

**Chemistry**  
**Higher level**  
**Paper 2**

Wednesday 7 November 2018 (afternoon)

Candidate session number

2 hours 15 minutes

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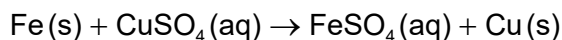
**Instructions to candidates**

- 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 **[95 marks]**.



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

1. 3.26 g of iron powder are added to 80.0 cm<sup>3</sup> of 0.200 mol dm<sup>-3</sup> copper(II) sulfate solution. The following reaction occurs:



- (a) (i) Determine the limiting reactant showing your working. [2]

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- (ii) The mass of copper obtained experimentally was 0.872 g. Calculate the percentage yield of copper. [2]

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- (b) (i) The reaction was carried out in a calorimeter. The maximum temperature rise of the solution was 7.5 °C.

Calculate the enthalpy change,  $\Delta H$ , of the reaction, in kJ, assuming that all the heat released was absorbed by the solution. Use sections 1 and 2 of the data booklet. [2]

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**(Question 1 continued)**

- (ii) State another assumption you made in (b)(i). [1]

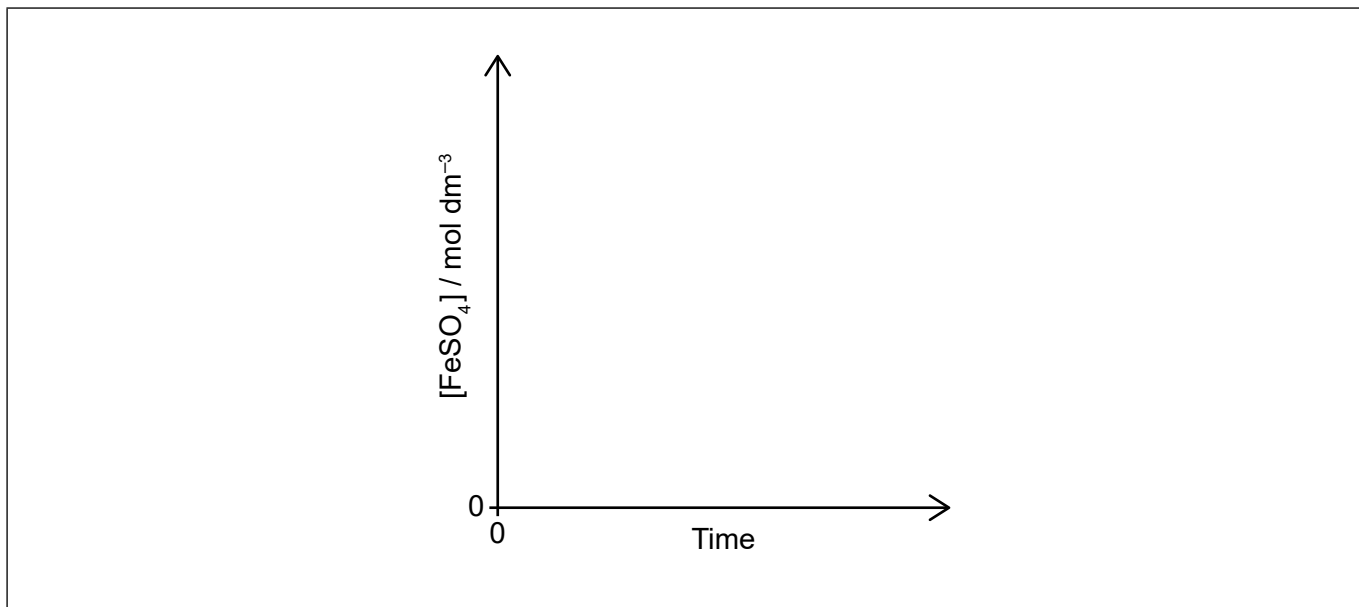
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- (iii) The only significant uncertainty is in the temperature measurement.

