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CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

Tuesday 18 November 2014 (afternoon)

2 hours 15 minutes

Examination code

8 8 1 4 – 6 1 0 2

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the 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]*.

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

1. A student used a pH meter to measure the pH of different samples of water at 298 K.

Sample	pH ± 0.1
Rain water	5.1
River water	4.4
Tap water	6.5
Bottled water	7.1

(a) Use the data in the table to identify the most acidic water sample. *[1]*

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(b) Calculate the percentage uncertainty in the measured pH of the rain water sample. *[1]*

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(c) Determine the ratio of $[H^+]$ in bottled water to that in rain water.

$$\frac{\textbf{[H}^+\textbf{] in bottled water}}{\textbf{[H}^+\textbf{] in rain water}}$$

[2]

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(Question 1 continued)

(d) Determine the concentration of hydroxide ions in the sample of river water. *[2]*

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(e) The acidity of non-polluted rain water is caused by dissolved carbon dioxide. State an equation for the reaction of carbon dioxide with water. *[1]*

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2. The reaction between ethene and steam is used in the industrial production of ethanol.

$$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$$

The enthalpy change of the reaction can be calculated either by using average bond enthalpies or by using standard enthalpies of formation.

(a) Determine the enthalpy change of the reaction, in $kJ\,mol^{-1}$, using the average bond enthalpies in Table 10 of the Data Booklet. *[3]*

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(b) (i) Define the term *standard enthalpy change of formation*. *[2]*

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(Question 2 continued)

(ii) Determine the enthalpy change of the reaction, in $kJ\,mol^{-1}$, between ethene and steam using the enthalpy change of formation values given below.

Compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$C_2H_5OH(g)$	–235
$C_2H_4(g)$	+52
$H_2O(g)$	–242

[2]

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(c) Comment on which of the values obtained in (a) and (b)(ii) is more accurate, giving a reason. *[1]*

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(d) Predict the sign of the entropy change of the reaction, ΔS, giving a reason. *[1]*

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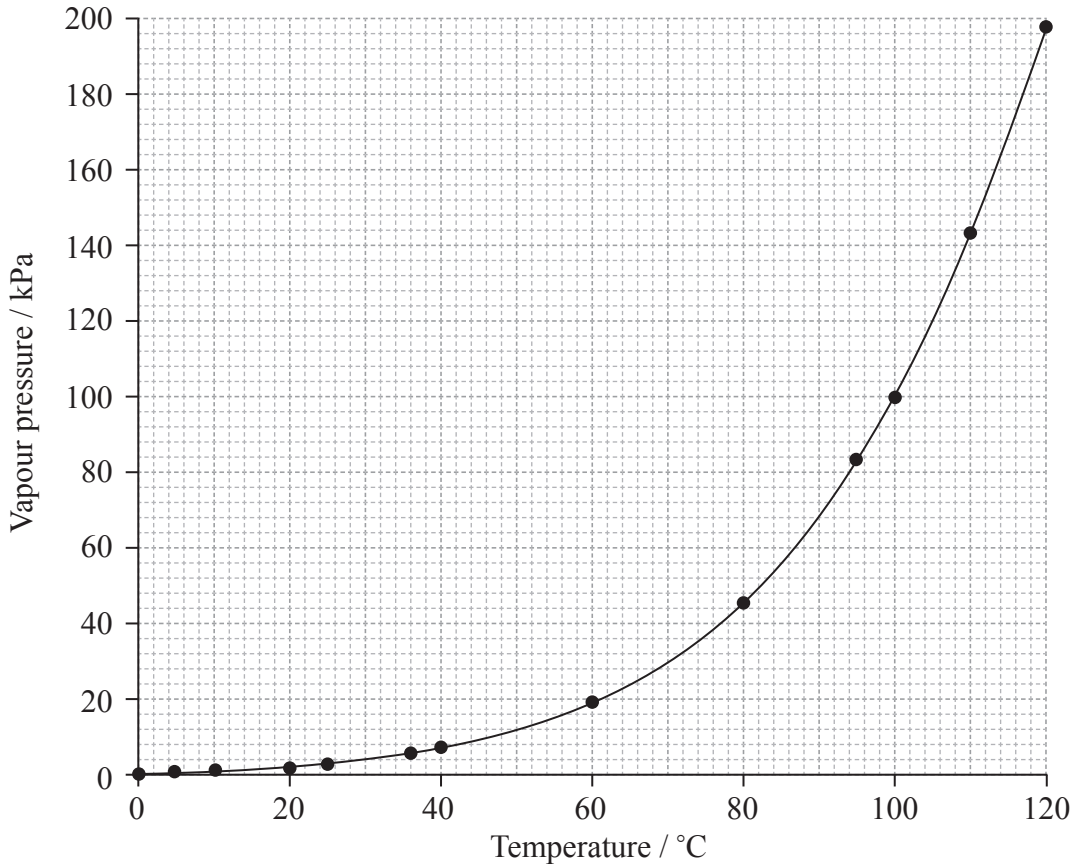
3. The vapour pressure of water changes with temperature according to the graph below.



