Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Wednesday 13 November 2019 (afternoon)

Candidate session number

2 hours 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

21 pages

8819 – 6102

Answer **all** questions. Answers must be written within the answer boxes provided.

1. The equations show steps in the formation and decomposition of ozone in the stratosphere, some of which absorb ultraviolet light.

Step 1 $O_2 \rightarrow 2O\bullet$

Step 2 $O\bullet + O_2 \rightarrow O_3$

Step 3 $O_3 \rightarrow O\bullet + O_2$

Step 4 $O\bullet + O_3 \rightarrow 2O_2$

(a) Draw the Lewis structures of oxygen, O_2, and ozone, O_3. [2]

(b) Outline why both bonds in the ozone molecule are the same length and predict the bond length in the ozone molecule. Refer to section 10 of the data booklet. [2]

Reason:

. . . .

. . . .

. . . .

Length:

. . . .

(c) Predict the bond angle in the ozone molecule. [1]

. . . .

(This question continues on the following page)

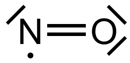
(Question 1 continued)

(d) Discuss how the different bond strengths between the oxygen atoms in O_2 and O_3 in the ozone layer affect radiation reaching the Earth's surface. [2]

(e) (i) Identify the steps which absorb ultraviolet light. [1]

(ii) Determine, showing your working, the wavelength, in m, of ultraviolet light absorbed by a single molecule in one of these steps. Use sections 1, 2 and 11 of the data booklet. [2]

(f) Ozone depletion is catalysed by nitrogen monoxide, NO, which is produced in aircraft and motor vehicle engines, and has the following Lewis structure.



Show how nitrogen monoxide catalyses the decomposition of ozone, including equations in your answer. [2]

2. The biochemical oxygen demand of a water sample can be determined by the following series of reactions. The final step is titration of the sample with sodium thiosulfate solution, $Na_2S_2O_3(aq)$.

$$2Mn^{2+}(aq) + O_2(aq) + 4OH^-(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)$$

$$MnO_2(s) + 2I^-(aq) + 4H^+(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)$$

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

A student analysed two $300.0\,cm^3$ samples of water taken from the school pond: one immediately (day 0), and the other after leaving it sealed in a dark cupboard for five days (day 5). The following results were obtained for the titration of the samples with $0.0100\,mol\,dm^{-3}$ $Na_2S_2O_3(aq)$.

Sample	**Titre / cm^3 $\pm$0.1 cm^3**
Day 0	25.8
Day 5	20.1

(a) (i) Determine the mole ratio of $S_2O_3^{2-}$ to O_2, using the balanced equations. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 2 continued)

(ii) Calculate the number of moles of oxygen in the day 0 sample. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

(iii) The day 5 sample contained 5.03×10^{-5} moles of oxygen.

Determine the 5-day biochemical oxygen demand of the pond, in mg dm^{-3} ("parts per million", ppm). [2]

. . . .

. . . .

. . . .

. . . .

. . . .

(b) (i) Calculate the percentage uncertainty of the day 5 titre. [1]

. . . .

. . . .

. . . .

(ii) Suggest a modification to the procedure that would make the results more reliable. [1]

. . . .

. . . .

3. Propene is an important starting material for many products. The following shows some compounds which can be made from propene, C_3H_6.

$$\text{Propene } (C_3H_6) \rightarrow C_3H_7Cl \rightarrow C_3H_8O \rightarrow C_3H_6O$$

(a) Consider the conversion of propene to C_3H_7Cl.

(i) State the type of reaction. [1]

. . . .

(ii) State the IUPAC name of the major product. [1]

. . . .

(iii) Outline why it is the major product. [1]

. . . .

. . . .

(iv) Write an equation for the reaction of the major product with aqueous sodium hydroxide to produce a C_3H_8O compound, showing structural formulas. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 3 continued)

(b) An experiment was carried out to determine the order of reaction between one of the isomers of C_3H_7Cl and aqueous sodium hydroxide. The following results were obtained.

