RAFFLES INSTITUTION
2020 Year 5 Term 3 Timed Practice
HIGHER 2

CHEMISTRY 9729

26 June 2020
2 hours 15 minutes

Additional Materials: Multiple Choice Answer Sheet

READ THESE INSTRUCTIONS FIRST

DO NOT open this booklet until you are told to do so.

Write your name, 6-digit exam index number and civics tutorial group in the spaces provided on the OMR Answer Sheet and the cover sheet on page **9**. 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.
Record your answers to this section in soft pencil on the separate OMR Answer Sheet. Your OMR Answer Sheet will be collected after the first 30 minutes.

Section B (30 marks) consists of 3 structured questions.
Answers to this section are to be written in the spaces provided in the question paper.

Section C (35 marks) consists of 2 free-response questions.
Answers to this section are to be written in the spaces provided in the question paper.

You are reminded of the need for good English and clear presentation in your answers.

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.

This document consists of **25** printed pages and **0** blank page.

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 The molar mass of a compound has the same units as its relative molecular mass.

B One mole of a compound contains the same number of atoms as there are atoms in 12.0 g of carbon-12.

C The relative atomic mass of fluorine is given by the following expression.

$$\frac{\text{weighted average mass of 1 molecule of fluorine}}{\frac{1}{12} \text{ x mass of 1 atom of carbon-12}}$$

D 12.0 dm^3 of oxygen gas contains the number of atoms as 24.0 dm^3 of argon at room temperature and pressure.

The following information is relevant for Questions **2** and **3**.

The reaction between urea, N_2H_4CO, and nitrous acid, HNO_2, produces water, carbon dioxide gas and nitrogen gas.

$$N_2H_4CO(aq) + 2HNO_2(aq) \rightarrow 3H_2O(l) + CO_2(g) + 2N_2(g)$$

2 What is the change in the oxidation number of nitrogen from nitrous acid to nitrogen gas?

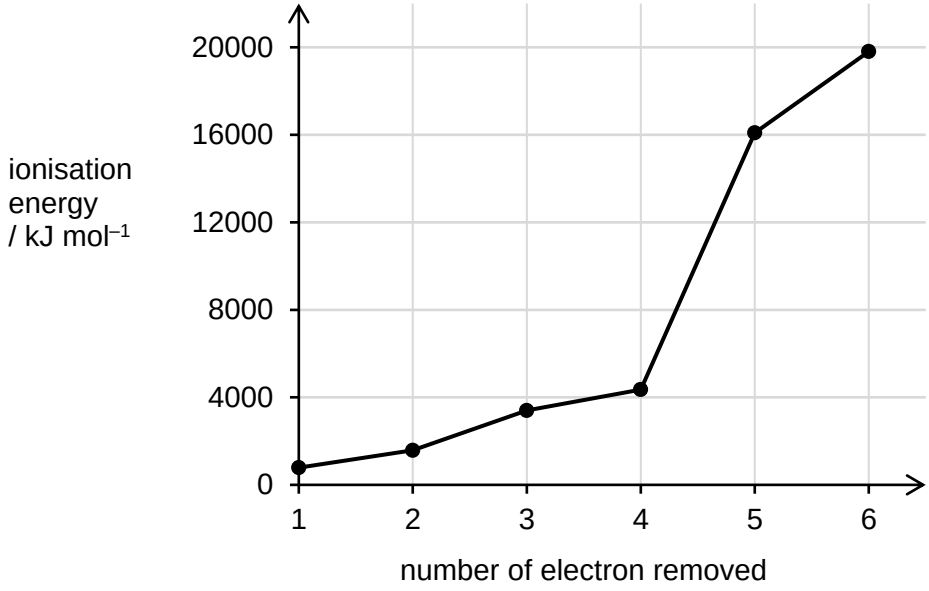
A –1 **B** –3 **C** +3 **D** +5

3 In an experiment, 1 mol of urea was reacted with nitrous acid. The mass of unreacted urea was 6.0 g.

What was the percentage of urea reacted?

A 87.5% **B** 89.7% **C** 90.0% **D** 90.3%

4 The first six successive ionisation energies of an element **Q** are plotted in the following diagram.



What is the electronic configuration of Q^{2+}?

A $1s^2\ 2s^2\ 2p^2$

B $1s^2\ 2s^2\ 2p^6$

C $1s^2\ 2s^2\ 2p^6\ 3s^2$

D $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$

5 "Mirror nuclei" are a pair of nuclei where the number of protons of element **A** equals the number of neutrons of element **B** and the number of protons of element **B** equals the number of neutrons in element **A**.

Which of the following statements are correct?

