RAFFLES INSTITUTION
2019 YEAR 5 PROMOTION EXAMINATION

Higher 2

CHEMISTRY 9729

2 October 2019

2 hours 30 minutes

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

READ THESE INSTRUCTIONS FIRST

Write your name, index number and civics tutorial group in the spaces provided on the OMR Sheet, the cover sheets on **pages 13 and 15**, and the writing paper used for Section **C**.
Do not use staples, paper clips, highlighters, glue or correction fluid.

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

Section A (15 marks)

Answer this section first. The OMR sheet will be collected after the **first 30 minutes.**

There are **fifteen** questions in this section. 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.

Read the instructions on the OMR Sheet very carefully.

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)

There are **three** questions in this section. Answers to this section are to be written in the spaces provided in the question paper.

Section C (40 marks)

There are **three** questions in this section. Answers to this section are to be written on the writing paper provided. You are to begin each question on a fresh sheet of paper.

Write in dark blue or black pen. You may use a pencil for any diagrams or graphs.
You are reminded of the need for good English and clear presentation in your answers.

At the end of the examination, fasten your answers to Section **C** securely together. Answers to Sections **A**, **B** and **C** are to be handed in separately.
The number of marks is given in brackets [ ] at the end of each question or part question.

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 Which statement is correct?

A One mole of a compound is the amount that contains the same number of atoms as there are atoms in 12.000 g of carbon-12.

B The relative molecular mass of a compound *E* is given by the following expression.

$$\frac{\text{average mass of one atom of } E}{\frac{1}{12} \text{ the mass of one molecule of carbon-12}}$$

C The relative isotopic mass of lithium-7 is given by the following expression.

$$\frac{\text{average mass of all isotopes of lithium}}{\frac{1}{12} \text{ the mass of one atom of carbon-12}}$$

D The relative atomic mass of oxygen is given by the following expression.

$$\frac{\text{average mass of one atom of oxygen}}{\frac{1}{12} \text{ the mass of one atom of carbon-12}}$$

2 $NaHCO_3$ (M_r = 84.0) undergoes decomposition to form Na_2CO_3, carbon dioxide and water vapour when heated.

When 3.50 g of an impure sample of $NaHCO_3$ was heated, the loss in mass was found to be 0.85 g. Assuming that the impurities do not decompose, calculate the percentage purity by mass of $NaHCO_3$ in the sample.

A 32.9%

B 34.2%

C 65.8%

D 67.1%

3 Flerovium, F*l*, is produced by bombarding atoms of plutonium, Pu, with atoms of element **X**. The reaction that takes place is shown below.

$$^{244}_{94}\text{Pu} + \mathbf{X} \longrightarrow {}^{289}_{114}\text{F}l + 3{}^{1}_{0}\text{n}$$

Which row in the table correctly describes the nuclear makeup of **X**?

	number of protons	number of neutrons
A	20	28
B	20	48
C	23	42
D	23	20

4 Which statements are correct for the CO_3^{2-} ion?

1 All the bond lengths are equal.

2 The hybridisation of the carbon atom is sp^2.

3 The bond angle in CO_3^{2-} is the same as that in SO_3^{2-}.

A 1, 2 and 3

B 1 and 2 only

C 2 and 3 only

D 1 only

5 The reaction between ammonia, NH_3, and ethyne, C_2H_2, to form butanenitrile, $CH_3CH_2CH_2CN$, is hypothesised to be responsible for the red-orange hue of Jupiter's Great Red Spot.

$$NH_3 + 2C_2H_2 \longrightarrow \overset{\overset{H_a}{|}}{C}H_2CH_2CH_2CN$$

Which statements are correct?

1 Ethyne and butanenitrile have the same number of π bonds.

2 Ethyne forms stronger intermolecular forces of attraction than butanenitrile.

3 The C–H bond energy in ethyne is greater than that of C–H_a in butanenitrile.

A 1 and 2 only

B 1 and 3 only

C 2 and 3 only

D 2 only

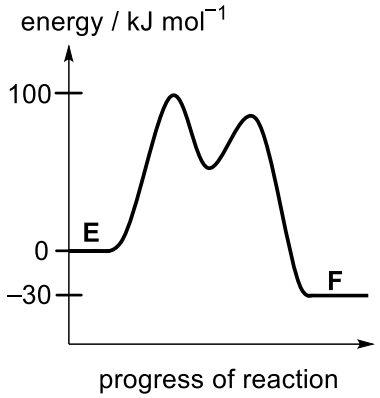
[Turn Over

6 Two separate bulbs contain ideal gases **A** and **B** at 30 °C and 20 °C respectively. At these temperatures, the density of gas **A** is three times that of gas **B**.