Determine the absolute uncertainty in the calculated value of  $\Delta H$  if the uncertainty in the temperature rise was  $\pm 0.2^\circ\text{C}$ . [2]

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- (c) (i) Sketch a graph of the concentration of iron(II) sulfate,  $\text{FeSO}_4$ , against time as the reaction proceeds. [2]



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**(Question 1 continued)**

- (ii) Outline how the initial rate of reaction can be determined from the graph in part (c)(i). [2]

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- (iii) Explain, using the collision theory, why replacing the iron powder with a piece of iron of the same mass slows down the rate of the reaction. [2]

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- (d) A student electrolyzed aqueous iron(II) sulfate,  $\text{FeSO}_4(\text{aq})$ , using platinum electrodes. State half-equations for the reactions at the electrodes, using section 24 of the data booklet. [2]

Anode (positive electrode):  
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Cathode (negative electrode):  
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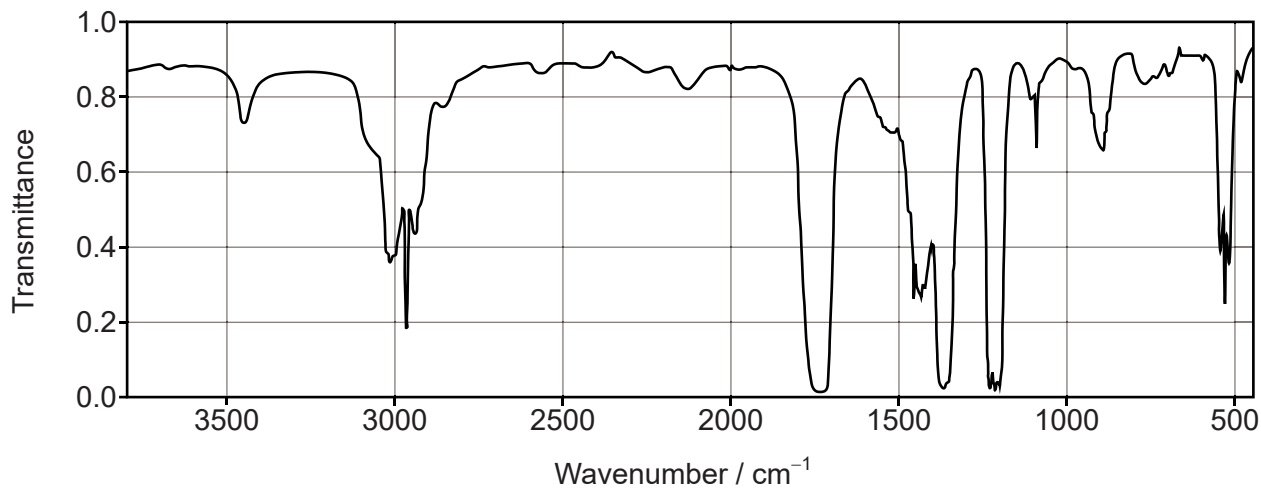


2. An organic compound containing carbon, hydrogen and oxygen has 62.02% carbon and 10.43% hydrogen by mass.

(a) Determine the empirical formula of the compound, showing your working. [3]

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(b) The infrared spectrum of the compound is shown. Deduce the functional group of the compound. [1]



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899]