1 Mirror nuclei have the same mass number.
2 ^{11}O and ^{11}Li are mirror nuclei.
3 ^{40}Ar and ^{40}Ca are mirror nuclei.

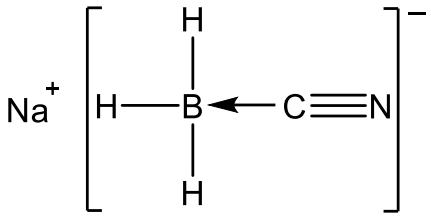
A 1 and 2 only

B 1, 2 and 3 only

C 2 and 3 only

D 1 only

6 Sodium cyanoborohydride is a reducing agent commonly used in organic synthesis. Its structure is shown below.



How many σ and π bonds are there in the cyanoborohydride anion?

	σ bonds	π bonds
A	5	2
B	5	1
C	4	3
D	4	2

7 In which of the following pair does the first species have a bigger bond angle than the second species?

A SF_2 and NF_4^+ **B** NF_4^+ and CO_3^{2-}

C ClO_3^- and CO_3^{2-} **D** ClO_3^- and SF_2

8 Water has a much higher boiling point than methane.

What are **major** reasons for this?

1 Strong hydrogen bonds exist between water molecules

2 The O–H bonds in water are stronger than the C–H bonds in methane

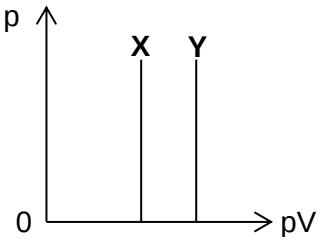
3 The water molecule contains more electrons than the methane molecule

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

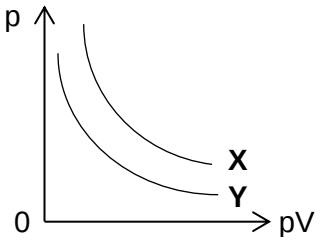
C 2 and 3 only **D** 1 only

9 Which of the following graphs shows the behaviour of ideal gases **X** and **Y** at constant temperature, where **X** has a higher molar mass than **Y**, and both samples have equal masses?

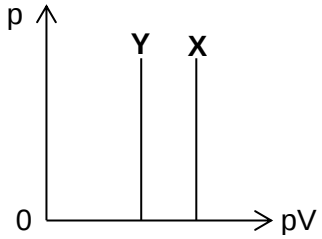
A



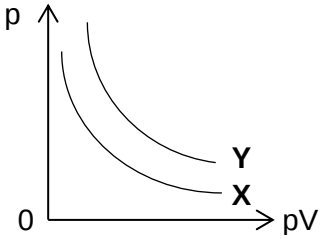
B



C



D



10 A fixed volume vessel contains 2.00 g of gas **A** at a pressure of 1.00 atm at 25 ^{o}C. When 3.00 g of inert gas **B** was added into the same vessel at the same temperature, the final pressure was found to be 2.50 atm. What is the ratio of the molar mass of gas **A** : gas **B**?

A 1 : 1

B 5 : 3

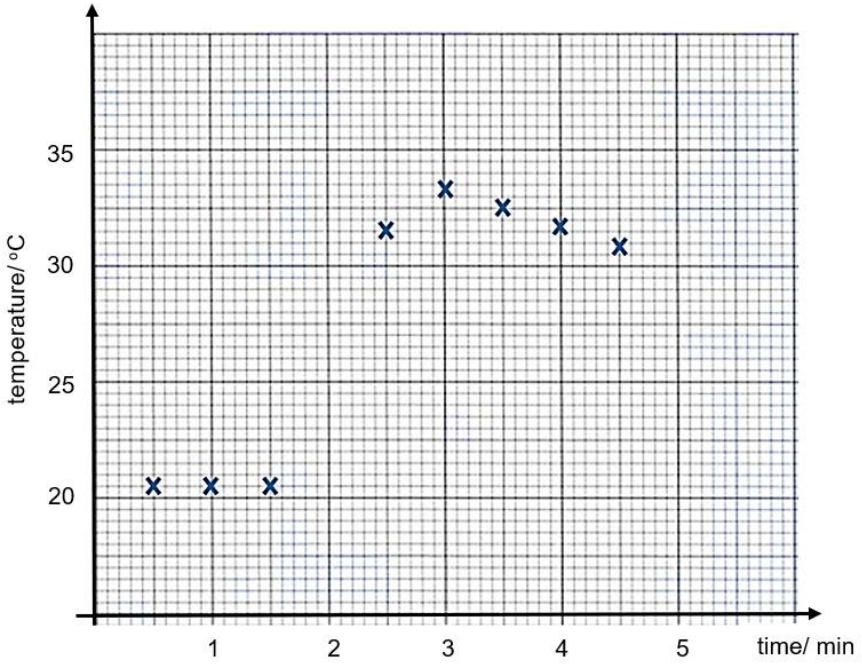
C 2 : 3

D 4 : 9

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

The temperature of a 250 cm^3 sample of water was measured at 0.5 min intervals.