Experiment	**[C_3H_7Cl] / mol dm^{-3}**	**[OH^-] / mol dm^{-3}**	**Initial rate / mol dm^{-3} s^{-1}**
1	0.05	0.10	3.1×10^{-4}
2	0.10	0.20	1.3×10^{-3}
3	0.15	0.10	9.2×10^{-4}

(i) Determine the rate expression from the results, explaining your method. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) Deduce the type of mechanism for the reaction of this isomer of C_3H_7Cl with aqueous sodium hydroxide. [1]

. . . .

(iii) Sketch the mechanism using curly arrows to represent the movement of electrons. [4]

(This question continues on the following page)

(Question 3 continued)

(c) (i) Write an equation for the complete combustion of the compound C_3H_8O formed in (a)(iv). [1]

. . . .
. . . .

(ii) Determine the enthalpy of combustion of this compound, in kJ mol^{-1}, using data from section 11 of the data booklet. [3]

. . . .
. . . .
. . . .
. . . .
. . . .

(d) (i) State the reagents for the conversion of the compound C_3H_8O formed in (a)(iv) into C_3H_6O. [1]

. . . .
. . . .

(ii) Explain why the compound C_3H_8O, produced in (a)(iv), has a higher boiling point than compound C_3H_6O, produced in d(i). [2]

. . . .
. . . .
. . . .
. . . .

(This question continues on the following page)

(Question 3 continued)

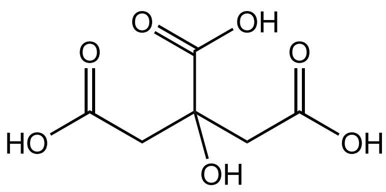
(iii) Explain why the ^{1}H NMR spectrum of C_3H_6O, produced in (d)(i), shows only one signal. [1]

. . . .

. . . .

(e) Propene is often polymerized. Draw a section of the resulting polymer, showing two repeating units. [1]

4. A molecule of citric acid, $C_6H_8O_7$, is shown.



The equation for the first dissociation of citric acid in water is

$$C_6H_8O_7(aq) + H_2O(l) \rightleftharpoons C_6H_7O_7^-(aq) + H_3O^+(aq)$$

(a) (i) Identify a conjugate acid–base pair in the equation. [1]

. . . .

. . . .

(ii) The value of K_a at 298 K for the first dissociation is 5.01×10^{-4}.

State, giving a reason, the strength of citric acid. [1]

. . . .

. . . .

(iii) The dissociation of citric acid is an endothermic process. State the effect on the hydrogen ion concentration, $[H^+]$, and on K_a, of increasing the temperature. [2]

Effect on $[H^+]$	**Effect on K_a**
. . . .	. . . .

(iv) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, in $kJ\,mol^{-1}$, for the first dissociation of citric acid at 298 K, using section 1 of the data booklet. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 4 continued)

(v) Comment on the spontaneity of the reaction at 298 K. [1]

. . . .

. . . .

(b) Outline **two** laboratory methods of distinguishing between solutions of citric acid and hydrochloric acid of equal concentration, stating the expected observations. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

