SECTION A

Answer ALL the questions in this section. You should aim to spend no more than 20 minutes on this section. For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 The overall equation for a reaction between two chemicals, M and N, is

$$M + 2N \rightarrow P + Q$$

(a) This reaction occurs spontaneously at room temperature. Which of the following **must** be true?

(1)

☒ **A** $\Delta H^{\ominus}_{reaction}$ is positive.

☒ **B** $\Delta H^{\ominus}_{reaction}$ is negative.

☒ **C** $\Delta S^{\ominus}_{total}$ is positive.

☒ **D** $\Delta S^{\ominus}_{total}$ is negative.

(b) The reaction above occurs in two stages via an intermediate, T.

$$M + N \rightarrow T \qquad \text{slow}$$

$$N + T \rightarrow P + Q \qquad \text{fast}$$

From this it can be deduced that the rate equation for the reaction between M and N is

(1)

☒ **A** rate = k[M][N]

☒ **B** rate = k[M][N]^2

☒ **C** rate = k[M][T]

☒ **D** rate = k[N][T]

(Total for Question 1 = 2 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

2 Calcium carbonate decomposes at high temperature to form calcium oxide and carbon dioxide:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

Calcium carbonate is **thermodynamically** stable at room temperature because for this reaction

☒ **A** the activation energy is high.

☒ **B** the enthalpy change, ΔH, is positive.

☒ **C** entropy change of the system (ΔS_{system}) is positive.

☒ **D** entropy change of the system (ΔS_{system}) is negative.

(Total for Question 2 = 1 mark)

3 2-methylpropane has a smaller standard molar entropy at 298 K than butane. The best explanation for this is that 2-methylpropane has

☒ **A** a lower boiling temperature.

☒ **B** a higher standard molar enthalpy change of formation.

☒ **C** fewer ways of distributing energy quanta.

☒ **D** more ways of distributing energy quanta.

(Total for Question 3 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

4 (a) For the equilibrium reaction between hydrogen and iodine

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

increasing the pressure of the system

(1)

☒ **A** has no effect on the rate or the position of equilibrium.

☒ **B** increases the rate but does not affect the position of equilibrium.

☒ **C** increases the rate and shifts the equilibrium to the right.

☒ **D** increases the rate and shifts the equilibrium to the left.

(b) The equation for the equilibrium reaction between hydrogen and iodine may also be written as

$$\tfrac{1}{2}H_2(g) + \tfrac{1}{2}I_2(g) \rightleftharpoons HI(g)$$

This change to the equation, compared to that in part (a),

(1)

☒ **A** has no effect on the value of the equilibrium constant.

☒ **B** halves the value of the equilibrium constant.

☒ **C** doubles the value of the equilibrium constant.

☒ **D** square roots the value of the equilibrium constant.

(Total for Question 4 = 2 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

5 The first stage in the manufacture of nitric acid is the oxidation of ammonia:

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \quad \Delta H = -906\ kJ\ mol^{-1}$$

(a) In modern industrial plants this reaction is carried out at a pressure of around 3 atm. Which of the following statements is **incorrect**? The raised pressure

(1)

- ☒ **A** helps push the reactants through the reactor.
- ☒ **B** shifts the position of equilibrium to the right.
- ☒ **C** increases the cost of the reactor.
- ☒ **D** increases the energy cost of this part of the process.

(b) A platinum-rhodium alloy catalyst is used in this reaction. Which of the following statements is **incorrect**? The catalyst

(1)

- ☒ **A** lowers the activation energy of the reaction.
- ☒ **B** has no effect on the equilibrium constant for the reaction.
- ☒ **C** alters the enthalpy change of the reaction.
- ☒ **D** reduces the energy cost of this part of the process.

(c) The operating temperature of this reaction is about 900 °C. The use of a high temperature

(1)

- ☒ **A** increases the rate of the reaction and the equilibrium yield.
- ☒ **B** increases the rate of the reaction and decreases the equilibrium yield.
- ☒ **C** decreases the rate of the reaction and the equilibrium yield.
- ☒ **D** decreases the rate of the reaction and increases the equilibrium yield.

(Total for Question 5 = 3 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

6 Ammonium chloride decomposes on heating:

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

The equilibrium constant, K_p, for this reaction equals

☒ **A** $P_{NH_3} \times P_{HCl}$

☒ **B** $\dfrac{1}{P_{NH_3} \times P_{HCl}}$

☒ **C** $\dfrac{P_{NH_3} \times P_{HCl}}{P_{NH_4Cl}}$

☒ **D** $\dfrac{P_{NH_4Cl}}{P_{NH_3} \times P_{HCl}}$

(Total for Question 6 = 1 mark)

7 The dissociation constant of water, K_w, increases with increasing temperature. When the temperature increases, water

☒ **A** remains neutral.