At 2.0 min, 6.0 g of solid $AlCl_3$ was added to the water and the mixture was stirred. The temperature measurements are shown in the following graph.



Which of the following statements are correct?

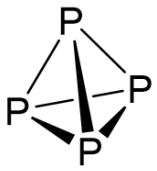
1 Products of this reaction are energetically more stable than the reactants.
2 Heat loss to surroundings is accounted for via extrapolation to time = 0.
3 The heat change of the reaction is +364 kJ.

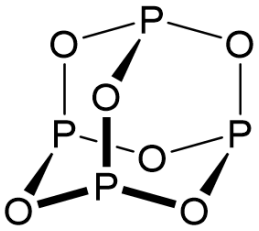
A 1, 2 and 3 **B** 1 and 3 only

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

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

Phosphorus trioxide, P_2O_3, exists in the form of P_4O_6. It is formed when P_4 reacts with O_2. The structures of P_4 and P_4O_6 are shown below.





What is the enthalpy change, in kJ mol^{-1}, of the following reaction?

$$P_4(g) + 3\ O_2(g) \rightarrow P_4O_6(g)$$

A +1392 **B** –1392

C +2430 **D** –2430

13 Sulfur exists in two common forms at room temperature, rhombic sulfur and monoclinic sulfur. The combustion of both forms of sulfur produce sulfur dioxide and their respective standard enthalpy changes of combustion are shown below.

S(monoclinic) = –297.2 kJ mol^{-1}
S(rhombic) = –296.9 kJ mol^{-1}

Which of the following deductions below are correct?

1 Rhombic sulfur is more stable than monoclinic sulfur.
2 Conversion of rhombic sulfur to monoclinic sulfur is endothermic.
3 Less energy is required to atomise 1 mol of rhombic sulfur than 1 mol of monoclinic sulfur.

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

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

14 Which of the following processes has a negative change in entropy?

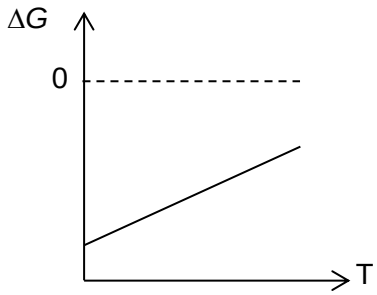
A $H_2O(s) \rightarrow H_2O(l)$

B $KNO_3(s) + aq \rightarrow KNO_3(aq)$

C $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$

D $2Al(s) + 6HCl(aq) \rightarrow Al_2Cl_6(aq) + 3H_2(g)$

15 The following graph plots the change in Gibbs free energy, ΔG, in kJ mol^{-1}, against temperature, T, in K, for a particular reaction.



Which of the following statements about the reaction are correct?

1 The reaction is exothermic.
2 There is an increase in disorder during the reaction.
3 The reaction becomes less exergonic as temperature increases.

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

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

– END OF SECTION A –

RAFFLES INSTITUTION
2020 Year 5 Term 3 Timed Practice
H2 Chemistry

COVER SHEET

Name: ( )	**Class:**

For Examiner's Use Only

Section		**Marks**
A		**/ 15**
B	**B1**	**/ 9**
	B2	**/ 9**
	B3	**/ 12**
C	**C1**	**/ 18**
	C2	**/ 17**
Total		**/ 80**
Percentage		**/ 100**
Grade		

[Turn Over

Section B

Answer **all** question from this section.

B1 This question is about Group 1 chlorides and their physical properties.

(a) **(i)** Define *lattice energy*.

……

……[1]

(ii) State and explain which compound, NaC*l* or KC*l*, has a larger magnitude of lattice energy.

……

……

……

……[2]

(iii) Hence, predict and explain the relative melting points of NaC*l* and KC*l*.

……

……[1]

(b) Some information of the Group 1 chlorides are given in the table below.

Table 1.1

compound	lattice energy / kJ mol^{-1}	sum of $\Delta H_{hydration}$ of ions in compound / kJ mol^{-1}	$\Delta H_{solution}$ / kJ mol^{-1}
LiC*l*	–860	–897	
NaC*l*	–787	–783	
KC*l*			+17.2

(i) Complete the table above by calculating the $\Delta H_{solution}$ of LiC*l* and NaC*l*. [1]

(ii) Hence, deduce, with reasoning, which compound in Table 1.1 is the most soluble in water.

