

Chemistry
Higher level
Paper 2

Wednesday 8 November 2017 (afternoon)

Candidate session number

2 hours 15 minutes

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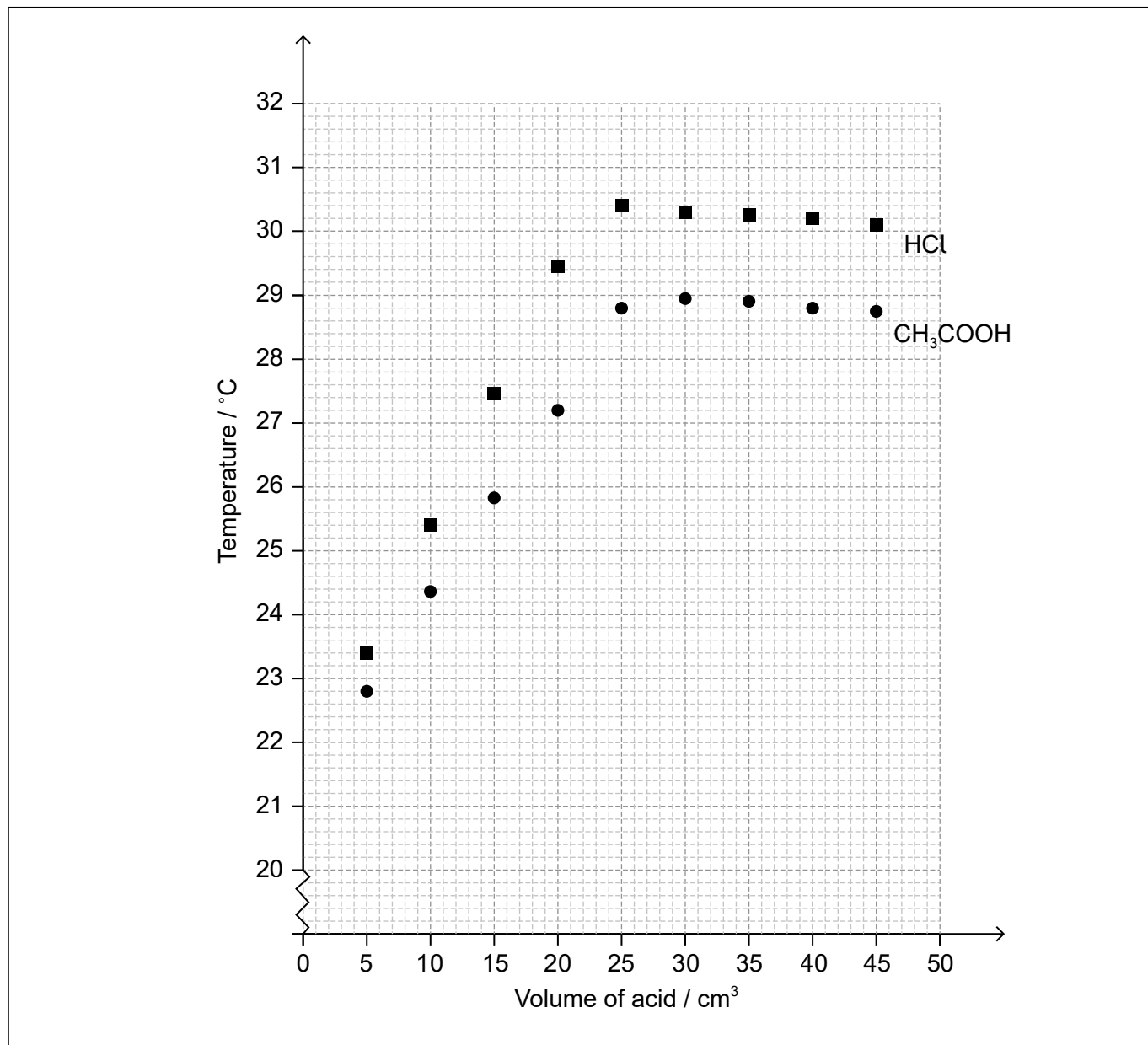
Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- 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 **[95 marks]**.



