Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Friday 14 May 2021 (morning)

2 hours 15 minutes

Candidate session number

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]**.

2221 – 6108

23 pages

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

1. Iron may be extracted from iron (II) sulfide, FeS.

(a) Outline why metals, like iron, can conduct electricity. [1]

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(b) Justify why sulfur is classified as a non-metal by giving **two** of its chemical properties. [2]

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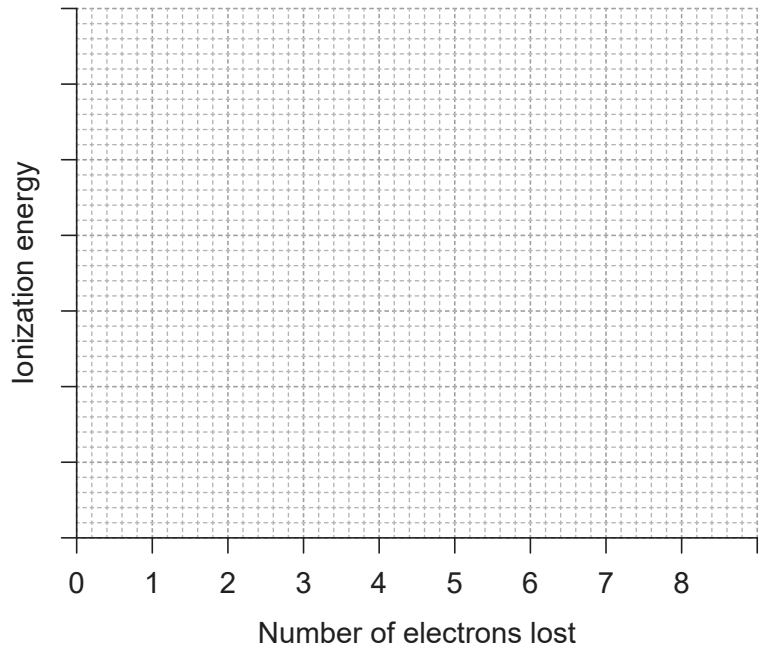
(c) Sketch the first eight successive ionisation energies of sulfur. [2]



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(Question 1 continued)

(d) Iron (II) sulfide, FeS, is ionically bonded.

(i) Describe the bonding in this type of solid. [2]

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(ii) State a technique that could be used to determine the crystal structure of the solid compound. [1]

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(iii) State the full electron configuration of the sulfide ion. [1]

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(iv) Outline, in terms of their electronic structures, why the ionic radius of the sulfide ion is greater than that of the oxide ion. [1]

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(v) Suggest why chemists find it convenient to classify bonding into ionic, covalent and metallic. [1]

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(This question continues on the following page)

(Question 1 continued)

(e) The first step in the extraction of iron from iron (II) sulfide is to roast it in air to form iron (III) oxide and sulfur dioxide.

(i) Write the equation for this reaction. [1]

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(ii) Deduce the change in the oxidation state of sulfur. [1]

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(iii) Suggest why this process might raise environmental concerns. [1]

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(f) Explain why the addition of small amounts of carbon to iron makes the metal harder. [2]

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2. Iron (II) sulfide reacts with hydrochloric acid to form hydrogen sulfide, H_2S.

(a) (i) Draw the Lewis (electron dot) structure of hydrogen sulfide. [1]

(ii) Predict the shape of the hydrogen sulfide molecule. [1]

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(b) In aqueous solution, hydrogen sulfide acts as an acid.

(i) State the formula of its conjugate base. [1]

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(ii) Saturated aqueous hydrogen sulfide has a concentration of 0.10 mol dm^{-3} and a pH of 4.0. Demonstrate whether it is a strong or weak acid. [1]

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(iii) Calculate the hydroxide ion concentration in saturated aqueous hydrogen sulfide. [1]

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(This question continues on the following page)

(Question 2 continued)

(c) A gaseous sample of nitrogen, contaminated only with hydrogen sulfide, was reacted with excess sodium hydroxide solution at constant temperature. The volume of the gas changed from 550 cm^3 to 525 cm^3.

Determine the mole percentage of hydrogen sulfide in the sample, stating one assumption you made. [3]

Mole percentage H_2S:

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Assumption:

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3. Magnetite, Fe_3O_4, is another ore of iron that contains both Fe^{2+} and Fe^{3+}.

(a) Deduce the ratio of Fe^{2+}:Fe^{3+} in Fe_3O_4. [1]

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(b) Iron exists as several isotopes.