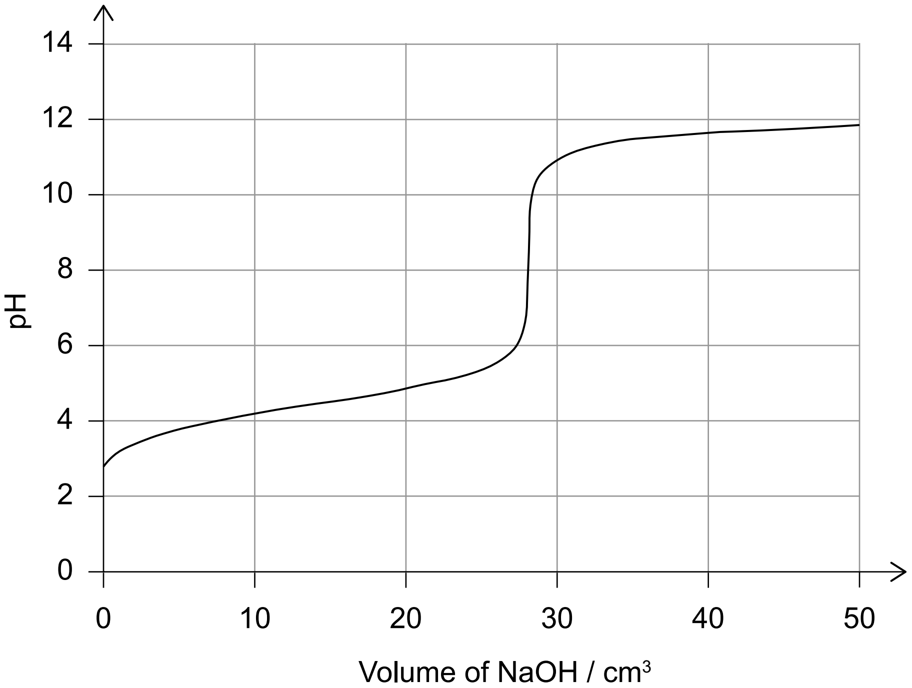
. . . .

Please **do not** write on this page.

Answers written on this page
will not be marked.

5. Another common acid found in food is ethanoic acid.

(a) A sample of ethanoic acid was titrated with sodium hydroxide solution, and the following pH curve obtained.



Annotate the graph to show the buffer region and the volume of sodium hydroxide at the equivalence point. [2]

(b) (i) Identify the most suitable indicator for the titration using section 22 of the data booklet. [1]

. . . .

(ii) Describe, using a suitable equation, how the buffer solution formed during the titration resists pH changes when a small amount of acid is added. [2]

. . . .

. . . .

. . . .

. . . .

6. Copper forms two chlorides, copper(I) chloride and copper(II) chloride.

(a) (i) State the electron configuration of the Cu^+ ion. [1]

. . . .

. . . .

(ii) Copper(II) chloride is used as a catalyst in the production of chlorine from hydrogen chloride.

$$4HCl(g) + O_2(g) \rightarrow 2Cl_2(g) + 2H_2O(g)$$

Calculate the standard enthalpy change, $\Delta H^{\ominus}$, in kJ, for this reaction, using section 12 of the data booklet. [2]

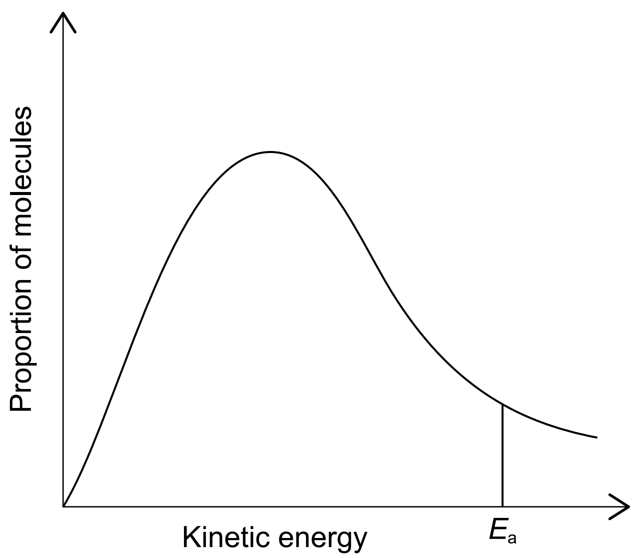
. . . .