Given that the relative molecular mass of gas **A** is one quarter that of gas **B**, what is the value of $\frac{\text{pressure of gas } \mathbf{A}}{\text{pressure of gas } \mathbf{B}}$?

A 0.776
B 1.13
C 12.4
D 18.0

7 The energy profile diagram for the conversion of **E** to **F** is shown below.



Which statement is **incorrect**?

A The overall enthalpy change of reaction is –30 kJ mol^{-1}.
B The activation energy for the first step is 100 kJ mol^{-1}.
C There is only one transition state in the reaction.
D The first step is the rate-determining step.

8 The radii and charges of six ions are given below.

ion	J^+	L^+	M^{2+}	X^-	Y^-	Z^{2-}
radius / nm	0.08	0.14	0.18	0.12	0.18	0.14

Which statements are correct?

1 **JY** has higher covalent character than **LY**.
2 The lattice energy of **MZ** is more exothermic than that of **JX**.
3 The hydration energy of $\mathbf{J}^+$ is less exothermic than that of $\mathbf{L}^+$.

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

[Turn Over

9 The reaction between propanone, CH_3COCH_3, and iodine is catalysed by H^+ ions.

$$CH_3COCH_3 + I_2 \xrightarrow{H^+} CH_3COCH_2I + HI$$

The reaction is zero order with respect to iodine.

A series of experiments was carried out using different volumes of aqueous solutions of propanone, iodine, hydrochloric acid and starch. Each reaction mixture was made up to the same total volume with water and the initial rate can be approximated as follows.

$$\text{initial rate} \propto \frac{\text{volume of aqueous } I_2}{\text{time taken for disappearance of deep blue colour}}$$

The following results were obtained.

reaction mixture	volume of aqueous CH_3COCH_3 / cm^3	volume of aqueous I_2 / cm^3	volume of aqueous HC*l* / cm^3	volume of starch solution / cm^3	volume of water / cm^3	time taken for disappearance of deep blue colour / s
1	20	10	10	1	5	54
2	15	10	10	1	10	72
3	20	5	10	1	10	y
4	15	10	15	1	5	48

Which statements are correct?

1 y has a value of 27.

2 The order of reaction with respect to propanone is 1.

3 When HC*l* is replaced by H_2SO_4 of the same concentration, the time taken for the disappearance of deep blue colour remains unchanged.

A 1 and 2 only

B 1 and 3 only

C 2 and 3 only

D 2 only

10 The rate equation for the reaction $2P + Q_2 + R \longrightarrow P_2Q + QR$ is given below.

$$\text{rate} = k[P]^2[Q_2]$$

What could be the mechanism for the reaction?

A
$2P + Q_2 \xrightarrow{\text{slow}} 2PQ$
$PQ + R \longrightarrow PQR$
$PQ \longrightarrow P + Q$

B
$Q_2 + R \longrightarrow QR + Q$
$P + P \xrightarrow{\text{slow}} P_2$
$P_2 + Q \longrightarrow P_2Q$

C
$P + Q_2 \xrightarrow{\text{slow}} PQ + Q$
$PQ + P \longrightarrow P_2Q$
$Q + R \longrightarrow QR$

D
$P + P \longrightarrow P_2$
$P_2 + Q_2 \xrightarrow{\text{slow}} P_2Q + Q$
$Q + R \longrightarrow QR$

11 When water is added to the following equilibrium, the solution turns pink.

$$\underset{\text{blue}}{CoCl_4^{2-}(aq)} + 6H_2O(l) \rightleftharpoons \underset{\text{pink}}{Co(H_2O)_6^{2+}(aq)} + 4Cl^-(aq)$$

Which statement best explains this observation?

A Water catalyses the forward reaction, hence the rate of the forward reaction increases more than that of the backward reaction.