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

1. A student titrated two acids, hydrochloric acid, HCl(aq) and ethanoic acid, CH₃COOH(aq), against 50.0 cm³ of 0.995 mol dm⁻³ sodium hydroxide, NaOH(aq), to determine their concentration. The temperature of the reaction mixture was measured after each acid addition and plotted against the volume of each acid.



- (a) Using the graph, estimate the initial temperature of the solutions.

[1]

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20EP02

(Question 1 continued)

- (b) Determine the maximum temperature reached in each experiment by analysing the graph. [2]

HCl:
CH ₃ COOH:

- (c) Calculate the concentration of ethanoic acid, CH₃COOH, in mol dm⁻³. [2]

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- (d) (i) Determine the heat change, q , in kJ, for the neutralization reaction between ethanoic acid and sodium hydroxide. Assume the specific heat capacities of the solutions and their densities are those of water. [2]

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- (ii) Calculate the enthalpy change, ΔH , in kJ mol⁻¹, for the reaction between ethanoic acid and sodium hydroxide. [2]

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20EP03

Turn over

(Question 1 continued)

- (e) Suggest why the enthalpy change of neutralization of CH_3COOH is less negative than that of HCl .

[2]

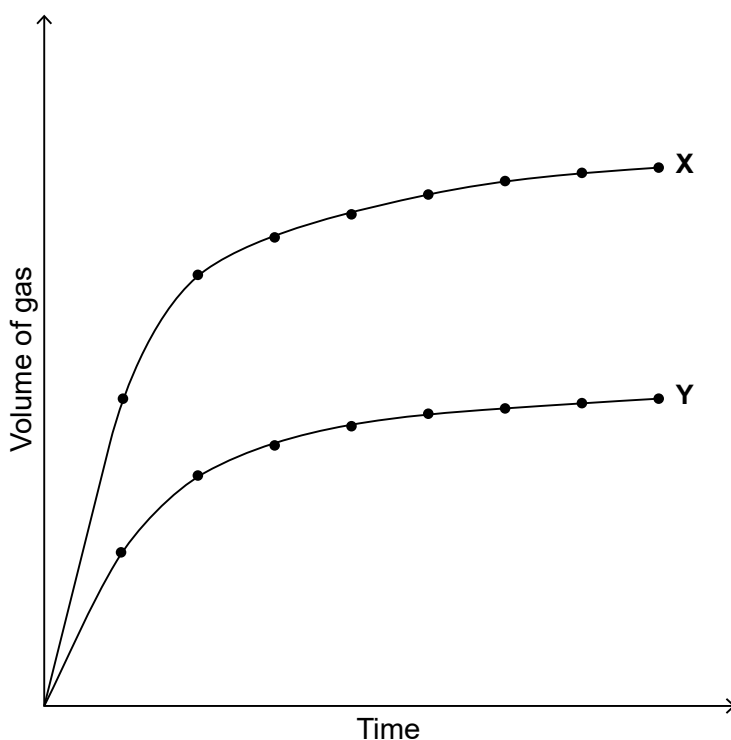
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- (f) Curves **X** and **Y** were obtained when a metal carbonate reacted with the same volume of ethanoic acid under two different conditions.



- (i) Explain the shape of curve **X** in terms of the collision theory.

[2]

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20EP04

(Question 1 continued)

(ii) Suggest **one** possible reason for the differences between curves **X** and **Y**. [1]

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2. Analytical chemistry uses instruments to separate, identify, and quantify matter.

(a) Describe the emission spectrum of hydrogen. [2]

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(b) Outline how this spectrum is related to the energy levels in the hydrogen atom. [1]

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(c) A sample of magnesium has the following isotopic composition.

