Class Adm No

Candidate Name: _____

2021 End-of-Year Exams
Pre-University 2

H1 CHEMISTRY **8873/02**

Paper 2 Structured Questions **20 Sep 2021**

2 hours

Candidates answer on the Question paper.

Additional materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not turn over this question paper until you are told to do so

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

Section A
Answer **all** the questions.

Section B
Answer **one** question.

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

A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

	Section A				Section B		
Question	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Marks	/18	/17	/14	/8	/20	/20	/80

Section A

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

1 Chromic acid, H_2CrO_4, is commonly used as a glassware cleaning reagent in laboratories. It is prepared by adding 60.0 g of potassium dichromate(VI), $K_2Cr_2O_7$, in 150 cm^3 of warm distilled water at 35.0 °C, and then slowly adding excess concentrated sulfuric acid to produce a 1 dm^3 chromic acid solution. During this process, the solution reached a maximum temperature of 38.5 °C. [Assume for the solution, density = 1.71 g cm^{-3} ; specific heat capacity = 4.18 J g^{-1} K^{-1}.]

Chromic acid is a strong acid which dissociates according to the following equation:

$$H_2CrO_4 \rightarrow H^+ + HCrO_4^- \quad \text{---------- } K_a$$

Chromic acid is also a strong oxidising agent, in which the $HCrO_4^-$ ion produced can be used to oxidise aldehydes (R-CHO) to carboxylic acids (R-COOH), where R represents an alkyl group. In the process, green Cr^{3+} ions are produced. The rate equation for this reaction is

$$\text{rate} = k\,[\text{R-CHO}]\,[HCrO_4^-]$$

(a) **(i)** Write a balanced ionic equation for the conversion of dichromate(VI) ions, $Cr_2O_7^{2-}$, into H_2CrO_4 during the preparation process.

……[1]

(ii) Calculate the amount of $K_2Cr_2O_7$ used in the preparation of chromic acid.

[1]

(iii) Hence, calculate the concentration of H_2CrO_4 in the 1 dm^3 solution formed from the preparation process outlined above.

[1]

(iv) Calculate the mass of the 1 dm^3 chromic acid solution.

[1]

(v) Hence, calculate the enthalpy change for the reaction in **(a)(i)**.

[2]

(b) **(i)** Determine the oxidation numbers of C in R-CHO and in R-COOH.
[Assume that the R group does not contribute to the oxidation number of C.]

R-CHO: …… R-COOH: ……... [1]

(ii) Determine the oxidation numbers of Cr in $HCrO_4^-$ and in Cr^{3+}.

$HCrO_4^-$: …… Cr^{3+}: ……... [1]

(iii) Hence, or otherwise, determine the molar ratio in which $HCrO_4^-$ reacts with R-CHO.

$HCrO_4^-$	:	R-CHO
	:	

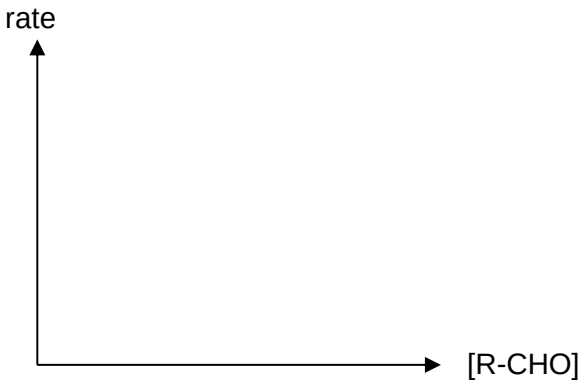
[1]

(iv) Sketch, on the axes below, how the rate of the oxidation reaction varies with the concentration of R-CHO at:

I: 298 K

II: 398 K

For this question, assume that the concentration of $HCrO_4^-$ remains constant.



[2]

(v) With the aid of a Maxwell-Boltzmann distribution diagram, explain how the rate of the reaction between R-CHO and $HCrO_4^-$ changed when the temperature was increased from 298 K to 398 K.

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……

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……[3]

(c) **(i)** By considering the electronic configuration of the Cr^{3+} ion, determine the number of unpaired electrons for the Cr^{3+} ion in the ground state.

…….... [1]

(ii) Suggest if the value of the dissociation constant of chromic acid, K_a, is larger or smaller than 1. Explain your answer.