……[1]

(c) Fajan's rules hypothesised that every ionic compound has some degree of covalent character. The percentage of ionic character in a compound can be calculated using the following equation.

$$\text{percentage of ionic character} = \frac{\mu_{\text{observed}}}{\mu_{\text{calculated}}} \times 100\%$$

where
μ_{observed} = actual bond dipole observed from experiment,
$\mu_{\text{calculated}}$ = theoretical bond dipole assuming the compound is 100% ionic.

The bond dipoles of some Group 1 chlorides are given in Table 1.2.

Table 1.2

compound	μ_{observed}	$\mu_{\text{calculated}}$	percentage ionic character / %
LiC*l*	7.13	9.70	
NaC*l*	9.00	11.33	

(i) Complete the table above by calculating the percentage ionic character of LiC*l* and NaC*l*. [1]

(ii) Using relevant data from the *Data Booklet*, explain the difference between the percentage ionic character of LiC*l* and NaC*l*.

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……

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……[2]

[Total: 9]

B2 Arsenic is a Group 15 element and is well-known for its toxicity.

(a) By considering relevant data from the *Data Booklet*, suggest a value for the first ionisation energy of arsenic. Briefly explain your answer.

……

……

.....[2]

Arsenic is present in contaminated water as the arsenite ion, AsO_3^{3-}. The amount of arsenic in contaminated water can be analysed using the following 3-step process.

Step **I** The arsenite present in a water sample is converted into arsenate, AsO_4^{3-}, by reaction with excess ozone, O_3.

$$O_3(g) + AsO_3^{3-}(aq) \rightarrow AsO_4^{3-}(aq) + O_2(g)$$

Step **II** The arsenate is then reacted with excess potassium iodide in an **alkaline** medium to produce iodine and arsenite.

Step **III** The liberated iodine is then titrated against standard aqueous sodium thiosulfate.

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

(b) Write a balanced equation for the reaction in step **II**, between arsenate, AsO_4^{3-}, and potassium iodide in **alkaline** medium.

.....[1]

(c) 10.0 cm^3 of a contaminated water sample was analysed using the 3-step process described on page 12. The iodine produced required 20.05 cm^3 of 1.00 x 10^{-5} mol dm^{-3} aqueous sodium thiosulfate for complete reaction.

(i) Calculate the minimum volume of ozone required in step **I,** at room temperature and pressure, for this 10.0 cm^3 water sample.

[3]

(ii) It is recommended that the arsenic in drinking water should not exceed 1.0 x 10^{-5} g dm^{-3}.

Suggest, with reasoning, whether this water sample analysed is safe for consumption.

[1]

Another common compound of arsenic, arsenic trioxide, As_2O_3, undergoes reduction with carbon to form a grey solid and carbon dioxide as the only products.

(d) It was found that 2.5 g of carbon reacted with 27.5 g of arsenic trioxide.

Deduce, with reasoning, the identity of the grey solid.

[2]

[Total: 9]

B3 Reverse osmosis (RO) is a process used to remove ions from seawater. The following table provides some data of chemical species present in a sample of seawater and their amounts before and after reverse osmosis.

Table 3.1

species	ionic size / nm	effective size in aqueous solution / nm	amount of ions per litre		percentage of ions separated
			before RO, **B** / mol	after RO, **A** / mol	
Na^+	0.19	0.72	0.543	0.0815	85.0%
K^+	0.28	0.66	0.0115	0.00242	79.0%
Mg^{2+}	0.13	0.86	0.0597	0.00119	98.0%
Ca^{2+}	0.20	0.82	0.0113	0.00113	90.0%
Cl^-	0.36	0.66	0.697	x	–
H_2O	–	0.26	–	–	–

(1 nm = 1 x 10^{-9} m)

(a) Explain the relative ionic size of Na^+ and Mg^{2+}.

