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Chemistry
Higher level
Paper 2

Wednesday 22 May 2019 (afternoon)

Candidate session number

2 hours 15 minutes

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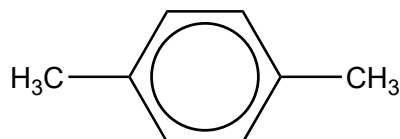
Instructions to candidates

- 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]**.



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 ^1H NMR signals for this isomer of xylene and the ratio in which they appear. [2]

Number of signals:

.....

Ratio:

.....

- (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]

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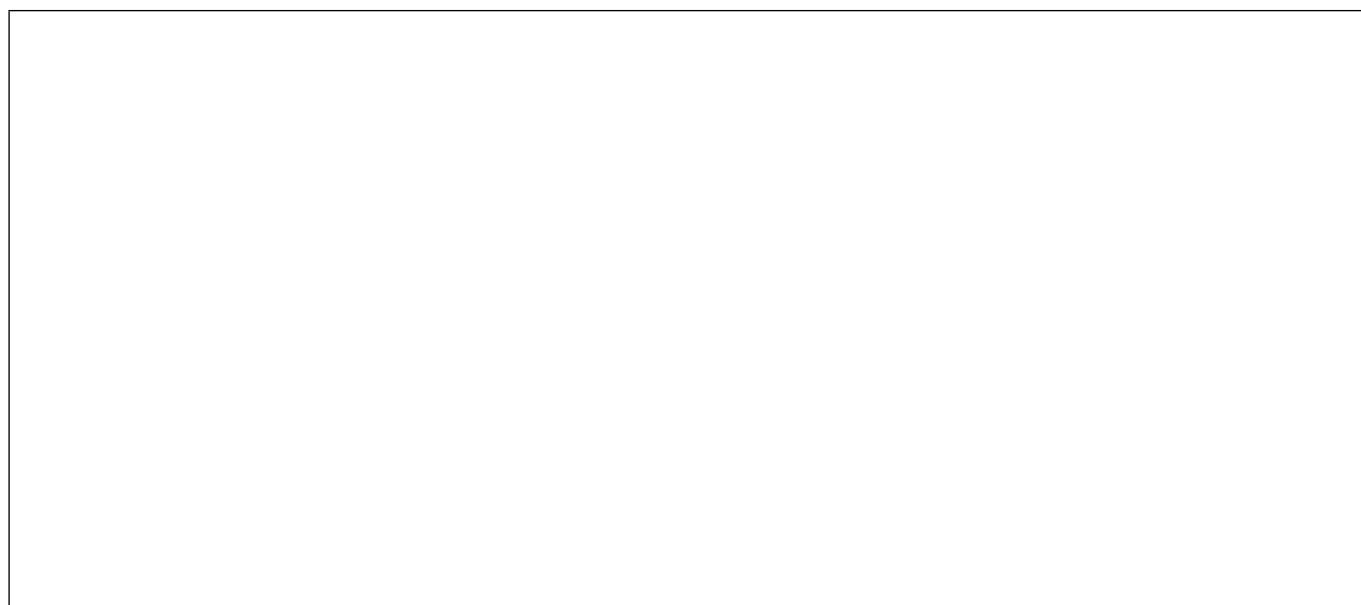
(b) Identify the spectroscopic technique that is used to measure the bond lengths in solid benzoic acid. [1]

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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:
.....

Reduced:
.....