B Because the amount of water increases, the forward reaction will be favoured in order to reduce the amount of water.

C Because the concentration of water increases, the forward reaction will be favoured in order to reduce the concentration of water.

D Because the concentration of all ions decreases, the forward reaction will be favoured in order to increase the concentration of ions.

12 A system at equilibrium is subjected to the following changes in separate experiments.

- pressure is increased at constant temperature
- temperature is decreased at constant pressure

Which reaction will have a decreased proportion of products at the new equilibrium for both experiments?

A $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = +57$ kJ mol^{-1}

B $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\Delta H = +53$ kJ mol^{-1}

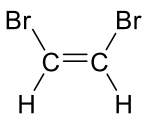
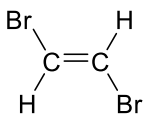
C $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -92$ kJ mol^{-1}

D $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H = -950$ kJ mol^{-1}

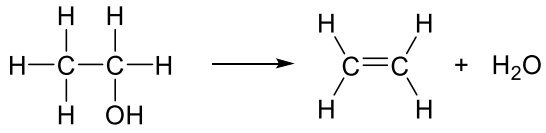
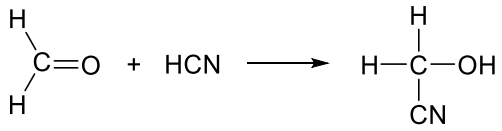
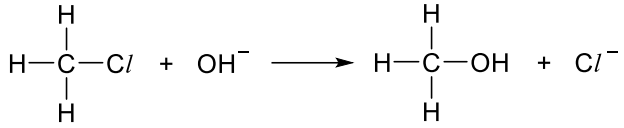
13 **V** and **W** are organic compounds. Given that

- **V** and **W** have the same empirical formula;
- **V** has a lower boiling point than **W**.

Which row gives the correct **V** and **W**?

	V	**W**
A	$(CH_3)_3CH$	$CH_3CH_2CH_2CH_3$
B	$CH_3CH_2CH_3$	$CH_3(CH_2)_4CH_3$
C	$CH_2{=}CH(CH_2)_3CH_3$	$CH_2{=}CH_2$
D		

14 Which types of reaction are correctly identified in the table?

	reaction	type of reaction
1		condensation
2		addition
3		substitution

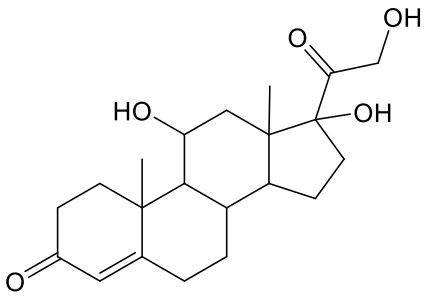
A 1, 2 and 3

B 1 and 2 only

C 2 and 3 only

D 3 only

15 Cortisol is a steroid hormone which is released in times of stress in the human body.



cortisol

How many stereoisomers does cortisol have?

A 2^6

B 2^7

C 2^8

D 2^9

Section C (40 marks)

Answer **all** questions in this section.

Write your answers on the writing paper provided. Begin **each** question on a **fresh sheet** of paper.

1 Phosgene, $COCl_2$, is an important chemical used in the production of urethanes and polycarbonate plastics.

(a) Phosgene can be produced by a reaction between CO(g) and Cl_2(g).

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g) \qquad \text{reaction (1)}$$

5.05 atm of carbon monoxide gas and 4.63 atm of chlorine gas were reacted in a 3000 cm^3 reaction vessel at 472 K.

After dynamic equilibrium was established, the total amount of gases inside the vessel was found to be 0.680 mol at 472 K.

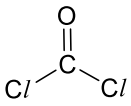
Calculate K_p for reaction (1) at 472 K, stating its units. [4]

(b) At constant temperature, the volume of the reaction vessel was increased and the system was allowed to reach equilibrium.