(a) A liquid boils when its vapour pressure equals atmospheric pressure. Determine the boiling point of water on a mountaintop on a day when the atmospheric pressure is 60.0 kPa. *[1]*

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(b) Sketch another curve on the axes above to show how the vapour pressure of a liquid that has weaker intermolecular forces than water, such as bromine, changes with temperature. *[1]*

(This question continues on the following page)

(Question 3 continued)

(c) (i) A sample of liquid bromine was left in a closed conical (Erlenmeyer) flask at 298 K and allowed to reach a state of equilibrium. State an observation that indicates that equilibrium was reached. *[1]*

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(ii) The temperature of the closed flask was increased and the system was allowed to reach a new equilibrium. Compare the equilibrium formed at the new temperature with the equilibrium at the original temperature on the molecular level. *[2]*

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4. Phosphorus(V) oxide, P_4O_{10} ($M_r = 283.88$), reacts vigorously with water ($M_r = 18.02$), according to the equation below.

$$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$$

(a) A student added 5.00 g of P_4O_{10} to 1.50 g of water. Determine the limiting reactant, showing your working. *[2]*

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(b) Calculate the mass of phosphoric(V) acid, H_3PO_4, formed in the reaction. *[2]*

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(c) Phosphoric(V) acid, H_3PO_4, has a pK_a of 2.12 (pK_{a1}) while phosphoric(III) acid, H_3PO_3, has a pK_a of 1.23 (pK_{a1}). Identify the weaker of the two acids, giving a reason for your choice. *[1]*

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(d) State a balanced equation for the complete reaction of solid phosphorus(V) chloride, PCl_5, with water, including state symbols. *[2]*

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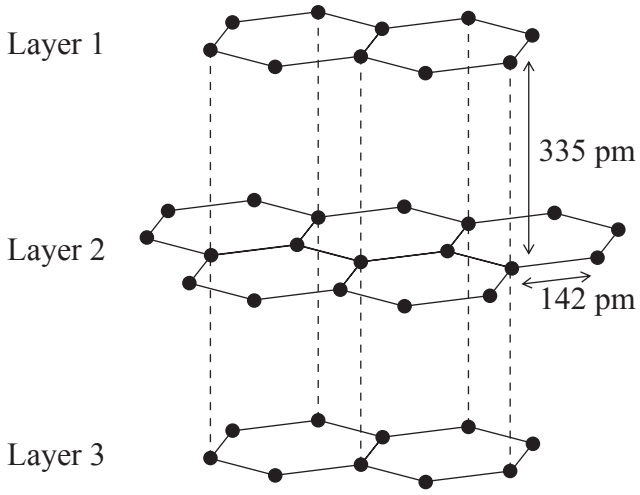
5. Graphite has a layered structure of carbon atoms. A section of the structure is shown below.



(a) Identify the type of attraction represented by the dotted lines shown between the layers. *[1]*

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(b) Graphite is used as a lubricant. Discuss **two** other uses of graphite with reference to its layered structure. *[4]*

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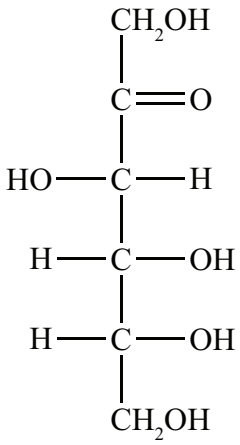
6. The open-chain structure of D-fructose is shown below.



