| Name: ( ) | Class: 23S0____ |
|---|---|

H

**RAFFLES INSTITUTION**
**2022 Year 5 Promotion Examination**

**HIGHER 2**

# CHEMISTRY 9729

**28 September 2022**
**2 hours 30 minutes**

Additional Materials: Multiple Choice Answer Sheet
Data Booklet

**READ THESE INSTRUCTIONS FIRST**

Write your name, 6-digit index number and civics tutorial group in the spaces provided on the OMR sheet and the cover sheets on pages **1** and **23**. Shade in your 6-digit exam index number on the OMR Answer 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. Your OMR Answer Sheet will be collected after the first 30 minutes. Record your answers to this section in soft pencil on the OMR Answer Sheet.

**Section B (35 marks) consists of 2 structured questions.**
Answer all questions. Answers to this section are to be written in the spaces provided in the question paper.

**Section C (40 marks) consists of 3 free-response questions.**
Write your answers in the spaces provided in the question paper. If additional space is required, you should use page 35 at the end of the booklet for Section C. The question number must be clearly shown.

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

Write in dark blue or black pen. You may be subject to penalty for writing answers in pencil.

Answers to Sections **B** and **C** are to be handed in **separately**.

| Question | Marks |
|---|---|
| B1 | / 19 |
| B2 | / 16 |

## 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** An equimolar mixture of $CS_2$ and $H_2S$ is completely burned in excess oxygen.

What will be the $SO_2$ : $CO_2$ mole ratio in the mixture obtained after complete combustion?

**A** 1 : 1 **B** 2 : 1 **C** 3 : 1 **D** 4: 1

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

An ion has
- a nucleon number of 267,
- 60 more neutrons than electrons,
- an atomic number of 104, 105, 106 or 107.

What could this ion be?

**A** $Rf^{2+}$ **B** $Db^{3+}$ **C** $Sg^{4+}$ **D** $Bh^{5+}$

**3** The ionisation energies (I.E.), in kJ $mol^{-1}$, of five elements are given in the table.

| | 3rd I.E. | 4th I.E. | 5th I.E. |
|---|---|---|---|
| O | 5320 | 7450 | 10990 |
| F | 6040 | 8410 | 11023 |
| Ne | 6150 | 9290 | 12177 |
| Na | 6940 | 9540 | 13354 |
| Mg | 7740 | 10500 | 13636 |

Which statement is correct?

**A** The 3rd I.E. of Na is higher than that of Ne because $Na^{2+}$ has one more shell than $Ne^{2+}$.

**B** The 4th I.E. of the above elements involves the removal of an electron from the same sub-shell.

**C** The 5th I.E. of F is higher than that of O because $F^{4+}$ has more outer shell electrons than $O^{4+}$.

**D** The successive I.E. of these elements increase because the nuclear charge increases.

**4** The table identifies the shape and polarity of four molecules.

Which row is correct?

| | molecule | molecular shape | polarity |
|---|---|---|---|
| **A** | nitrogen trifluoride | trigonal planar | polar |
| **B** | difluoromethane | tetrahedral | non-polar |
| **C** | sulfur dioxide | linear | polar |
| **D** | phosphorus pentachloride | trigonal bipyramidal | non-polar |

**5** Which statements are correct?

1 $NaHF_2$ forms hydrogen bonds with water molecules.

2 $H_2O_2$ forms more extensive hydrogen bonds than $N_2H_2$.

3 $SF_4$ molecules form permanent dipole–permanent dipole interactions with polar molecules.

4 The interactions between $CH_3(CH_2)_{17}OH$ molecules are predominantly instantaneous dipole–induced dipole interactions.

**A** 1, 2 and 3 are correct.

**B** 2, 3 and 4 are correct.

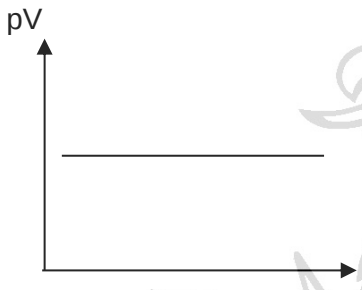
**C** 1 and 2 are correct.

**D** 3 and 4 are correct.

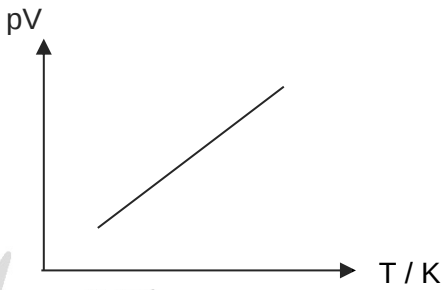
**6** A fixed mass of gas is placed in a cylinder with a moveable piston and subjected to different temperatures above the boiling point at constant pressure. Under these experimental conditions, the gas exhibits deviation from ideal gas behaviour.

Which graph correctly describes the behaviour of the gas?

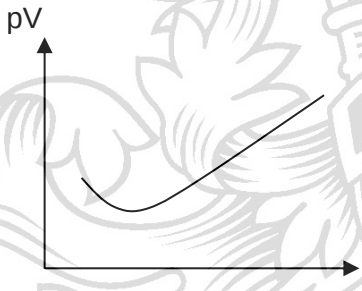
**A**



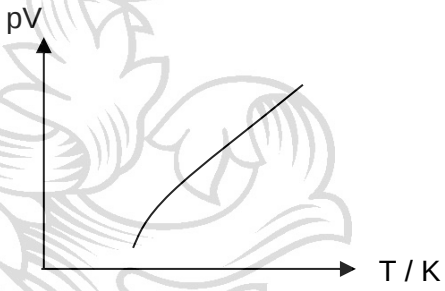

**B**




**C**




**D**




**7** In an experiment to measure the enthalpy change of neutralisation for the reaction between $H_2SO_4$ and NaOH, 20 $cm^3$ of a solution containing 0.04 mol of $H_2SO_4$ is placed in a plastic cup of negligible heat capacity.