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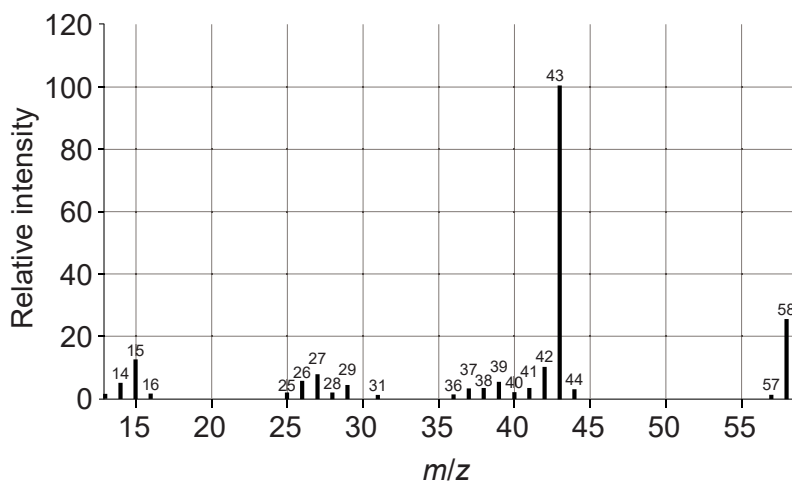
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**(Question 2 continued)**

- (c) The mass spectrum of the compound is shown. Deduce the relative molecular mass of the compound. [1]



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899]

- (d) The compound could not be oxidized using acidified potassium dichromate(VI).

Deduce the structural formula of the compound. [1]

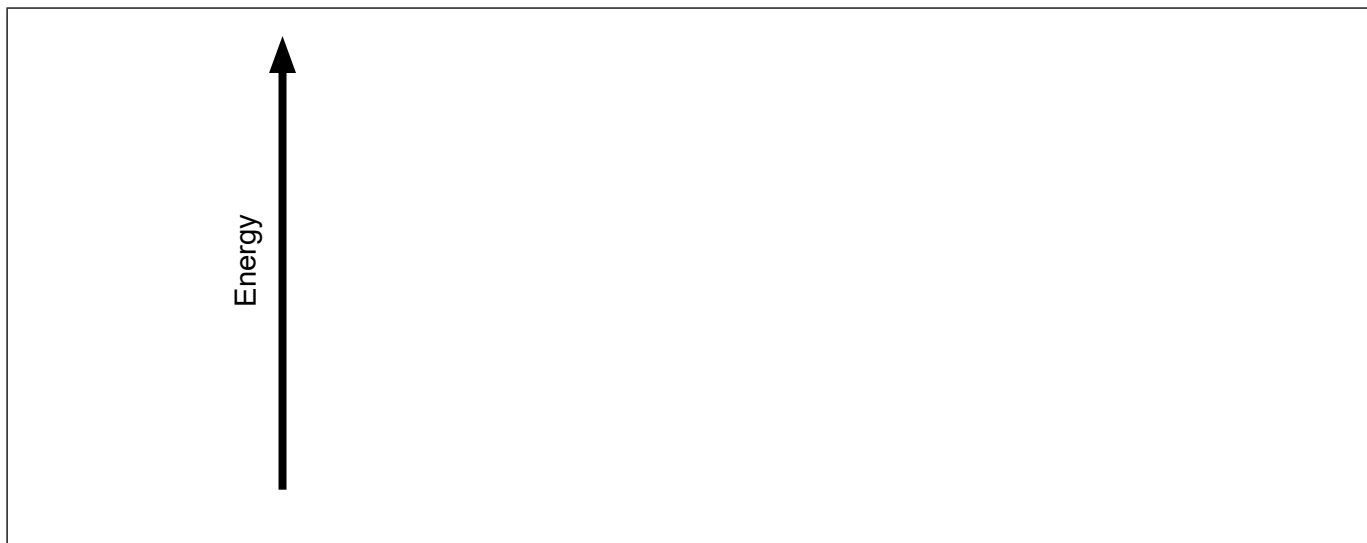


3. Bromine can form the bromate(V) ion,  $\text{BrO}_3^-$ .

(a) (i) State the electron configuration of a bromine atom. [1]

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(ii) Sketch the orbital diagram of the **valence shell** of a bromine atom (ground state) on the energy axis provided. Use boxes to represent orbitals and arrows to represent electrons. [1]



(b) (i) Draw two Lewis (electron dot) structures for  $\text{BrO}_3^-$ . [2]

