



88136102

**CHEMISTRY  
HIGHER LEVEL  
PAPER 2**

Monday 18 November 2013 (afternoon)

2 hours 15 minutes

Candidate session number

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Examination code

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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.
- 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].

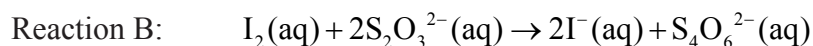
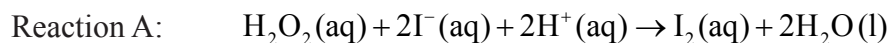


32EP01

## SECTION A

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

1. Reaction kinetics can be investigated using the iodine clock reaction. The equations for two reactions that occur are given below.



Reaction B is much faster than reaction A, so the iodine,  $\text{I}_2$ , formed in reaction A immediately reacts with thiosulfate ions,  $\text{S}_2\text{O}_3^{2-}$ , in reaction B, before it can react with starch to form the familiar blue-black, starch-iodine complex.

In one experiment the reaction mixture contained:

$5.0 \pm 0.1 \text{ cm}^3$  of  $2.00 \text{ mol dm}^{-3}$  hydrogen peroxide ( $\text{H}_2\text{O}_2$ )

$5.0 \pm 0.1 \text{ cm}^3$  of 1% aqueous starch

$20.0 \pm 0.1 \text{ cm}^3$  of  $1.00 \text{ mol dm}^{-3}$  sulfuric acid ( $\text{H}_2\text{SO}_4$ )

$20.0 \pm 0.1 \text{ cm}^3$  of  $0.0100 \text{ mol dm}^{-3}$  sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ )

$50.0 \pm 0.1 \text{ cm}^3$  of water with  $0.0200 \pm 0.0001 \text{ g}$  of potassium iodide (KI) dissolved in it.

After 45 seconds this mixture suddenly changed from colourless to blue-black.

- (a) The concentration of iodide ions,  $\text{I}^-$ , is assumed to be constant. Outline why this is a valid assumption. [1]

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- (b) For this mixture the concentration of hydrogen peroxide,  $\text{H}_2\text{O}_2$ , can also be assumed to be constant. Explain why this is a valid assumption. [2]

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*(Question 1 continued)*

- (c) Explain why the solution suddenly changes colour. [2]

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- (d) (i) Calculate the total uncertainty, in  $\text{cm}^3$ , of the volume of the reaction mixture. [1]

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- (ii) Calculate the percentage uncertainty of the concentration of potassium iodide solution added to the overall reaction mixture. [1]

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- (iii) Determine the percentage uncertainty in the concentration of potassium iodide in the final reaction solution. [1]

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*(This question continues on the following page)*



(Question 1 continued)

- (e) The colour change occurs when  $1.00 \times 10^{-4}$  mol of iodine has been formed. Use the total volume of the solution and the time taken, to calculate the rate of the reaction, including appropriate units. [4]