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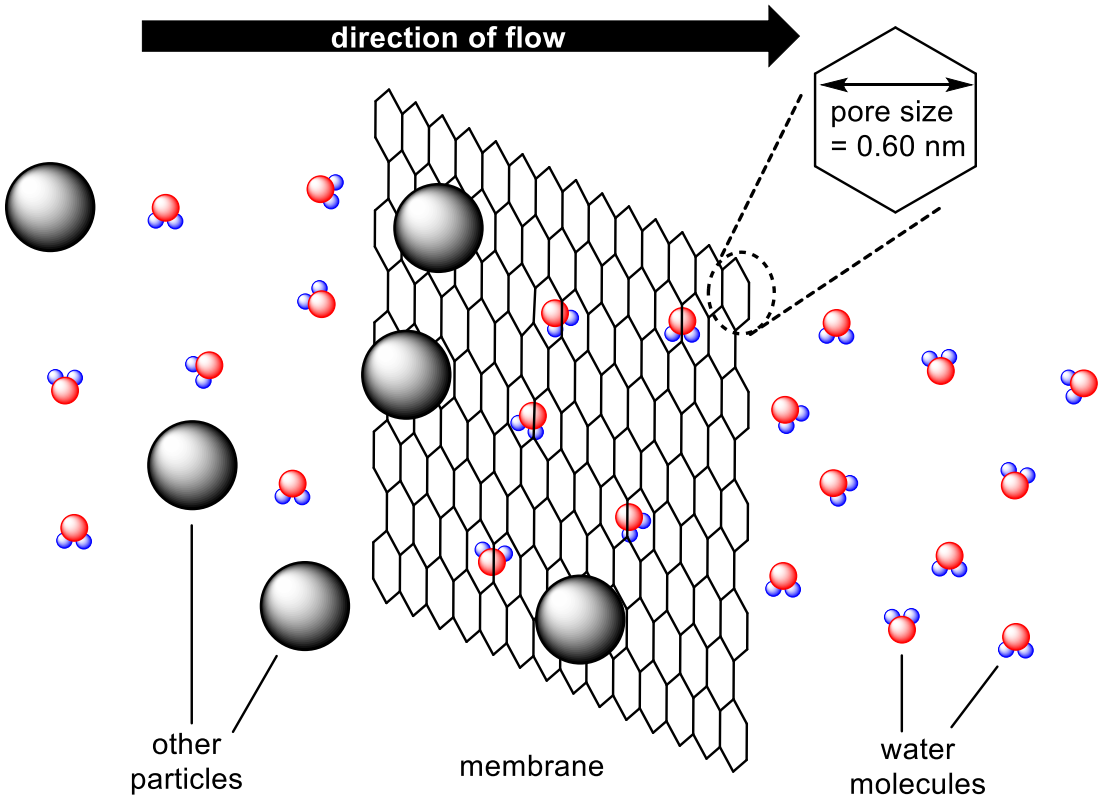
……[2]

In RO, seawater is pushed through a membrane under pressure. In one particular RO facility, the membrane used has a pore size of 0.60 nm which allows the ions to be separated from water.



(b) Draw a diagram to explain why the effective size of Na^+ in aqueous solution is greater than its ionic size. Label the diagram to show any type of interactions involved.

[2]

(c) Explain why a pore size of 0.60 nm is suitable to separate water molecules from the ions present in the sample of seawater.

……..……

……..……

……..……..[2]

(d) The data shows that a small amount of ions passed through the membrane even if a new and undamaged membrane is used.

(i) Suggest a reason for the above observation.

……..……

……..……[1]

(ii) A trend can be observed in the percentage of cations separated in terms of the charge and size of the cations.

Choose a pair of cations and account for their relative percentage separated.

……..……

……..……

……..……

……..……

……..……...[2]

(iii) The amount of chloride ions present after RO balances the charges of the cations such that the final solution has no net charge.

Calculate the amount of chloride ions per litre, x, present in the solution after RO.

[1]

(e) The main by-product of RO is a highly concentrated solution of salts i.e. brine. The brine is typically disposed back into the sea, which has a negative impact on marine life. The graph below shows how the solubility of O_2 varies with the concentration of Na*Cl*.