A 20 $cm^3$ sample containing 0.04 mol of NaOH, at the same initial temperature, is added and the temperature rises by 14 K.

If the specific heat capacity of the final solution is 4.2 J $K^{-1}$ $cm^{-3}$, what is the enthalpy change of neutralisation for the reaction between $H_2SO_4$ and NaOH?

**A** $-2.35$ kJ $mol^{-1}$ **B** $-29.4$ kJ $mol^{-1}$

**C** $-58.8$ kJ $mol^{-1}$ **D** $-118$ kJ $mol^{-1}$

**8** Which statements help to explain why magnesium and chlorine react to form $MgCl_2$ rather than MgCl?

1 The $Mg^{2+}(g)$ ion is more stable than the $Mg^{+}(g)$ ion.

2 The lattice energy of $MgCl_2$ is more negative than the lattice energy of MgCl.

3 The standard enthalpy change of formation of $MgCl_2$ is more negative than that of MgCl.

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

**C** 2 and 3 only **D** 1, 2 and 3

**9** Some thermodynamic data for the reaction between $SO_2(g)$ and $O_2(g)$ are given.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H_r^{\ominus} = -197 \text{ kJ mol}^{-1}, \quad \Delta S_r^{\ominus} = -189 \text{ J K}^{-1} \text{ mol}^{-1}$$

$T_0$ is the temperature, in Kelvin, at which the forward reaction becomes spontaneous.

Assuming $\Delta H_r^{\ominus}$ and $\Delta S_r^{\ominus}$ do not change with temperature, which row is correct?

| | $T_0$ / K | value of $\Delta G_r^{\ominus}$ with increasing temperature |
|---|---|---|
| **A** | 1040 | increases |
| **B** | 1.04 | increases |
| **C** | 1040 | decreases |
| **D** | 1.04 | decreases |

**10** The kinetics of the acid-catalysed reaction between propanone and iodine

$$CH_3COCH_3(aq) + I_2(aq) \xrightarrow{H^+} CH_2ICOCH_3(aq) + HI(aq)$$

can be investigated experimentally by varying the concentrations of the three substances involved and determining the time for the colour of the iodine to disappear. In this method, the rate of reaction is measured in terms of the rate at which the iodine concentration changes.

The following results were obtained in a series of experiments.

| experiment | volume of propanone / $cm^3$ | volume of iodine / $cm^3$ | volume of sulfuric acid / $cm^3$ | volume of water / $cm^3$ | time taken for iodine colour to disappear / s |
|---|---|---|---|---|---|
| 1 | 8 | 4 | 8 | 0 | 1 |
| 2 | 8 | 2 | 8 | 2 | 0.5 |
| 3 | 4 | 4 | 8 | 4 | 2 |
| 4 | 8 | 8 | 2 | 2 | 8 |

Which conclusions can be drawn from the results?

1 The rate constant has units of $mol^{-1}\ dm^3\ s^{-1}$.

2 The rate equation is rate = $k$[propanone][iodine].

3 The rate of reaction for experiment 2 is the fastest.

**A** 1 only **B** 3 only

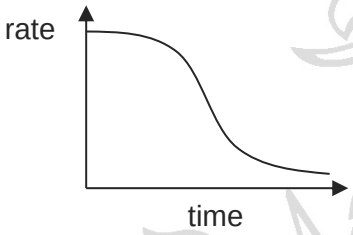
**C** 1 and 3 only **D** 1, 2 and 3

**11** The reaction of manganate(VII) ions with ethanedioate ions in acid solution is an auto-catalytic reaction.

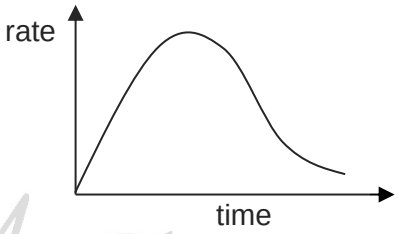
$$2MnO_4^-(aq) + 16H^+(aq) + 5C_2O_4^{2-}(aq) \longrightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 10CO_2(g)$$

Which graph correctly represents the kinetics of this reaction?

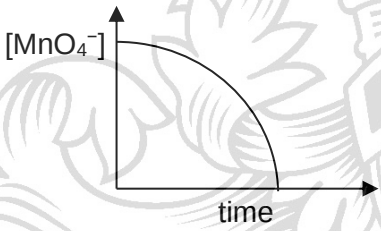
**A**



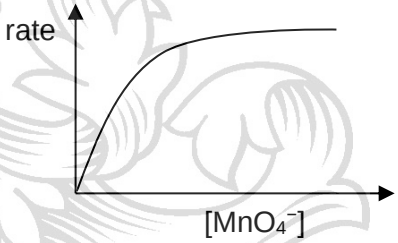

**B**




**C**

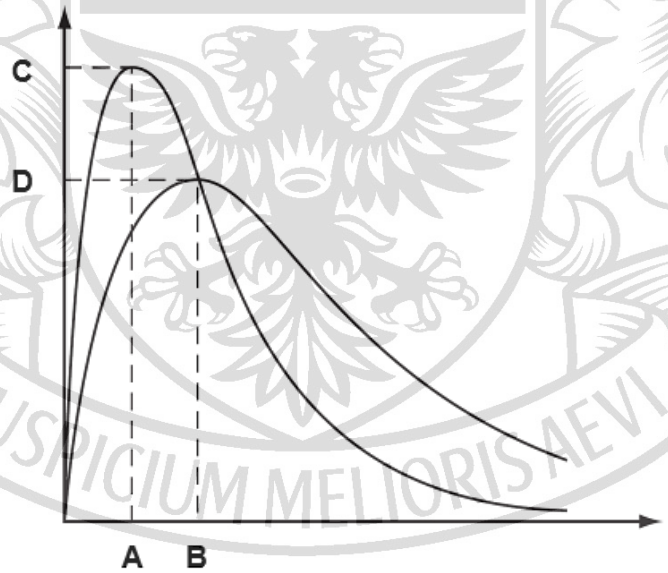



**D**




**12** The diagram shows the Maxwell–Boltzmann energy distribution curves for molecules of a sample of a gas at two different temperatures.