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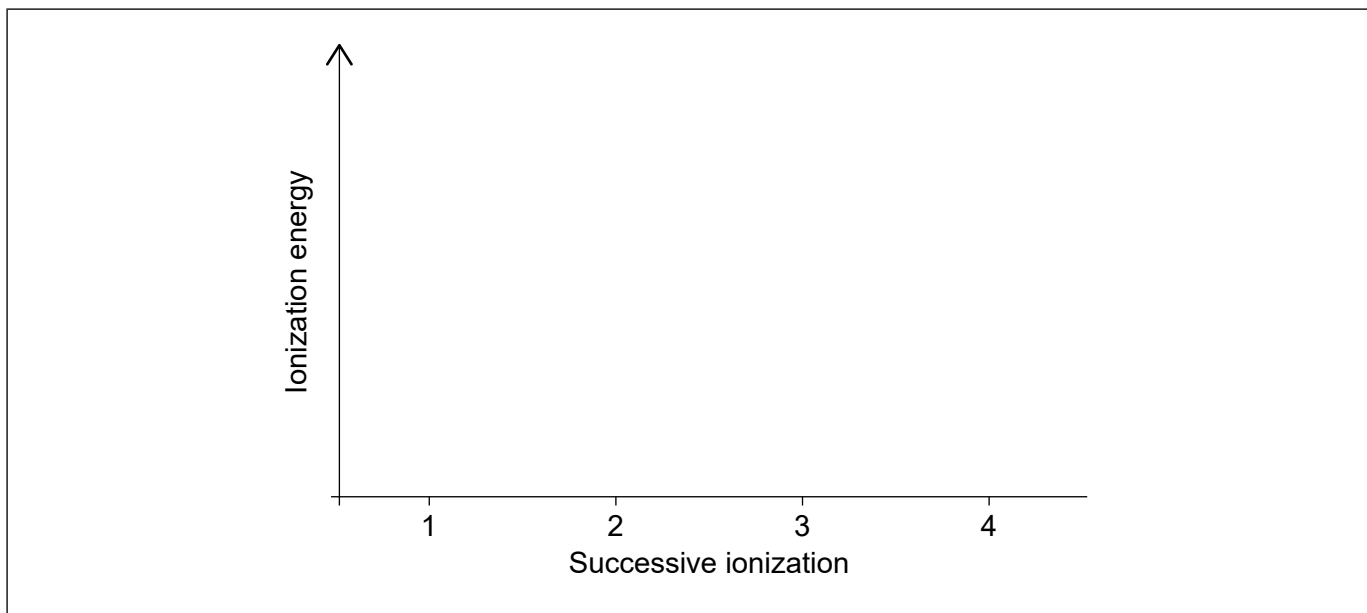
- (i) State the reagent used to convert benzoic acid to phenylmethanol (benzyl alcohol), $C_6H_5CH_2OH$. [1]

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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]



(This question continues on the following page)



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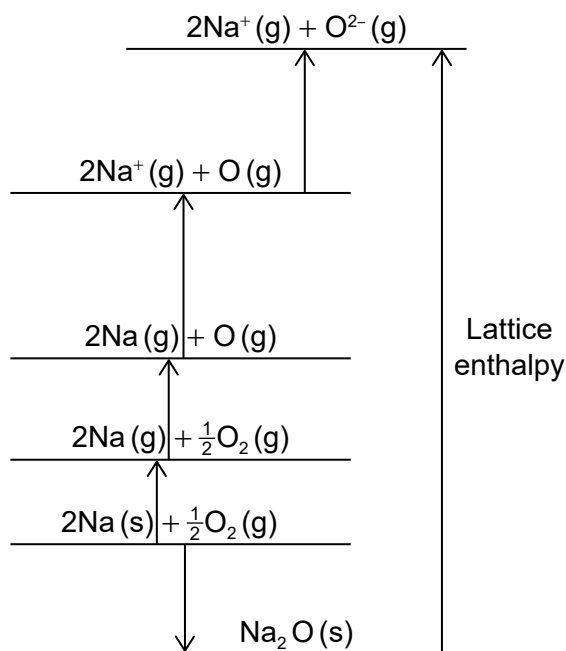
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(d) The Born-Haber cycle for sodium oxide is shown (not to scale).



