^2}{(1-x)^2}$

C $\dfrac{4x^2}{(1-2x)^2}$ **D** $\dfrac{16x^2}{(1-2x)^2}$

13 In a reaction vessel, N_2 and H_2 are allowed to react to form NH_3, as shown in the equation below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

Which change to the conditions will increase the rate of formation of NH_3 **and** increase the percentage composition of NH_3 in the mixture?

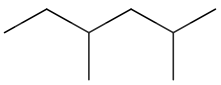
A adding iron catalyst

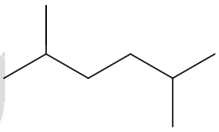
B decreasing the temperature

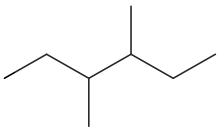
C reducing the total volume at constant temperature

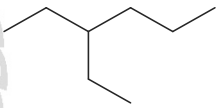
D adding argon to the mixture but keeping the total volume constant

14 Which molecule has only one chiral centre?

A 

B 

C 

D 

15 The two compounds, E and F, have the following structures.

E F

Which statements are correct?

1 Both molecules are polar.
2 E and F are constitutional isomers.
3 Both compounds can rotate plane-polarised light.

A 2 only **B** 1 and 2 **C** 1 and 3 **D** 2 and 3

Section B (35 marks)

This section consists of **3** questions.
Answer **all** the questions in this section in the spaces provided.

1 The kinetics of the reaction between **A** and **B** are studied.

$$\mathbf{A}(g) + \mathbf{B}(g) \longrightarrow \mathbf{C}(g)$$

To determine the rate equation for this reaction, two separate experiments were carried out in a vessel of fixed volume with initial concentrations of **A** and **B** as shown below.

experiment	1	2
initial [**A**(g)] / mol dm^{-3}	0.12	0.12
initial [**B**(g)] / mol dm^{-3}	2.00	1.00

For each experiment, the concentration of **C** was determined at regular time intervals as the reaction progressed.

Fig. 1.1 shows the results of experiments 1 and 2.