Which letter on the axes represents the most probable energy of the molecules at the lower temperature?



**13** A gas **Z** dissociates to form two other gases, **X** and **Y**, according to the following equation.

$$2\mathbf{Z}(g) \rightleftharpoons \mathbf{X}(g) + 2\mathbf{Y}(g)$$

A sample of **Z** was placed in a rigid container of fixed volume at a pressure of 0.86 atm and allowed to reach equilibrium at 600 K. The total pressure at equilibrium was 1.11 atm.

Which statements are correct?

1 The degree of dissociation of **Z** is 0.581.

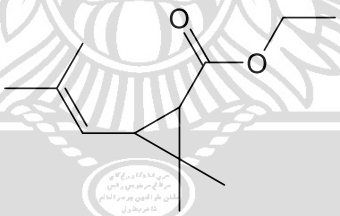
2 Addition of a catalyst increases the equilibrium partial pressure of **X**.

3 When an inert gas is added to the container, the position of equilibrium will shift to the right.

**A** 1 only **B** 1 and 3 only

**C** 2 and 3 only **D** 1, 2 and 3

**14** Compound **A** is related to a variety of insecticides.




**A**

Which statements about compound **A** are correct?

1 It has $2^3$ stereoisomers.

2 It has nine $sp^3$ hybridised carbons.

3 It contains four $\pi$ electrons.

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

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

When dichlorodifluoromethane, $CCl_2F_2$, is released into the atmosphere, it forms free radicals which react with ozone in a chain reaction.

A part of the chain reaction is shown.

$$X\bullet + O_3 \longrightarrow XO\bullet + O_2$$

$$2XO\bullet \longrightarrow 2X\bullet + O_2$$

X• represents the halogen radical.

Which statements are correct?

1 In the initiation step, F• is more readily formed than Cl•.

2 In the propagation steps, the halogen radical acts as a catalyst.

3 In the termination step, the halogen radical is consumed.

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

**- END OF SECTION A -**

## Section B (35 marks)

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

**B1** Ethanol, $CH_3CH_2OH$, can be oxidised by potassium dichromate, $K_2Cr_2O_7$, and this reaction is used in various applications.

**(a)** A series of experiments was carried out to investigate the kinetics of the reaction between $Cr_2O_7^{2-}$ and $CH_3CH_2OH$ in acidic medium.

$$Cr_2O_7^{2-}(aq) + 3CH_3CH_2OH(aq) + 8H^+(aq) \longrightarrow 3CH_3CHO(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$$

Table 1.1 provides some information from these experiments.

**Table 1.1**

| experiment | initial $[Cr_2O_7^{2-}]$ / mol $dm^{-3}$ | initial $[CH_3CH_2OH]$ / mol $dm^{-3}$ | initial $[H_2SO_4]$ / mol $dm^{-3}$ | initial rate / mol $dm^{-3}$ $min^{-1}$ |
|---|---|---|---|---|
| 1 | 0.00180 | 0.050 | 4.0 | 0.00035 |
| 2 | 0.00180 | 0.050 | 2.0 | 0.00009 |
| 3 | 0.00180 | 0.025 | 4.0 | |

In the experiments, $CH_3CH_2OH$ and $H_2SO_4$ were used in large excess.

**(i)** Determine the order of reaction with respect to $H_2SO_4$. You should show all your working.

[1]

Fig. 1.1 shows how the concentration of $Cr_2O_7^{2-}$ varied with time in **Experiment 1**.