(a) State the names of **two** functional groups in D-fructose. *[1]*

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(b) Deduce the empirical formula of D-fructose. *[1]*

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(c) Calculate the percentage composition by mass of D-fructose. *[2]*

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7. The Contact process involves an exothermic reversible reaction.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad K_c \gg 1 \text{ at } 200\ ^\circ\text{C and } 1\text{ atm}$$

(a) Deduce the extent of the reaction at 200 °C and 1 atm. *[1]*

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(b) An engineer at a Contact process plant hypothesized that using pure oxygen, instead of air, would increase the profits. Comment on whether or not her hypothesis is valid, giving your reasons. *[2]*

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SECTION B

*Answer **two** questions. Write your answers in the boxes provided.*

8. A sample of magnesium contains three isotopes: magnesium-24, magnesium-25 and magnesium-26, with abundances of 77.44 %, 10.00 % and 12.56 % respectively.

(a) (i) Calculate the relative atomic mass of this sample of magnesium correct to **two** decimal places. *[2]*

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(ii) Predict the relative atomic radii of the three magnesium isotopes, giving your reasons. *[2]*

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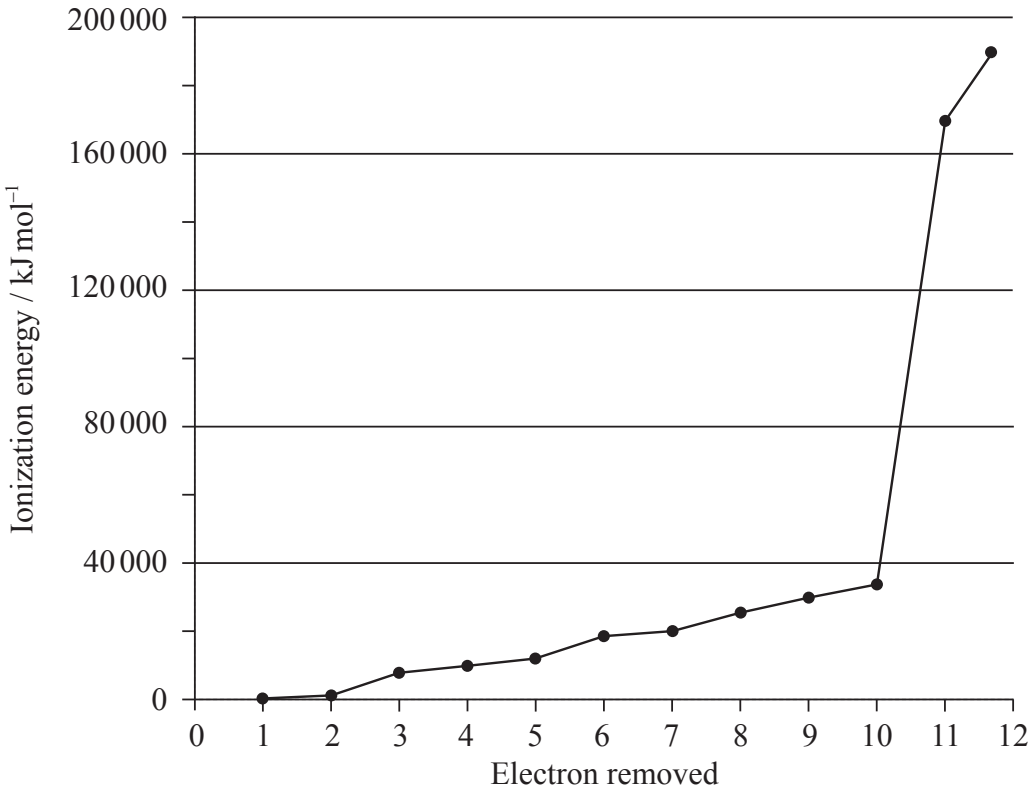
(Question 8 continued)

(b) A graph of the successive ionization energies of magnesium is shown below.



