Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Wednesday 22 May 2019 (afternoon)

Candidate session number

2 hours 15 minutes

Instructions to candidates

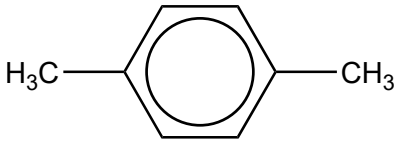
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for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

2219 – 6108

23 pages

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

1. Xylene is a derivative of benzene. One isomer is 1,4-dimethylbenzene.



(a) State the number of ^{1}H NMR signals for this isomer of xylene and the ratio in which they appear. [2]

Number of signals:

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Ratio:

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(b) Draw the structure of one other isomer of xylene which retains the benzene ring. [1]

(This question continues on the following page)

(Question 1 continued)

(c) Xylene, like benzene, can be nitrated.

(i) Write the equation for the production of the active nitrating agent from concentrated sulfuric and nitric acids. [1]

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(ii) Explain the mechanism for the nitration of benzene, using curly arrows to indicate the movement of electron pairs. [4]

(This question continues on the following page)

(Question 1 continued)

(d) Bromine reacts with alkanes.

(i) Identify the initiation step of the reaction and its conditions. [2]

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(ii) 1,4-dimethylbenzene reacts as a substituted alkane. Draw the structures of the two products of the overall reaction when one molecule of bromine reacts with one molecule of 1,4-dimethylbenzene. [2]

(e) The organic product is not optically active. Discuss whether or not the organic product is a racemic mixture. [1]

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2. Benzoic acid, C_6H_5COOH, is another derivative of benzene.

(a) Identify the wavenumber of one peak in the IR spectrum of benzoic acid, using section 26 of the data booklet. [1]

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(b) Identify the spectroscopic technique that is used to measure the bond lengths in solid benzoic acid. [1]

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(c) Outline **one** piece of physical evidence for the structure of the benzene ring. [1]

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(d) Draw the structure of the conjugate base of benzoic acid showing **all** the atoms and **all** the bonds. [1]

(This question continues on the following page)

(Question 2 continued)

(e) Outline why both C to O bonds in the conjugate base are the same length and suggest a value for them. Use section 10 of the data booklet. [2]

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(f) (i) The pH of an aqueous solution of benzoic acid at 298 K is 2.95. Determine the concentration of hydroxide ions in the solution, using section 2 of the data booklet. [2]

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(ii) Formulate the equation for the complete combustion of benzoic acid in oxygen using only integer coefficients. [2]

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(g) The combustion reaction in (f)(ii) can also be classed as redox. Identify the atom that is oxidized and the atom that is reduced. [1]

Oxidized:

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Reduced:

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(This question continues on the following page)

(Question 2 continued)

(h) Suggest how benzoic acid, $M_r = 122.13$, forms an apparent dimer, $M_r = 244.26$, when dissolved in a non-polar solvent such as hexane. [1]

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(i) State the reagent used to convert benzoic acid to phenylmethanol (benzyl alcohol), $C_6H_5CH_2OH$. [1]

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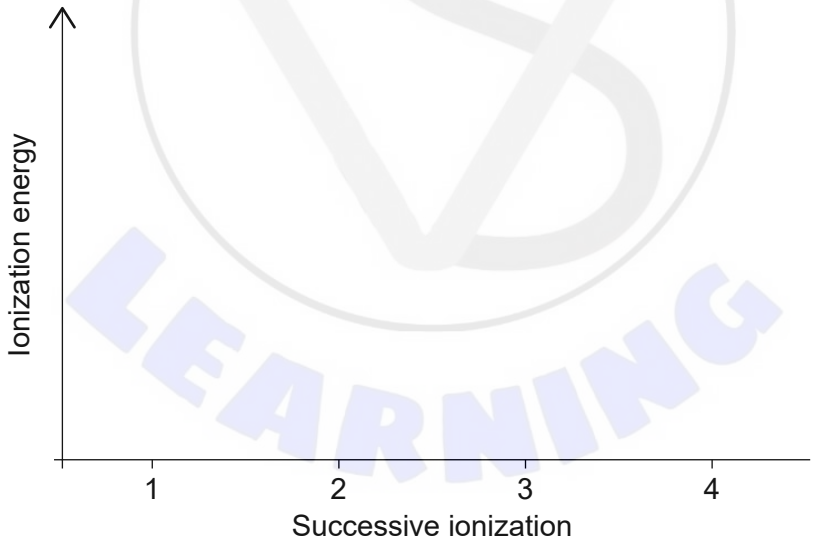
3. This question is about sodium and its compounds.