Structure I – follows octet rule:

Structure II – does not follow octet rule:

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**(Question 3 continued)**

- (ii) Determine the preferred Lewis structure based on the formal charge on the bromine atom, giving your reasons. [2]

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- (c) Predict, using the VSEPR theory, the geometry of the  $\text{BrO}_3^-$  ion and the O–Br–O bond angles. [3]

Geometry:  
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Reason:  
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O–Br–O angle:  
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- (d) (i) Bromate(V) ions act as oxidizing agents in acidic conditions to form bromide ions.  
Deduce the half-equation for this reduction reaction. [2]

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**(Question 3 continued)**

- (ii) Bromate(V) ions oxidize iron(II) ions,  $\text{Fe}^{2+}$ , to iron(III) ions,  $\text{Fe}^{3+}$ .

Deduce the equation for this redox reaction.

[1]

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- (iii) Calculate the standard Gibbs free energy change,  $\Delta G^\ominus$ , in J, of the redox reaction in (ii), using sections 1 and 24 of the data booklet.

$$E^\ominus (\text{BrO}_3^- / \text{Br}^-) = +1.44 \text{ V}$$

[2]

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- (e) State and explain the magnetic property of iron(II) and iron(III) ions.

[2]

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**4. Properties of elements and their compounds can be related to the position of the elements in the periodic table.**

- (a) Explain the decrease in atomic radius from Na to Cl.

[2]

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**(Question 4 continued)**

- (b) Explain why the radius of the sodium ion,  $\text{Na}^+$ , is smaller than the radius of the oxide ion,  $\text{O}^{2-}$ . [2]

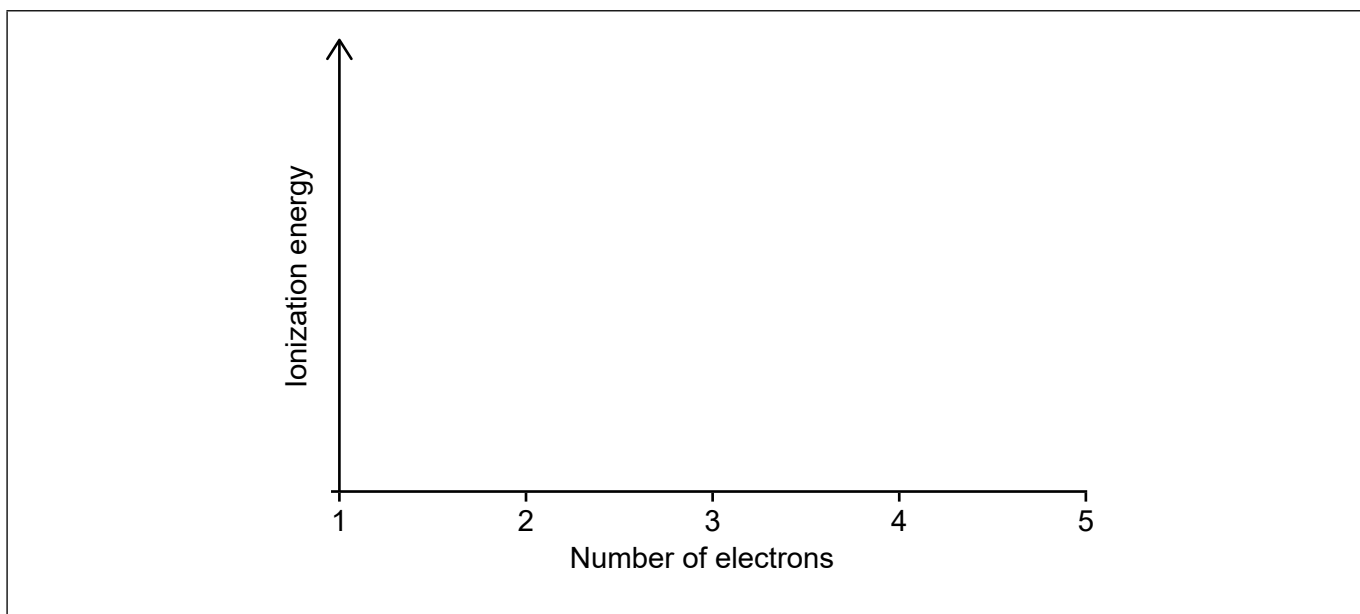
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- (c) Sketch a graph to show the relative values of the successive ionization energies of boron. [2]