……

……

…….... [1]

(iii) Given that H_2CrO_4 is a simple molecule containing two Cr=O double bonds and two Cr–O single bonds, draw the displayed formula of H_2CrO_4 and state the predominant intermolecular interaction between two molecules of H_2CrO_4.

……[2]

[Total: 18]

2 At a fixed temperature, nitrogen dioxide, $NO_2(g)$, was placed into a closed vessel of fixed volume and allowed to reach *dynamic equilibrium*. The equilibrium concentration of $NO_2(g)$ was found to be 0.800 mol dm^{-3} and the equilibrium constant, K_c, has a value of 0.400.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

(a) **(i)** Define the term *dynamic equilibrium*.

……

……

…… [1]

(ii) Write an expression for the equilibrium constant, K_c, and state its units.

[2]

(iii) Calculate the equilibrium concentration of $N_2O_4(g)$.

[1]

(iv) Using your answer in **(a)(iii)**, calculate the initial concentration of $NO_2(g)$ that was placed into the closed vessel.

[2]

(v) Using your answer in **(a)(iii)**, calculate the average molecular mass, to **4 significant figures**, of all the gases in the mixture at equilibrium.

[2]

(b) **(i)** Draw a 'dot-and-cross' diagram for the NO_2 molecule.

[1]

(ii) Based on your answer in **(b)(i)** and using information from the *Data Booklet*, suggest a value for the enthalpy change for the dimerisation of nitrogen dioxide. Include the sign and units in your answer.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

[1]

(iii) Hence, draw a well-labelled energy profile diagram for the reaction in **(b)(ii)**.

[2]

(iv) Hence, or otherwise, explain how increasing the temperature will affect the position of equilibrium and suggest a value for the equilibrium constant.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

……

……

……

……

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……[2]

(c) **(i)** Explain why the first ionisation energy of nitrogen is higher than that of oxygen.

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……

……[1]

(ii) Explain if the ionic radius of oxygen is smaller or larger than that of nitrogen.

……

……

……

……

……[2]

[Total: 17]

3 **(a)** When magnesium chloride, $MgCl_2$, and phosphorus pentachloride, PCl_5, are separately placed in a beaker of hot water, they produce solutions of different pH values. Write balanced chemical equations, with state symbols, for the separate reactions of magnesium chloride and phosphorus pentachloride with hot water, and suggest the pH of the resulting solutions.

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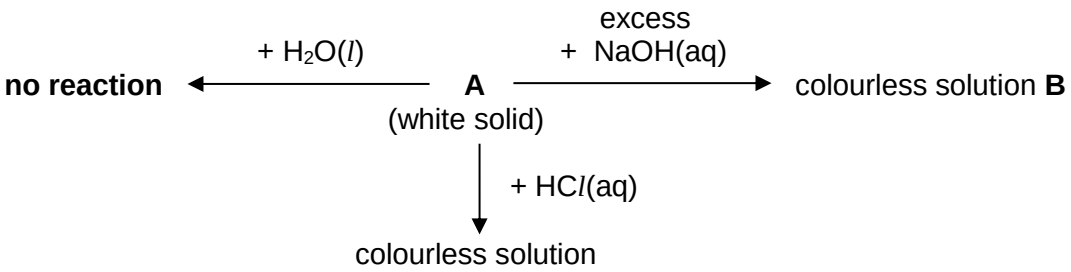
……..….. [4]

(b) A period 3 oxide, **A**, was subjected to the following reactions.



(i) Suggest the identities of **A** and **B**.

A: …… **B**: ……... [2]

(ii) Explain why period 3 elements are able to accommodate more than 8 electrons in their valence shell.

……

……... [1]

(c) The following table shows the observations when three group 17 elements, $\mathbf{D_2}$, $\mathbf{E_2}$, and $\mathbf{F_2}$, are reacted with their halide ions in aqueous solution.

	To a test tube containing 1 cm^3 of $\mathbf{D^-}$(aq)	To a test tube containing 1 cm^3 of $\mathbf{E^-}$(aq)	To a test tube containing 1 cm^3 of $\mathbf{F^-}$(aq)
Add 1 cm^3 of $\mathbf{D_2}$(aq)	-	Solution turns brown	No reaction
Add 1 cm^3 of $\mathbf{E_2}$(aq)	No reaction	-	No reaction
Add 1 cm^3 of $\mathbf{F_2}$(aq)	Solution turns orange	Solution turns brown	-

(i) Suggest the identities of elements **D**, **E**, and **F**.