(i) Explain the effect this will have on the composition of the reaction mixture. [3]

(ii) Predict how the value of K_p will change. [1]

(c) The structural formulae and entropy data for the three gases are given below.

gas	structure	$S^{\ominus}$ / J K^{-1} mol^{-1}
CO	C≡O	+198
Cl_2	Cl—Cl	+223
$COCl_2$		+283

(i) Using data from the *Data Booklet*, calculate $\Delta H^{\ominus}$ of reaction (1). [1]

(ii) Using the entropy data given above and your answer in **(c)(i)**, calculate $\Delta G^{\ominus}$ of the forward reaction of reaction (1) at 298 K. [2]

(iii) Based on the $\Delta G^{\ominus}$ calculated in **(c)(ii)**, comment on the position of equilibrium of reaction (1) at 298 K. [1]

[Total: 12]

2 Cubane, C_8H_8, is a solid alkane with a highly symmetrical structure as shown below.

cubane

Cubane and its derivatives can be used as high-energy fuels, explosives, propellants and intermediates in pharmaceutical preparations.

(a) **(i)** With the aid of an equation, explain what is meant by the standard enthalpy change of combustion of cubane. [2]

(ii) Use the data given below to calculate the standard enthalpy change of combustion of cubane. [2]

compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$C_8H_8(s)$	+602
$CO_2(g)$	−394
$H_2O(l)$	−286

(b) Cubane is known to be a highly strained molecule with 12 identical C−C bonds and 8 identical C−H bonds.

(i) Using the data in **(a)(ii)**, comment on the energetic stability of cubane relative to its elements under standard conditions. [1]

(ii) Using the data given below and relevant data from the *Data Booklet*, construct an energy cycle to calculate the actual value of the C−C bond energy in cubane. [3]

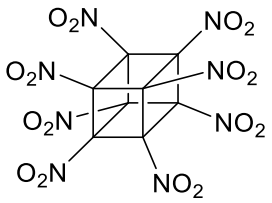
standard enthalpy change of formation of cubane, $C_8H_8(s)$ = +602 kJ mol^{-1}

standard enthalpy change of atomisation of C(s) = +715 kJ mol^{-1}

standard enthalpy change of sublimation of cubane, $C_8H_8(s)$ = +79.5 kJ mol^{-1}

(iii) The value calculated in **(b)(ii)** is **significantly** different from the value of the C−C bond energy in the *Data Booklet.* Suggest an explanation for the difference. [1]

(c) Octanitrocubane, $C_8(NO_2)_8$, is a derivative of cubane where the H atoms in cubane are replaced by $-NO_2$ groups.



octanitrocubane

Octanitrocubane can be used as a military explosive and as a fuel in rockets.

The explosion involves the following reaction.

$$C_8(NO_2)_8(s) \longrightarrow 8CO_2(g) + 4N_2(g) \qquad \Delta H^{\ominus} = -3475 \text{ kJ mol}^{-1}$$

(i) Explain how the value and sign of $\Delta G^{\ominus}$ would compare to the value and sign of $\Delta H^{\ominus}$ for the above reaction. [2]

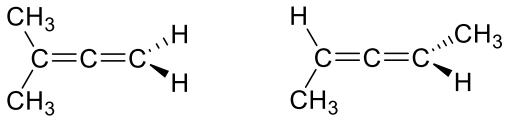
(ii) By considering factors other than the $\Delta H^{\ominus}$ given above, suggest why octanitrocubane can be used as an explosive. [1]

(iii) Rockets leave a trail of products as they move through the air. It is important for military rockets used in stealth missions to remain undetected after launch.

Suggest why rockets that use hydrogen as fuel are more likely to be detected after launch than those that use octanitrocubane as fuel. [1]

[Total: 13]

3 Allenes, such as compounds **A** and **B**, contain the C=C=C functional group.



A **B**

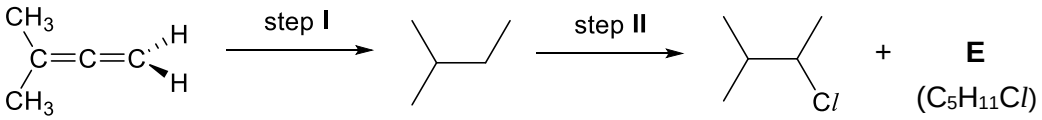
(a) State the isomeric relationship between compounds **A** and **B**. [1]

(b) Despite not having any chiral carbon atoms, compound **B** exhibits enantiomerism and is able to rotate plane polarised light.