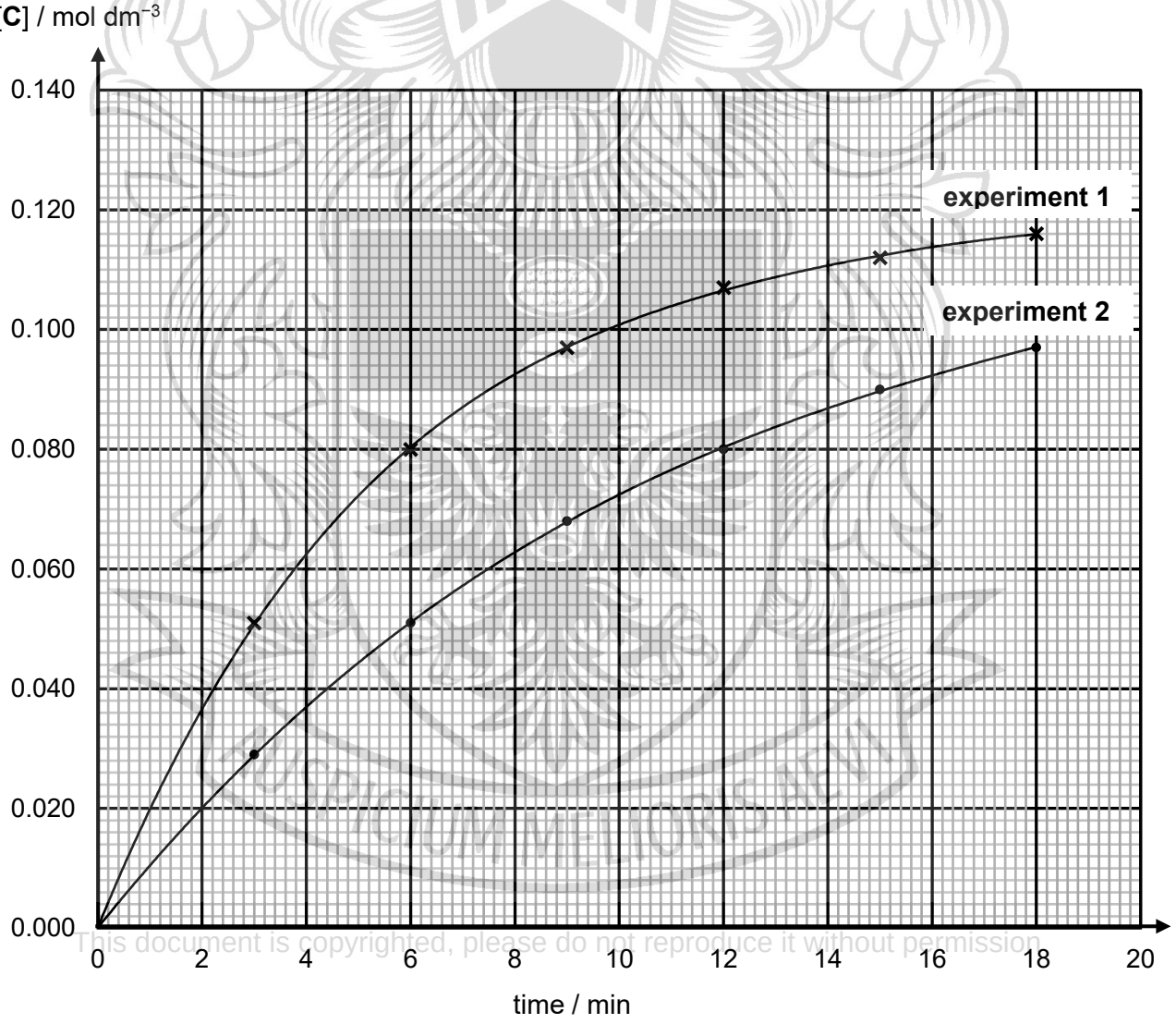


Fig. 1.1

(a) **(i)** Explain why **B** was used in large excess.

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…… [1]

(ii) Determine the final concentration of **C** if the reaction were to go to completion.

Hence, show that the order of reaction with respect to **A** is one, showing your working clearly.

[3]

(iii) Using the graphs in Fig. 1.1, determine the order of reaction with respect to **B**, showing your working clearly.

[2]

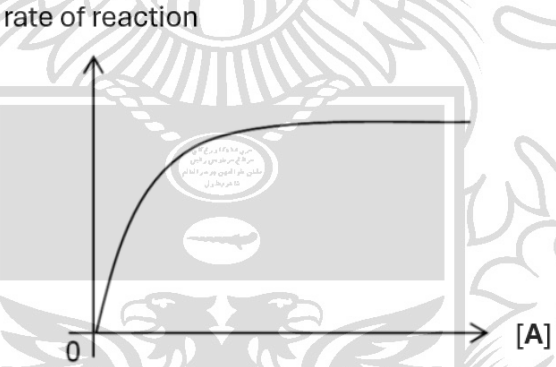
(iv) Hence, write the rate equation for the reaction between **A** and **B**.

……. [1]

(v) Calculate the rate constant for the reaction and state its units.

[2]

(b) The same reaction was carried out with the addition of a small amount of heterogeneous catalyst. The rate of reaction was measured at different initial concentrations of **A** and the following graph was obtained.



Account for the shape of the graph.

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……[2]

(c) With an appropriate sketch of the Boltzmann distribution, explain how an increase in temperature can cause an increase in the rate of reaction.

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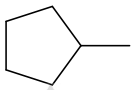
……[3]

[Total: 14]

2 Methylcyclopentane is a colourless, flammable liquid with a faint odour.



methylcyclopentane

(a) Suggest two reasons why methylcyclopentane is generally unreactive.