(a) Plot the relative values of the first four ionization energies of sodium. [1]



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(Question 3 continued)

(b) Outline why the alkali metals (group 1) have similar chemical properties. [1]

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(c) Describe the structure and bonding in solid sodium oxide. [2]

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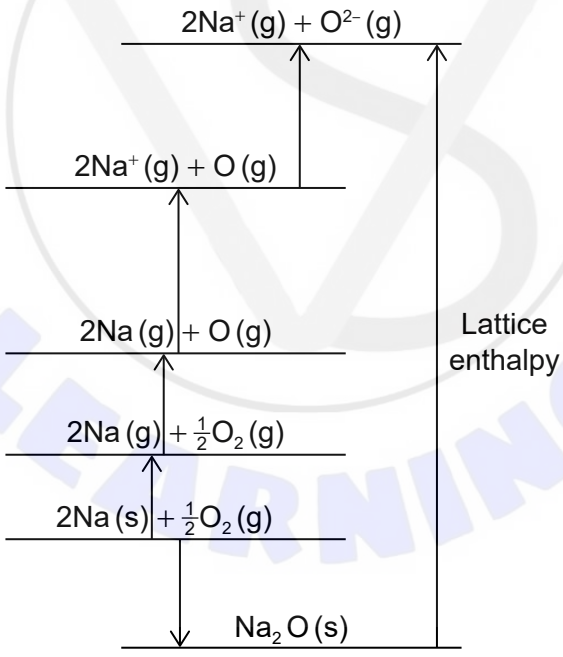
(d) The Born-Haber cycle for sodium oxide is shown (not to scale).



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(Question 3 continued)

(i) Calculate values for the following changes using section 8 of the data booklet. [2]

$\Delta H_{atomisation}$ (Na) = 107 kJ mol^{-1}

$\Delta H_{atomisation}$ (O) = 249 kJ mol^{-1}

$\frac{1}{2}O_2(g) \rightarrow O^{2-}(g)$:

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$Na(s) \rightarrow Na^{+}(g)$:

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(ii) The standard enthalpy of formation of sodium oxide is –414 kJ mol^{-1}. Determine the lattice enthalpy of sodium oxide, in kJ mol^{-1}, using section 8 of the data booklet and your answers to (d)(i). [2]

(If you did not get answers to (d)(i), use +850 kJ mol^{-1} and +600 kJ mol^{-1} respectively, but these are not the correct answers.)

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(Question 3 continued)

(iii) Justify why K_2O has a lower lattice enthalpy (absolute value) than Na_2O. [1]

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(e) Write equations for the separate reactions of solid sodium oxide and solid phosphorus(V) oxide with excess water and differentiate between the solutions formed. [3]

Sodium oxide, Na_2O:

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Phosphorus(V) oxide, P_4O_{10}:

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Differentiation:

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(f) Sodium peroxide, Na_2O_2, is formed by the reaction of sodium oxide with oxygen.

$$2Na_2O(s) + O_2(g) \rightarrow 2Na_2O_2(s)$$

Calculate the percentage yield of sodium peroxide if 5.00 g of sodium oxide produces 5.50 g of sodium peroxide. [2]

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(Question 3 continued)

(g) Sodium peroxide is used in diving apparatus to produce oxygen from carbon dioxide.

$$2Na_2O_2(s) + 2CO_2(g) \rightarrow 2Na_2CO_3(s) + O_2(g)$$

(i) Determine the enthalpy change, ΔH, in kJ, for this reaction using data from the table and section 12 of the data booklet. [3]

	ΔH_f / kJ mol^{-1}
$Na_2O_2(s)$	–510.9
$Na_2CO_3(s)$	–1130.7

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will not be marked.