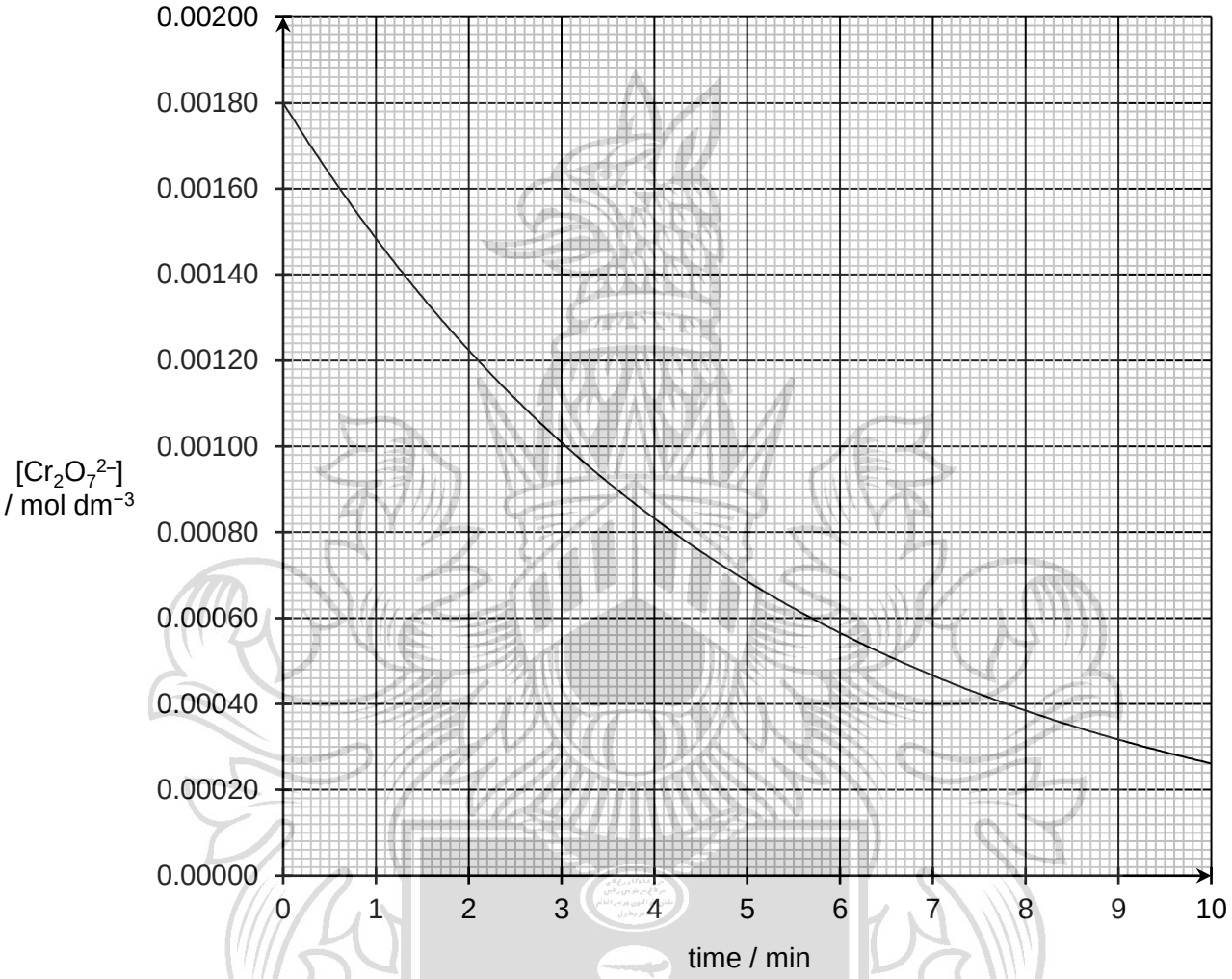



**Fig. 1.1**

**(ii)** Describe how the initial rate of 0.00035 mol $dm^{-3}$ $min^{-1}$ for this experiment could be determined from Fig. 1.1.

……

……[1]

**(iii)** Use Fig. 1.1 to determine the order of reaction with respect to $Cr_2O_7^{2-}$. You should show all your working and draw any construction lines clearly on your graph.



[2]

**(iv)** The order of reaction with respect to $CH_3CH_2OH$ is known to be 1.

Hence, write the rate equation for the reaction.

……[1]

**(v)** Determine the time taken for the concentration of $Cr_2O_7^{2-}$ to decrease from 0.00180 mol $dm^{-3}$ to 0.00090 mol $dm^{-3}$ in **Experiment 3**.

[1]

**BLANK PAGE**

A breathalyser is a device used by the police to test drivers suspected of drink-driving. It works by measuring the level of ethanol in the driver's breath.

The driver is asked to exhale into the breathalyser, which contains acidified $K_2Cr_2O_7$, which is orange in colour. Any ethanol present in the breath reacts with the $K_2Cr_2O_7$, and a photometer measures the amount of light that is absorbed by the unreacted $K_2Cr_2O_7$. The amount of light absorbed by $K_2Cr_2O_7$ is the *absorbance value*.

**(b)** The calibration graph in Fig. 1.2 shows how the absorbance value changes with the concentration of $K_2Cr_2O_7$.

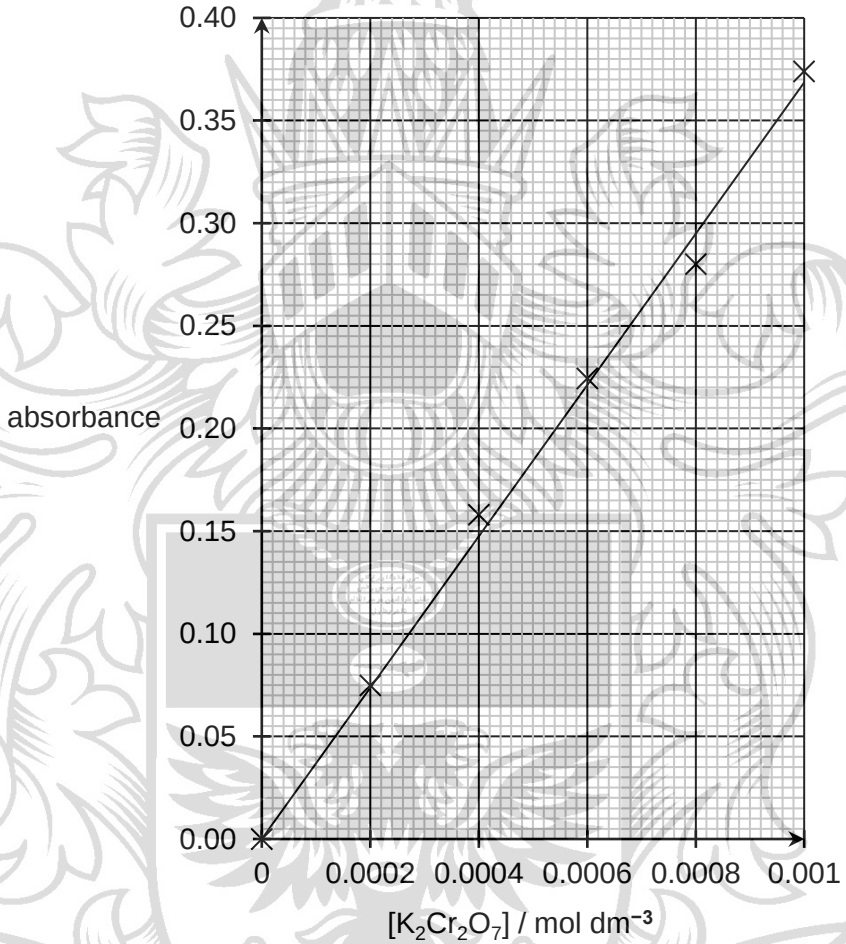



**Fig. 1.2**

A 50.0 $cm^3$ sample of air exhaled by a driver suspected of drink-driving was analysed by a breathalyser.

The breathalyser contains 3.0 $cm^3$ of $8.5 \times 10^{-4}$ mol $dm^{-3}$ of acidified $K_2Cr_2O_7$. The ethanol in the exhaled air reacted with the $Cr_2O_7^{2-}$ as shown below.

$$Cr_2O_7^{2-}(aq) + 3CH_3CH_2OH(aq) + 8H^+(aq) \longrightarrow 3CH_3CHO(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$$



The photometer in the breathalyser gave an absorbance value of 0.25 which corresponds to the concentration of unreacted $K_2Cr_2O_7$.