(i) Explain the increase in ionization energy values from the 3rd to the 8th electrons. *[1]*

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(ii) Explain the sharp increase in ionization energy values between the 10th and 11th electrons. *[2]*

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(Question 8 continued)

(c) (i) Magnesium reacts with oxygen to form an ionic compound, magnesium oxide. Describe how the ions are formed, and the structure and bonding in magnesium oxide. *[2]*

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(ii) Carbon reacts with oxygen to form a covalent compound, carbon dioxide. Describe what is meant by a covalent bond. *[1]*

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(iii) State why magnesium and oxygen form an ionic compound while carbon and oxygen form a covalent compound. *[1]*

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(This question continues on the following page)

(Question 8 continued)

(d) (i) Predict the type of hybridization of the carbon and oxygen atoms in CO_2. *[2]*

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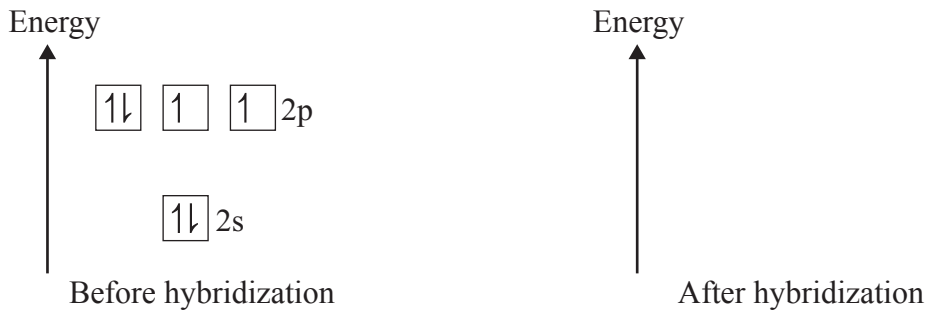
(ii) Sketch the orbitals of an oxygen atom in CO_2 on the energy level diagram provided, including the electrons that occupy each orbital. *[2]*



(iii) Define the term *electronegativity*. *[1]*

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(iv) Explain why oxygen has a larger electronegativity than carbon. *[2]*

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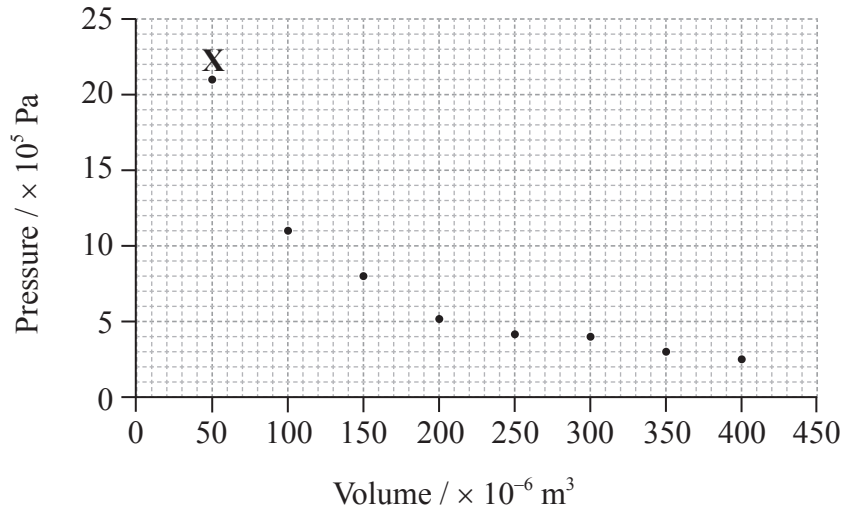
(Question 8 continued)

(e) The graph below shows pressure and volume data collected for a sample of carbon dioxide gas at 330 K.



(i) Draw a best-fit curve for the data on the graph. *[1]*

(ii) Use the data point labelled **X** to determine the amount, in mol, of carbon dioxide gas in the sample. *[3]*

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(Question 8 continued)

(f) (i) Most indicators are weak acids. Describe qualitatively how indicators work. *[2]*

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(ii) Identify a suitable indicator for a titration between a weak acid and a strong base, using Table 16 of the Data Booklet. *[1]*

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9. Consider the following list of organic compounds.

Compound 1: $CH_3CH_2CH(OH)CH_3$

Compound 2: $CH_3CH_2COCH_3$

Compound 3: $CH_3CH_2CH_2OH$

Compound 4: $CH_3CH_2CH_2CHO$

(a) Apply IUPAC rules to state the names of the four compounds. *[4]*

Compound	Name
$CH_3CH_2CH(OH)CH_3$	. . . . .
$CH_3CH_2COCH_3$	. . . . .
$CH_3CH_2CH_2OH$	. . . . .
$CH_3CH_2CH_2CHO$	. . . . .