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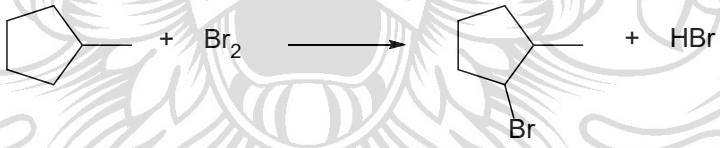
……[2]

(b) However, in the presence of ultraviolet light, methylcyclopentane undergoes bromination to form a mono-brominated product, as shown below.



(i) Use equations to describe the steps in the mechanism for this reaction.

[3]

(ii) The mechanism in **(b)(i)** can produce other isomeric mono-brominated alkanes.

Draw the structure of one such isomer that does not rotate plane polarised light and give its systematic name.

structure of isomer

systematic name: ..... [2]

(c) Cyclopenta-1,3-diene is a colourless liquid with an irritating, terpene-like odour.

cyclopenta-1,3-diene

(i) Complete Table 2.1 which describes the total number of σ bonds and π bonds in cyclopenta-1,3-diene.

Table 2.1

bond type present	total number of each bond type
σ	
π	

[1]

(ii) Cyclopenta-1,3-diene reacts with an excess of hot acidified concentrated $KMnO_4$ to produce an organic product.

Draw the skeletal structure of this organic product in the box below.

organic product

[1]

(d) Cyclopentene reacts with bromine to form different products depending on the conditions.

Fig. 2.2 shows two reactions of cyclopentene.

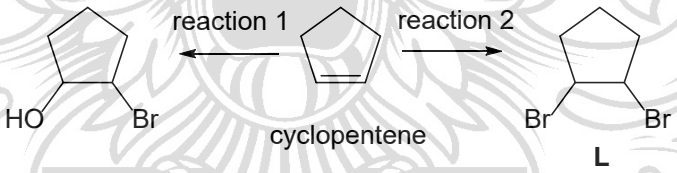


Fig. 2.2

(i) State the type of reaction cyclopentene undergoes as shown in Fig. 2.2.

……[1]

(ii) State the reagents and conditions for reactions 1 and 2.

reaction 1: .....

reaction 2: .....

[1]

(iii) Explain whether **L** can exhibit cis-trans isomerism.

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……[2]

[Total: 13]

3 A manufacturing company claims that their colourless health syrup contains 90 mg of vitamin C per 10 cm^3 serving. The molecular formula of vitamin C is $C_6H_8O_6$, which has a relative molecular mass of 176.0.

You are to plan an experiment to determine the exact mass of vitamin C in a serving of the syrup. The technique used in this experiment is known as *back titration*. Using this technique, a known amount of aqueous iodine is added to the syrup. The iodine reacts with the vitamin C in the syrup as shown in equation 1.

equation 1 $$I_2 + \underset{\text{vitamin C}}{C_6H_8O_6} \longrightarrow 2I^- + 2H^+ + C_6H_6O_6$$

The amount of iodine must be sufficient to react with the maximum possible amount of vitamin C present in the syrup, and also leave a small excess of iodine. You may assume that vitamin C is the only substance in the syrup which reacts with iodine.

To determine the amount of unreacted iodine, the final reaction mixture is first diluted with deionised water in a 250 cm^3 volumetric flask. Next, 25.0 cm^3 of the diluted mixture is titrated against aqueous sodium thiosulfate of known concentration. The reaction between iodine and sodium thiosulfate is shown in equation 2.

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

From the titre values, the mass of vitamin C in a serving of the syrup can be calculated.

You may assume that you are provided with:

- a 10 cm^3 serving of the health syrup in a 100 cm^3 beaker
- 0.10 mol dm^{-3} iodine, I_2
- 0.010 mol dm^{-3} sodium thiosulfate, $Na_2S_2O_3$
- starch solution
- deionised water
- the equipment normally found in a school or college laboratory.

(a) (i) Calculate the amount of iodine that will react with the vitamin C in the 10 cm^3 serving of health syrup. Assume that the serving contains 90 mg of vitamin C.