D: …… **E**: …… **F**: …… [1]

(ii) Rank bromine, chlorine and iodine in decreasing oxidising strength. Explain your answer.

……

……

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……[2]

(d) Recent technological advances have found that silicon nanoparticles (SiNPs) can be used as metal-free quantum dots exhibiting photoluminescence, i.e. SiNPs can emit light, such as in light-emitting diodes (LEDs) used in television screens. SiNPs are also researched as a reusable catalyst for the synthesis of sulfur-containing organic compounds.

(i) Suggest a reason why SiNPs are corrosion-resistant compared to nanoparticles made from metals.

……

……[1]

(ii) Explain why silicon nanoparticles are preferred for use a catalyst over bulk silicon with dimensions of 1 cm x 1 cm.

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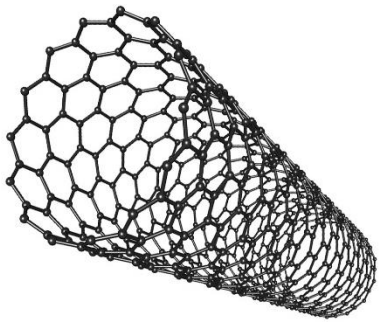
……[1]

(e) Another group 14 element, carbon, exists as several forms. One such form is called a carbon nanotube, which consists of a layer of graphene rolled into a cylindrical shape.



carbon nanotube

Carbon nanotubes can be used as biosensors implanted in the human body due to its high electrical conductivity, high durability, low density, and absence of toxic metals.

(i) Explain whether a carbon nanotube is likely to be classified as a nanomaterial or nanoparticle.

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……

…… [1]

(ii) Explain why a carbon nanotube is able to conduct electricity.

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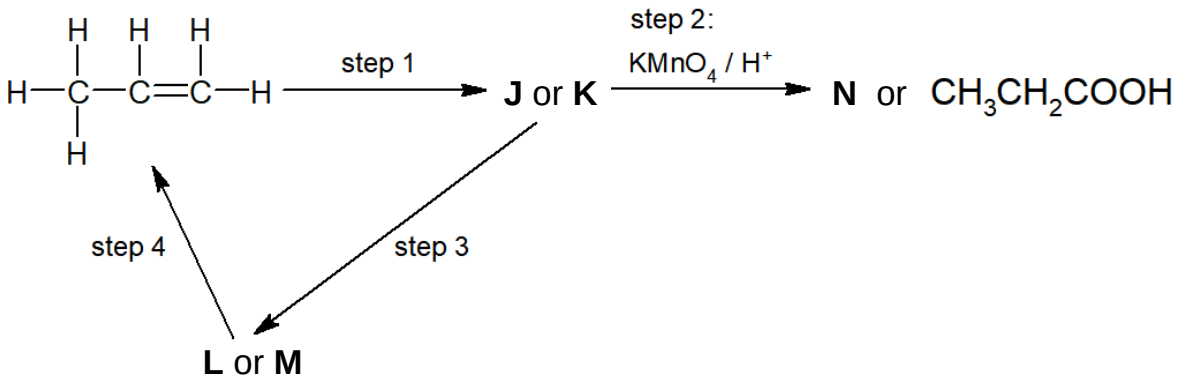
…… [1]

[Total: 14]

4 **(a)** The following schematic shows reactions involving propene.



J, **K**, **L**, **M** and **N** are all organic compounds. **J** is a constitutional isomer of **K**, while **L** is a constitutional isomer of **M**.

J reacts via step 2 to form **N**, and **J** reacts via step 3 to form **L**.

(i) State the reagents and conditions for steps 1, 3 and 4.

step 1: ……

step 3: ……

step 4: …….. [3]

(ii) Draw the structures of **J**, **K**, **L**, **M** and **N**.

[5]

(b) The bond energies of C–C*l* and C–Br are 340 kJ mol^{-1} and 280 kJ mol^{-1} respectively. Explain the difference in bond energies.

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…… [2]

[Total: 10]

Section B

Answer **one** question from this section in the spaces provided.