☒ **B** dissociates less.

☒ **C** becomes acidic.

☒ **D** becomes alkaline.

(Total for Question 7 = 1 mark)

8 The reaction between concentrated sulfuric acid and pure ethanoic acid is

$$CH_3COOH + H_2SO_4 \rightleftharpoons CH_3COOH_2^+ + HSO_4^-$$

The Brønsted-Lowry acids in this equilibrium are

☒ **A** CH_3COOH and H_2SO_4

☒ **B** $CH_3COOH_2^+$ and HSO_4^-

☒ **C** H_2SO_4 and $CH_3COOH_2^+$

☒ **D** CH_3COOH and HSO_4^-

(Total for Question 8 = 1 mark)

9 An aqueous solution of ethanoic acid is gradually diluted. Which of the following statements is **incorrect**?

☒ **A** The pH decreases.

☒ **B** The value of K_a is unchanged.

☒ **C** The concentration of ethanoic acid molecules decreases.

☒ **D** The proportion of ethanoic acid molecules which dissociates increases.

(Total for Question 9 = 1 mark)

10 Methyl orange and phenolphthalein are both acid-base indicators. In the titration of a strong acid against a weak alkali

☒ **A** methyl orange is a suitable indicator but phenolphthalein is not.

☒ **B** phenolphthalein is a suitable indicator but methyl orange is not.

☒ **C** both phenolphthalein and methyl orange are suitable indicators.

☒ **D** neither phenolphthalein nor methyl orange is a suitable indicator.

(Total for Question 10 = 1 mark)

Question 11: N/A

Question 12: N/A

Question 13: N/A

Question 14: N/A

Question 15: N/A

Question 16: N/A

SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

17 The equation for the combustion of hydrogen is

$$H_2(g) \quad + \quad ½O_2(g) \quad \rightarrow \quad H_2O(l)$$

(a) Use the standard molar entropies on page 2 and page 25 of the data booklet to calculate the standard entropy change of the system ($\Delta S^{\ominus}_{system}$) for this reaction.

Note that the standard molar entropies of the elements are given **per atom** so that the standard molar entropy of oxygen, $S^{\ominus}[½O_2(g)] = +102.5\ \text{J mol}^{-1}\ \text{K}^{-1}$.

(3)

(b) The standard enthalpy change for the combustion of hydrogen is $-285.8\ \text{kJ mol}^{-1}$. Use this value to calculate the entropy change of the surroundings for the combustion of hydrogen at 298 K. Give your answer to **3** significant figures and include a sign and units.

(3)

(c) Use your answers to (a) and (b) to calculate the total entropy change ($\Delta S^{\ominus}_{total}$) for the combustion of 1 mol of hydrogen. Include a sign and units in your answer.

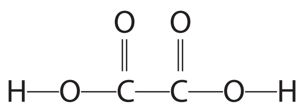
(2)

*(d) By considering both the thermodynamic stability and the kinetic inertness of a mixture of hydrogen and oxygen, explain why hydrogen does not react with oxygen unless ignited.

(2)

(Total for Question 17 = 10 marks)

18 Ethanedioic acid, $H_2C_2O_4$, is a dicarboxylic acid which occurs in many plants, for example in rhubarb leaves, and is used as a rust remover and strong descaler. The structure of ethanedioic acid is shown below.



Ethanedioic acid is a much stronger acid than carboxylic acids such as ethanoic acid, having a pK_a of 1.38. The hydrogenethanedioate ion, $HC_2O_4^-$, is a weaker acid than ethanedioic acid, having a pK_a of 4.28, although slightly stronger than ethanoic acid.

(a) (i) Write an equation for the reaction of the hydrogenethanedioate ion with water to form an acidic solution. Include state symbols in your equation.

(2)

(ii) Write the expression for the acid dissociation constant, K_a, of the weak acid, $HC_2O_4^-$.

(1)

(iii) A solution containing hydrogenethanedioate ions behaves as a typical weak acid. Use your answer to (a)(ii) and the pK_a of the hydrogenethanedioate ion to calculate the pH of a 0.050 mol dm^{-3} solution of sodium hydrogenethanedioate, $NaHC_2O_4$.

(3)

(b) (i) State **two** approximations used in the calculation of pH in (a)(iii).

(2)

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2. ....

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*(ii) Explain why the calculation of the pH of a solution of sodium hydrogenethanedioate gives a more accurate value than a similar calculation for ethanedioic acid.