(i) State the type of spectroscopy that could be used to determine their relative abundances. [1]

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(ii) State the number of protons, neutrons and electrons in each species. [2]

	Protons	Neutrons	Electrons
$^{54}_{26}Fe$	. . . . .	. . . . .	. . . . .
$^{56}_{26}Fe^{3+}$	. . . . .	. . . . .	. . . . .

(c) Iron has a relatively small specific heat capacity; the temperature of a 50 g sample rises by 44.4 °C when it absorbs 1 kJ of heat energy.

Determine the specific heat capacity of iron, in J g^{-1} K^{-1}. Use section 1 of the data booklet. [1]

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(Question 3 continued)

(d) A voltaic cell is set up between the $Fe^{2+}(aq) \mid Fe(s)$ and $Fe^{3+}(aq) \mid Fe^{2+}(aq)$ half-cells.

Deduce the equation and the cell potential of the spontaneous reaction. Use section 24 of the data booklet. [2]

Equation:

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Cell potential:

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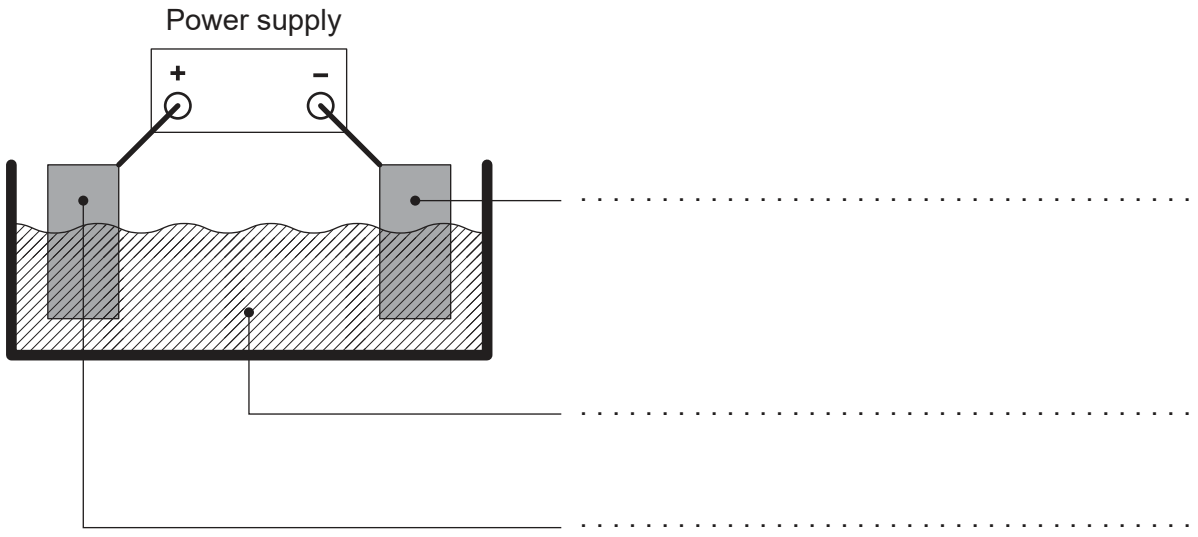
(e) The figure shows an apparatus that could be used to electroplate iron with zinc. Label the figure with the required substances. [2]



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(Question 3 continued)

(f) Outline why, unlike typical transition metals, zinc compounds are not coloured. [1]

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(g) Transition metals like iron can form complex ions. Discuss the bonding between transition metals and their ligands in terms of acid-base theory. [2]

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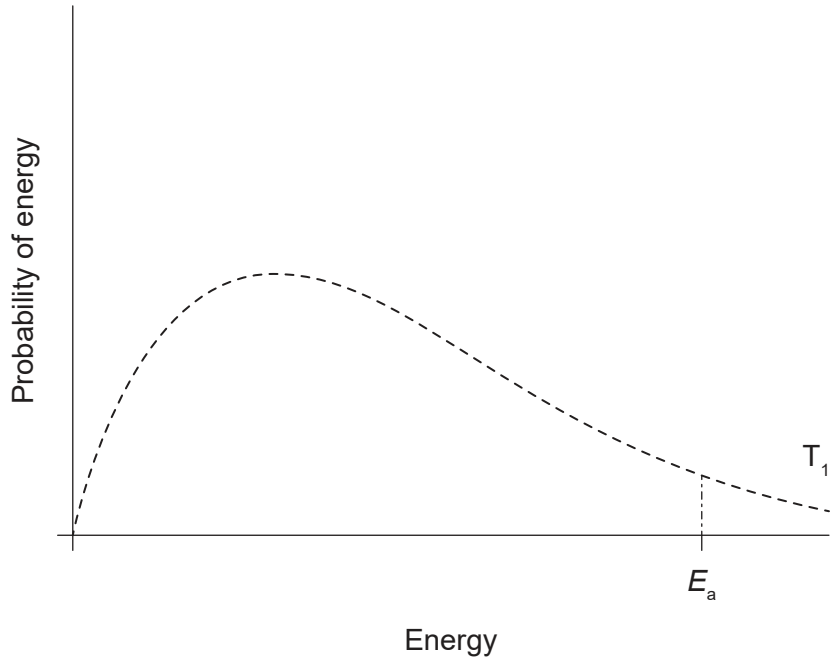
4. Hydrogen peroxide can react with methane and oxygen to form methanol. This reaction can occur below 50°C if a gold nanoparticle catalyst is used.