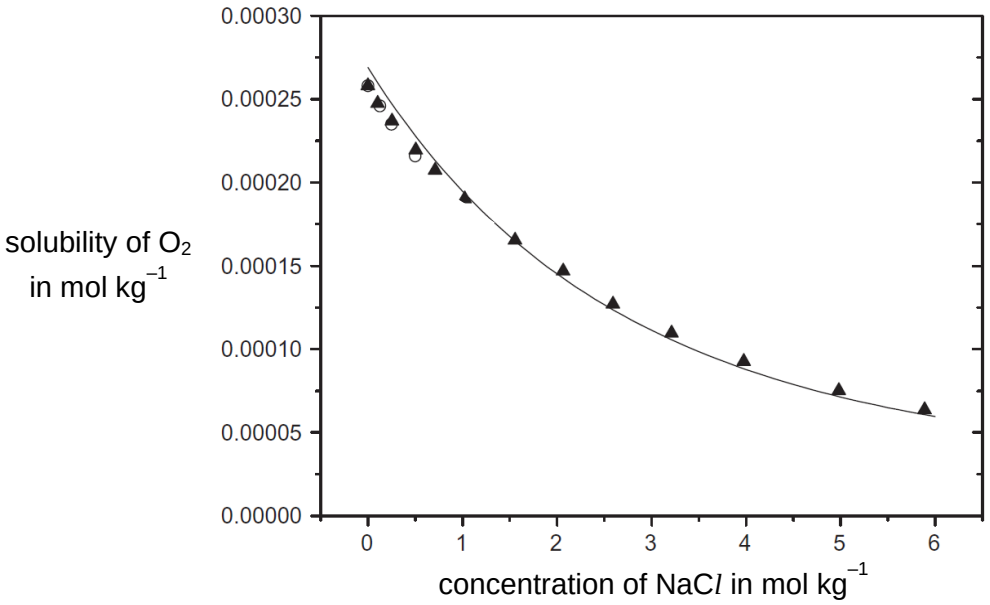


Fig. 3.1

(i) Use the data in Fig. 3.1 to explain the negative impact of disposing brine into the sea on marine life.

……

……[1]

(ii) By considering the interactions between relevant chemical species, explain the trend observed in the above graph.

……

……

……

……[1]

[Total: 12]

– END OF SECTION B –

Section C

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

C1 **(a)** A mixture of N_2H_4 and N_2O_4 was used as a propellant for the Curiosity Rover which landed on Mars in 2012.

(i) N_2H_4 and N_2O_4 contain an N–N bond each. Draw dot-and-cross diagrams to show the bonding in N_2H_4 and N_2O_4.

[2]

(ii) State and explain, with reference to the Valence Shell Electron Pair Repulsion Theory, the shapes of N_2H_4 and N_2O_4 with respect to an N atom.

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……..……..

.....[2]

(iii) State a value for the N-N-H bond angle in N_2H_4. Explain your answer.

……..……..

.....[2]

(iv) Draw a labelled diagram showing the orbital overlap between the nitrogen atoms in N_2.

[2]

(b) Fig. 1.1 shows the behaviour of 1 mole each of N_2 and CO_2 at 293 K.

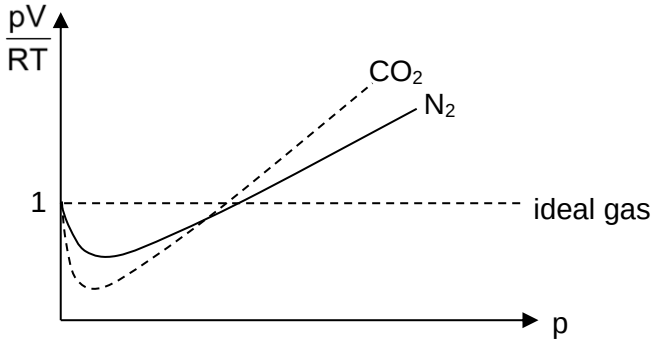

Fig. 1.1

Give two reasons to account for the differences in the graphs of CO_2 and N_2.

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……

……

……

……

……[2]

The atmospheric composition of Mars was collected and compared with that of Earth's in Table 1.1.

Table 1.1

	Mars	Earth
gas	% by volume	% by volume
CO_2	95.32	0.04
N_2	2.70	78.05
Ar	1.60	0.93
O_2	0.13	20.95
CO	0.08	0.00
trace gases	0.17	0.03

(c) The relationship between density and pressure for a gas on Earth is plotted in Fig. 1.2. The experiment was conducted at 180 °C.