(b) (i) Define the term *structural isomers*. *[1]*

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(ii) Identify the two compounds in the list that are structural isomers of each other. *[1]*

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(This question continues on the following page)

(Question 9 continued)

(c) (i) Determine the organic product formed when each of the compounds is heated under reflux with excess acidified potassium dichromate(VI). If no reaction occurs write NO REACTION in the table. *[4]*

Compound	Organic product
$CH_3CH_2CH(OH)CH_3$	. . . . .
$CH_3CH_2COCH_3$	. . . . .
$CH_3CH_2CH_2OH$	. . . . .
$CH_3CH_2CH_2CHO$	. . . . .

(ii) Describe the colour change during the reactions that occur in part (i). *[1]*

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(d) Deduce the two-stage reaction pathway for converting 1-bromobutane into 1-pentanamine (1-pentylamine). Include reagents and structural formulas of organic products for each stage. *[4]*

	Reagent	Product
Stage 1	. . . . .	. . . . .
Stage 2	. . . . .	. . . . .

(This question continues on the following page)

(Question 9 continued)

(e) Explain the mechanism for the elimination of HBr from 1-bromobutane. Use curly arrows to represent the movement of electron pairs. *[4]*

(f) (i) Pentanoic acid reacts with ethanol. State the structural formula of the organic product and the name of the functional group it contains. *[2]*

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(ii) State the type of reaction in part (i). *[1]*

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(g) Describe what is meant by a weak Brønsted–Lowry base, including an equation for the reaction of ammonia with water. *[3]*

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will not be marked.

10. Iron rusts in the presence of oxygen and water. Rusting is a redox process involving several steps that produces hydrated iron(III) oxide, $Fe_2O_3 \bullet nH_2O$, as the final product.
The half-equations involved for the first step of rusting are given below.

Half-equation 1: $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

Half-equation 2: $O_2(aq) + 4e^- + 2H_2O(l) \rightarrow 4OH^-(aq)$

(a) (i) Identify whether half-equation 1 represents oxidation or reduction, giving a reason for your answer. *[1]*

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(ii) Identify the oxidation number of each atom in the three species in half-equation 2. *[2]*

$O_2(aq) + 4e^- + 2H_2O(l) \rightarrow 4OH^-(aq)$

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(iii) Deduce the overall redox equation for the first step of rusting by combining half-equations 1 and 2. *[1]*

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(iv) Identify the reducing agent in the redox equation in part (iii). *[1]*

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(This question continues on the following page)

(Question 10 continued)

(b) The oxygen in half-equation 2 is atmospheric oxygen that is found dissolved in water in very small concentrations. Explain, in terms of intermolecular forces, why oxygen is not very soluble in water. *[2]*

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(c) State the relationship between the electron arrangement of an element and its group and period in the periodic table. *[2]*

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(d) Transition metals and their compounds often catalyse reactions. The catalyzed decomposition of hydrogen peroxide by CuO is an example. State **two other** examples of catalyzed reactions giving the transition metal or its compound acting as catalyst. *[2]*

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(e) (i) State a chemical equation for the partial dissociation of water into ions, including state symbols. *[1]*

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(This question continues on the following page)

(Question 10 continued)

(ii) The dissociation of water into ions is reversible. State the expression for the ionic product constant of water. *[1]*

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(iii) The ionic product constant of water was measured at three different temperatures.

Temperature / K	K_w
298	1.00×10^{-14}
313	2.92×10^{-14}
373	5.13×10^{-13}

Deduce whether the ionization of water is exothermic or endothermic, giving your reason. *[2]*

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(iv) Use the data in part (iii) to determine the pH of water at 373 K, correct to **two** decimal places. *[2]*

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(Question 10 continued)

(f) (i) An aqueous solution of sodium chloride is electrolysed using inert electrodes. Explain which product is obtained at the positive electrode (anode) if the concentration of sodium chloride is high. *[3]*

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(ii) State the half-equations occurring at the electrodes during the electrolysis of the **concentrated** aqueous solution of sodium chloride. *[2]*

Negative electrode (cathode):

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Positive electrode (anode):

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(g) Describe how electrolysis can be used to electroplate a bracelet with a layer of silver metal. Include the choice of electrodes and electrolyte needed in your description. *[3]*