(2)

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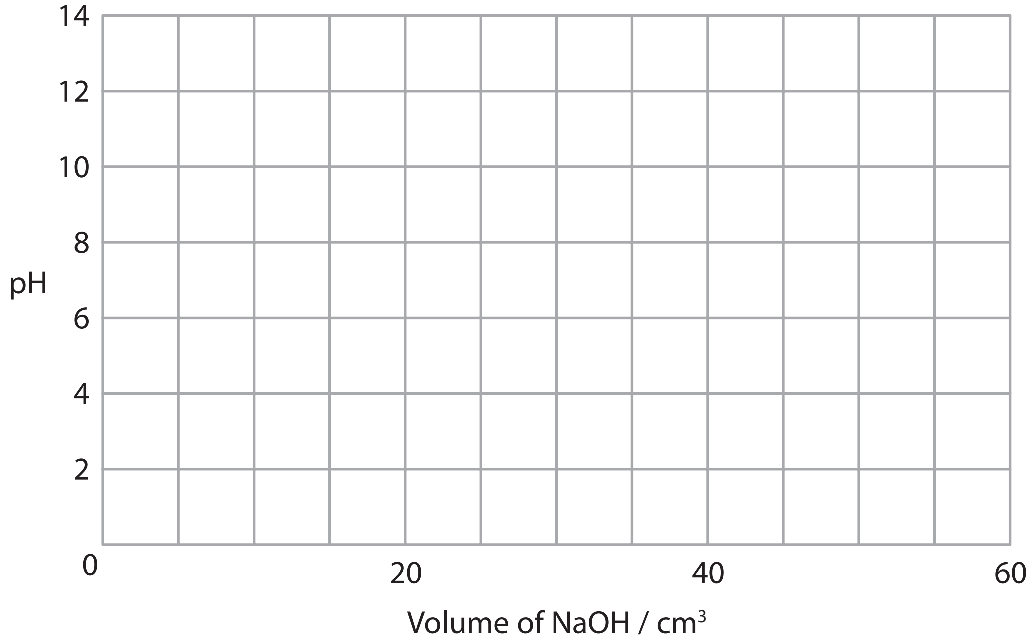
(c) 25 cm^3 of a 0.050 mol dm^{-3} solution of sodium hydrogenethanedioate was titrated with a sodium hydroxide solution of the same concentration.

(i) On the axis below, sketch the curve for this titration.

(3)



*(ii) When 25 cm^3 of a 0.050 mol dm^{-3} solution of **ethanedioic acid** is titrated with sodium hydroxide solution of the same concentration using phenolphthalein as the indicator, the end point is 50 cm^3.

When methyl yellow indicator is used, the colour changes at around 25 cm^3.

Using the information given at the start of the question and quoting data from page 19 of your data booklet, suggest why these volumes are different.

(2)

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(Total for Question 18 = 15 marks)

Question 19: N/A

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

20 The ionic equation for the reaction of ammonium peroxodisulfate (persulfate), $(NH_4)_2S_2O_8$, with potassium iodide, KI, is

$$S_2O_8^{2-}(aq) \quad + \quad 2I^-(aq) \quad \rightarrow \quad 2SO_4^{2-}(aq) \quad + \quad I_2(aq)$$

(a) In a series of experiments to determine the rate equation for this reaction, 10 cm^3 of 0.0050 mol dm^{-3} sodium thiosulfate was mixed with 20 cm^3 of $(NH_4)_2S_2O_8$ solution and 5 drops of starch solution. 20 cm^3 of KI solution was added with mixing and the time taken for the solution to darken was noted. The initial concentrations of the $(NH_4)_2S_2O_8$ and KI solutions and the times for the mixture to darken are shown below.

Experiment Number	Initial concentration / mol dm^{-3}		Time for solution to darken / s
	$S_2O_8^{2-}$	I^-	
1	0.10	0.20	35
2	0.05	0.20	69
3	0.10	0.10	70

(i) Explain the purpose of the sodium thiosulfate solution.

(2)

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(ii) Use the data in the table to deduce the rate equation for the reaction between $S_2O_8^{2-}$ and I^- ions. Explain, by referring to the data, how you arrived at your answer.

(3)

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(b) A further experiment was carried out to confirm the order of the reaction with respect to iodide ions. $(NH_4)_2S_2O_8$ was mixed with KI to form a solution in which the initial concentration of $(NH_4)_2S_2O_8$ was 2.0 mol dm^{-3} and that of KI was 0.025 mol dm^{-3}. The concentration of iodine was measured at various times until the reaction was complete.