[1]

(ii) Calculate the volume of aqueous iodine to be added to the 10 cm^3 serving of health syrup such that suitable titre values of sodium thiosulfate can be obtained.

[2]

(b) Plan a procedure to determine the exact mass of vitamin C in the 10 cm^3 serving of health syrup.

In your plan, you should include details of:

- the apparatus you would use,
- the procedure you would follow to:
  - dilute the final reaction mixture
  - titrate the diluted reaction mixture against sodium thiosulfate
- the measurements you would make

It is **not** necessary to show how the mass of vitamin C can be calculated from the obtained titre values.

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For examiner's use only

(c) A student left the beaker containing the health syrup exposed to the air for a long period of time before conducting the experiment.

Explain how this might cause the titre values to be higher than if the health syrup had not been exposed to the air.

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………[1]

[Total: 8]

Additional answer space

If you use the following page to complete the answer to any question, the question number must be clearly shown.

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RAFFLES INSTITUTION
2024 YEAR 5 PROMOTION EXAMINATION

Higher 2

C

CANDIDATE NAME

CLASS | INDEX NUMBER

CHEMISTRY 9729

24 September 2024

Section		Marks
A		/ 15
B	B1	/ 14
	B2	/ 13
	B3	/ 8
C	C1	/ 17
	C2	/ 10
	C3	/ 13
Total		/ 90
Percentage		/ 100
Penalty		
Overall		/ 100

Section C (40 marks)

This section consists of **3** questions.
Answer **all** the questions in this section in the spaces provided.

1 In the body, cellular respiration produces energy from the oxidation of glucose, which in turn produces adenosine triphosphate (ATP), the energy currency in the cell.

(a) An experiment was carried out to determine the energy produced per mole of glucose. A calorimeter, with heat capacity of 893 J K^{-1}, contains 775 g of water. 3.12 g of glucose, $C_6H_{12}O_6$, was burnt and the temperature of both the calorimeter and water increased from 30.6 °C to 42.4 °C.

(i) Define the term *standard enthalpy change of combustion of glucose, $C_6H_{12}O_6(s)$.* [1]

(ii) Using data from the Data Booklet and data from above, calculate the amount of heat produced by the combustion of the glucose sample, and hence determine the enthalpy change of combustion of glucose (M_r = 180.0). [3]

(iii) The theoretical value of the standard enthalpy change of combustion of glucose is –2900 kJ mol^{-1}.

Suggest a reason why your answer in **(a)(ii)** differs from the theoretical value. [1]

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(b) The reaction scheme in Fig. 1.1 below shows how adenosine-5'-triphosphate (ATP) is hydrolysed (in reaction 1) to release energy in the cell, forming adenosine diphosphate (ADP) and phosphate ion, which are then converted back (in reaction 2) to ATP.