(Question 3 continued)

(ii) Outline why bond enthalpy values are not valid in calculations such as that in (g)(i). [1]

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(h) An allotrope of molecular oxygen is ozone. Compare, giving a reason, the bond enthalpies of the O to O bonds in O_2 and O_3. [1]

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(i) Outline why a real gas differs from ideal behaviour at low temperature and high pressure. [1]

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(j) The reaction of sodium peroxide with excess water produces hydrogen peroxide and one other sodium compound. Suggest the formula of this compound. [1]

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(k) State the oxidation number of carbon in sodium carbonate, Na_2CO_3. [1]

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4. This question is about the decomposition of hydrogen peroxide.

(a) Suggest why many chemicals, including hydrogen peroxide, are kept in brown bottles instead of clear colourless bottles. [1]

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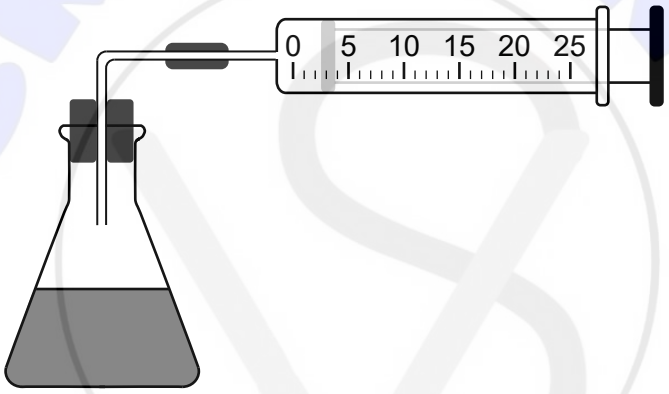
(b) Hydrogen peroxide decomposes to water and oxygen when a catalyst such as potassium iodide, KI, is added.

$$2H_2O_2(aq) \xrightarrow{KI(aq)} O_2(g) + 2H_2O(l)$$

(i) In a laboratory experiment solutions of potassium iodide and hydrogen peroxide were mixed and the volume of oxygen generated was recorded. The volume was adjusted to 0 at $t = 0$.



The data for the first trial is given below.

