Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Wednesday 22 May 2019 (afternoon)

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]**.

23 pages

24EP01

International Baccalaureate
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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.

$$H_3C \longrightarrow \bigcirc \longrightarrow CH_3$$
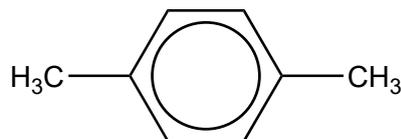
(a)   State the number of ^{1}H NMR signals for this isomer of xylene and the ratio in which they appear.   [2]

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)

24EP02

(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]
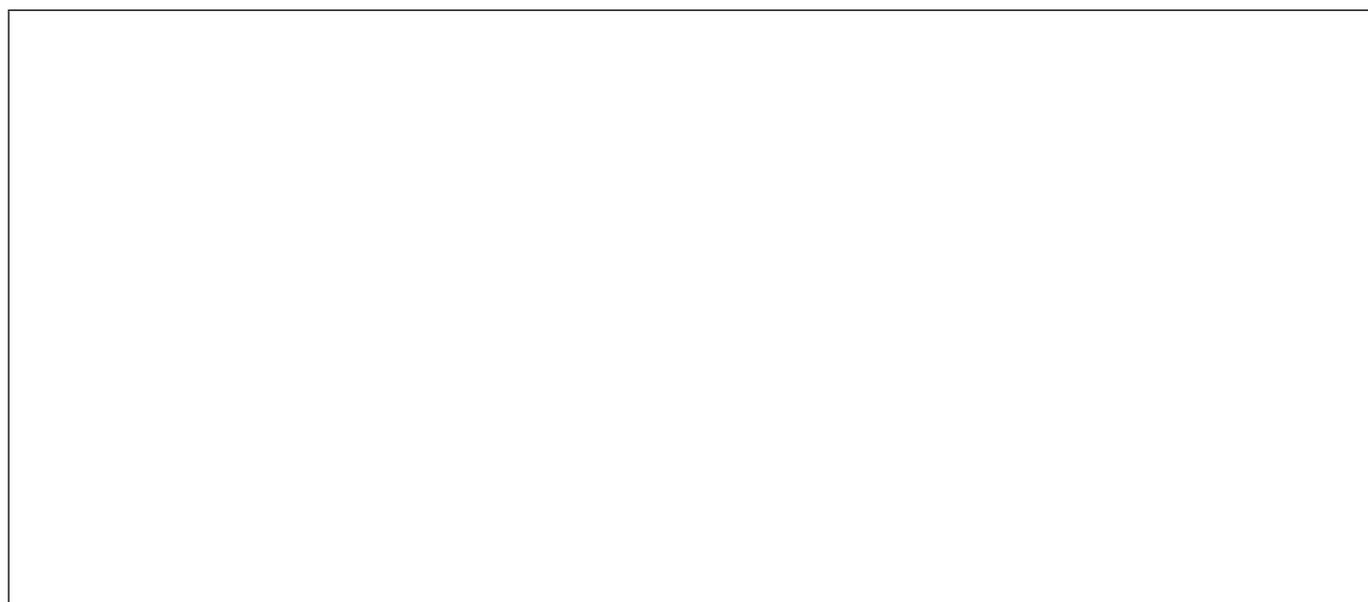
(This question continues on the following page)

(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:

        . . . .

    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]