(i) Draw the enantiomer of compound **B**. [1]

(ii) By referring to its structure, explain why compound **A** does **not** exhibit enantiomerism. [1]

(c) Compound **A** can be used to synthesise compounds **D** and **E** as shown in the scheme below.



A **C** **D** ($C_5H_{11}Cl$)

(i) Compound **C** is an alkane and is much less reactive than **A**.

Explain why alkanes are generally unreactive. [2]

(ii) Suggest the reagents and conditions required for steps **I** and **II**. [2]

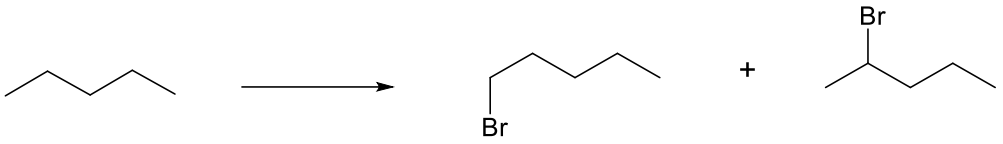
Compounds **D** and **E** each exists as a pair of enantiomers.

(iii) Suggest the structure of compound **E**. [1]

(iv) Outline the mechanism for step **II** to form compound **D**. [3]

[Turn Over

(d) Pentane, which can be synthesised from **B**, reacts with Br_2. **F** and **G** are two possible monobromoalkanes that can be formed in this reaction.



pentane **F** **G**

(i) Predict the relative proportions of **F** and **G** that are likely to be produced from pentane. Explain your answer. [2]

(ii) When the bromination was carried out and the products were analysed, it was found that the mole ratio of **F** : **G** formed was about 1 : 1.

Suggest an explanation for the difference between this ratio and the one you gave in **(d)(i)**. [2]

[Total: 15]

C

RAFFLES INSTITUTION
2019 Year 5 Promotion Examination
H2 Chemistry

COVER SHEET

Name: ( )	**Class:**

For Examiner's Use Only

Question	Marks
C1	/ 12
C2	/ 13
C3	/ 15

Attach this cover sheet to your writing paper.

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RAFFLES INSTITUTION
2019 YEAR 5 PROMOTION EXAMINATION

Higher 2

COVER SHEET

Name: ( )	**Class:**

For Examiner's Use Only

Section		**Marks**
A		**/ 15**
B	**B1**	**/ 12**
	B2	**/ 9**
	B3	**/ 14**
C	**C1**	**/ 12**
	C2	**/ 13**
	C3	**/ 15**
Promotion Examination	**Total**	**/ 90**
	Percentage	**/ 100**
	Grade	

[Turn Over

Section B (35 marks)

This section consists of **3** questions.

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

For examiner's use

1 NH_4NO_3 (M_r = 80.0) is commonly used in cold packs. When $NH_4NO_3(s)$ is added to water, an endothermic process occurs.

$$NH_4NO_3(s) + aq \longrightarrow NH_4^+(aq) + NO_3^-(aq) \qquad \Delta H_{soln} \approx +23 \text{ kJ mol}^{-1}$$

The maximum temperature change, ΔT, occurring during this process may be determined graphically. The ΔT obtained can be used to calculate the heat change, q, for this experiment. Using q, a value for ΔH_{soln} may be determined.

In this question, you are to plan a procedure that would provide sufficient data to allow you to determine an **accurate** and **reliable** value for ΔH_{soln} of $NH_4NO_3(s)$.

(a) Plan an investigation to determine the maximum temperature change, ΔT, graphically for the dissolution of $NH_4NO_3(s)$.

Measurements should be taken:

- before,
- during, and
- for some time after the dissolution process is complete.

You may assume that you are provided with:

- 10 g of $NH_4NO_3(s)$,
- Styrofoam cup,
- thermometer,
- stopwatch,
- weighing bottle,
- the equipment normally found in a school or college laboratory.

In your plan you should include brief details of:

- the apparatus you would use,
- the quantities you would use, so that there is a decrease of about 5 ^oC in 50 cm^3 of water (assume that the specific heat capacity and density of the solution are 4.18 J g^{-1} K^{-1} and 1.0 g cm^{-3} respectively),
- the procedure you would follow,
- the measurements you would make to allow a suitable temperature-time graph to be drawn,
- how you would ensure **accuracy** and **reliability** in your experimental results.