Isotope	²⁴ Mg	²⁵ Mg	²⁶ Mg
Relative abundance / %	78.6	10.1	11.3

Calculate the relative atomic mass of magnesium based on this data, giving your answer to **two** decimal places. [2]

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20EP05

Turn over

(Question 2 continued)

(d) Menthol is an organic compound containing carbon, hydrogen and oxygen.

(i) Complete combustion of 0.1595 g of menthol produces 0.4490 g of carbon dioxide and 0.1840 g of water. Determine the empirical formula of the compound showing your working. [3]

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(ii) 0.150 g sample of menthol, when vaporized, had a volume of 0.0337 dm³ at 150°C and 100.2 kPa. Calculate its molar mass showing your working. [2]

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(iii) Determine the molecular formula of menthol using your answers from parts (d)(i) and (ii). [1]

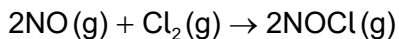
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(Question 2 continued)

(e) Nitric oxide reacts with chlorine.



The following experimental data were obtained at 101.3 kPa and 263 K.

Experiment	Initial [NO] / mol dm^{-3}	Initial [Cl ₂] / mol dm^{-3}	Initial rate / $\text{mol dm}^{-3} \text{min}^{-1}$
1	1.30×10^{-1}	1.30×10^{-1}	3.95×10^{-1}
2	1.30×10^{-1}	2.60×10^{-1}	7.90×10^{-1}
3	2.60×10^{-1}	2.60×10^{-1}	3.16

(i) Deduce the order of reaction with respect to Cl₂ and NO.

[2]

Cl₂:
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NO:
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(ii) State the rate expression for the reaction.

[1]

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(iii) Calculate the value of the rate constant at 263 K.

[1]

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3. Trends in physical and chemical properties are useful to chemists.

(a) Explain the general increasing trend in the first ionization energies of the period 3 elements, Na to Ar. [2]

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(b) Explain why the melting points of the group 1 metals (Li → Cs) decrease down the group whereas the melting points of the group 17 elements (F → I) increase down the group. [3]

Group 1:
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Group 17:
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(Question 3 continued)

(c) State an equation for the reaction of phosphorus(V) oxide, $P_4O_{10}(s)$, with water. [1]

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(d) Cobalt forms the transition metal complex $[Co(NH_3)_4(H_2O)Cl]Br$.

(i) State the shape of the complex ion. [1]

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(ii) Deduce the charge on the complex ion and the oxidation state of cobalt. [2]

Charge on complex ion:
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Oxidation state of cobalt:
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(e) Describe, in terms of acid-base theories, the type of reaction that takes place between the cobalt ion and water to form the complex ion. [2]

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4. Lewis (electron dot) structures are useful models.

(a) Draw the Lewis (electron dot) structures of PF_3 and PF_5 and use the VSEPR theory to deduce the molecular geometry of each species including bond angles. [6]

	PF_3	PF_5
Lewis (electron dot) structure		
Molecular geometry
Bond angles

(b) Predict whether the molecules PF_3 and PF_5 are polar or non-polar. [1]

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(c) State the type of hybridization shown by the phosphorus atom in PF_3 . [1]

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5. Ethane-1,2-diol, HOCH₂CH₂OH, reacts with thionyl chloride, SOCl₂, according to the reaction below.



- (a) Calculate the standard enthalpy change for this reaction using the following data. [2]

	HOCH ₂ CH ₂ OH (l)	SOCl ₂ (l)	ClCH ₂ CH ₂ Cl (l)	SO ₂ (g)	HCl (g)
ΔH_f^\ominus / kJ mol ⁻¹	-454.7	-245.7	-165.2	-296.9	-92.3

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- (b) Calculate the standard entropy change for this reaction using the following data. [1]

	HOCH ₂ CH ₂ OH (l)	SOCl ₂ (l)	ClCH ₂ CH ₂ Cl (l)	SO ₂ (g)	HCl (g)
S^\ominus / JK ⁻¹ mol ⁻¹	166.9	278.6	208.5	248.1	186.8

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- (c) The standard free energy change, ΔG^\ominus , for the above reaction is -103 kJ mol⁻¹ at 298 K. Suggest why ΔG^\ominus has a large negative value considering the sign of ΔH^\ominus in part (a). [2]

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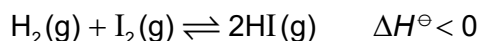
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6. Many reactions are in a state of equilibrium.