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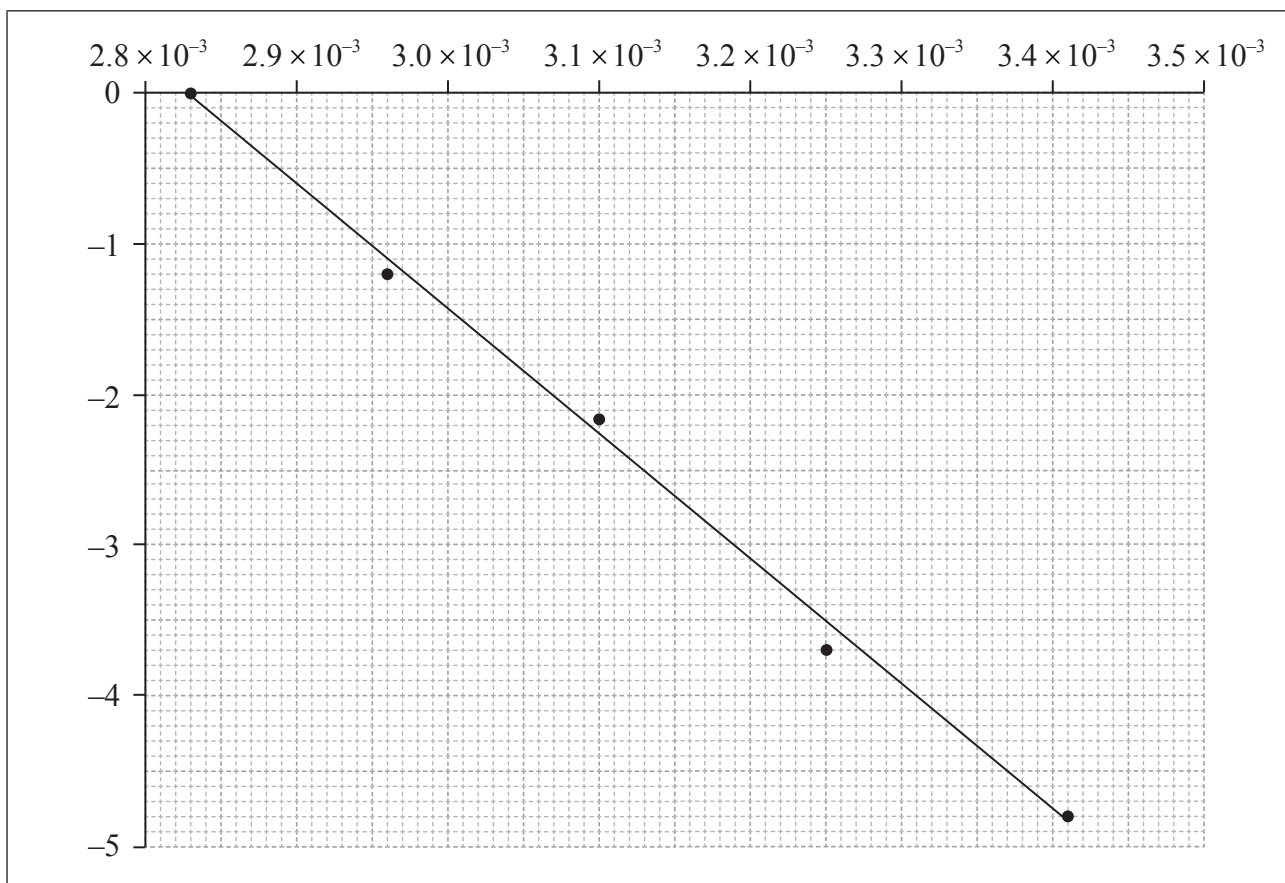
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- (f) The activation energy can be determined using the Arrhenius equation, which is given in Table 1 of the Data Booklet. The experiment was carried out at five different temperatures. An incomplete graph to determine the activation energy of the reaction, based on these results, is shown below.



(This question continues on the following page)



(Question 1 continued)

- (i) State the labels for each axis. [2]

x-axis:  
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y-axis:  
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- (ii) Use the graph to determine the activation energy of the reaction, in  $\text{kJ mol}^{-1}$ , correct to **three** significant figures. [3]

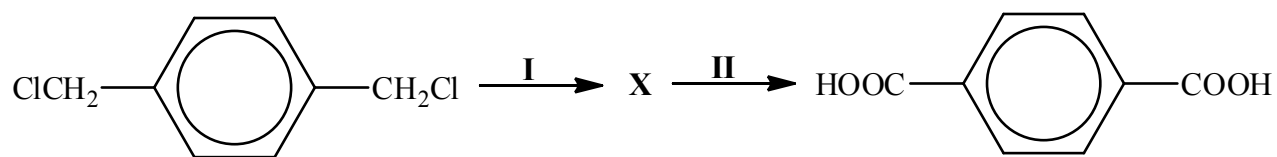
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- (g) In another experiment, 0.100 g of a black powder was also added while all other concentrations and volumes remained unchanged. The time taken for the solution to change colour was now 20 seconds. Outline why you think the colour change occurred more rapidly and how you could confirm your hypothesis. [2]

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2. Consider the two-stage reaction pathway below.



- (a) Deduce the structural formula of compound **X**.

[1]

- (b) State the reagents and conditions required for stage **II** of the pathway.