(i) Outline a method, **not** involving sampling the mixture, which would be suitable for measuring the iodine concentrations in this experiment. Experimental details are not required but you should state how you would use your measurements to obtain iodine concentrations.

(3)

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(ii) Explain why the initial concentration of $(NH_4)_2S_2O_8$ is much higher than that of KI.

(1)

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(iii) State how the initial rate of reaction may be obtained from the results of this type of experiment.

(2)

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(iv) In such an experiment a student calculated the initial rate of reaction to be 8.75×10^{-5} mol dm^{-3} s^{-1}. Use this value, the initial concentrations in (b) and the rate equation that you obtained in (a)(ii), to calculate the rate constant for this reaction. Include units in your answer.

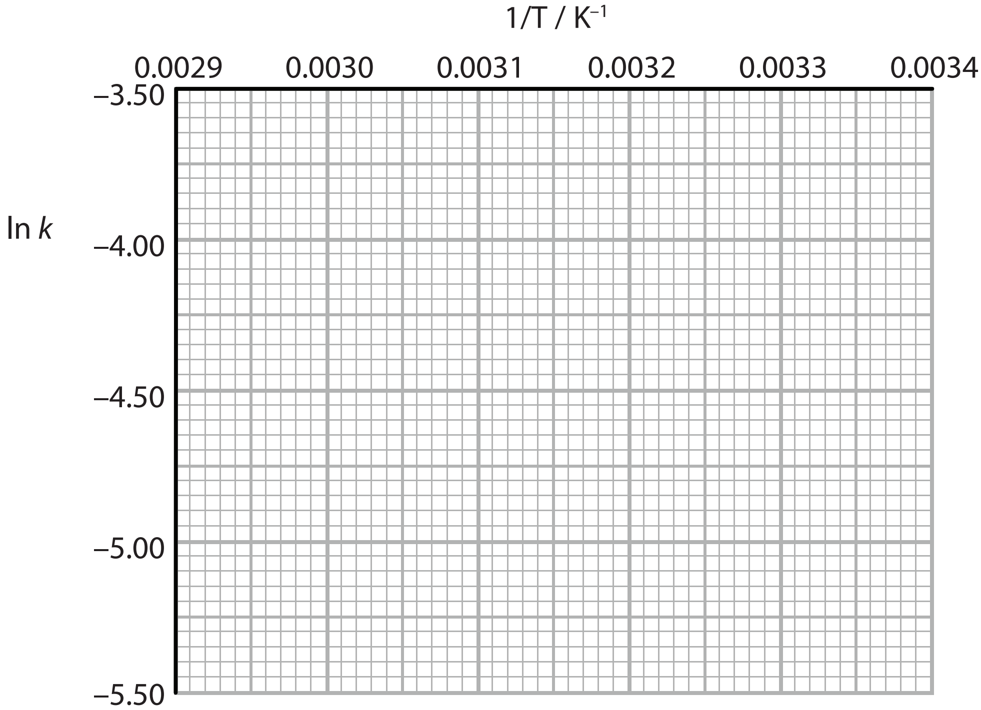
(2)

(c) Using the method outlined in (b), the rate constant for this reaction was determined at various temperatures. The data from these experiments are shown in the table below. Note that none of the temperatures corresponds to that used in (b) and that the rate constant is given in appropriate units.

Temperature T / K	Rate constant *k*	ln *k*	1/T / K^{-1}
300	0.00513	–5.27	0.00333
310	0.00833	–4.79	0.00323
320	0.0128	–4.36	0.00313
330	0.0201	–3.91	0.00303
340	0.0301	–3.50	0.00294

(i) Use the data in the table to plot a graph of ln *k* (on the y axis) against 1/T (on the x axis) and draw a best fit line through the points.

(2)



(ii) Determine the gradient of the best fit line in (c)(i) and use this value to calculate the activation energy, E_a, of the reaction, stating the units.

(4)

The rate constant of a reaction, *k*, is related to the temperature, T, by the expression

$$\ln k = -\frac{E_a}{R} \times \frac{1}{T} + \text{constant} \qquad R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$$

(Total for Question 20 = 19 marks)

21 In which of these reactions is the hydrogensulfate ion, HSO_4^-, behaving as a Brønsted-Lowry base?

☒ **A** $HSO_4^- + H_3O^+ \rightarrow H_2SO_4 + H_2O$

☒ **B** $HSO_4^- + Ba^{2+} \rightarrow BaSO_4 + H^+$

☒ **C** $HSO_4^- + H_2O \rightarrow SO_4^{2-} + H_3O^+$

☒ **D** $HSO_4^- + CO_3^{2-} \rightarrow SO_4^{2-} + HCO_3^-$

(Total for Question = 1 mark)