Time / s	Volume of O_2 (g) / cm^3
100	2.5
300	6.5
500	11.0
700	15.0

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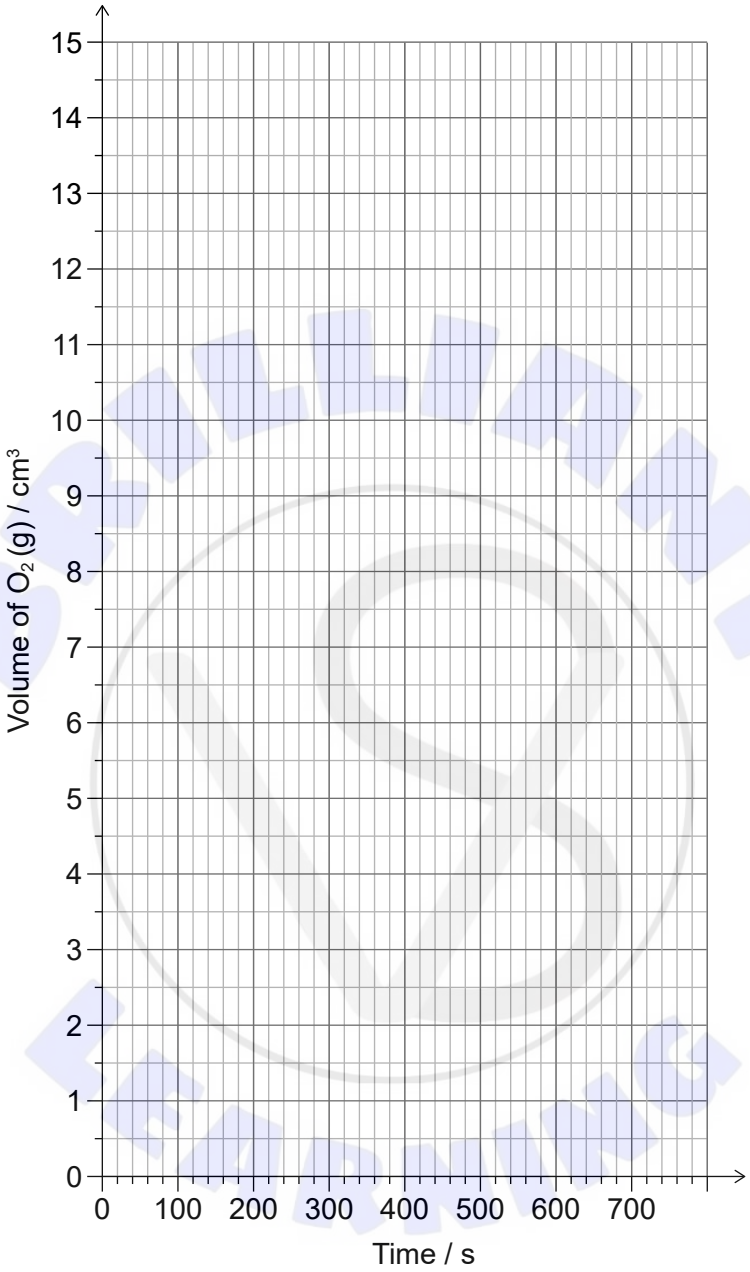
(Question 4 continued)

Plot a graph on the axes below and from it determine the average rate of formation of oxygen gas in $cm^3\ O_2(g)\ s^{-1}$. [3]



Average rate of reaction:

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(Question 4 continued)

(ii) Two more trials (2 and 3) were carried out. The results are given below.

Trials	Volume of 0.20 mol dm^{-3} KI (aq) / cm^3	Volume of deionised water / cm^3	Volume of 3 % H_2O_2 (aq) / cm^3	Average rate of reaction / cm^3 O_2 (g) s^{-1}
1	10.0	15.0	5.0	
2	10.0	10.0	10.0	0.0429
3	20.0	5.0	5.0	0.0451

Determine the rate equation for the reaction and its overall order, using your answer from (b)(i). [2]

Rate equation:

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Overall order:

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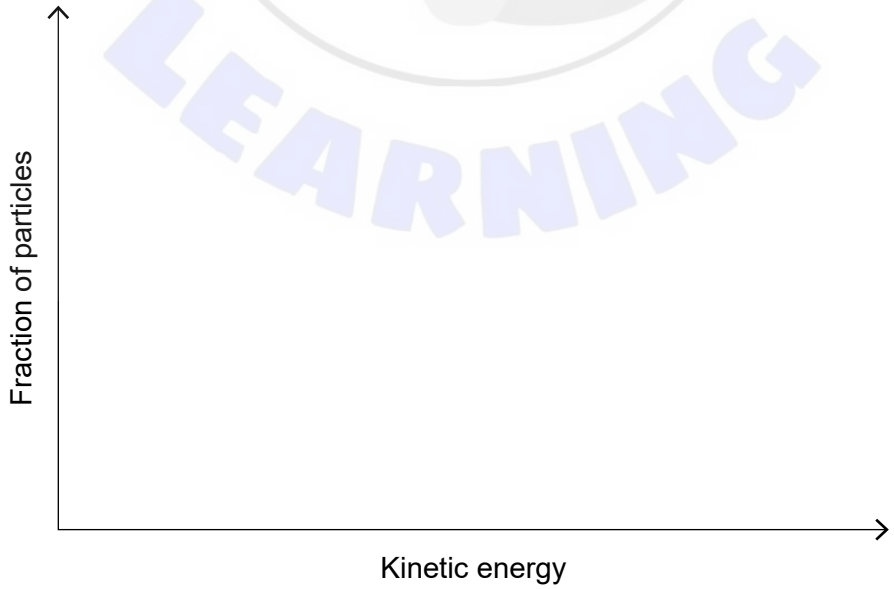
(iii) Additional experiments were carried out at an elevated temperature. On the axes below, sketch Maxwell–Boltzmann energy distribution curves at two temperatures T_1 and T_2, where $T_2 > T_1$. [2]