**(i)** Using Fig. 1.2, determine the concentration of unreacted $K_2Cr_2O_7$ in the sample.

[1]

**(ii)** Using your answer to **(b)(i)**, calculate the number of moles of ethanol in the 50.0 $cm^3$ sample of air exhaled by the driver.

[2]

**(iii)** In Singapore, the legal drink-driving limit is 0.08% blood alcohol content (BAC), i.e., 0.08 g of ethanol in 100 $cm^3$ of blood. If the BAC exceeds 0.08%, the driver is guilty of drink-driving.

The amount of ethanol in 2100 $cm^3$ of exhaled air is equivalent to the same amount in 1 $cm^3$ of blood.

Calculate the BAC of the driver and, hence, deduce whether the driver was guilty of drink-driving.

$M_r$ of ethanol = 46.0



[2]

**(c)** The calibration graph in Fig 1.2 was obtained by measuring the absorbance values of solutions of accurately known concentrations. Plan a procedure to prepare the five solutions required to plot the calibration graph.

Solution **A** is a 250 $cm^3$ solution of 0.00500 mol $dm^{-3}$ acidified $K_2Cr_2O_7$.

You should plan to

- prepare solution **A** using solid $K_2Cr_2O_7$ and 1.00 mol $dm^{-3}$ sulfuric acid.
- dilute portions of solution **A** using 1.00 mol $dm^{-3}$ sulfuric acid to prepare 100 $cm^3$ each of the five solutions.

Calculate the volume of solution **A** required for each dilution and fill in the table below.

| concentration of diluted solution **A** / mol $dm^{-3}$ | volume of solution **A** required for dilution / $cm^3$ |
|---|---|
| $1.00 \times 10^{-3}$ | |
| $0.800 \times 10^{-3}$ | |
| $0.600 \times 10^{-3}$ | |
| $0.400 \times 10^{-3}$ | |
| $0.200 \times 10^{-3}$ | |

You are provided with the following

- solid $K_2Cr_2O_7$ (molar mass = 294.2 g $mol^{-1}$),
- 1.00 mol $dm^{-3}$ sulfuric acid,
- 250 $cm^3$ graduated flasks,
- 100 $cm^3$ graduated flasks,
- burette,
- the equipment normally found in a school laboratory.

In your plan you should include details of

- the quantities of chemicals you would use,
- the apparatus you would use,
- the procedure you would follow to,
- the measurements you would make.

……

……

.....

.....



……

.....

.....

[5]

**(d)** In the human body, ethanol, $CH_3CH_2OH$, is removed through the action of an enzyme, alcohol dehydrogenase (ADH).

Fig. 1.3 shows part of an active site of ADH.

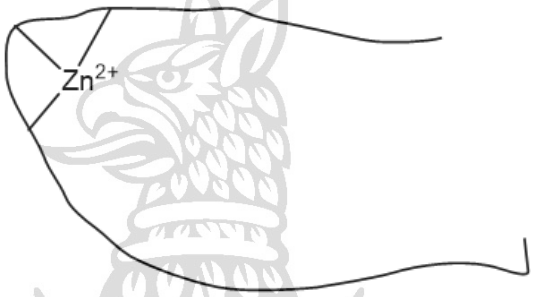



**Fig. 1.3**

**(i)** Ethanol binds to the active site by forming interactions with the $Zn^{2+}$ and other functional groups on ADH.

On Fig. 1.3, draw and label the interaction formed between a $CH_3CH_2OH$ molecule and the $Zn^{2+}$ in ADH. [1]

**(ii)** A driver whose breathalyser test showed a blood alcohol content (BAC) above the legal limit was given the breathalyser test every 15 minutes for 3 hours.

Fig. 1.4 shows the change in the driver's BAC over 3 hours.

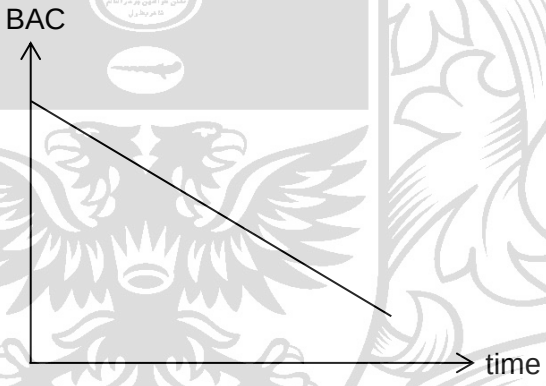



**Fig. 1.4**

Comment on the rate of removal of ethanol from the body by ADH. Explain your answer with reference to the action of enzymes.

……

……

……

……[2]

**[Total: 19]**

**B2** In recent years, methanol, $CH_3OH$, has been promoted as a clean-burning, biodegradable fuel.

Methanol is produced from syngas, which is a mixture of hydrogen gas, carbon monoxide and carbon dioxide.

**(a)** Syngas is produced via steam reforming of natural gas and the water-gas shift reaction.

steam reforming: $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$

water-gas shift reaction: $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$

Fig. 2.1 shows the % of CO conversion in the water-gas shift reaction at different temperatures.