- (d) Predict, giving your reasons, whether  $\text{Mn}^{2+}$  or  $\text{Fe}^{2+}$  is likely to have a more exothermic enthalpy of hydration. [2]

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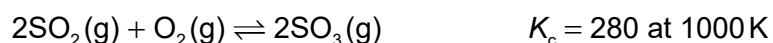
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5. This reaction is used in the manufacture of sulfuric acid.



(a) State why this equilibrium reaction is considered homogeneous. [1]

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(b) Predict, giving your reason, the sign of the standard entropy change of the forward reaction. [1]

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(c) Calculate the standard Gibbs free energy change,  $\Delta G^\ominus$ , in kJ, for this reaction at 1000K. Use sections 1 and 2 of the data booklet. [2]

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(d) Predict, giving your reasons, whether the forward reaction is endothermic or exothermic. Use your answers to (b) and (c). [2]

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**(Question 5 continued)**

- (e) 0.200 mol sulfur dioxide, 0.300 mol oxygen and 0.500 mol sulfur trioxide were mixed in a 1.00 dm<sup>3</sup> flask at 1000 K.

Predict the direction of the reaction showing your working.

[3]

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6. Butanoic acid, CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>COOH, is a weak acid and ethylamine, CH<sub>3</sub>CH<sub>2</sub>NH<sub>2</sub>, is a weak base.

(a) (i) State the equation for the reaction of each substance with water.

[2]

Butanoic acid:  
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Ethylamine:  
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(ii) Draw a diagram showing the delocalization of electrons in the conjugate base of butanoic acid.

[1]

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**(Question 6 continued)**

- (iii) Deduce the average oxidation state of carbon in butanoic acid. [1]

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- (b) (i) A  $0.250 \text{ mol dm}^{-3}$  aqueous solution of butanoic acid has a concentration of hydrogen ions,  $[\text{H}^+]$ , of  $0.00192 \text{ mol dm}^{-3}$ . Calculate the concentration of hydroxide ions,  $[\text{OH}^-]$ , in the solution at 298 K. [1]

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- (ii) Determine the pH of a  $0.250 \text{ mol dm}^{-3}$  aqueous solution of ethylamine at 298 K, using section 21 of the data booklet. [3]