(a) The diagram shows the Maxwell-Boltzmann curve for the uncatalyzed reaction.

Draw a distribution curve at a lower temperature (T_2) **and** show on the diagram how the addition of a catalyst enables the reaction to take place more rapidly than at T_1. [2]



(b) The hydrogen peroxide could cause further oxidation of the methanol. Suggest a possible oxidation product. [1]

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(Question 4 continued)

(c) Methanol is usually manufactured from methane in a two-stage process.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$
$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(l)$$

(i) Determine the overall equation for the production of methanol. [1]

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(ii) 8.00 g of methane is completely converted to methanol. Calculate, to three significant figures, the final volume of hydrogen at STP, in dm^3. Use sections 2 and 6 of the data booklet. [3]

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(Question 4 continued)

(d) Consider the first stage of the reaction.

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

(i) Determine the enthalpy change, ΔH, in kJ. Use section 11 of the data booklet.

Bond enthalpy of CO = 1077 kJ mol^{-1}. [3]

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(ii) State **one** reason why you would expect the value of ΔH calculated from the $\Delta H_f^{\ominus}$ values, given in section 12 of data booklet, to differ from your answer to (d)(i). [1]

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(iii) State the expression for K_c for this stage of the reaction. [1]

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(iv) State and explain the effect of increasing temperature on the value of K_c. [1]

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(Question 4 continued)

(e) Now consider the second stage of the reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(l) \quad \Delta H^{\ominus} = -129\,kJ$$

(i) The equilibrium constant, K_c, has a value of 1.01 at 298 K.

Calculate $\Delta G^{\ominus}$, in kJ mol^{-1}, for this reaction. Use sections 1 and 2 of the data booklet. [2]

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(ii) Calculate a value for the entropy change, $\Delta S^{\ominus}$, in J K^{-1} mol^{-1} at 298 K. Use your answers to (e)(i) and section 1 of the data booklet.

If you did not get answers to (e)(i) use −1 kJ, but this is not the correct answer. [2]

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(iii) Justify the sign of ΔS with reference to the equation. [1]

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(Question 4 continued)

(iv) Predict, giving a reason, how a change in temperature from 298 K to 273 K would affect the spontaneity of the reaction. [1]

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5. Ethanol is obtained by the hydration of ethene, C_2H_4.

(a) (i) State the class of compound to which ethene belongs. [1]

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(ii) State the molecular formula of the next member of the homologous series to which ethene belongs. [1]

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(b) (i) Justify why ethene has only a single signal in its ^1H NMR spectrum. [1]

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(ii) Deduce the chemical shift of this signal. Use section 27 of the data booklet. [1]

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(c) Suggest **two** possible products of the incomplete combustion of ethene that would not be formed by complete combustion. [1]

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(Question 5 continued)

(d) A white solid was formed when ethene was subjected to high pressure.

Deduce the type of reaction that occurred. [1]

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(e) Alternative synthetic routes exist to produce alcohols.

(i) Sketch the mechanism for the reaction of propene with hydrogen bromide using curly arrows. [3]

(ii) Explain why the major organic product is 2-bromopropane and not 1-bromopropane. [2]

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(Question 5 continued)

(iii) 2-bromopropane can be converted directly to propan-2-ol. Identify the reagent required. [1]

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(iv) Propan-2-ol can also be formed in one step from a compound containing a carbonyl group.

State the name of this compound and the type of reaction that occurs. [2]

Name of carbonyl compound:

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Type of reaction:

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6. When dinitrogen pentoxide, N_2O_5, is heated the colourless gas undergoes thermal decomposition to produce brown nitrogen dioxide:

$$N_2O_5(g) \rightarrow 2NO_2(g) + \frac{1}{2} O_2(g)$$

(a) Suggest how the extent of decomposition could be measured. [1]

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(b) Data for the decomposition at constant temperature is given.