5 **(a)** **(i)** Define what is meant by the terms *acid* and *base* using the Brønsted-Lowry theory of acids and bases.

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…… [1]

(ii) State the conjugate acid of $H_2PO_4^-$.

…… [1]

(iii) Write a balanced ionic equation for the ionic product of water, K_w.

…… [1]

(iv) Water has a K_w value of 5.13×10^{-13} at 100 °C.

Calculate the pH of pure water at 100 °C.

[2]

(v) Hence, explain if a solution with a pH of 6.3 is considered to be acidic or basic at 100 °C.

…… [1]

(b) Chloroethene, C_2H_3Cl, polymerises to form poly(chloroethene), also known as polyvinyl chloride, PVC. The process can be considered as involving the breaking of a C=C bond and forming two C-C bonds per molecule of chloroethene.

(i) Draw two repeat units for poly(chloroethene).

[1]

(ii) Using information from the *Data Booklet*, calculate the enthalpy change for the polymerisation of ethene into poly(ethene), in terms of kJ per mol of ethene.

[1]

(iii) Suggest a reason why the value calculated in **(b)(ii)** is less exothermic than the actual enthalpy change for the polymerisation process.

……

……

…….. [1]

(iv) Suggest an object that is made of PVC and describe a property of PVC that enables it to be used as a material for that object.

……

……

…….. [2]

(v) It is possible to form chloroethene from ethene in a way similar to their alkane counterparts. However, the yield of chloroethene turns out to be very low.

State the reagent and conditions for the formation of chloroethane from ethane and suggest a reason why the same reagents and conditions results in a low yield when applied to ethene.

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…….... [2]

(vi) State the shape and bond angle about the carbon atoms in chloroethene, C_2H_3Cl, and explain if the molecule is polar.

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…….... [3]

(c) A sample of chlorine atoms were ionised. When a beam of $^{35}Cl^+$ ions are passed through an electric field, it was deflected by an angle of +5.25° relative to the horizontal axis. A detector plate was placed at that angle and counted 1036 of the $^{35}Cl^+$ ions hitting the plate.

(i) Determine the angle and direction of deflection, relative to the horizontal axis, when $^{37}Cl^{2-}$ ions were passed through the same electric field.
Give your answer to 3 significant figures.

[1]

(ii) If another detector plate counted 258 of the $^{37}Cl^{2-}$ ions, calculate the relative atomic mass of chlorine in the sample. Give your answer to 2 decimal places.
(Assume that only $^{35}Cl^{+}$, $^{37}Cl^{2-}$ ions are formed from the ionisation of the sample.)

[1]

(d) Explain, in terms of oxidation number changes, why the following reaction is considered to be a disproportionation reaction.