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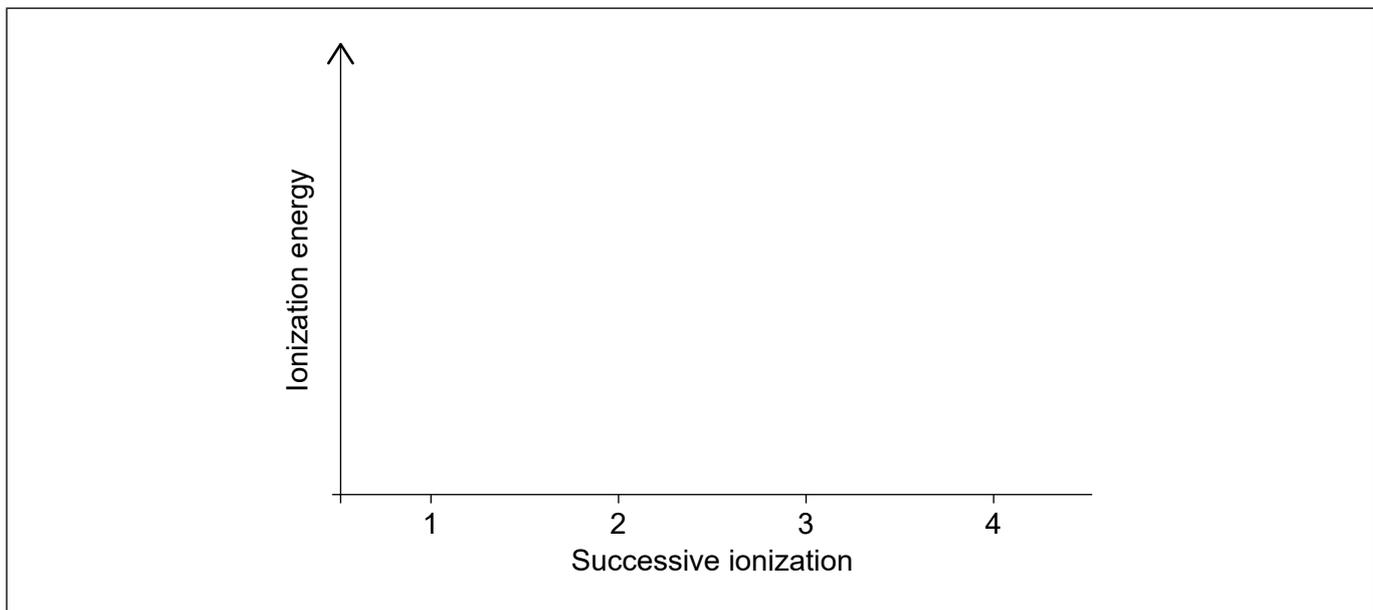
(Question 3 continued)

(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).

$$2Na^+(g) + O^{2-}(g)$$

$$2Na^+(g) + O(g)$$

$$2Na(g) + O(g)$$ Lattice enthalpy

$$2Na(g) + \tfrac{1}{2}O_2(g)$$

$$2Na(s) + \tfrac{1}{2}O_2(g)$$

$$Na_2O(s)$$
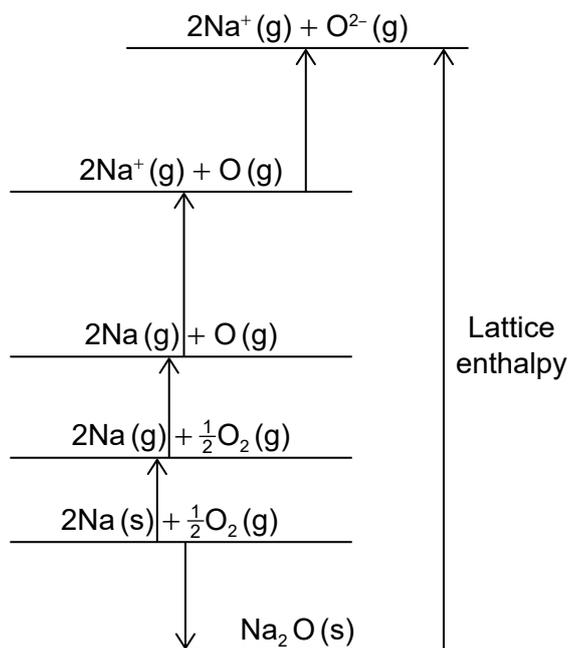
(This question continues on the following page)

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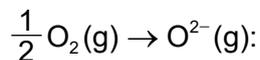
    (ii)   The standard enthalpy of formation of sodium oxide is $-414\,kJ\,mol^{-1}$. Determine the lattice enthalpy of sodium oxide, in $kJ\,mol^{-1}$, using section 8 of the data booklet and your answers to (d)(i).   [2]

        (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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(This question continues on the following page)

(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.

$$2Na_2O\,(s) + O_2\,(g) \rightarrow 2Na_2O_2\,(s)$$
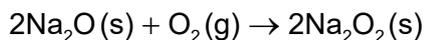
        Calculate the percentage yield of sodium peroxide if 5.00 g of sodium oxide produces
        5.50 g of sodium peroxide.   [2]

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(This question continues on the following page)

(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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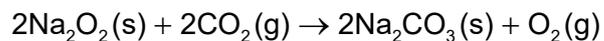
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Answers written on this page
will not be marked.