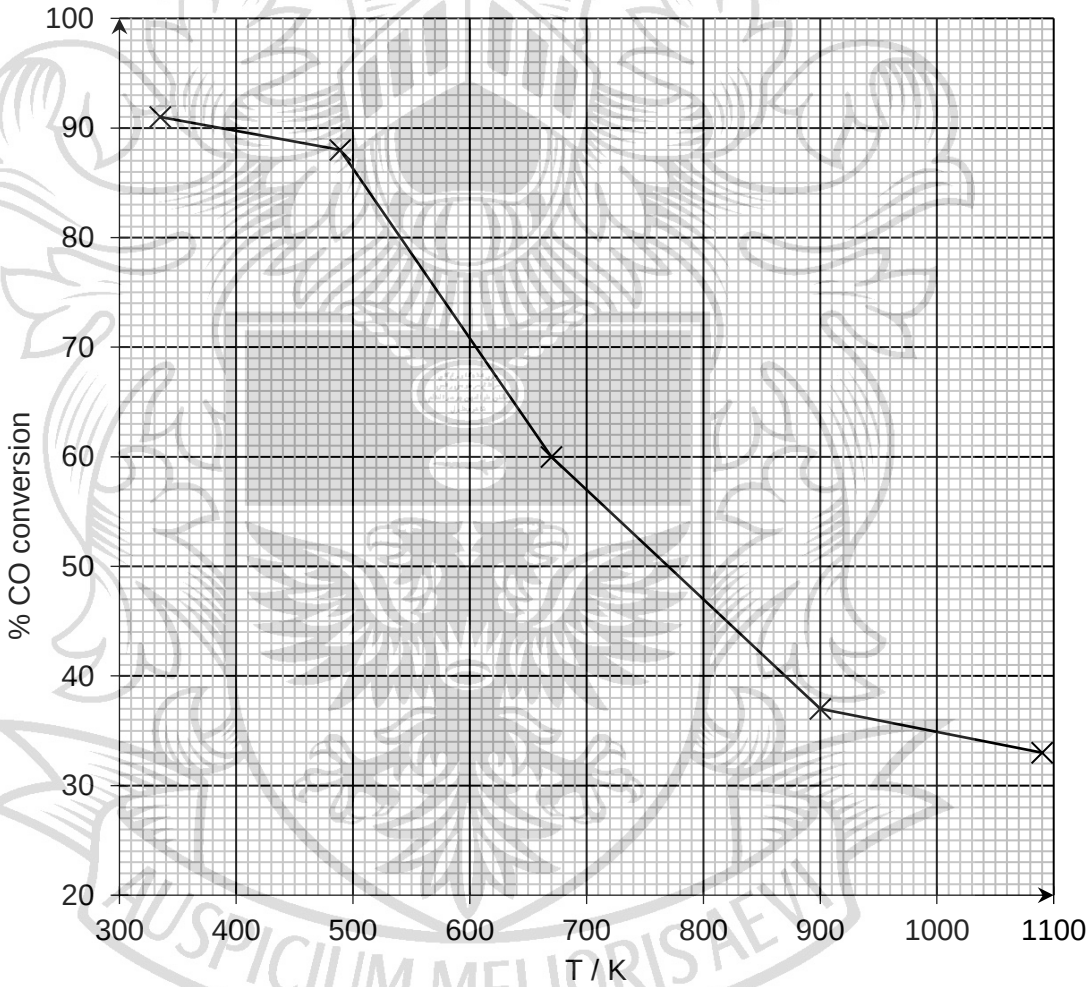



**Fig 2.1**

**(i)** Using Fig. 2.1, deduce whether the forward reaction of the water-gas shift reaction is endothermic or exothermic.

……

……

……

……[2]

**(ii)** Write an expression for the equilibrium constant, $K_c$, for the water-gas shift reaction.

[1]

**(iii)** Equimolar amounts of $H_2O$ and CO were introduced into a sealed container and allowed to reach equilibrium at 1000 K.

Using Fig. 2.1, calculate the equilibrium constant, $K_c$, at 1000 K.

[2]

**(iv)** Using your answer to **(a)(iii)**, or otherwise, state and explain the sign for $\Delta G^{\ominus}$ at 1000 K.

……

……...[1]

**(b)** The synthesis of methanol using syngas occurs via the following reaction which has an equilibrium constant, $K_p$.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad K_p$$

The value of $K_p$ was determined by two separate experiments carried out at the same temperature.

**(i)** In the first experiment, $K_{p1}$ was determined for the reaction shown in equation 2.1.

equation 2.1 $\qquad CO(g) + H_2(g) \rightleftharpoons CH_2O(g) \qquad K_{p1}$

In the experiment, 0.500 mol of CO and 0.600 mol of $CH_2O$ were placed in a sealed vessel and allowed to reach equilibrium at a constant pressure of $2.80 \times 10^5$ Pa.

At equilibrium, the partial pressure of $H_2$ was found to be the same as the partial pressure of $CH_2O$.

Calculate $K_{p1}$ for equation 2.1. State the units.

[4]

**(ii)** In the second experiment, $K_{p2}$ was determined for the reaction shown in equation 2.2.

equation 2.2 $\qquad CH_2O(g) + H_2(g) \rightleftharpoons CH_3OH(g) \qquad K_{p2}$

Write an expression for $K_p$ of the methanol synthesis in terms of $K_{p1}$ and $K_{p2}$.



[1]

**(iii)** State a change in the reaction conditions that would favour a high yield of methanol and explain why.

……

……

……...[2]

**(iv)** In the reaction shown in equation 2.2, formaldehyde, $CH_2O$, was reduced to methanol, $CH_3OH$.

State the oxidation number of carbon in formaldehyde and methanol.

oxidation number of C in formaldehyde: ……..

oxidation number of C in methanol: …….. [1]

**(c)** The graph below shows the behaviour of 1 mol of methanol gas at 343 K as compared to an ideal gas.


Sketch, on the above axes, the behaviour of 1 mol of methanol gas at 500 K. Briefly explain your answer.

……

……

…… [2]

**[Total: 16]**



**– END OF SECTION B –**

**RAFFLES INSTITUTION**

**2022 Year 5 Promotion Examination**
**H2 Chemistry**

**COVER SHEET**

**C**

| **Name:** | **(  )** | **Class: 23S0____** |
|---|---|---|

**For Examiner's Use Only**

| **Section** | | **Marks** |
|---|---|---|
| **A** | | **/ 15** |
| **B** | **B1** | **/ 19** |
| | **B2** | **/ 16** |
| **C** | **C1** | **/ 13** |
| | **C2** | **/ 12** |
| | **C3** | **/ 15** |
| **Promotion Examination** | **Total** | **/ 90** |
| | **Percentage** | **/ 100** |

## Section C (40 marks)

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

**C1** This question is about free radical reactions involving various hydrocarbons.

**(a)** When 2-methylpropane is treated with bromine in the presence of UV light, two monobrominated products are produced in unequal proportions. The major product obtained does **not** contain any tertiary hydrogens.