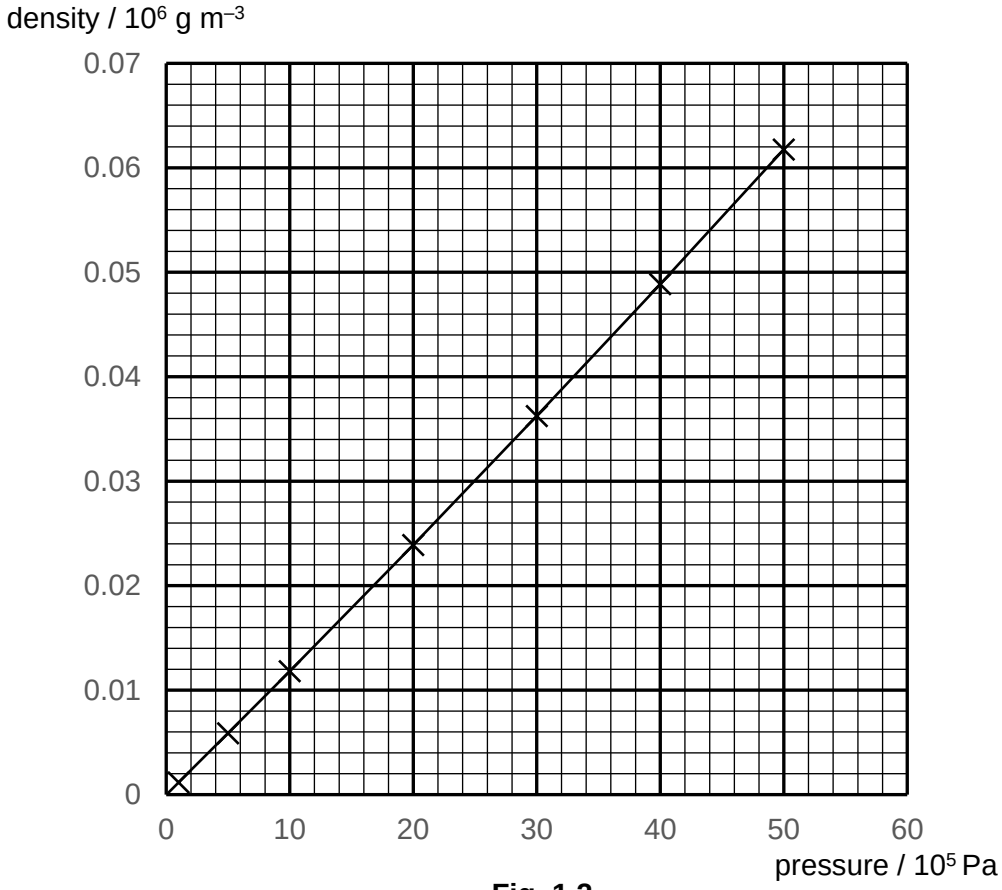

Fig. 1.2

(i) Determine a value for the gradient of the graph.

[1]

(ii) Assuming that the gas behaves like an ideal gas, determine its M_r and identity by using your answer in **(c)(i)**. Show your working clearly.

[2]

(d) On Mars, the average temperature is about –60 ^oC and atmospheric pressure is 600 Pa.

(i) Predict, with a suitable reason, on which planet are the gases more likely to obey the Ideal Gas Equation.

……

……

……..……...……..

……[2]

(ii) The atmosphere of Mars does not support human life which depends on O_2 for cellular respiration. On average, an adult needs 2625 dm^3 of air per day at r.t.p. Based on the information given above, calculate the average volume of air needed by an adult per day on Mars.

[3]

[Total: 18]

C2 Alcohols (e.g. ethanol and butanol) are used as fuels for internal combustion engines.

(a) Define the term standard enthalpy change of combustion of ethanol, $CH_3CH_2OH(l)$.

……

……[1]

(b) Experiments are carried out to investigate the relationship between the number of carbon atoms in an alcohol and its enthalpy change of combustion, ΔH_c.

To determine the enthalpy change of combustion, some ethanol was burnt in a spirit burner to heat 100 cm^3 of water as shown in Fig. 2.1 The experiment was repeated using butanol. All experimental data collected are shown below in Tables 2.1 and 2.2.

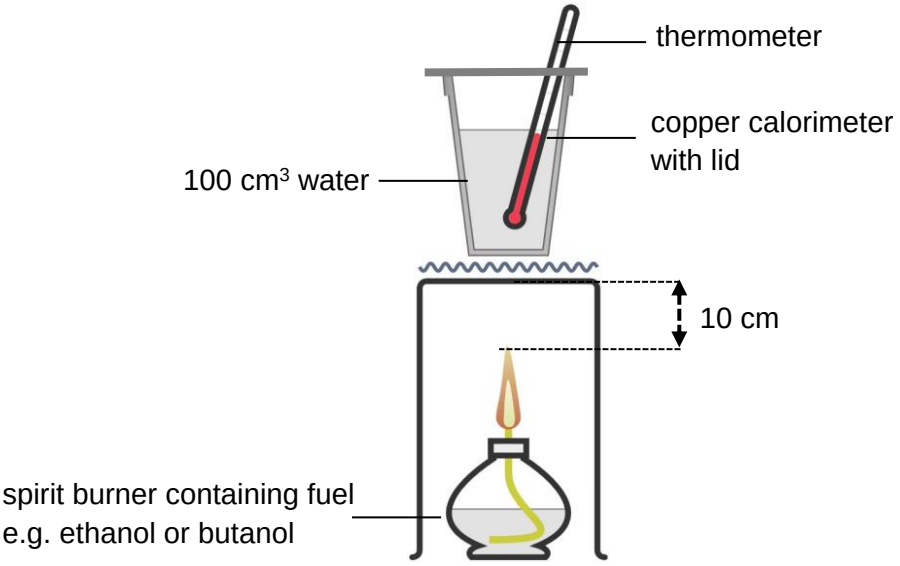

Fig. 2.1

Table 2.1

	fuel used	
	ethanol CH_3CH_2OH	butanol $CH_3(CH_2)_2CH_2OH$
initial temperature of water / °C	22	26
highest temperature of water / °C	55	59