For examiner's use

For examiner's use

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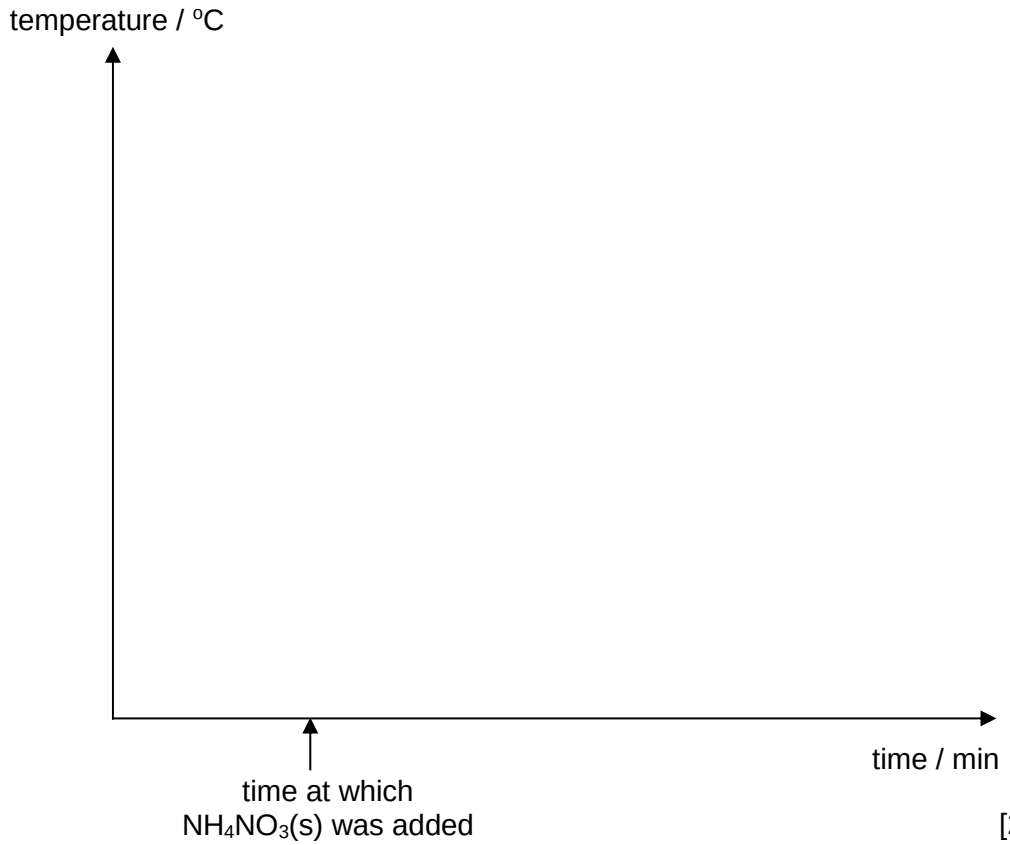
……[5]

(b) **(i)** By sketching the temperature-time graph for the measurements you expect to obtain in **(a)**, show how the maximum temperature change, ΔT, can be determined.



[2]

For examiner's use

(ii) When y g of NH_4NO_3(s) is dissolved in V cm^3 of water, ΔT was found to be –5.0 °C. Write an expression for ΔH_{soln} in terms of y and V.

[2]

(iii) The maximum temperature change, ΔT, can also be determined by direct measurement of the initial temperature and the lowest temperature reached only.

Explain why the graphical method is likely to give a more accurate value for ΔT than the direct measurement method.

……

……[1]

(c) Both NH_4NO_3 and NH_4Cl are salts that are commonly used in cold packs. Using the data given in Table 1.1, calculate ΔH_{soln} of NH_4NO_3(s), z.