22 The reaction below is carried out at 25 °C. Use the equation and the data to answer the questions that follow.

$$SO_2(g) + 2H_2S(g) \rightarrow 3S(s) + 2H_2O(g) \qquad \Delta H = -107.4 \text{ kJ mol}^{-1}$$

Substance	Standard molar entropy, $S^\ominus$ / J mol^{-1} K^{-1}
$SO_2(g)$	248
$H_2S(g)$	206
$H_2O(g)$	189
S(s)	32

(a) The standard entropy change of the system, in J mol^{-1} K^{-1}, is

(1)

☒ **A** −186

☒ **B** +186

☒ **C** −233

☒ **D** +233

(b) The standard entropy change of the surroundings, in J mol^{-1} K^{-1}, is

(1)

☒ **A** 107.4 × 1000 / 25

☒ **B** −107.4 × 1000 / 25

☒ **C** 107.4 × 1000 / 298

☒ **D** −107.4 × 1000 / 298

(Total for Question = 2 marks)

23 A halogenoalkane, RX, reacts with hydroxide ions, OH^-, to form an alcohol.

$$RX + OH^- \rightarrow ROH + X^-$$

The rate equation for the reaction is rate = k[RX]. Which of these statements is **incorrect**?

- ☒ **A** Rate ∝ [RX].
- ☒ **B** RX is a primary halogenoalkane.
- ☒ **C** The reaction mechanism is S_N1.
- ☒ **D** A carbocation intermediate forms in the reaction.

(Total for Question = 1 mark)

24 The rate equation for the reaction between hydrogen gas and nitrogen monoxide gas is

$$\text{rate} = k[NO]^2[H_2]$$

If the concentration of both reactants is doubled, the rate will increase by a factor of

- ☒ **A** 3
- ☒ **B** 4
- ☒ **C** 6
- ☒ **D** 8

(Total for Question = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

25 A reaction has the rate equation rate = k [X][Y]^2[Z]. The concentrations of each reactant are shown in the table below.

Reactant	Concentration / mol dm^{-3}
X	0.040
Y	0.20
Z	0.12

(a) If the rate of reaction under these conditions has a value of 0.24 mol dm^{-3} s^{-1}, then the numerical value of k is

(1)

- ☒ **A** 0.00080
- ☒ **B** 0.533
- ☒ **C** 1.875
- ☒ **D** 1250

(b) The units for the rate constant, k, are

(1)

- ☒ **A** mol^{-3} dm^{9} s^{-1}
- ☒ **B** mol^{3} dm^{9} s^{-1}
- ☒ **C** mol^{-3} dm^{-9} s^{-1}
- ☒ **D** mol^{3} dm^{-9} s^{-1}

(Total for Question = 2 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

26 This question is about the four organic substances shown below.

A $CH_3CH_2CH_2CH_2CHO$

B $CH_3CH_2CH_2CH_2COOH$

C $CH_3COCH_2CH_2CH_3$

D $CH_3CH_2CH_2CH_2COCl$

Which substance will

(a) give a positive result with both Brady's and Tollens' reagents?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(b) be formed by the oxidation of a secondary alcohol?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(c) form the most acidic solution when equal amounts are each mixed with 100 cm^3 of water?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(d) form steamy fumes in the reaction with PCl_5?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question = 4 marks)

Answer ALL the questions. Write your answers in the spaces provided.

27 In a pH titration, 30 cm^3 of sodium hydroxide solution was added, in 1 cm^3 portions, to 20 cm^3 of ethanoic acid solution, $CH_3COOH(aq)$. The concentration of both solutions was 0.50 mol dm^{-3}. After the addition of each 1 cm^3, the pH was recorded using a pH meter.

(a) (i) Write the K_a expression for ethanoic acid.

(1)

(ii) Using your answer to (i), calculate the pH of the 0.50 mol dm^{-3} ethanoic acid solution before the titration starts. Refer to page 18 of the data booklet.

(2)

(iii) Deduce the volume of sodium hydroxide solution required to reach the end point.