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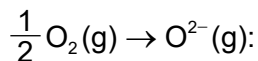


(Question 3 continued)

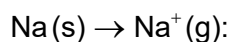
- (i) Calculate values for the following changes using section 8 of the data booklet. [2]

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

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



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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 $+850 \text{ kJ mol}^{-1}$ and $+600 \text{ kJ mol}^{-1}$ 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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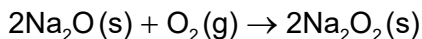
(e) Write equations for the separate reactions of solid sodium oxide and solid phosphorus(V) oxide with excess water and differentiate between the solutions formed. [3]

Sodium oxide, Na_2O :
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.....

Phosphorus(V) oxide, P_4O_{10} :
.....
.....

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



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

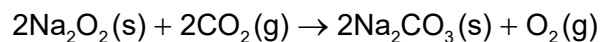
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(Question 3 continued)

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



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

[3]

	$\Delta H_f / \text{kJ mol}^{-1}$
$\text{Na}_2\text{O}_2(\text{s})$	-510.9
$\text{Na}_2\text{CO}_3(\text{s})$	-1130.7

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(This question continues on page 13)



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24EP12

(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 O₂ and O₃. [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, Na₂CO₃. [1]

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

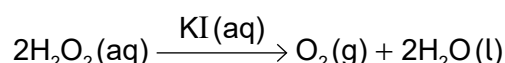
- (a) Suggest why many chemicals, including hydrogen peroxide, are kept in brown bottles instead of clear colourless bottles.

[1]

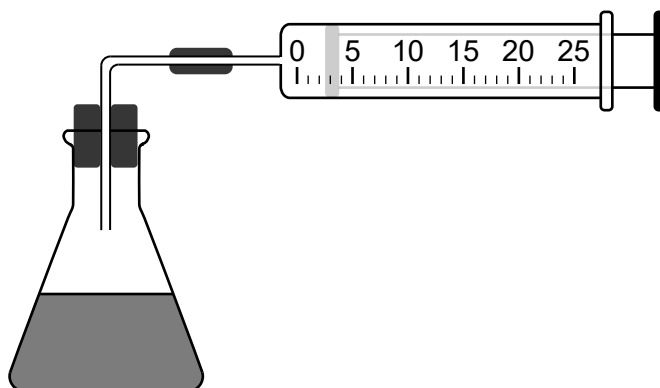
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- (b) Hydrogen peroxide decomposes to water and oxygen when a catalyst such as potassium iodide, KI, is added.