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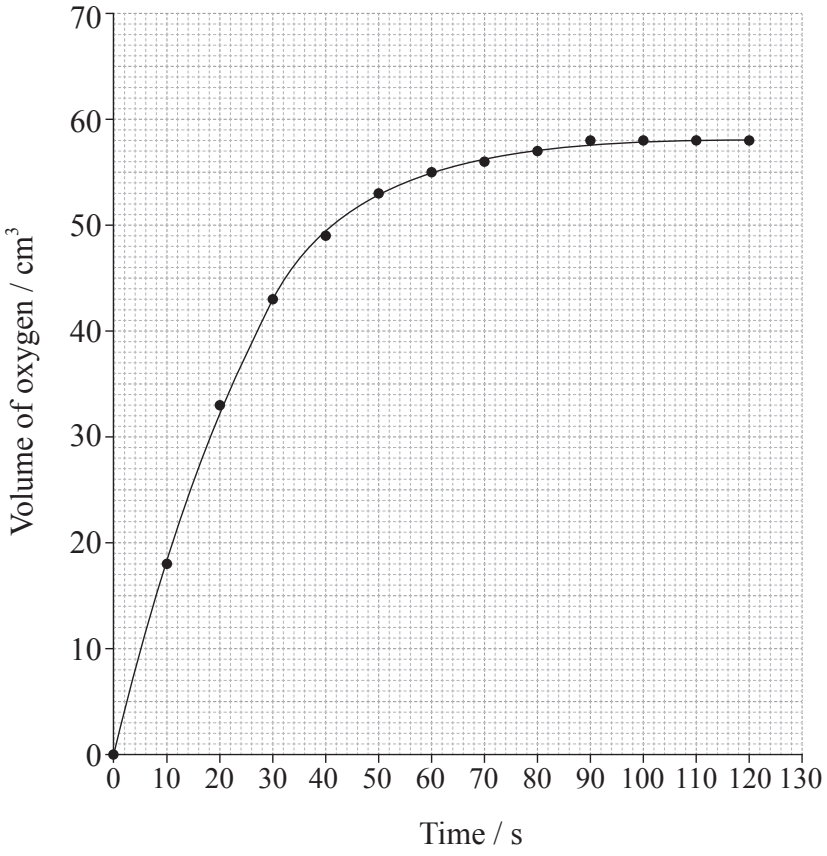
11. Hydrogen peroxide decomposes according to the equation below.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The rate of the decomposition can be monitored by measuring the volume of oxygen gas released. The graph shows the results obtained when a solution of hydrogen peroxide decomposed in the presence of a CuO catalyst.



(a) (i) Outline how the initial rate of reaction can be found from the graph. *[2]*

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(Question 11 continued)

(ii) Explain how and why the rate of reaction changes with time. *[3]*

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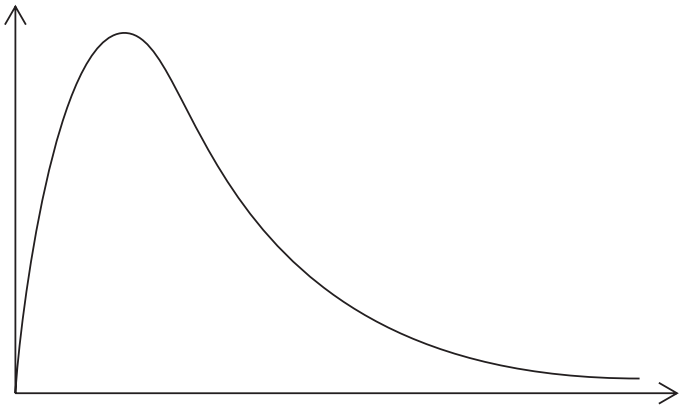
(b) A Maxwell–Boltzmann energy distribution curve is drawn below. Label both axes and explain, by annotating the graph, how catalysts increase the rate of reaction. *[3]*



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(Question 11 continued)

(c) (i) In some reactions, increasing the concentration of a reactant does not increase the rate of reaction. Describe how this may occur. *[1]*

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(ii) Consider the reaction

$$2\,A + B \rightarrow C + D$$

The reaction is first order with respect to **A**, and zero order with respect to **B**. Deduce the rate expression for this reaction. *[1]*