Table 1.1

	NH_4NO_3	NH_4Cl
lattice energy / kJ mol^{-1}	–646	–705
enthalpy change of hydration of the anion, ΔH_{hyd} / kJ mol^{-1}	–314	–381
enthalpy change of solution, ΔH_{soln} / kJ mol^{-1}	z	+17

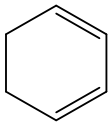
[2]

[Total: 12]

[Turn Over

For examiner's use

2 Cyclohexa-1,3-diene is a cyclic organic compound that is a common precursor in organic synthesis.



cyclohexa-1,3-diene

(a) **(i)** State the type of hybridisation of the carbon atoms in the C=C bond.

type of hybridisation …….. [1]

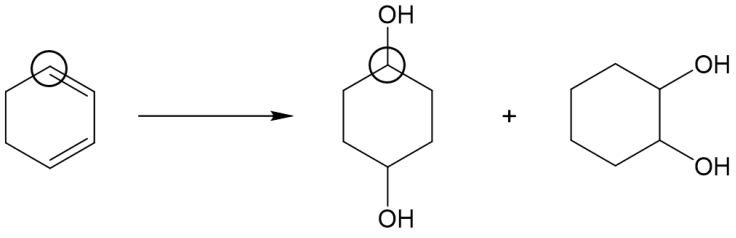
(ii) With the aid of a fully labelled diagram showing the orbitals involved, describe the bonding in the C=C bond.

……..……..

……..……..

……[2]

(b) Cyclohexa-1,3-diene undergoes reaction to produce compounds **A** and **B** as shown below.



cyclohexa-1,3-diene **A** **B**

(i) State the oxidation number for each of the circled C atoms in cyclohexa-1,3-diene and compound **A**.

oxidation number of the circled C atom in cyclohexa-1,3-diene ……

oxidation number of the circled C atom in **A** …… [1]

For examiner's use

(ii) With the aid of a suitable diagram, explain why **B** has a lower boiling point than **A**.

……..……..

……..……..

……..……..

……..……..

……[3]

(iii) Draw the skeletal formulae of the stereoisomers of **A**, and state the type of isomerism they exhibit.

type of isomerism …….. [2]

[Total: 9]

For examiner's use

3 (a) Nitrogen monoxide, NO, reacts with chlorine gas according to the following equation.

$$2NO(g) + Cl_2(g) \longrightarrow 2NOCl(g)$$

To study the kinetics of the reaction, two experiments were performed with concentrations of the reactants shown below.

experiment	initial [Cl_2] / mol dm^{-3}	initial [NO] / mol dm^{-3}
1	0.01000	0.10
2	0.01000	0.20

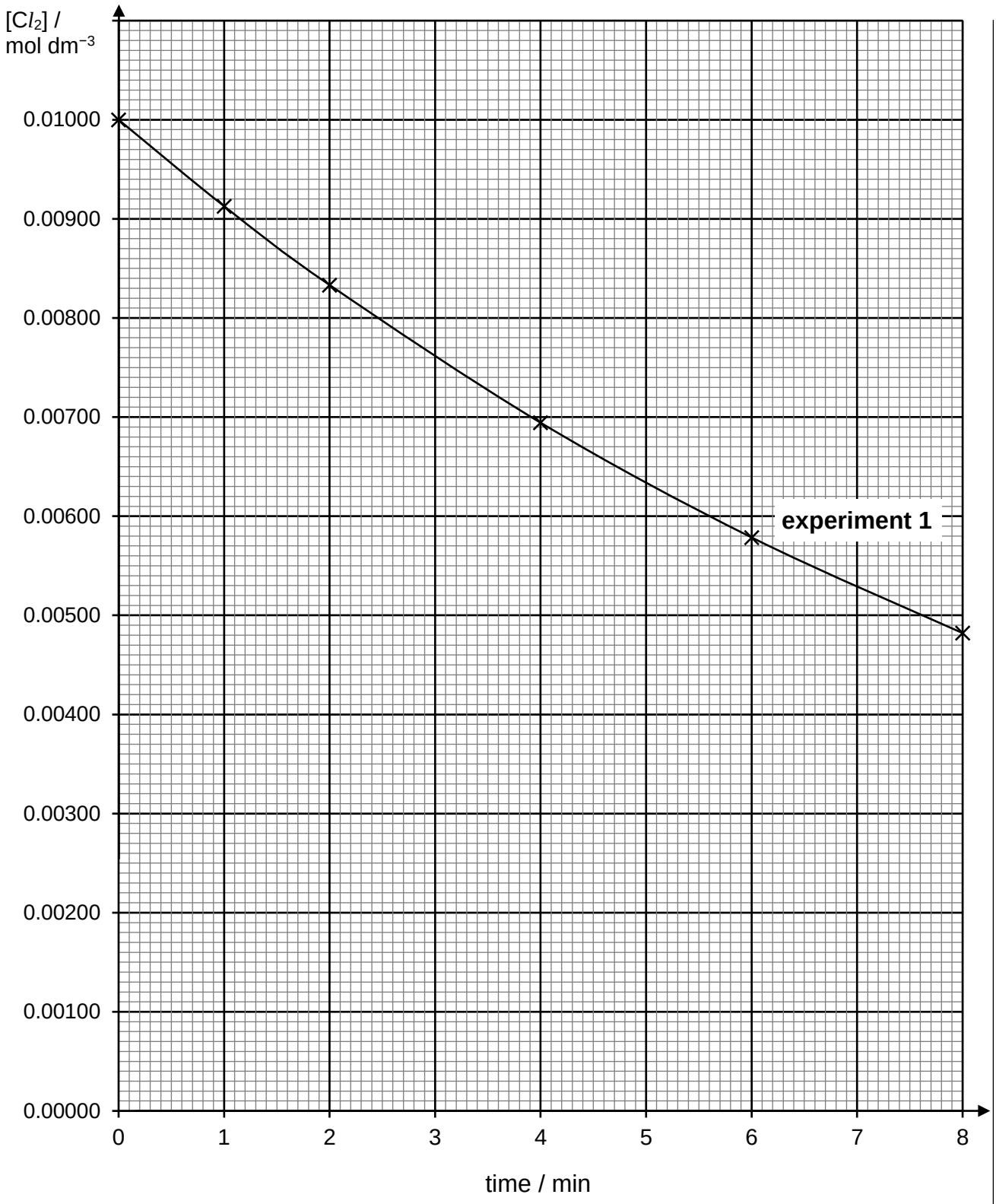
Table 3.1 shows the variation of [Cl_2] with time.