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(Question 4 continued)

(iv) Apart from a greater frequency of collisions, explain, by annotating your graphs in (b)(iii), why an increased temperature causes the rate of reaction to increase. [2]

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(v) MnO_2 is another possible catalyst for the reaction. State the IUPAC name for MnO_2. [1]

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(c) Comment on why peracetic acid, CH_3COOOH, is always sold in solution with ethanoic acid and hydrogen peroxide.

$$H_2O_2(aq) + CH_3COOH(aq) \rightleftharpoons CH_3COOOH(aq) + H_2O(l)$$ [1]

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(d) Sodium percarbonate, $2Na_2CO_3 \cdot 3H_2O_2$, is an adduct of sodium carbonate and hydrogen peroxide and is used as a cleaning agent.

$$M_r\,(2Na_2CO_3 \cdot 3H_2O_2) = 314.04$$

Calculate the percentage by mass of hydrogen peroxide in sodium percarbonate, giving your answer to two decimal places. [2]

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5. Both vinegar (a dilute aqueous solution of ethanoic acid) and bleach are used as cleaning agents.

(a) Outline why ethanoic acid is classified as a weak acid. [1]

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(b) A solution of bleach can be made by reacting chlorine gas with a sodium hydroxide solution.

$$Cl_2(g) + 2NaOH(aq) \rightleftharpoons NaOCl(aq) + NaCl(aq) + H_2O(l)$$

Suggest, with reference to Le Châtelier's principle, why it is dangerous to mix vinegar and bleach together as cleaners. [3]

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(c) Bleach reacts with ammonia, also used as a cleaning agent, to produce the poisonous compound chloramine, NH_2Cl.

(i) Draw a Lewis (electron dot) structure of chloramine. [1]

(ii) State the hybridization of the nitrogen atom in chloramine. [1]

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(This question continues on the following page)

(Question 5 continued)

(iii) Deduce the molecular geometry of chloramine and estimate its H–N–H bond angle. [2]

Molecular geometry:

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H–N–H bond angle:

. . . . . .

(iv) State the type of bond formed when chloramine is protonated. [1]

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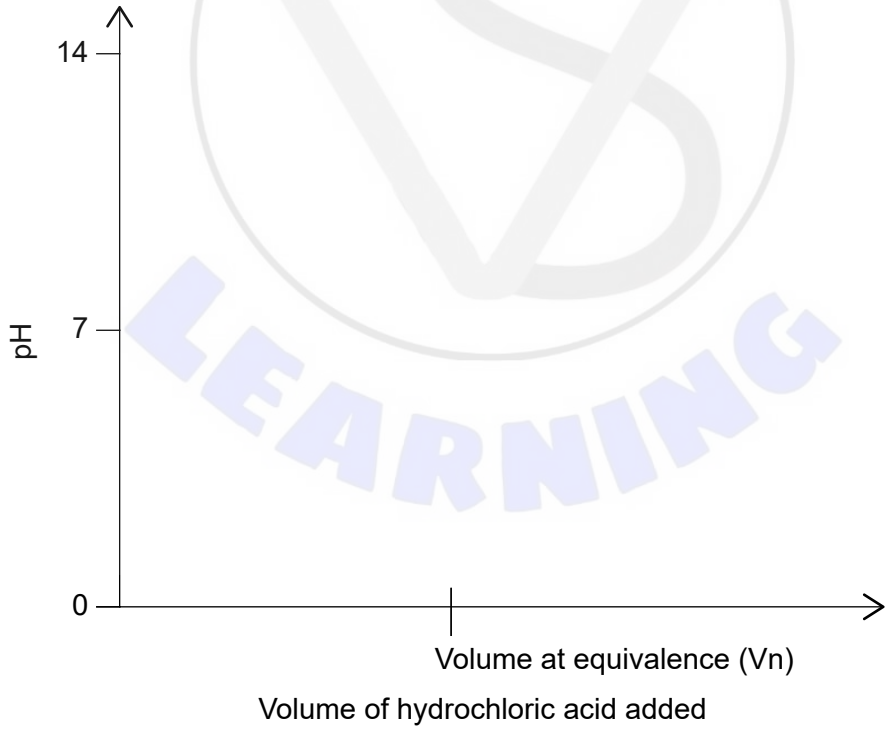
(d) (i) Sketch a graph of pH against volume of hydrochloric acid added to ammonia solution, showing how you would determine the pK_a of the ammonium ion. [2]