$[N_2O_5]$ / 10^{-3} mol dm^{-3}	Rate / 10^{-3} mol dm^{-3} min^{-1}
2.74	0.078
3.68	0.121
6.89	0.197
16.27	0.498
24.30	0.710

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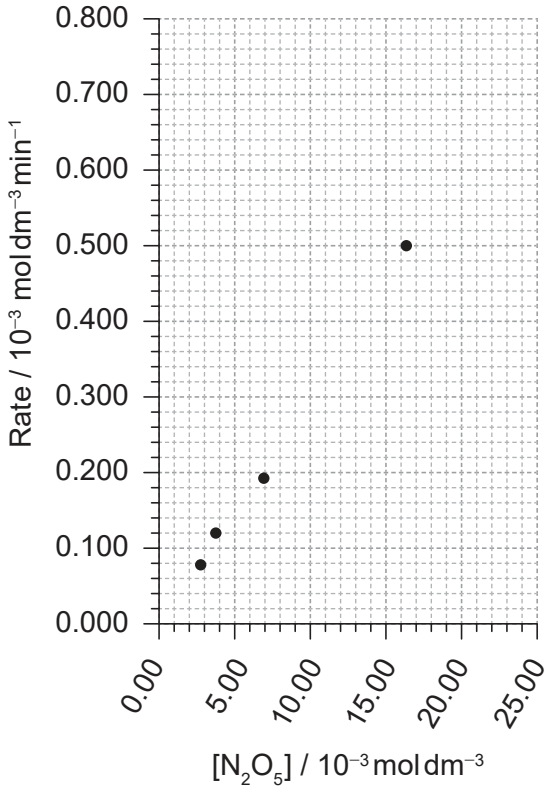
(Question 6 continued)

(i) Plot the missing point on the graph and draw the best-fit line. [2]



(ii) Outline why increasing the concentration of N_2O_5 increases the rate of reaction. [1]

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(iii) Write the rate expression for this reaction. [1]

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(Question 6 continued)

(iv) Calculate the value of the rate constant, k, giving its units. [3]

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7. Oxygen exists as two allotropes, diatomic oxygen, O_2, and ozone, O_3.

(a) (i) Draw a Lewis (electron dot) structure for ozone. [1]

(ii) Discuss the relative length of the two O–O bonds in ozone. [2]

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(b) Explain why there are frequencies of UV light that will dissociate O_3 but not O_2. [2]

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(Question 7 continued)

(c) Explain, using equations, how the presence of CCl_2F_2 results in a chain reaction that decreases the concentration of ozone in the stratosphere. [2]

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8. Propanoic acid, CH_3CH_2COOH, is a weak organic acid.

(a) Calculate the pH of 0.00100 mol dm^{-3} propanoic acid solution. Use section 21 of the data booklet. [3]

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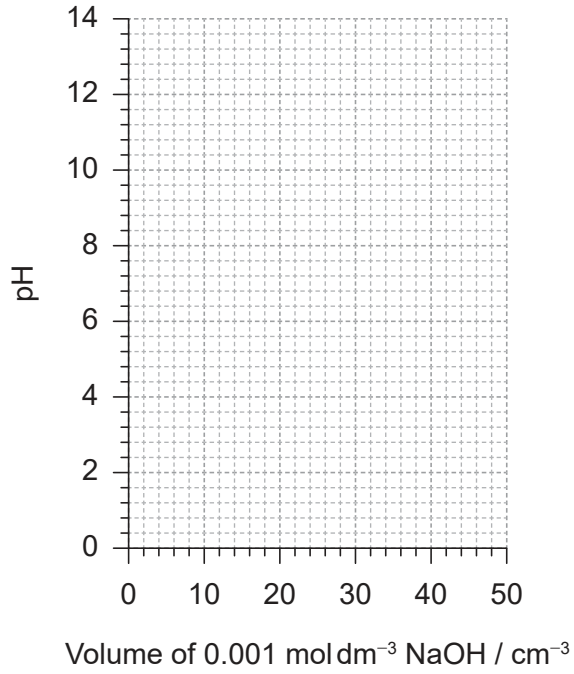
(b) Sketch the general shape of the variation of pH when 50 cm^3 of 0.001 mol dm^{-3} NaOH (aq) is gradually added to 25 cm^3 of 0.001 mol dm^{-3} CH_3CH_2COOH (aq). [3]



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