(1)

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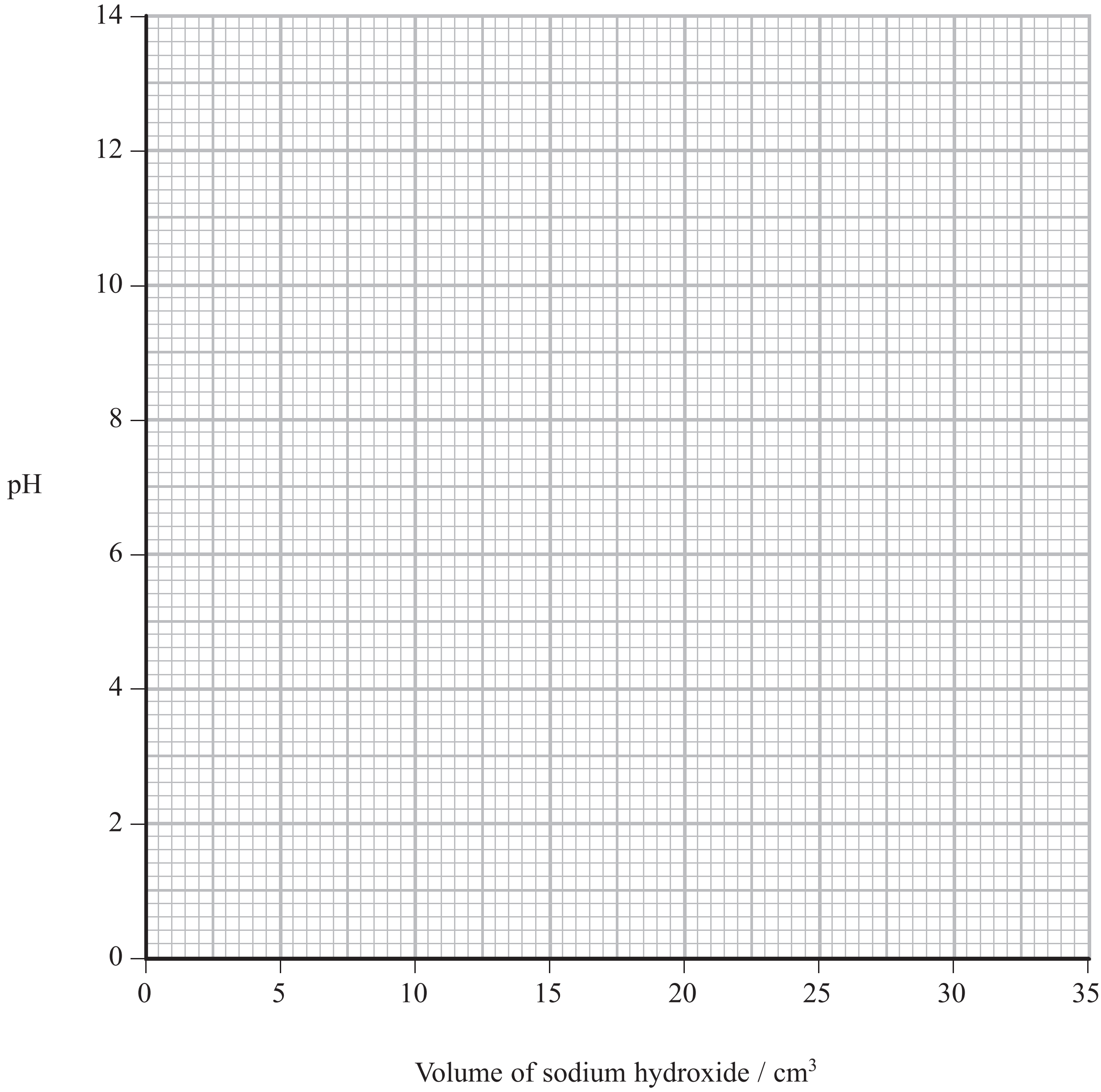
(iv) Calculate the pH of the solution after all of the sodium hydroxide is added.

(4)

(v) On the axes below sketch a graph to show how the pH changes during the titration.

(3)



(b) An acidic buffer solution can be made by mixing together a solution of ethanoic acid and solid sodium ethanoate.

(i) Calculate the mass of solid sodium ethanoate (molar mass = 82 g mol^{-1}) that would be added to 500 cm^3 of ethanoic acid, concentration 1.0 mol dm^{-3}, in order to make a buffer solution of pH = 4.70.

(4)

(Total for Question = 18 marks)

28 Iodine reacts with propanone in the presence of an acid catalyst.

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + HI(aq)$$

An experiment was carried out to investigate the kinetics of this reaction by monitoring the concentration of iodine. The progress of the reaction was followed by mixing together the reagents, removing samples of the mixture every five minutes, quenching the reaction and then titrating to find the concentration of iodine at a given time.

(a) (i) Suggest a suitable reagent with which you could titrate the iodine.

(1)

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(ii) State and explain how you would quench the reaction.