- (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

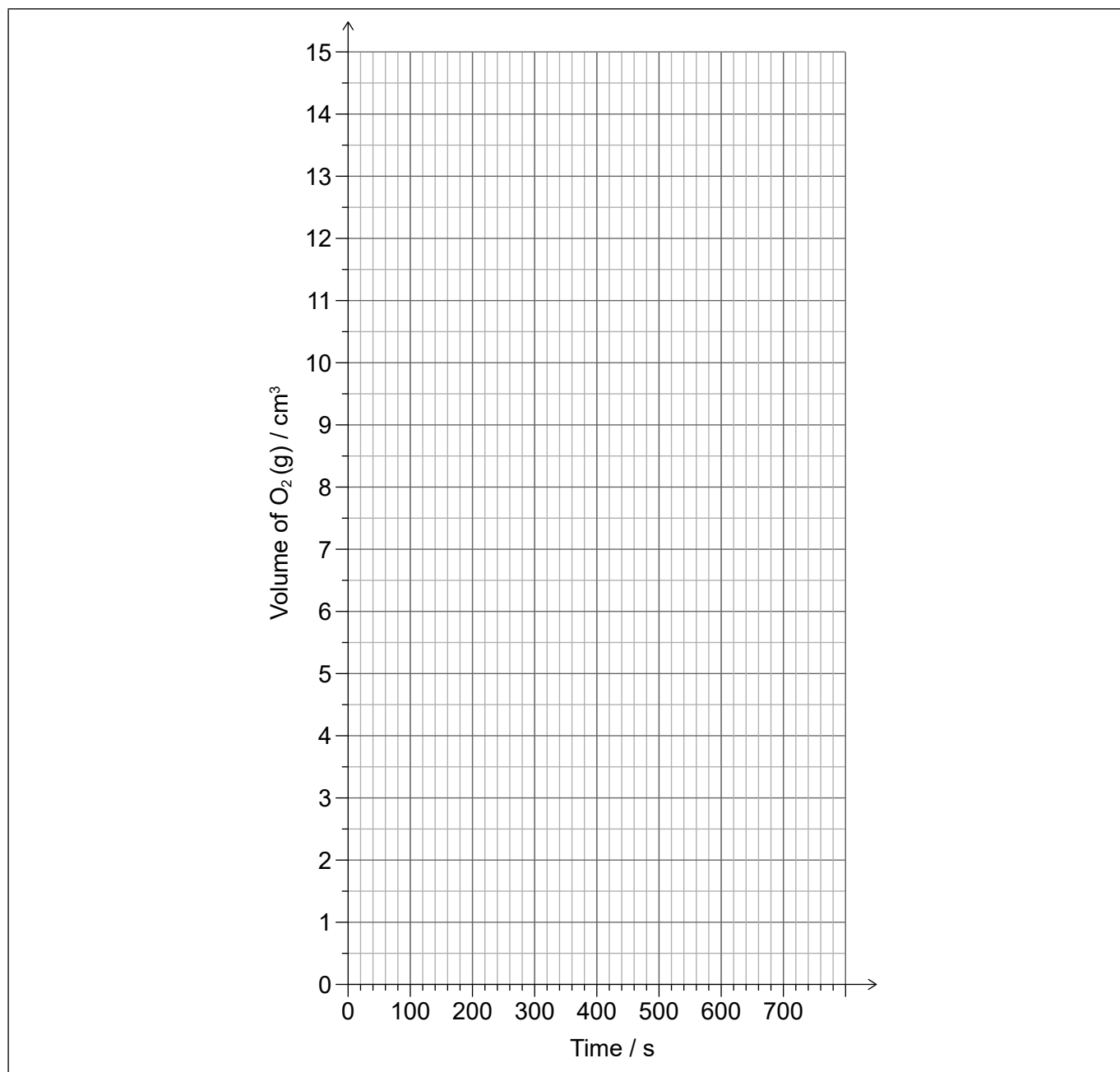
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(Question 4 continued)

Plot a graph on the axes below and from it determine the average rate of formation of oxygen gas in $\text{cm}^3 \text{O}_2(\text{g}) \text{s}^{-1}$.

[3]



Average rate of reaction:

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(This question continues on the following page)