(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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Turn over

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.

$$2H_2O_2(aq) \xrightarrow{KI(aq)} O_2(g) + 2H_2O(l)$$
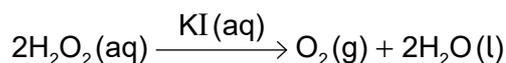
(i)   In a laboratory experiment solutions of potassium iodide and hydrogen peroxide
     were mixed and the volume of oxygen generated was recorded. The volume was
     adjusted to 0 at $t = 0$.
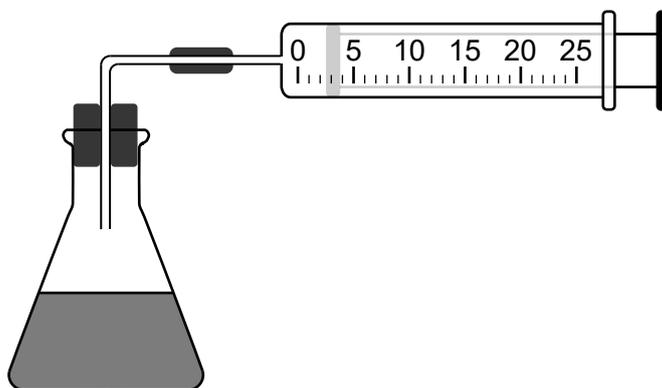
The data for the first trial is given below.

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]
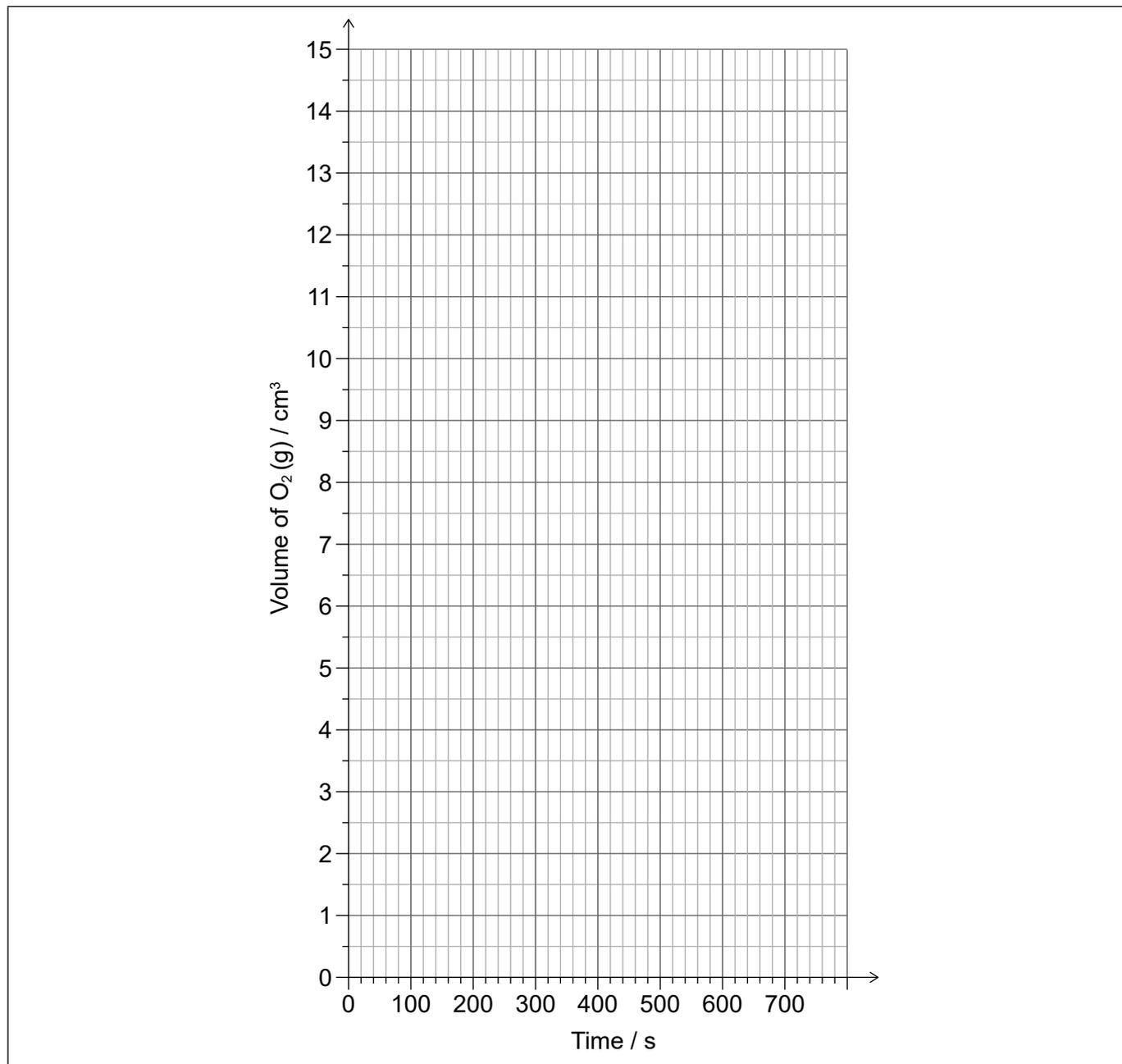
Average rate of reaction:

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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]
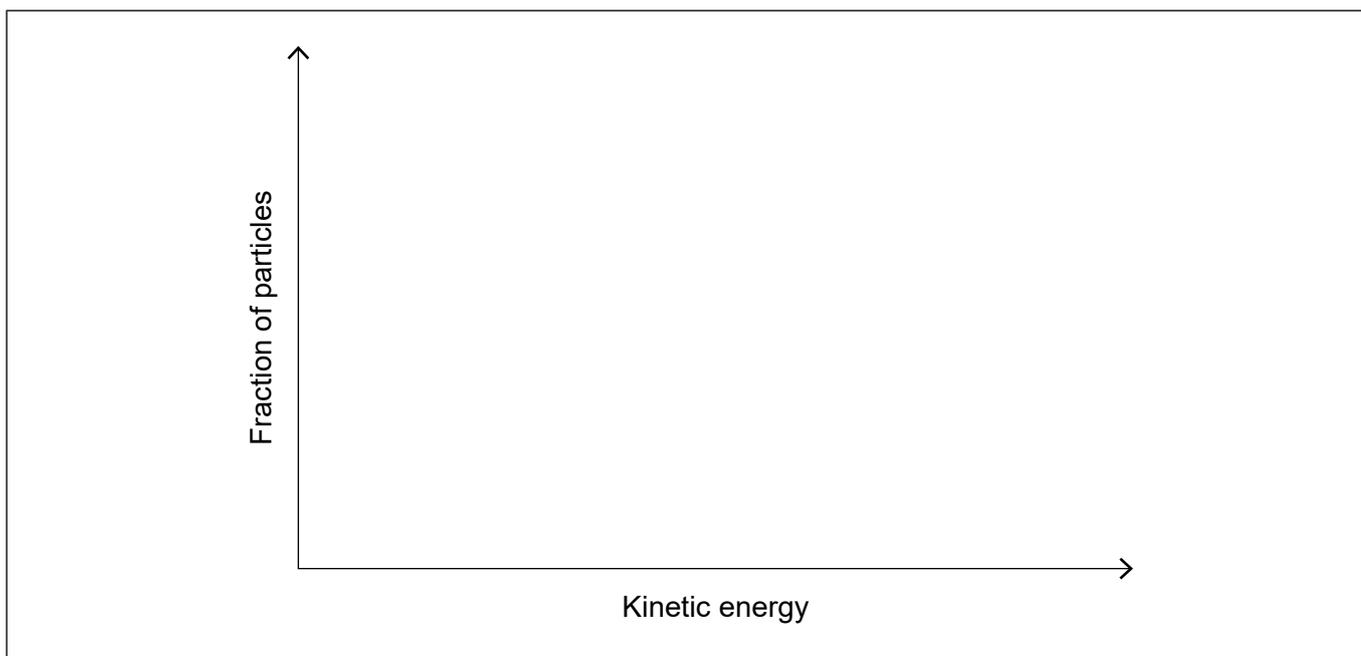

Fraction of particles

Kinetic energy

(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.

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

14 —

7 —

pH

0 —

Volume at equivalence (Vn)

Volume of hydrochloric acid added

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(This question continues on the following page)

Turn over

(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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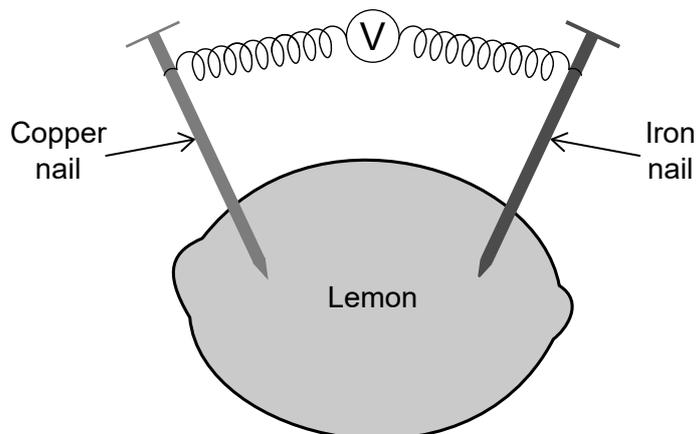...

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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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(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, $AgNO_3$(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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