$$2Cl_2 + 2H_2O \rightarrow ClO_2^- + 3Cl^- + 4H^+$$

……

……

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……

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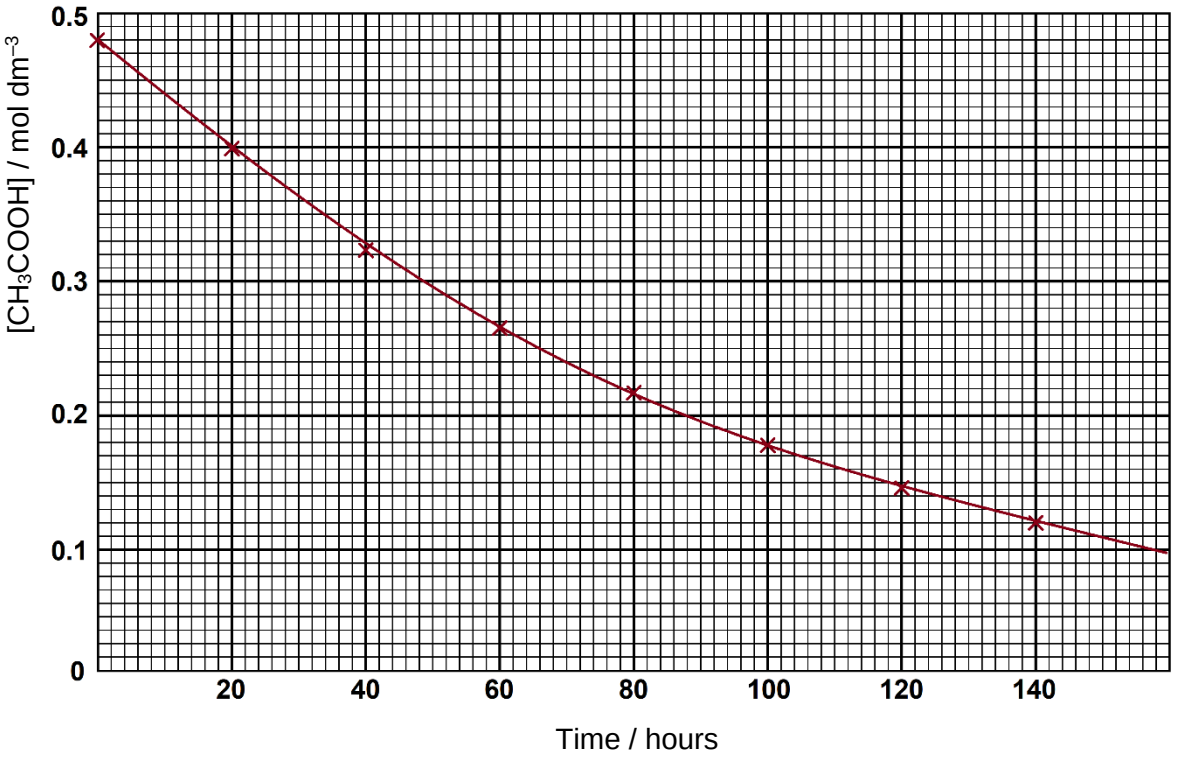
…… [2]

[Total: 20]

6 (a) The following balanced equation shows the reaction between ethanoic acid and methanol.

$$CH_3COOH(l) + CH_3OH(l) \rightleftharpoons CH_3COOCH_3(l) + H_2O(l)$$

The rate of reaction can be found by determining the remaining ethanoic acid concentration, through titration, against fixed time intervals (in hours) as seen in the graph below.



(i) Using the graph, determine the order of reaction with respect to $[CH_3COOH]$.

[2]

(ii) Given that the overall order of reaction is 2, write the rate equation for the reaction.

……[1]

(iii) Suggest a reagent that can be added to the reaction mixture to speed up the reaction.

…… [1]

(iv) Explain how a catalyst speeds up the rate of a reaction.

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……[2]

(v) Define the term *standard enthalpy change of formation*.

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……[1]

(vi) Given the following values, calculate the standard enthalpy change of reaction for the reaction between ethanoic acid and methanol in **(a)**.

Standard enthalpy change of formation of $CH_3COOH(l)$ / kJ mol^{-1}	– 483.52
Standard enthalpy change of formation of $CH_3OH(l)$ / kJ mol^{-1}	– 238.54
Standard enthalpy change of formation of $CH_3COOCH_3(l)$ / kJ mol^{-1}	– 445.66
Standard enthalpy change of formation of $H_2O(l)$ / kJ mol^{-1}	– 285.82

[2]

(vii) The concentration of H^+ ions is 6.86×10^{-3} mol dm^{-3} in the ethanoic acid solution before reaction with methanol.

Calculate the acid dissociation constant, K_a, for ethanoic acid, stating its units.

[2]

(b) Ethanoic acid can be reacted with CH_3NH_2 to form an amide. This reaction is difficult to occur without the presence of an activating agent.

State the reagent needed for the reaction to occur more readily and draw the skeletal structure of the resulting amide.

…….. [2]

(c) The following are some properties of two period 3 elements **Q** and **R**.

	Q	**R**
Electrical conductivity in the solid state	Poor	Good
Melting point / °C	-101	660
Solubility in water	Poor	Insoluble

(i) Suggest the identities of **Q** and **R**. For each element, choose one property and explain your answer in terms of structure and bonding.

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……

…… [3]

(ii) Draw and label the two different types of orbitals in the valence shell of a period 3 element.

[2]

(iii) *Use of the Data Booklet is relevant to this question.*

In a certain reaction, a voltage was applied causing the reduction of nitrate ions, NO_3^-, to nitrogen gas, N_2, in acidic solution. Water is concurrently oxidised to oxygen gas.

Write the balanced ion-electron equations for the reduction and oxidation, and hence write the overall balanced ionic equation for the reaction.

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…… [2]

[Total: 20]

END OF PAPER 2

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