[2]

Reagents:

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Conditions:

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*(This question continues on the following page)*



(Question 2 continued)

(c) The final product can react with ethane-1,2-diol, HOCH<sub>2</sub>-CH<sub>2</sub>OH, to produce a polymer.

(i) State the type of polymerization involved. [1]

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(ii) Draw the structure of a section of the polymer produced containing **two** molecules of each monomer. [1]



3. Calcium nitrate contains both covalent and ionic bonds.

(a) (i) State the formula of **both** ions present and the nature of the force between these ions. [2]

Ions:  
.....  
Nature of force:  
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(ii) State which atoms are covalently bonded. [1]

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(b) Bonding in the nitrate ion involves electron delocalization. Explain the meaning of electron delocalization and how it affects the ion. [2]

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*(This question continues on the following page)*





*(Question 3 continued)*

(c) Nitrogen also forms oxides, which are atmospheric pollutants.

(i) Outline the source of these oxides. [1]

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(ii) State **one** product formed from their reaction with water. [1]

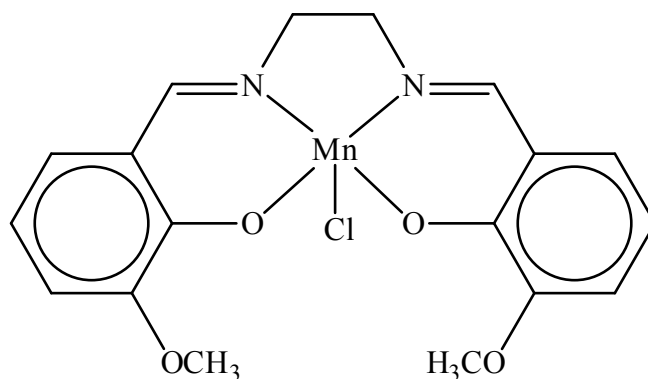
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(iii) State **one** environmental problem caused by these atmospheric pollutants. [1]

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4. EUK-134, the structure of which is shown below, is a complex ion of manganese(III) that is used in expensive sun-protection products because of its powerful antioxidant properties.



- (a) State the electron configuration of the manganese ion in EUK-134. [1]

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- (b) State the name given to species that bond to a central metal ion, and identify the type of bond present. [2]

Name given:  
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Type of bond:  
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- (c) Transition metals have certain characteristic properties. State **two** properties that are involved in EUK-134 rapidly decreasing the concentration of oxidizing agents. [2]

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*(Question 4 continued)*

- (d) Substances like EUK-134 are often coloured. Explain why compounds of transition metals absorb visible radiation. [3]

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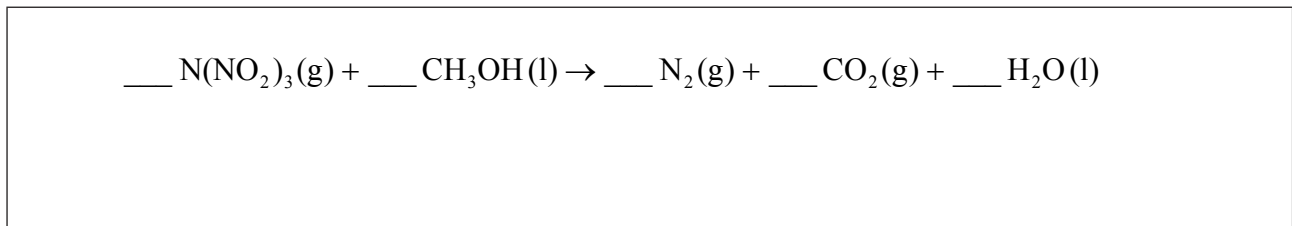


**SECTION B**

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

5. In December 2010, researchers in Sweden announced the synthesis of N,N-dinitronitramide,  $\text{N}(\text{NO}_2)_3$ . They speculated that this compound, more commonly called trinitramide, may have significant potential as an environmentally friendly rocket fuel oxidant.