(a) The following reaction was allowed to reach equilibrium at 761 K.



(i) State the equilibrium constant expression, K_c , for this reaction. [1]

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(ii) The following equilibrium concentrations in mol dm^{-3} were obtained at 761 K.

$[\text{H}_2(\text{g})]$	$[\text{I}_2(\text{g})]$	$[\text{HI}(\text{g})]$
8.72×10^{-4}	2.72×10^{-3}	1.04×10^{-2}

Calculate the value of the equilibrium constant at 761 K. [1]

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(iii) Determine the value of ΔG^\ominus , in kJ, for the above reaction at 761 K using section 1 of the data booklet. [1]

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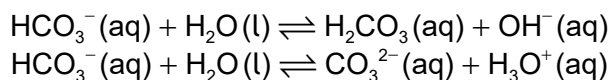


(Question 6 continued)

- (iv) Outline the effect, if any, of each of the following changes on the position of equilibrium, giving a reason in each case. [2]

	Effect	Reason
Increasing the volume, at constant temperature
Increasing the temperature, at constant pressure

- (b) The equations for two acid-base reactions are given below.



- (i) Identify two different amphiprotic species in the above reactions. [1]

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- (ii) State what is meant by the term conjugate base. [1]

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- (iii) State the conjugate base of the hydroxide ion, OH⁻. [1]

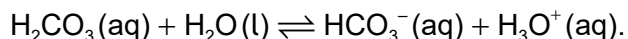
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(Question 6 continued)

(c) The pH of 0.010 mol dm⁻³ carbonic acid, H₂CO₃(aq), is 4.17 at 25 °C.



(i) Calculate [H₃O⁺] in the solution and the dissociation constant, K_a, of the acid at 25 °C.

[3]

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(ii) Calculate K_b for HCO₃⁻ acting as a base.

[1]

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(d) A student working in the laboratory classified HNO₃, H₂SO₄, H₃PO₄ and HClO₄ as acids based on their pH. He hypothesized that “all acids contain oxygen and hydrogen”. Evaluate his hypothesis.

[2]

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7. Consider the following half-cell reactions and their standard electrode potentials.

	E^\ominus / V
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{s})$	-1.18
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s})$	-0.26
$\text{I}_2(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq})$	+0.54

(a) Deduce a balanced equation for the overall reaction when the standard nickel and iodine half-cells are connected. [1]

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(b) Predict, giving a reason, the direction of movement of electrons when the standard nickel and manganese half-cells are connected. [2]

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(c) Calculate the cell potential, in V, when the standard iodine and manganese half-cells are connected. [1]

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(d) Identify the best reducing agent in the table above. [1]

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(Question 7 continued)

- (e) State and explain the products of electrolysis of a concentrated aqueous solution of sodium chloride using inert electrodes. Your answer should include half-equations for the reaction at each electrode.

[4]

Positive electrode (anode):

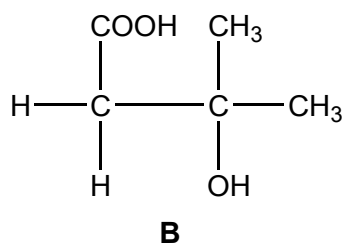
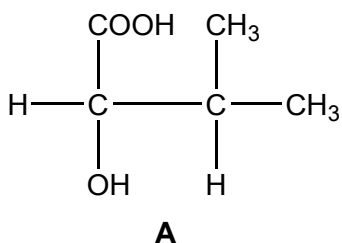
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Negative electrode (cathode):

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8. The reactivity of organic compounds depends on the nature and positions of their functional groups.

- (a) The structural formulas of two organic compounds are shown below.