(2)

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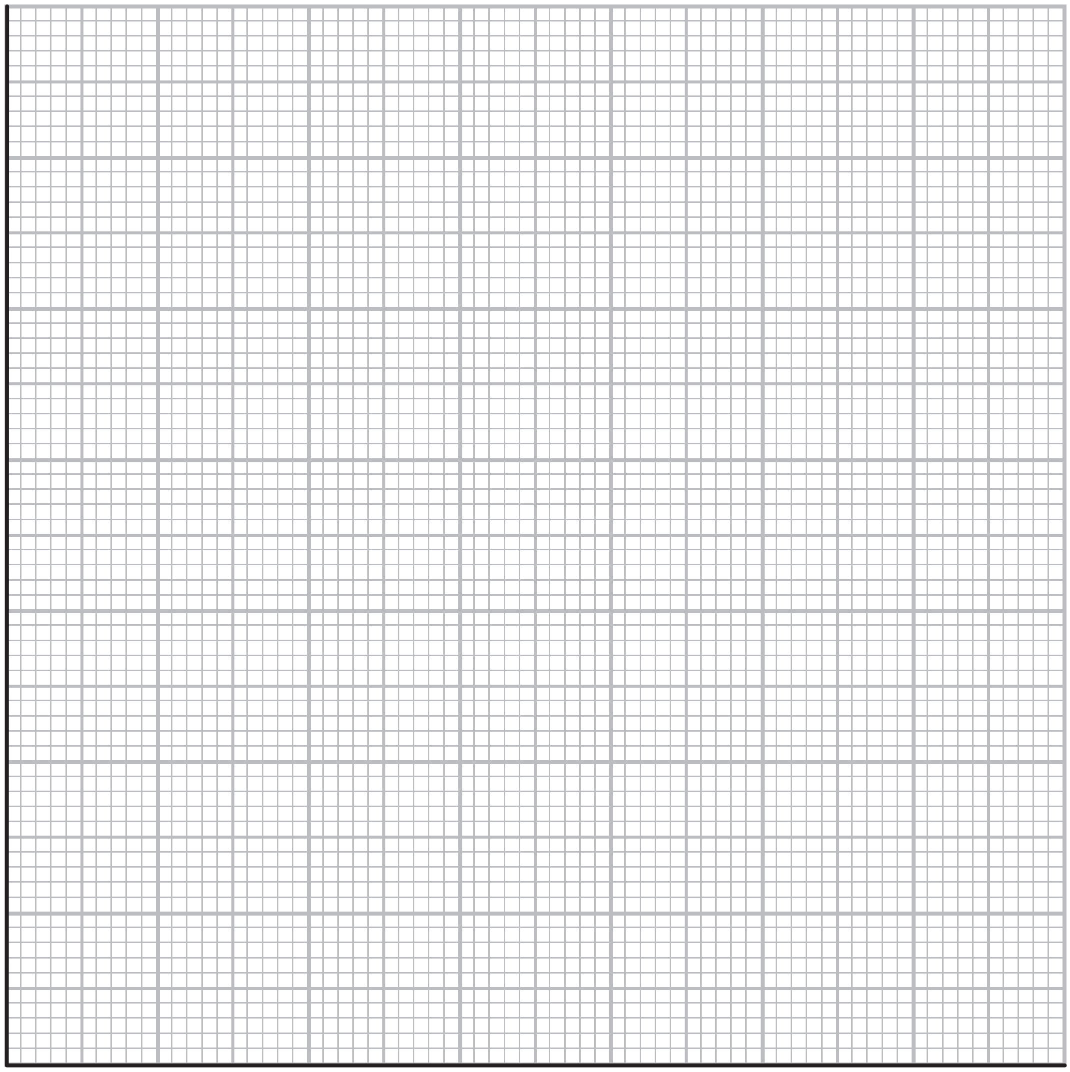
(b) (i) Data obtained from the experiment are shown in the table below. Use the data to plot a suitable graph to determine the order of the reaction with respect to iodine and state this order.

(3)

Time / mins	$[I_2(aq)]$ / mol dm^{-3}
5	9.74×10^{-4}
10	9.50×10^{-4}
15	9.25×10^{-4}
20	9.03×10^{-4}
25	8.80×10^{-4}
30	8.55×10^{-4}

$[I_2(aq)]$ / mol dm^{-3}



Time / minutes

Order with respect to iodine ....

(ii) Explain how you determined the order using your graph.

(2)

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(c) State an alternative practical procedure that could be used to monitor the concentration of iodine.