Table 3.1

time / min	experiment 1	experiment 2
	[Cl_2] / mol dm^{-3}	[Cl_2] / mol dm^{-3}
0	0.01000	0.01000
1	0.00913	0.00694
2	0.00833	0.00482
4	0.00694	0.00232
6	0.00579	0.00112
8	0.00482	0.00054

The data for experiment 1 is plotted in the graph on page 23.

[Turn Over



For examiner's use

(i) Draw the graph for experiment 2 using the same axes as experiment 1. [2]

For examiner's use

(ii) Using the graphs, determine the order of reaction with respect to each of the two reactants, ICl_2 and NO. Show your working and reasoning, and draw clearly any construction lines on the graphs.

order of reaction with respect to ICl_2 is ……

order of reaction with respect to NO is …… [3]

(iii) Write the rate equation for the reaction.

……..[1]

(iv) Calculate the rate constant and state its units.

[2]

For examiner's use

(b) The exhaust gas of cars contains pollutants such as NO and CO. Table 3.2 shows the masses of NO and CO in a sample of exhaust gas before and after passing through a catalytic converter.

Table 3.2

pollutant	mass of pollutant / g per km of travel	
	before passing through catalytic converter	**after** passing through catalytic converter
NO	1.9	0.63
CO	15	2.1

Conversion efficiency is a measure of how efficiently a converter removes a pollutant, **X**, and it can be calculated using the following formula.

$$\text{conversion efficiency of } \mathbf{X} = \left(1 - \frac{\text{mass of } \mathbf{X} \text{ after passing through converter}}{\text{mass of } \mathbf{X} \text{ before passing through converter}}\right) \times 100\%$$

The conversion efficiency of NO is 66.8%.

(i) The conversion efficiency of CO is higher than that of NO. Calculate the conversion efficiency of CO.

[1]

(ii) Write equations to show the redox reactions involving NO and CO in a catalytic converter.

Hence, explain why the conversion efficiency of CO is higher than that of NO.

……

……

……

……

……[2]

For examiner's use

(iii) The catalytic converter contains catalysts which greatly increase the rate of removal of pollutants.

With the aid of a Boltzmann distribution curve, explain how the use of a catalyst can increase the rate of reaction.

……

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……

……

……

……

……[3]

[Total: 14]