**(i)** Draw the skeletal structures of both products. [2]

**(ii)** Describe the mechanism for the formation of the major product. [3]

**(iii)** Assuming all the hydrogen atoms have similar reactivity, predict the ratio in which the two monobrominated products will be formed. [1]

**(iv)** Explain why the actual proportion differs from the ratio in **(a)(iii)**. [1]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

**(b)** When compound **A** was treated with bromine under conditions that favour dibromination, a mixture of three stereoisomers was obtained.


**(i)** Draw the structures of all the stereoisomers formed and circle the pair of enantiomers in your answer. [2]

**(ii)** Explain why there are only three instead of four stereoisomers. [1]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



.....

.....

**(c)** While free radical reactions are commonly associated with alkanes, it is also possible for alkenes to undergo free radical bromination using N-bromosuccinimide (NBS) as a reagent instead of $Br_2$. An example is given in Fig. 3.1.

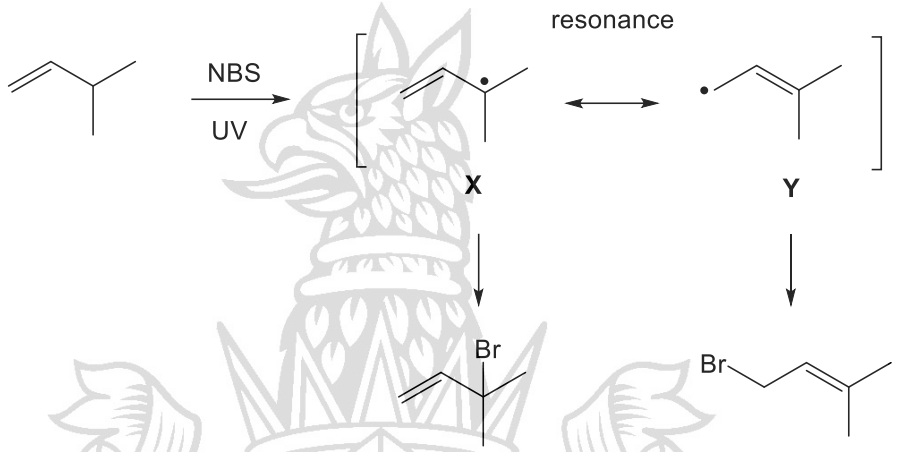
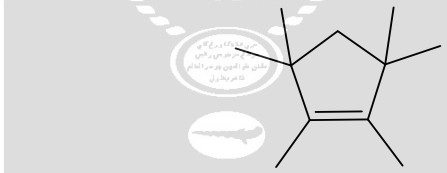



**Fig. 3.1**

**(i)** On Fig. 3.1, draw curly arrows on **X** to illustrate the movement of electrons to produce **Y**. [1]

**(ii)** Using the information in Fig. 3.1, predict the products formed when the following compound is treated with NBS in the presence of UV light. [2]



.....

.....

.....

.....

.....

.....

.....

.....

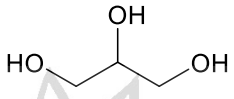


.....

.....

**[Total: 13]**

**C2** **(a)** Glycerol, $C_3H_8O_3$, can be used to prevent water from freezing.




glycerol

In ice, $H_2O$ molecules are arranged in a rigid lattice structure.

**(i)** Draw a labelled diagram to show the interactions between five $H_2O$ molecules in the structure of ice. [2]

**(ii)** In the presence of glycerol, water does not become ice even at 0 °C.
By considering the structure and bonding of water and glycerol, explain why. [1]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

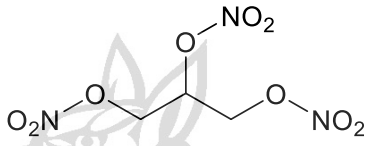
.....



.....

.....

**(b)** Nitroglycerin, $C_3H_5N_3O_9$, is an explosive oil at room temperature and it is an active component of dynamite. It is produced by reacting glycerol with concentrated nitric and sulfuric acids.



nitroglycerin

**(i)** In a closed system such as a bomb calorimeter, nitroglycerin undergoes decomposition as follows.

$$C_3H_5N_3O_9(l) \longrightarrow 3CO_2(g) + \frac{5}{2}H_2O(l) + \frac{3}{2}N_2(g) + \frac{1}{4}O_2(g)$$

Using the data in Table 4.1, calculate the standard enthalpy change of decomposition of nitroglycerin. [1]

**Table 4.1**

| | $\Delta H_f^{\ominus}$ / kJ mol$^{-1}$ |
|---|---|
| standard enthalpy change of formation of $C_3H_5N_3O_9(l)$ | −370 |
| standard enthalpy change of formation of $H_2O(l)$ | −293 |
| standard enthalpy change of formation of $CO_2(g)$ | −394 |

**(ii)** In an open environment, nitroglycerin decomposes explosively to produce carbon monoxide, steam, nitrogen and oxygen gases.

$$C_3H_5N_3O_9(l) \longrightarrow 3CO(g) + \frac{5}{2}H_2O(g) + \frac{3}{2}N_2(g) + \frac{7}{4}O_2(g)$$

Using the data in Table 4.2, together with data from the *Data Booklet*, draw an energy cycle to calculate the standard enthalpy change of reaction for the decomposition of nitroglycerin in an open environment. [4]

**Table 4.2**

| | |
|---|---|
| standard enthalpy change of formation of $C_3H_5N_3O_9(l)$ | −370 kJ mol$^{-1}$ |
| standard enthalpy change of formation of $H_2O(g)$ | −242 kJ mol$^{-1}$ |
| standard enthalpy change of atomisation of C(s) | +720 kJ mol$^{-1}$ |

.....