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(Question 5 continued)

(ii) Suggest a suitable indicator for the titration, using section 22 of the data booklet. [1]

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(iii) Explain, using **two** equations, how an equimolar solution of ammonia and ammonium ions acts as a buffer solution when small amounts of acid or base are added. [2]

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6. This question is about iron.

(a) Deduce the **full** electron configuration of Fe^{2+}. [1]

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(b) Explain why, when ligands bond to the iron ion causing the d-orbitals to split, the complex is coloured. [2]

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(c) State the nuclear symbol notation, ${}^{A}_{Z}X$, for iron-54. [1]

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(d) Mass spectrometry analysis of a sample of iron gave the following results:

	% abundance
Fe-54	5.84
Fe-56	91.68
Fe-57	2.17
Fe-58	0.31

Calculate the relative atomic mass, A_r, of this sample of iron to two decimal places. [2]

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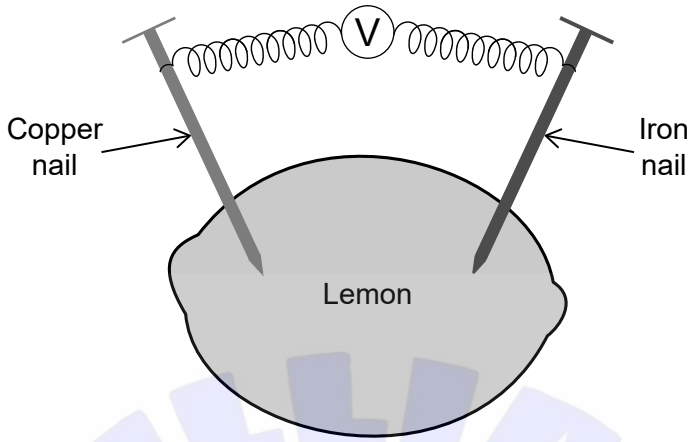
(Question 6 continued)

(e) An iron nail and a copper nail are inserted into a lemon.



Explain why a potential is detected when the nails are connected through a voltmeter. [2]

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(f) (i) Calculate the standard electrode potential, in V, when the $Fe^{2+}(aq) \mid Fe(s)$ and $Cu^{2+}(aq) \mid Cu(s)$ standard half-cells are connected at 298 K. Use section 24 of the data booklet. [1]

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(ii) Calculate $\Delta G^{\ominus}$, in kJ, for the spontaneous reaction in (f)(i), using sections 1 and 2 of the data booklet. [1]

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(Question 6 continued)

(iii) Calculate a value for the equilibrium constant, K_c, at 298 K, giving your answer to two significant figures. Use your answer to (f)(ii) and section 1 of the data booklet. [2]

(If you did not obtain an answer to (f)(ii), use $-140\,kJ\,mol^{-1}$, but this is not the correct value.)

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7. An aqueous solution of silver nitrate, $AgNO_3(aq)$, can be electrolysed using platinum electrodes.

Formulate the half-equations for the reaction at each electrode during electrolysis. [2]

Cathode (negative electrode):

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Anode (positive electrode):

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