Table 2.2

	before combustion	after combustion
mass of spirit burner containing ethanol / g	85.6	83.1
mass of spirit burner containing butanol / g	83.1	81.1

(i) Explain why it is important for the change in temperature of water for both sets of experiments to be similar.

……..……..…..…..

.....……..……..……[1]

(ii) Using relevant data in **(b)** and from the *Data Booklet*, calculate the apparent ΔH_c of ethanol. [M_r of ethanol = 46.0]

[3]

The experiment was repeated for pentanol and hexanol. Table 2.3 shows the apparent ΔH_c found.

Table 2.3

alcohol	apparent ΔH_c / kJ mol^{-1}
butanol, $CH_3(CH_2)_2CH_2OH$	−510
pentanol, $CH_3(CH_2)_3CH_2OH$	−635
hexanol, $CH_3(CH_2)_4CH_2OH$	−770
heptanol, $CH_3(CH_2)_5CH_2OH$	

(iii) Comment on the relationship between the number of carbon atoms in an alcohol and its ΔH_c, and estimate a value, in kJ mol^{-1}, for the apparent ΔH_c of heptanol.

..……..……..……...

..……..……..……...

.....……..……[2]

(iv) The true value of ΔH_c of pentanol is −3329 kJ mol^{-1}.

Suggest two reasons for the discrepancy between the true value and the apparent ΔH_c of pentanol.

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.....

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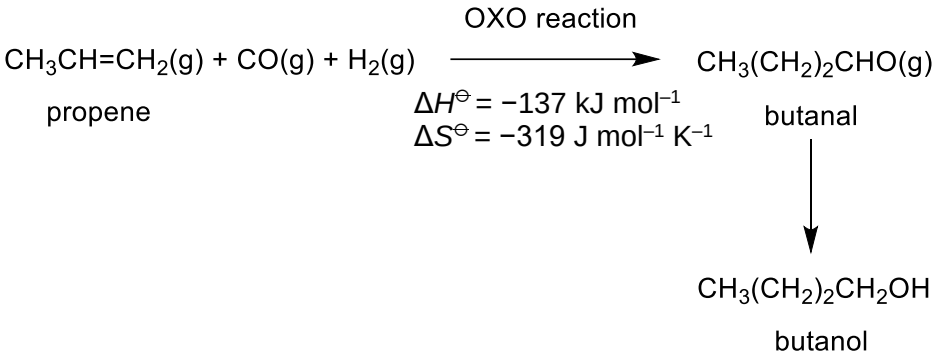
.....[2]

(c) The OXO reaction is part of an industrial process to produce alcohols. Butanol can be synthesised from propene via an OXO reaction as shown below.



(i) Define the term *entropy* of a chemical system.

.....

.....[1]

(ii) Comment on the sign of $\Delta S^{\ominus}$ for the OXO reaction.

.....

.....[1]

(iii) Calculate $\Delta G^{\ominus}$ for the OXO reaction.

[1]

(iv) The OXO reaction can be safely carried out between 40 °C and 200 °C.

State and explain why it is less desirable to carry out the reaction at a higher temperature of 170 °C compared to a lower temperature of 50 °C.

……

……[2]

(d) The standard enthalpy changes involving butanol can be used to calculate the standard enthalpy change of formation of butanoic acid.

Use the information given below to construct an energy cycle to calculate the standard enthalpy change of formation of butanoic acid, $\Delta H_f^{\ominus}[C_3H_7COOH(l)]$.

$\Delta H_f^{\ominus}[C_3H_7CH_2OH(l)]$	$= -327$ kJ mol^{-1}
$\Delta H_c^{\ominus}[C_3H_7CH_2OH(l)]$	$= -2676$ kJ mol^{-1}
$\Delta H_c^{\ominus}[C_3H_7COOH(l)]$	$= -2183$ kJ mol^{-1}
$\Delta H_f^{\ominus}[H_2O(l)]$	$= -287$ kJ mol^{-1}

[3]

[Total: 17]

– END OF PAPER –