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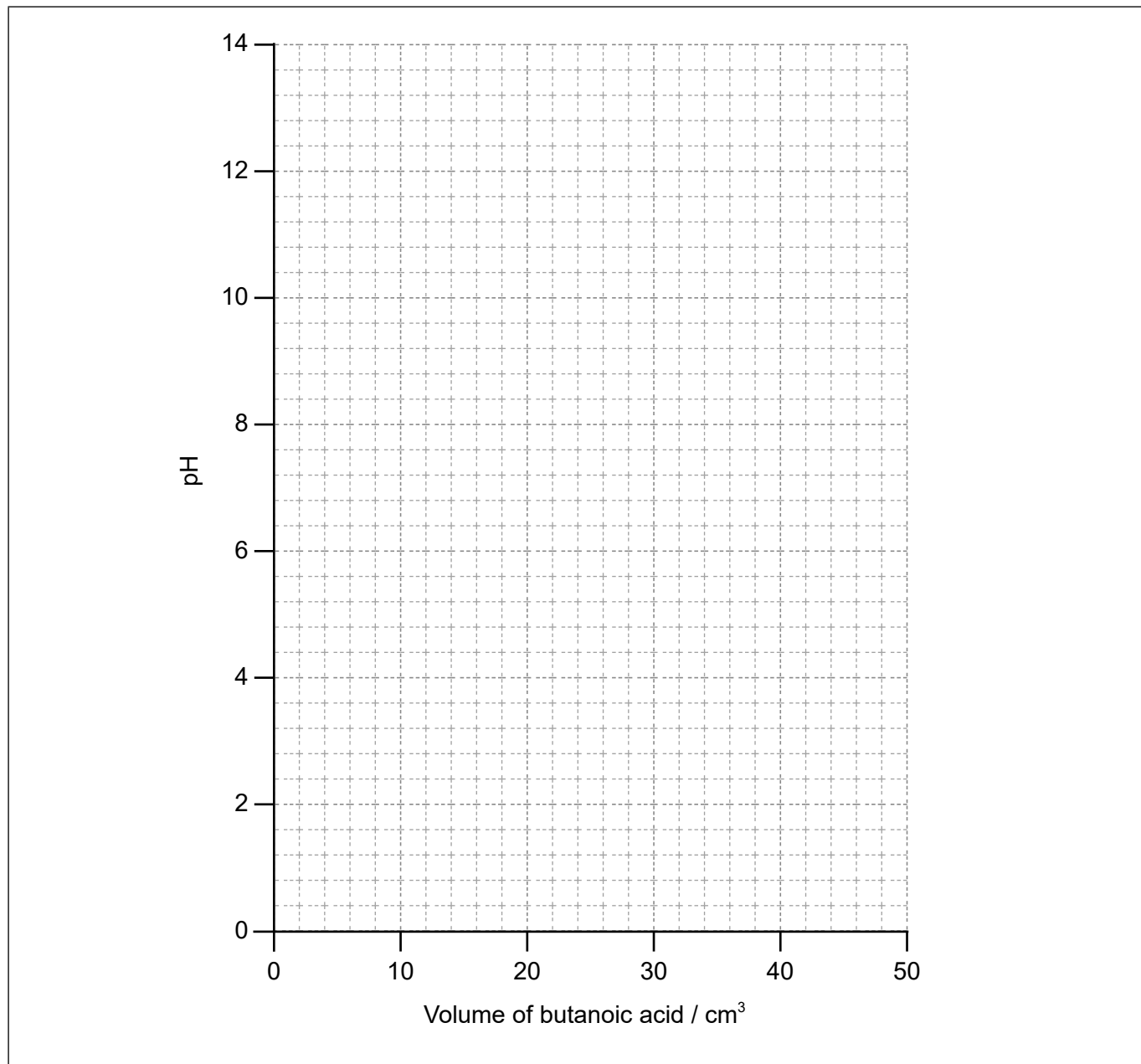
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**(Question 6 continued)**

- (c) Sketch the pH curve for the titration of 25.0 cm<sup>3</sup> of ethylamine aqueous solution with 50.0 cm<sup>3</sup> of butanoic acid aqueous solution of equal concentration. No calculations are required.

[3]



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**(Question 6 continued)**

(d) Explain why butanoic acid is a liquid at room temperature while ethylamine is a gas at room temperature. [2]

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(e) (i) State a suitable reagent for the reduction of butanoic acid. [1]

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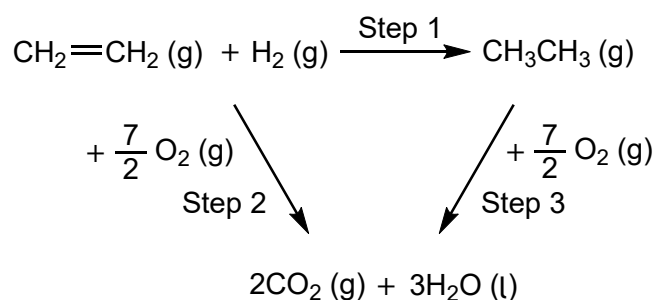
(ii) Deduce the product of the complete reduction reaction in (e)(i). [1]