- (i) Deduce the type of chemical reaction and the reagents used to distinguish between these compounds.

[1]

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(Question 8 continued)

(ii) State the observation expected for each reaction giving your reasons. [2]

Compound A :
Compound B :

(iii) Deduce the number of signals and the ratio of areas under the signals in the ¹H NMR spectra of the two compounds. [4]

Compound	Number of signals	Ratio of areas
A
B

(iv) Deduce, giving a reason, which of the two compounds can show optical activity. [1]

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(Question 8 continued)

- (v) Draw three-dimensional representations of the two enantiomers. [1]

- (b) Explain, with the help of equations, the mechanism of the free-radical substitution reaction of ethane with bromine in presence of sunlight. [4]

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- (c) State the reagents used in the nitration of benzene. [1]

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- (d) State an equation for the formation of NO_2^+ . [1]

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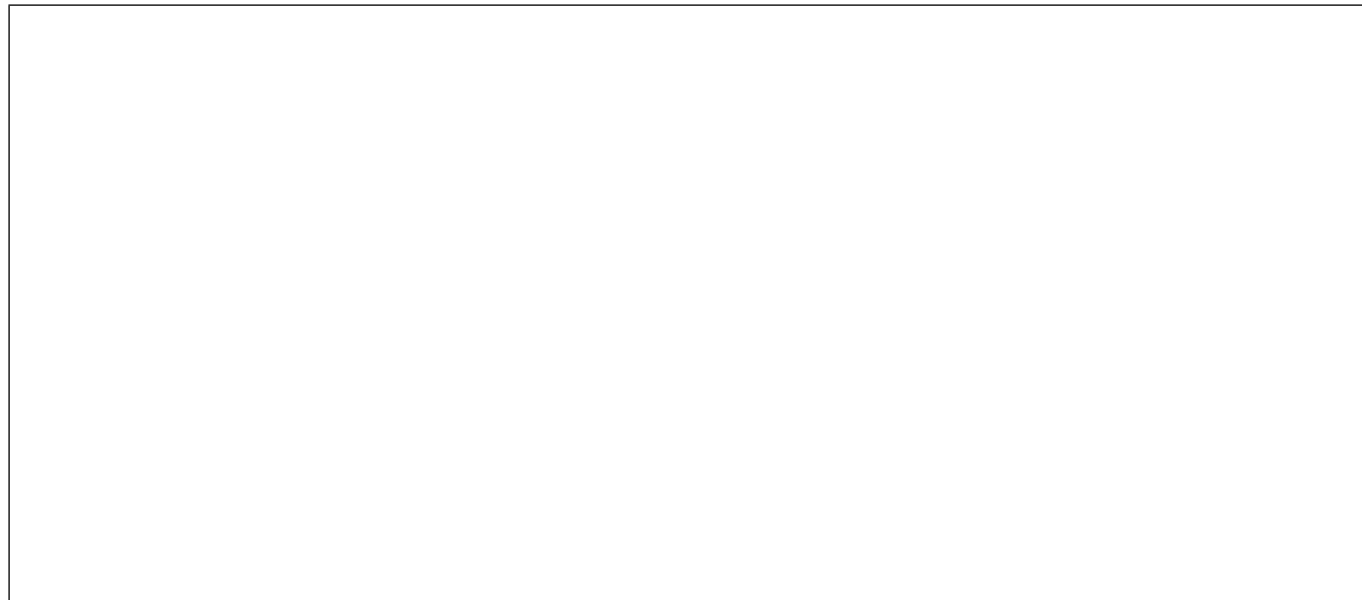
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(Question 8 continued)

- (e) Explain the mechanism of the reaction between 2-bromo-2-methylpropane, $(\text{CH}_3)_3\text{CBr}$, and aqueous sodium hydroxide, $\text{NaOH}(\text{aq})$, using curly arrows to represent the movement of electron pairs. [4]



Please **do not** write on this page.

Answers written on this page
will not be marked.



20EP20