(a) Methanol reacts with trinitramide to form nitrogen, carbon dioxide and water. Deduce the coefficients required to balance the equation for this reaction. [1]



(b) Suggest **one** reason why trinitramide might be more environmentally friendly than other rocket fuel oxidants such as ammonium perchlorate ( $\text{NH}_4\text{ClO}_4$ ). [1]

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*(Question 5 continued)*

- (c) Calculate the enthalpy change, in  $\text{kJ mol}^{-1}$ , when one mole of trinitramide decomposes to its elements, using bond enthalpy data from Table 10 of the Data Booklet. Assume that all the N–O bonds in this molecule have a bond enthalpy of  $305 \text{ kJ mol}^{-1}$ . [3]

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- (d) The entropy change,  $\Delta S$ , for the decomposition of trinitramide has been estimated as  $+700 \text{ J K}^{-1} \text{ mol}^{-1}$ . Comment on the sign of  $\Delta S$ . [2]

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*(Question 5 continued)*

- (e) Using  $+700 \text{ J K}^{-1} \text{ mol}^{-1}$  as the value for the entropy change, along with your answer to part (c), calculate  $\Delta G$ , in  $\text{kJ mol}^{-1}$ , for this reaction at 300 K. (If you did not obtain an answer for part (c), then use the value  $-1000 \text{ kJ mol}^{-1}$ , but this is not the correct value.) [3]

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- (f) Explain how changing the temperature will affect whether or not the decomposition of trinitramide is spontaneous. [2]

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- (g) Outline how the length of the N–N bond in trinitramide compares with the N–N bond in nitrogen gas,  $\text{N}_2$ . [2]

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(Question 5 continued)

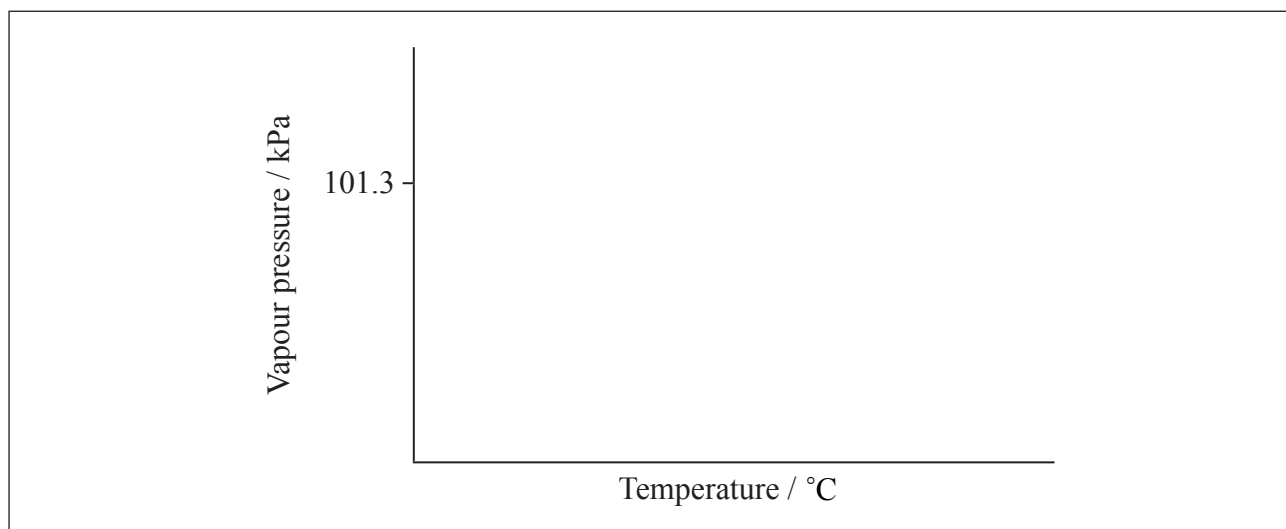
- (h) Deduce the N–N–N bond angle in trinitramide and explain your reasoning. [3]

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- (i) Predict, with an explanation, the polarity of the trinitramide molecule. [2]

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- (j) The normal boiling point of a liquid is the temperature at which its vapour pressure is equal to standard atmospheric pressure (101.3 kPa). On the axes provided, sketch a graph showing how the vapour pressure of water varies with temperature and state its boiling point at 101.3 kPa. [2]



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Turn over

*(Question 5 continued)*

- (k) Outline why the boiling point of water is lower in places well above sea level, where the atmospheric pressure is considerably below 101.3 kPa. [1]

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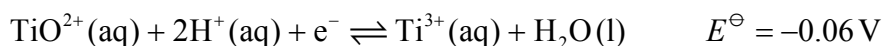
- (l) Describe the equilibrium that exists between a liquid and its vapour and how, in terms of kinetic theory, this is affected by an increase in temperature. [3]

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6. In acidic solution, ions containing titanium can react according to the half-equation below.