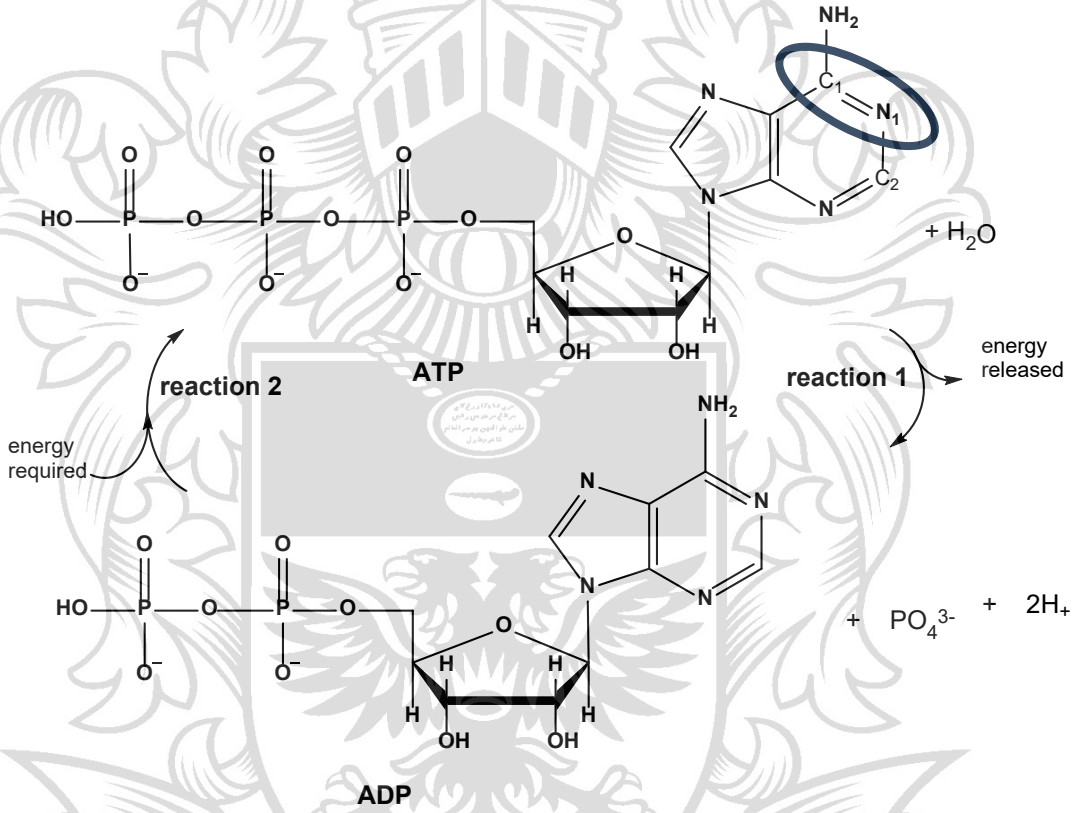

Fig. 1.1

(i) Draw a dot-and-cross diagram of the PO_4^{3-} ion and explain its shape using the Valence Shell Electron Pair Repulsion theory. [3]

(ii) By considering your answer in **(b)(i)**, suggest the hybridisation of the orbitals in the phosphorus atom of PO_4^{3-} and draw a labelled diagram to show the hybrid orbitals. [2]

(iii) State and explain if the circled bond between C_1 and N_1 in ATP is shorter, longer or the same as that between C_2 and N_1. [1]

(iv) Suggest a reason why ATP is relatively unstable and tends to give away its phosphate group to become ADP. [1]

(c) Phosphorus is a building block for ATP. Sodium phosphate, Na_3PO_4, is a common additive to food.

Table 1.1 shows the values of some enthalpy changes.

Table 1.1

	value / kJ mol^{-1}
lattice energy of Na_3PO_4(s)	–3907
standard enthalpy change of formation of Na_3PO_4(s)	–1936
standard enthalpy change of atomisation of Na(s)	+107

(i) Write an equation to represent the *standard enthalpy change of formation of PO_4^{3-}(g)*. [1]

(ii) Using the data in Table 1.1, together with data from the Data Booklet, draw an energy level diagram, and hence calculate the standard enthalpy change of formation of PO_4^{3-}(g). [4]

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[Total: 17]

2 To study the ionisation energy of an element, a sample of the element is first vapourised in a vacuum chamber and then transferred into an ionisation chamber, where a potential difference is applied.

(a) In the first stage of the experiment, element **M** was vapourised at 1200 °C in a 2 dm^3 vacuum chamber. The resultant pressure is *P* bar.

For safety reasons, the pressure in the chamber should not be greater than 50 bar.

(i) Calculate the maximum safe amount of **M** that can be initially placed into the vacuum chamber. [1]

(ii) The vapour is then completely channelled into a 5 dm^3 evacuated ionisation chamber at the same temperature.