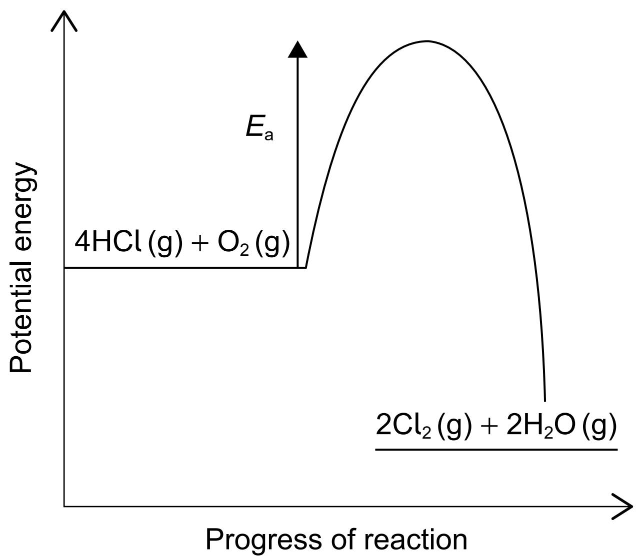
. . . .

. . . .

(iii) The diagram shows the Maxwell–Boltzmann distribution and potential energy profile for the reaction without a catalyst.

Annotate both charts to show the activation energy for the catalysed reaction, using the label $E_{a\,(cat)}$. [2]





(This question continues on the following page)

(Question 6 continued)

(iv) Explain how the catalyst increases the rate of the reaction. [2]

. . . .
. . . .
. . . .
. . . .

(b) Solid copper(II) chloride absorbs moisture from the atmosphere to form a hydrate of formula $CuCl_2{\bullet}xH_2O$.

A student heated a sample of hydrated copper(II) chloride, in order to determine the value of x. The following results were obtained:

Mass of crucible = 16.221 g
Initial mass of crucible and hydrated copper(II) chloride = 18.360 g
Final mass of crucible and anhydrous copper(II) chloride = 17.917 g

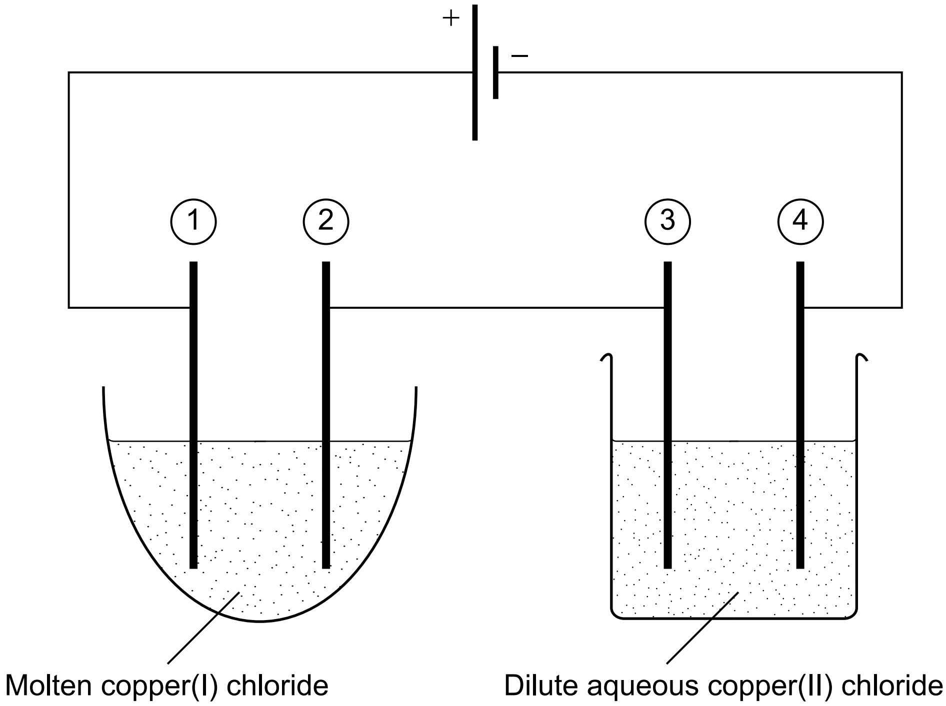
Determine the value of x. [3]

. . . .
. . . .
. . . .
. . . .
. . . .
. . . .