(a) Define the term *standard electrode potential*,  $E^{\ominus}$ . [1]

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(b) (i) State the initial and final oxidation numbers of titanium and hence deduce whether it is oxidized or reduced in this change. [2]

Initial oxidation number	Final oxidation number	Oxidized / reduced

(ii) Considering the above equilibrium, predict, giving a reason, how adding more acid would affect the strength of the  $\text{TiO}^{2+}$  ion as an oxidizing agent. [2]

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*(Question 6 continued)*

- (c) In the two experiments below, predict whether a reaction would occur and deduce an equation for any reaction that takes place. Refer to Table 14 of the Data Booklet if necessary. [3]

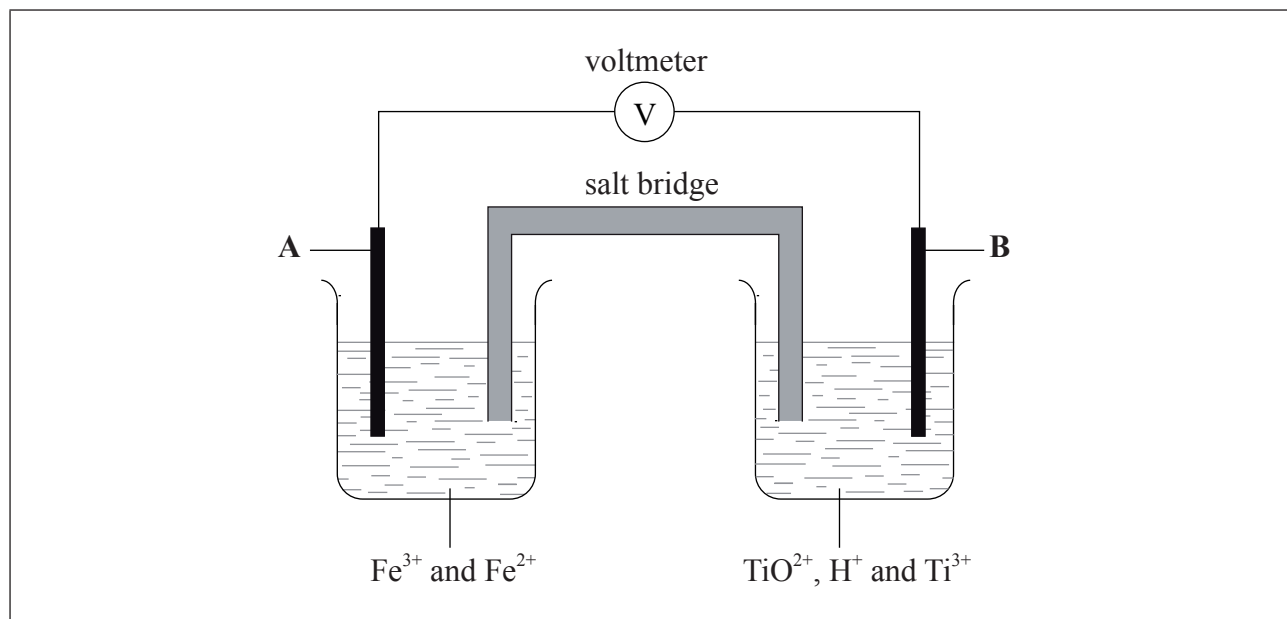
<p>KI(aq) is added to a solution containing <math>Ti^{3+}(aq)</math> ions:</p> <p>.....</p> <p>.....</p> <p>Zn(s) is added to a solution containing <math>TiO^{2+}(aq)</math> and <math>H^+(aq)</math> ions:</p> <p>.....</p> <p>.....</p>
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(Question 6 continued)

- (d) In the diagram below, **A** and **B** are inert electrodes and, in the aqueous solutions, all ions have a concentration of  $1 \text{ mol dm}^{-3}$ .