(1)

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(Total for Question = 9 marks)

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

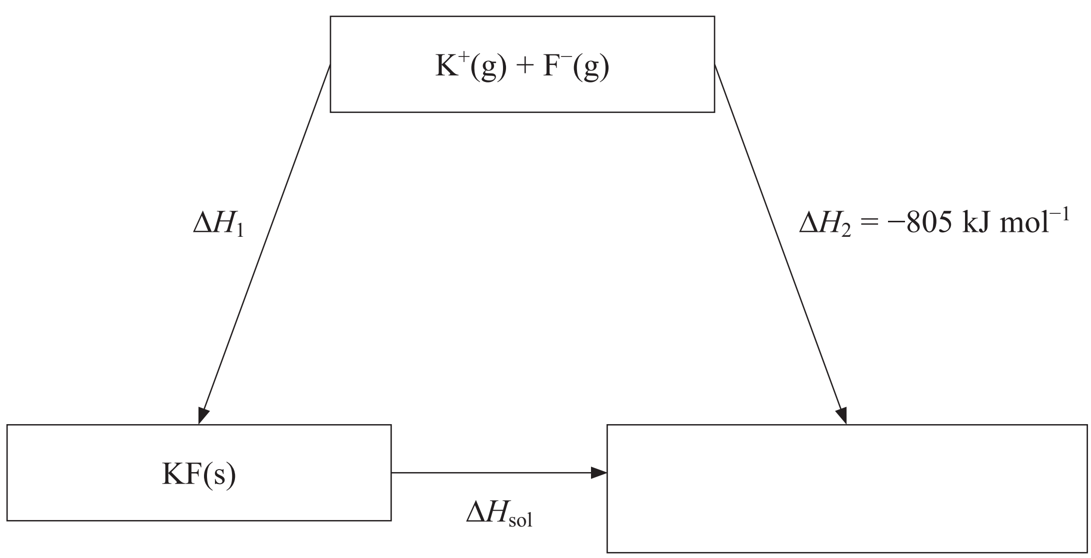
29 This question is about the solubility of some Group 1 halides.

(a) Potassium fluoride is a soluble, white, crystalline solid used in etching glass. A Hess cycle can be used to calculate its enthalpy of solution, using data including enthalpies of hydration of ions.

Define the term **enthalpy of hydration** of an ion.

(2)

(b) Consider the Hess cycle below.



(i) Complete the cycle by filling in the empty box.

(1)

(ii) Apply Hess's Law to obtain an expression for ΔH_{sol} in terms of ΔH_1 and ΔH_2 .

(1)

$\Delta H_{sol} =$

(iii) Give the name of the energy change ΔH_1.

(1)

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(iv) Referring to page 12 of the data booklet and your answer to (ii), calculate the standard enthalpy of solution of potassium fluoride.

(2)

(c) The standard enthalpy of solution of sodium chloride is + 3 kJ mol^{-1}.

(i) 1 g of sodium chloride was added to 250 cm^3 of water in a beaker and stirred with a thermometer graduated in intervals of 1 °C. Describe and explain what would happen to the reading on the thermometer as the sodium chloride dissolves. No calculation is required.

(3)

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*(ii) Explain, in terms of entropy changes, why sodium chloride dissolves in water under standard conditions. No calculation is required.

(4)

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*(d) Lithium iodide is generally much more soluble in organic solvents than lithium chloride. Explain this observation using values of lattice energies from your data booklet and your knowledge of the trend in ionic radii down Group 7.

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(Total for Question 29 = 18 marks)

The Periodic Table of Elements

Key

relative atomic mass **atomic symbol** name atomic (proton) number

1.0 **H** hydrogen 1

1	2											3	4	5	6	7	0 (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
																	4.0 **He** helium 2
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12											27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	95.9 **Mo** molybdenum 42	[98] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La*** lanthanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

* Lanthanide series	140 **Ce** cerium 58	141 **Pr** praseodymium 59	144 **Nd** neodymium 60	[147] **Pm** promethium 61	150 **Sm** samarium 62	152 **Eu** europium 63	157 **Gd** gadolinium 64	159 **Tb** terbium 65	163 **Dy** dysprosium 66	165 **Ho** holmium 67	167 **Er** erbium 68	169 **Tm** thulium 69	173 **Yb** ytterbium 70	175 **Lu** lutetium 71
* Actinide series	232 **Th** thorium 90	[231] **Pa** protactinium 91	238 **U** uranium 92	[237] **Np** neptunium 93	[242] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[245] **Bk** berkelium 97	[251] **Cf** californium 98	[254] **Es** einsteinium 99	[253] **Fm** fermium 100	[256] **Md** mendelevium 101	[254] **No** nobelium 102	[257] **Lr** lawrencium 103