(This question continues on the following page)

(Question 6 continued)

(c) Two electrolysis cells were assembled using graphite electrodes and connected in series as shown.



(i) State how current is conducted through the wires and through the electrolyte. [2]

Wires:

. . . .

Electrolyte:

. . . .

(ii) Write the half-equation for the formation of gas bubbles at electrode 1. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 6 continued)

(iii) Bubbles of gas were also observed at another electrode. Identify the electrode and the gas. [1]

Electrode number (on diagram):

. . . .

Name of gas:

. . . .

(iv) Deduce the half-equation for the formation of the gas identified in (c)(iii). [1]

. . . .

. . . .

(d) Determine the enthalpy of solution of copper(II) chloride, using data from sections 18 and 20 of the data booklet.

The enthalpy of hydration of the copper(II) ion is $-2161\,kJ\,mol^{-1}$. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question 6 continued)

(e) Copper(I) chloride undergoes a disproportionation reaction, producing copper(II) chloride and copper.

$$2Cu^{+}(aq) \rightarrow Cu(s) + Cu^{2+}(aq)$$

(i) Calculate the cell potential at 298 K for the disproportionation reaction, in V, using section 24 of the data booklet. [1]

. . . .

. . . .

(ii) Comment on the spontaneity of the disproportionation reaction at 298 K. [1]

. . . .

. . . .

(iii) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, to two significant figures, for the disproportionation at 298 K. Use your answer from (e)(i) and sections 1 and 2 of the data booklet. [1]

. . . .

. . . .

. . . .

(iv) Suggest, giving a reason, whether the entropy of the system increases or decreases during the disproportionation. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 6 continued)

(v) Deduce, giving a reason, the sign of the standard enthalpy change, $\Delta H^{\ominus}$, for the disproportionation reaction at 298 K. [1]

. . . .

. . . .

. . . .

(vi) Predict, giving a reason, the effect of increasing temperature on the stability of copper(I) chloride solution. [1]

. . . .

. . . .

. . . .

(f) Dilute copper(II) chloride solution is light blue, while copper(I) chloride solution is colourless.

(i) Describe how the blue colour is produced in the Cu(II) solution. Refer to section 17 of the data booklet. [3]

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) Deduce why the Cu(I) solution is colourless. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 6 continued)

(iii) When excess ammonia is added to copper(II) chloride solution, the dark blue complex ion, $[Cu(NH_3)_4(H_2O)_2]^{2+}$, forms.

State the molecular geometry of this complex ion, and the bond angles within it. [1]

Molecular geometry:

. . . .

Bond angles:

. . . .

(iv) Examine the relationship between the Brønsted–Lowry and Lewis definitions of a base, referring to the ligands in the complex ion $[CuCl_4]^{2-}$. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

7. Automobile air bags inflate by a rapid decomposition reaction. One typical compound used is guanidinium nitrate, $C(NH_2)_3NO_3$, which decomposes very rapidly to form nitrogen, water vapour and carbon.

(a) (i) Deduce the equation for the decomposition of guanidinium nitrate. [1]

. . . .

. . . .

(This question continues on the following page)

(Question 7 continued)

(ii) Calculate the total number of moles of gas produced from the decomposition of 10.0 g of guanidinium nitrate. [1]

. . . .

. . . .

. . . .

(iii) Calculate the pressure, in kPa, of this gas in a 10.0 dm^3 air bag at 127 °C, assuming no gas escapes. [1]

. . . .

. . . .

. . . .

(iv) Suggest why water vapour deviates significantly from ideal behaviour when the gases are cooled, while nitrogen does not. [2]

. . . .

. . . .

. . . .

. . . .

(b) Another airbag reactant produces nitrogen gas and sodium.

Suggest, including an equation, why the products of this reactant present a safety hazard. [2]

. . . .

. . . .

. . . .

. . . .

. . . .

Please **do not** write on this page.

Answers written on this page
will not be marked.

Please **do not** write on this page.

Answers written on this page
will not be marked.

Please **do not** write on this page.

Answers written on this page
will not be marked.