24EP15

(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) / cm³	Volume of deionised water / cm³	Volume of 3% H₂O₂ (aq) / cm³	Average rate of reaction / cm³ O₂ (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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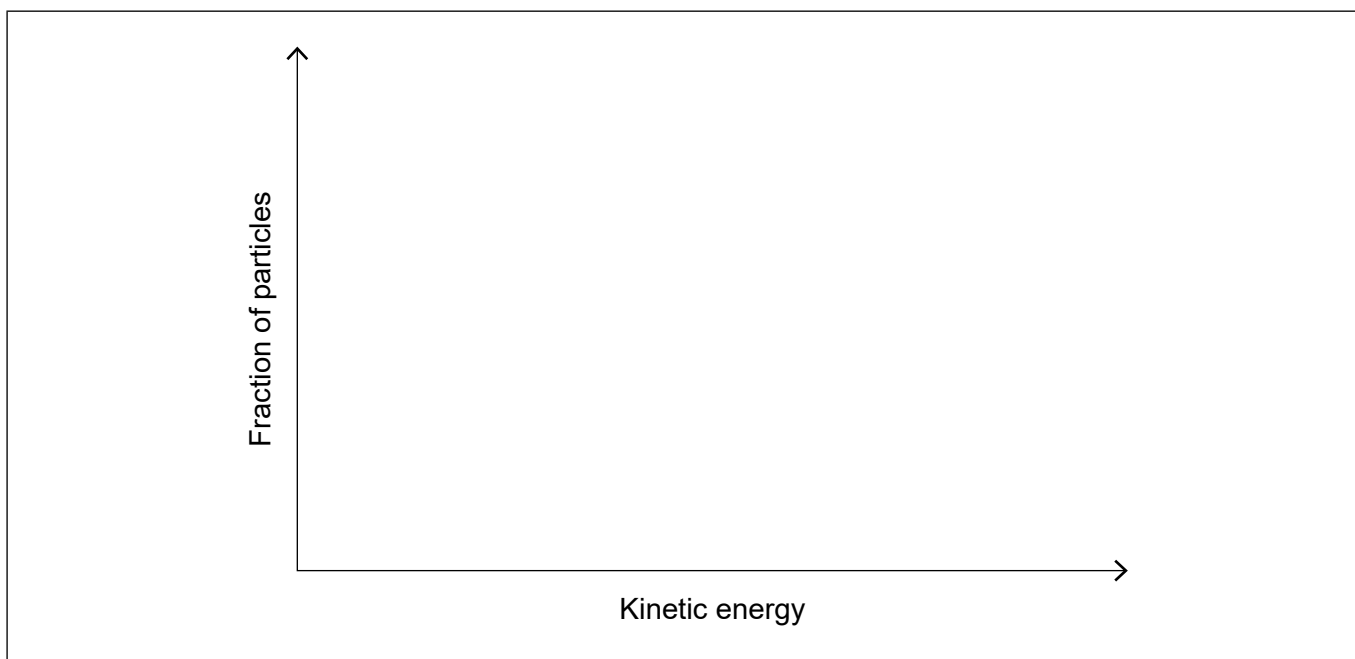
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Overall order:

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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 T₁ and T₂, where T₂ > T₁.

[2]



(This question continues on the following page)



(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.



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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.



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]

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(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]