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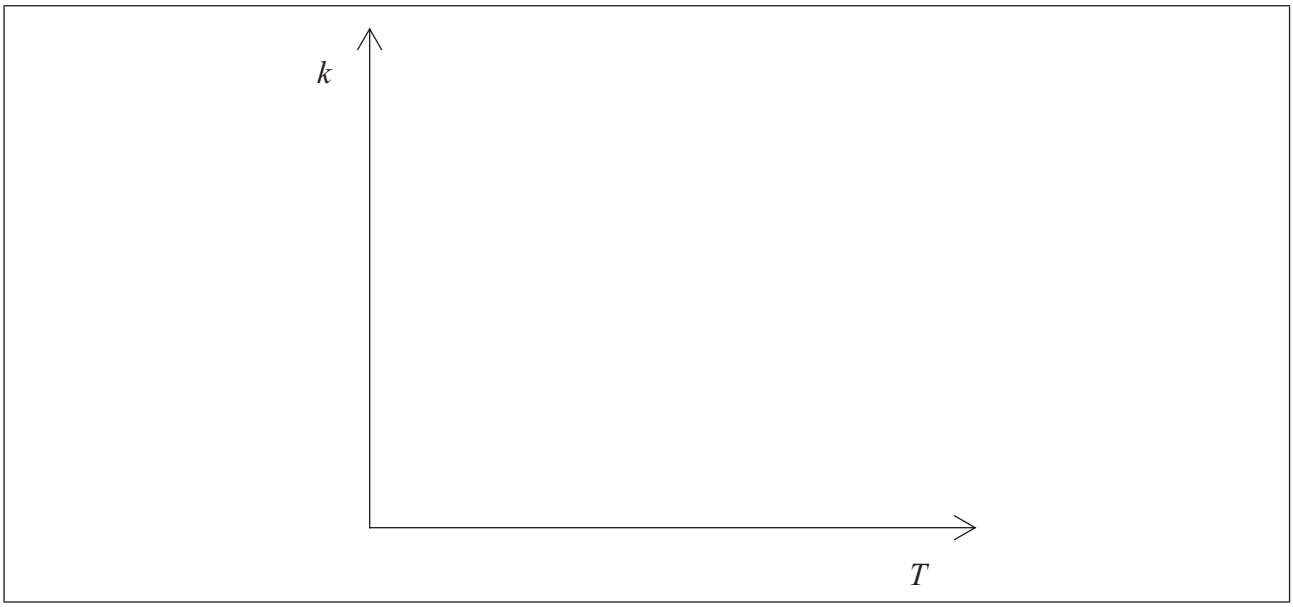
(d) Sketch a graph of rate constant (k) versus temperature. *[1]*



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(Question 11 continued)

(e) Hydrochloric acid neutralizes sodium hydroxide, forming sodium chloride and water.

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) \qquad \Delta H^{\ominus} = -57.9\,kJ\,mol^{-1}$$

(i) Define *standard enthalpy change of reaction*, $\Delta H^{\ominus}$. *[2]*

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(ii) Determine the amount of energy released, in kJ, when $50.0\,cm^3$ of $1.00\,mol\,dm^{-3}$ sodium hydroxide solution reacts with $50.0\,cm^3$ of $1.00\,mol\,dm^{-3}$ hydrochloric acid solution. *[2]*

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(Question 11 continued)

(iii) In an experiment, 2.50 g of solid sodium hydroxide was dissolved in 50.0 cm^3 of water. The temperature rose by 13.3 °C. Calculate the standard enthalpy change, in $kJ\,mol^{-1}$, for dissolving one mole of solid sodium hydroxide in water.

$$NaOH(s) \rightarrow NaOH(aq)$$ *[3]*

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(iv) Using relevant data from previous question parts, determine $\Delta H^{\ominus}$, in $kJ\,mol^{-1}$, for the reaction of solid sodium hydroxide with hydrochloric acid.

$$NaOH(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$ *[2]*

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(This question continues on the following page)

(Question 11 continued)

(f) (i) Zinc is found in the d-block of the periodic table. Explain why it is not considered a transition metal. *[2]*

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(ii) Explain why Fe^{3+} is a more stable ion than Fe^{2+} by reference to their electron configurations. *[3]*

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