- (i) Using Table 14 of the Data Booklet, state the balanced half-equation for the reaction that occurs at electrode **A** and whether it involves oxidation or reduction. [2]

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- (ii) Calculate the cell potential in V. [1]

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- (iii) On the diagram above label with an arrow
- the direction of electron flow in the wire
  - the direction in which the positive ions flow in the salt bridge.
- [1]

(This question continues on the following page)



(Question 6 continued)

(e) Sodium, silicon and sulfur are elements in period 3 of the periodic table that all form oxides.

(i) Compare the properties of the three oxides by completing the table below. [3]

	$\text{Na}_2\text{O}$	$\text{SiO}_2$	$\text{SO}_2$
<b>Bonding type</b>			
<b>Standard state</b>			
<b>Effect on pH of water</b>			

(ii) Sulfur dioxide is a significant contributor to acid deposition. Identify a major, man-made source of this pollutant. [1]

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(iii) As well as the oxide above, sodium forms a peroxide that contains the peroxide ion,  $\text{O}_2^{2-}$ . Draw the Lewis (electron dot) structure of the peroxide ion. [2]

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(Question 6 continued)

(f) Although carbon and silicon both belong to group 4 of the periodic table, carbon dioxide and silicon dioxide are different in many ways.

(i) Describe the differences in the hybridization of these group 4 elements and the precise nature of the bonds that they form with the oxygen atoms. [3]

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(ii) Xenon, although a noble gas, forms an oxide, XeO<sub>2</sub>, that has a structure related to that of SiO<sub>2</sub>. Compare the geometry around the silicon atoms in SiO<sub>2</sub> with the geometry around the xenon atoms in XeO<sub>2</sub>, using the valence shell electron pair repulsion (VSEPR) theory. [3]

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(g) Silicon also forms a tetrachloride, SiCl<sub>4</sub>. State the equation for the reaction of SiCl<sub>4</sub> with water. [1]

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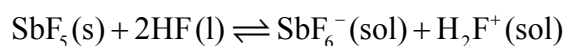


7. Antimony, Sb, forms a fluoride, SbF<sub>5</sub>.

- (a) State the element that you would expect to have chemical properties most similar to those of antimony. [1]

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The equilibrium that occurs when antimony(V) fluoride is dissolved in liquid hydrogen fluoride can be represented by the equation below.



- (b) (i) Describe the relationship between SbF<sub>5</sub> and SbF<sub>6</sub><sup>-</sup> in terms of the Lewis theory of acids. [2]

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- (ii) Explain the behaviour of HF in terms of the Brønsted–Lowry theory of acids. [2]

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*(Question 7 continued)*

(c) Outline how the following factors account for the fact that HCl is a strong acid and HF is a weak acid.

(i) The strength of the hydrogen–halogen bond. [1]

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(ii) The interaction between an undissociated hydrogen halide molecule and a water molecule. [1]

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(d) Some students were provided with a  $0.100\text{ mol dm}^{-3}$  solution of a monobasic acid, HQ, and given the problem of determining whether HQ was a weak acid or a strong acid.

(i) Neelu and Charles decided to solve the problem by determining the volume of  $0.100\text{ mol dm}^{-3}$  sodium hydroxide solution needed to neutralize  $25.0\text{ cm}^3$  of the acid. Outline whether this was a good choice. [2]

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(Question 7 continued)

- (ii) Identify **one** indicator that could be used when titrating aqueous sodium hydroxide with both a strong acid and a weak acid, and outline the reason for your choice. [2]

Indicator:

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Reason:

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- (iii) Neelu and Charles decided to compare the volume of sodium hydroxide solution needed with those required by known  $0.100 \text{ mol dm}^{-3}$  strong and weak acids. Unfortunately they chose sulfuric acid as the strong acid. Outline why this was an unsuitable choice. [1]

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- (iv) Francisco and Shamiso decided to measure the pH of the initial solution, HQ, and they found that its pH was 3.7. Deduce, giving a reason, the strength (weak or strong) of the acid HQ. [2]

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(Question 7 continued)

(e) The second problem set for the students was to determine the acid dissociation constant,  $K_a$ , of the acid HQ and its  $pK_a$ .