Find the pressure of the gas in the ionisation chamber. Express your answer in terms of *P* bar. [1]

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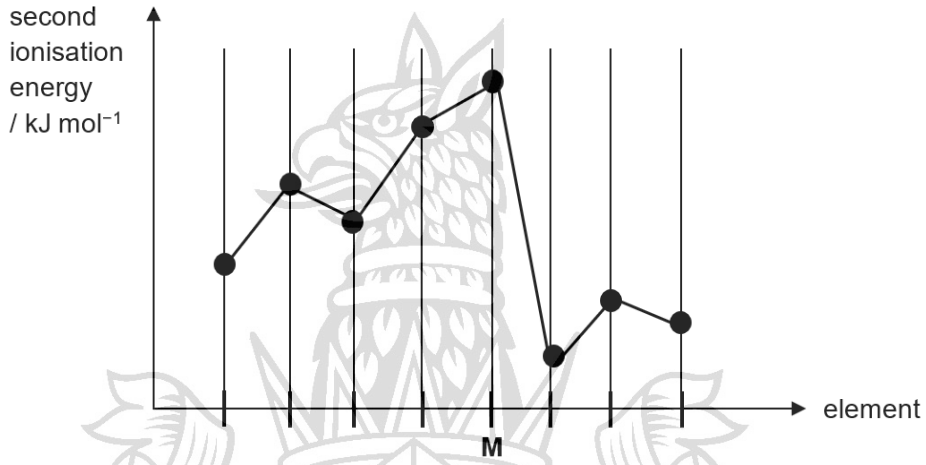
(b) **(i)** State the two main assumptions of the kinetic theory as applied to an ideal gas. [2]

(ii) Sketch the pV vs p graph for 1 mol of ideal gas at constant temperature. [1]

(iii) **M**(g) can be ionised to give $\mathbf{M}^+$(g).

Using the same axes in **(b)(ii)**, sketch the pV vs p graph for 1 mol of $\mathbf{M}^+$(g) at constant temperature and explain your answer. Label your graph appropriately. [2]

(c) The following diagram shows the second ionisation energies of eight consecutive elements in the Periodic Table, including element **M**. The atomic numbers of these elements are less than 20.



(i) Identify element **M**. [1]

(ii) Sketch the trend of successive ionisation energies for the first seven electrons of **M**. [2]

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[Total: 10]

3 When copper(II) sulfate is heated to 720 K, it decomposes to copper(II) oxide and sulfur trioxide. With further heating to 1050 K, sulfur trioxide converts to sulfur dioxide and oxygen.

The equations for the above two reversible reactions and the values of their equilibrium constants, K_c, at 1050 K are shown in Table 3.1.

Table 3.1

reaction	equation	value of K_c at 1050 K
1	$CuSO_4(s) \rightleftharpoons CuO(s) + SO_3(g)$	1.38×10^{-3}
2	$SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}O_2(g)$	y

(a) A sample of $CuSO_4(s)$ was introduced into a 0.5 dm^3 sealed vessel. Reactions 1 and 2 take place and the system is allowed to reach equilibrium at 1050 K.

At equilibrium, the total mass of the solids in the vessel was found to have decreased by 0.400 g.

(i) Write an expression for K_c for reaction 1 and state its units. [2]

(ii) Hence, calculate the mass of $SO_3(g)$ at equilibrium. [2]

(iii) Calculate the total mass of $SO_2(g)$ and $O_2(g)$ at equilibrium.

If you were unable to obtain a value in **(a)(ii)**, you may use the value of 0.0400 g. This is **not** the correct answer. [1]

(iv) Calculate the equilibrium amount of $SO_2(g)$ as well as that of $O_2(g)$. [2]

(v) Write the expression for K_c for reaction 2.

Using your answers in **(a)(iv)**, calculate the value of K_c, y, for reaction 2 at 1050 K. [2]

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(b) SO_3 is a liquid while SO_2 is a gas at room temperature and pressure.

Explain, in terms of structure and bonding, why the boiling point of SO_3 is higher than that of SO_2. [2]

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(c) The melting point of SO_2 is 201 K and the boiling point is 263 K.

Sketch a graph to show how the entropy of SO_2 changes between 0 K and 300 K.

Explain your reasoning. [2]

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[Total: 13]

Additional answer space

If you use the following page to complete the answer to any question, the question number must be clearly shown.