.....



.....

.....

.....

**(iii)** In an explosion, there is rapid generation of high temperatures and pressures.

By considering the information and your answer in **(b)(ii)**, discuss how the decomposition of nitroglycerin in an open environment is explosive in nature.
[2]

**(iv)** To reduce the risk of explosion, liquid nitroglycerin should be maintained at low temperatures for safety reasons.

Explain why this method is safer but does not prevent the decomposition of nitroglycerin. [2]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



.....

**[Total: 12]**

**C3** A nitride is a class of compounds in which nitrogen has an oxidation state of –3.

**(a)** Group 13 nitrides have been used in dental applications and electronic devices.

**(i)** Aluminium nitride, A*l*N, is widely used in light emitting diodes.

Explain the difference between the ionic radii of $Al^{3+}$ and $N^{3-}$. [2]

Boron nitride, BN, exists as two forms, α-BN and β-BN.

α-BN has a planar, layered, hexagonal structure similar to that of graphite. B and N occupy alternate positions within a layer. α-BN has limited electrical conductivity as compared to graphite.

β-BN, an electrical insulator, has a diamond-like structure in which B is bonded to four other N atoms.

**(ii)** State the hybridisations of B and N in α-BN and β-BN. [2]

**(iii)** Explain why α-BN has limited electrical conductivity as compared to graphite. [1]

**(iv)** Explain why β-BN is an electrical insulator. [1]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

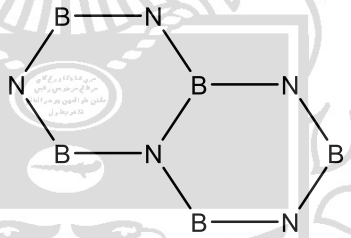
.....

.....

**(v)** Permanent dipole–permanent dipole interactions exist between the layers in α-BN.

A part in a layer of α-BN has been drawn in Fig. 5.1.

**Fig. 5.1**




Complete the diagram in Fig. 5.1 to illustrate the bonding in α-BN, labelling the following clearly.



- the types of bonding **within** and **between** two layers in α-BN
- the partial charges on at least two B and two N atoms [2]

**(b)** At 800 °C, BN undergoes combustion in an open furnace to produce a liquid oxide and an inert diatomic gas.

**(i)** Write a balanced equation for the oxidation of BN, including state symbols. [1]

**(ii)** $\Delta G^{\ominus}$ for the reaction was plotted against temperature as shown in Fig 5.2.

Determine $\Delta S^{\ominus}$, including units, and explain its sign. [2]

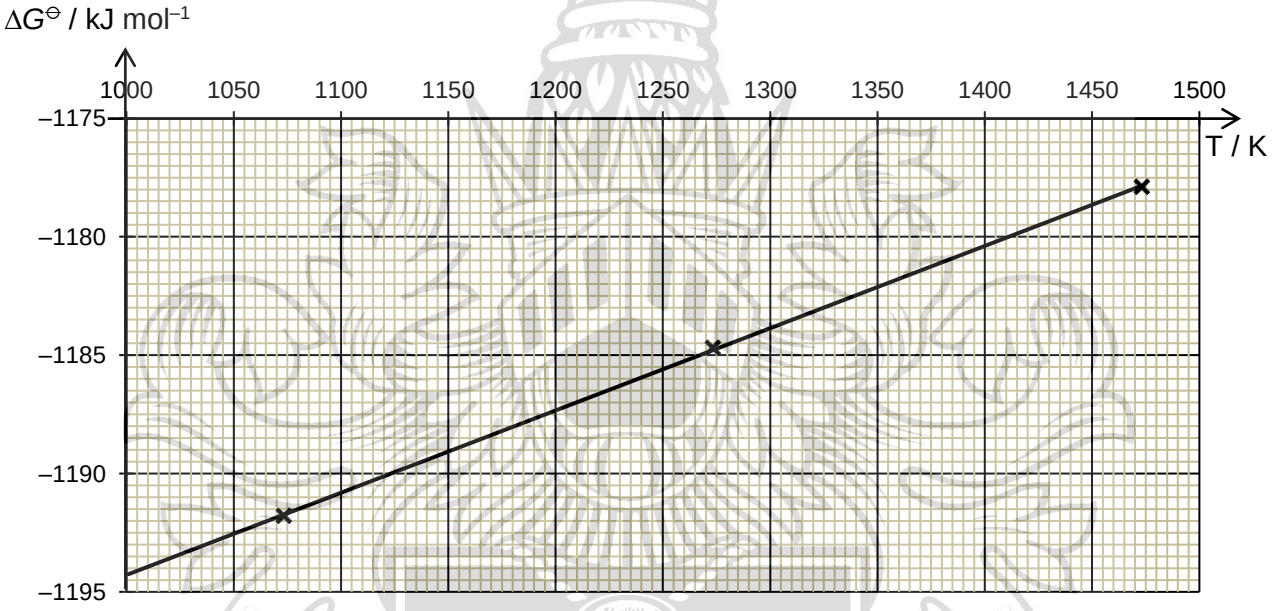



**Fig. 5.2**

**(c)** Cyanogen, $C_2N_2$, a carbon nitride, contains a carbon–carbon single bond.

**(i)** Draw a dot-and-cross diagram of cyanogen. [1]

**(ii)** Compare, with brief explanations, the boiling points of cyanogen and ethanol, $C_2H_5OH$. [2]

**(iii)** At high pressure, cyanogen is transformed to a macromolecule known as paracyanogen, $(C_4N_4)_n$, which has a planar structure.

Each repeat unit

- has the formula $C_4N_4$,
- contains a six-membered ring consisting of two C–C bonds, two C–N bonds and two C=N bonds.

Draw the structure of a repeat unit of paracyanogen. [1]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



**[Total: 15]**

**– END OF SECTION C –**

**Additional answer space**

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