(i) Explain how the  $pK_a$  could be determined from a graph of pH against the volume of  $0.100 \text{ mol dm}^{-3}$  sodium hydroxide added. [2]

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(ii) Francisco and Shamiso found that the pH of the initial  $0.100 \text{ mol dm}^{-3}$  solution was 3.7. However, this reading was inaccurate because they forgot to wash the pH probe. Calculate the  $pK_a$  of HQ using the reading they obtained. [4]

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8. 2-methylbutan-2-ol,  $(\text{CH}_3)_2\text{C}(\text{OH})\text{CH}_2\text{CH}_3$ , is a liquid with a smell of camphor that was formerly used as a sedative. One way of producing it starts with 2-methylbut-2-ene.

(a) State the other substances required to convert 2-methylbut-2-ene to 2-methylbutan-2-ol. [2]

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(b) Explain whether you would expect 2-methylbutan-2-ol to react with acidified potassium dichromate(VI). [2]

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(c) As well as 2-methylbutan-2-ol, the reaction also produces a small quantity of an optically active isomer, X.

(i) State what is meant by *optical activity*. [1]

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(ii) State what optical activity indicates about the structure of the molecule. [1]

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*(Question 8 continued)*

(iii) Optical activity can be detected using a polarimeter. Explain how this works. [3]

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(iv) Deduce the structural formula of X. [1]

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(d) Explain why 2-methylbut-2-ene is less soluble in water than 2-methylbutan-2-ol. [2]

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*(This question continues on the following page)*



*(Question 8 continued)*

(e) 2-methylbutan-2-ol can also be produced by the hydrolysis of 2-chloro-2-methylbutane,  $(\text{CH}_3)_2\text{CClC}_2\text{H}_5$ , with aqueous sodium hydroxide.

(i) Explain the mechanism of this reaction using curly arrows to represent the movement of electron pairs. [4]

(ii) State the rate expression for this reaction and the units of the rate constant. [2]

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**Turn over**

*(Question 8 continued)*

- (iii) Suggest why, for some other halogenoalkanes, this hydrolysis is much more effective in alkaline rather than in neutral conditions. [1]

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- (f) 2-chloro-2-methylbutane contains some molecules with a molar mass of approximately  $106 \text{ g mol}^{-1}$  and some with a molar mass of approximately  $108 \text{ g mol}^{-1}$ .

- (i) Outline why there are molecules with different molar masses. [1]

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- (ii) Suggest, with a reason, whether the molecules with different molar masses will undergo hydrolysis at different rates. [1]

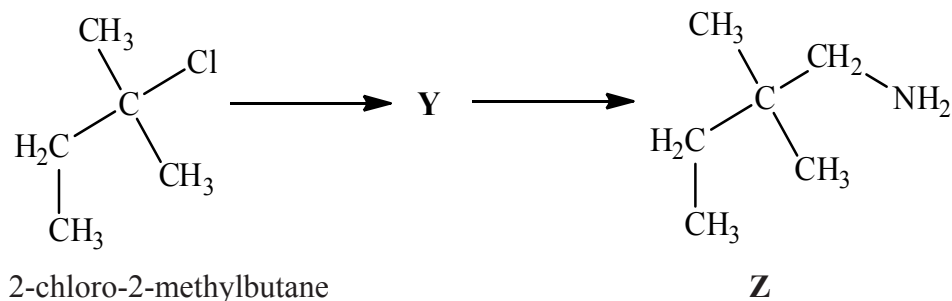
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(Question 8 continued)

- (g) 2-chloro-2-methylbutane can also be converted into compound **Z** by a two-stage reaction via compound **Y**:



- (i) Draw the structure of **Y**.

[1]

- (ii) State the reagent and any catalyst required for both the formation of **Y** and the conversion of **Y** into **Z**.

[3]

Formation of **Y**:

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 .....

Conversion of **Y** into **Z**:

.....  
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Answers written on this page  
will not be marked.



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