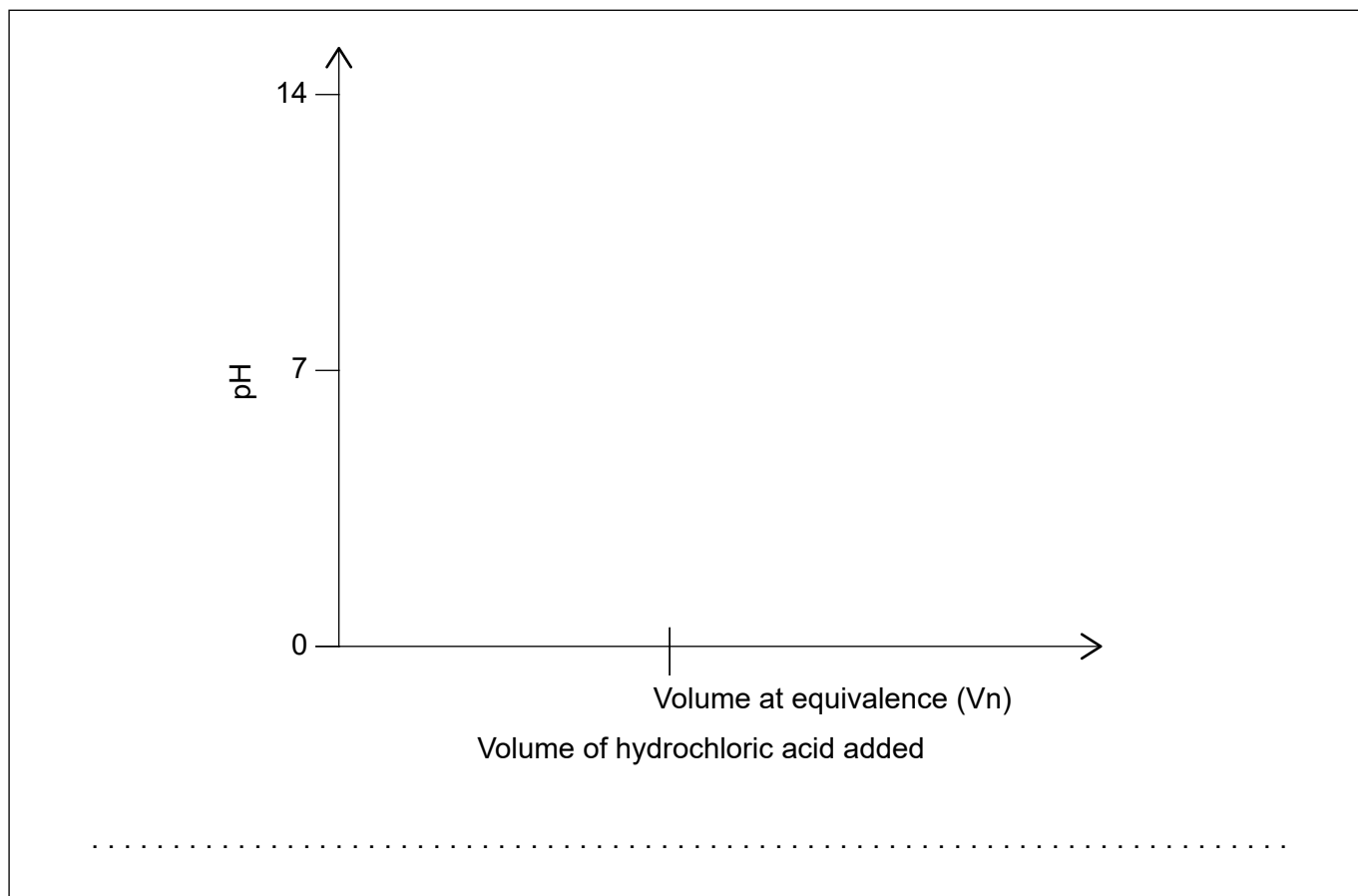
Molecular geometry:
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H–N–H bond angle:
.....

(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]



(This question continues on the following page)



(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 Fe²⁺. [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, ${}^A_Z\text{X}$, 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]

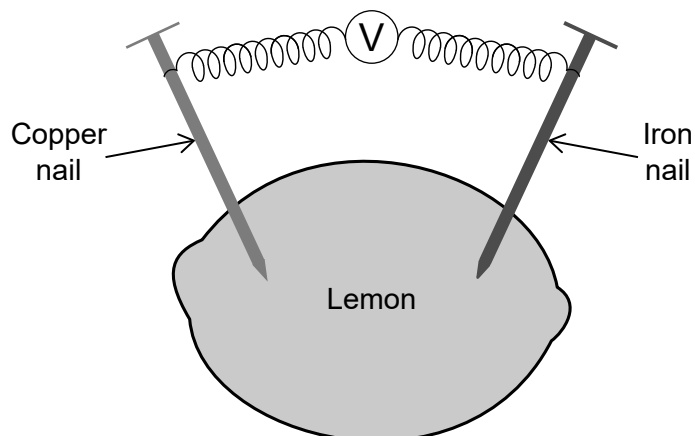
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(Question 6 continued)

(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 $\text{Fe}^{2+}(\text{aq}) | \text{Fe}(\text{s})$ and $\text{Cu}^{2+}(\text{aq}) | \text{Cu}(\text{s})$ standard half-cells are connected at 298 K. Use section 24 of the data booklet. [1]

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

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(This question continues on the following page)



(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, $\text{AgNO}_3(\text{aq})$, 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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