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7. Consider the following Hess's law cycle:



(a) Identify the type of reaction in step 1. [1]

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(b) Calculate the standard enthalpy change,  $\Delta H^\ominus$ , of step 2 using section 13 of the data booklet. [1]

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(c) Determine the standard enthalpy change,  $\Delta H^\ominus$ , of step 1. [1]

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**(Question 7 continued)**

- (d) Suggest one reason why the calculated value of  $\Delta H^\ominus$  using Hess's Law in part (c) can be considered accurate and one reason why it can be considered approximate. [2]

Accurate:

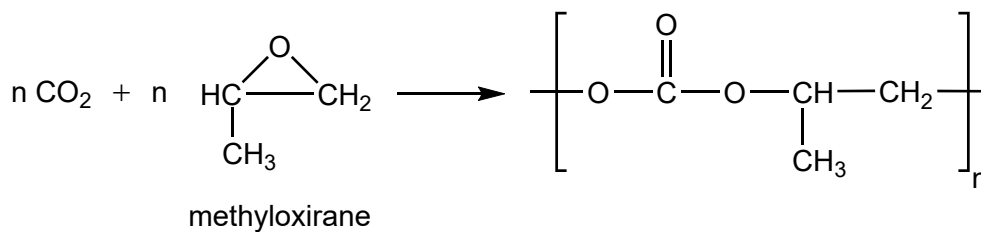
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Approximate:

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8. Carbon dioxide contributes significantly to global warming. It can be used as a raw material with methyloxirane to form polymers.



(a) Suggest why the three-membered ring in methyloxirane is unstable. [1]

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(b) (i) Draw **two** structural isomers of methyloxirane. [2]

(ii) State, giving a reason, whether methyloxirane can form *cis-trans* isomers. [1]

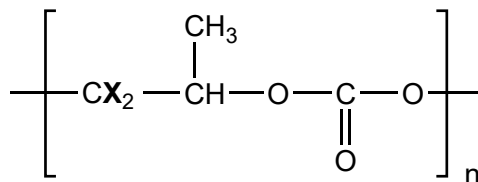
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**(Question 8 continued)**

- (c) Predict the chemical shift and splitting pattern of the signal produced by the hydrogen atoms labelled **X** in the <sup>1</sup>H NMR spectrum of the polymer. Use section 27 of the data booklet. [2]



Chemical shift:

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Splitting pattern:

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9. Halogenoalkanes undergo nucleophilic substitution reactions with sodium hydroxide.

- (a) State a reason why most halogenoalkanes are more reactive than alkanes. [1]

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- (b) Classify 1-bromopropane as a primary, secondary or tertiary halogenoalkane, giving a reason. [1]

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(Question 9 continued)

- (c) Explain the mechanism of the reaction between 1-bromopropane with aqueous sodium hydroxide using curly arrows to represent the movement of electron pairs. [4]

- (d) State, giving your reason, whether the hydroxide ion acts as a Lewis acid, a Lewis base, or neither in the nucleophilic substitution. [1]

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- (e) Suggest **two** advantages of understanding organic reaction mechanisms. [2]

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10. The following mechanism is proposed for a reaction:



(a) Classify substances B and D as reactant, product, catalyst, or intermediate, based on the proposed mechanism. [2]

B:  
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D:  
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(b) Deduce the rate expression. [1]

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(c) Calculate the initial rate of reaction for experiment 2, if measured under the same conditions. [1]

Experiment	[A] / mol dm <sup>-3</sup>	[B] / mol dm <sup>-3</sup>	Initial rate / mol dm <sup>-3</sup> s <sup>-1</sup>
1	0.200	0.200	1.20
2	0.300	0.200	

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