This is a Class 1 exam

Lebanon Evangelical School
for Boys and Girls
Loueizeh - Baabda

SE01 Exam

10NOV2025

Do NOT write in this box. Your MARK will be placed here.

Subject :	A Level : Chemistry 2
Class :	12A
Teacher :	Mrs. Saydeh Nasrallah
Duration :	2 hours
You are to answer the questions to this exam on : This exam paper	

Your name :		*Time taken to complete exam*
Your Class :		
Exam Room :		
How many sheets, including cover sheet :		

- Do not open this paper until the teacher in charge instructs you to do so.
- The most important thing to remember in taking an exam is NEVER PANIC.
- If you are caught cheating in this exam, you will be awarded zero for ALL exams that are taken on this day.

SECTION A

Answer ALL the questions in this section.
You should aim to spend no more than 25 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 Ostwald Process is a method for making nitric acid.
The equation for the first stage of this process is

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905 \text{ kJ mol}^{-1}$$

(a) The equilibrium yield of nitrogen monoxide, NO, is **increased** by

(1)

☐ **A** increasing both the pressure and the temperature.
☐ **B** decreasing both the pressure and the temperature.
☐ **C** decreasing the pressure and increasing the temperature.
☐ **D** increasing the pressure and decreasing the temperature.

(b) For this stage of the process, the catalyst is an alloy of platinum and rhodium.
A pressure of between 4 and 10 atm and a temperature of 1150 K are used.
Unreacted reactants are recycled.

Which one of the following changes will affect the value of the equilibrium constant, K_p?

(1)

☐ **A** Changing the composition of the platinum-rhodium catalyst.
☐ **B** Increasing the pressure above 10 atm.
☐ **C** Decreasing the temperature below 1150 K.
☐ **D** Not recycling unreacted reactants.

(Total for Question 1 = 2 marks)

2. The reaction between carbon monoxide and hydrogen reaches a dynamic equilibrium.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Which of these statements about a dynamic equilibrium is **not** true?

☐ **A** The forward rate of reaction is equal to the backward rate of reaction.
☐ **B** The concentrations of the products and reactants do not change.
☐ **C** The concentrations of the products and reactants are equal.
☐ **D** The equilibrium can be approached from either direction.

(Total for Question 2 = 1 mark)

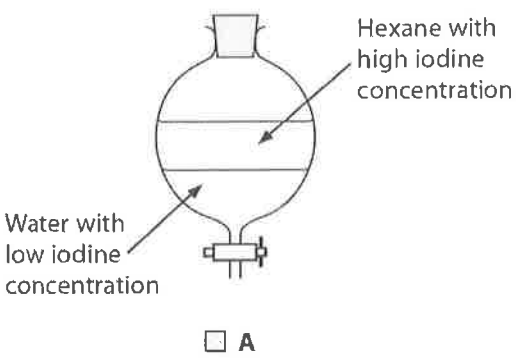
3. Iodine is soluble in both water and hexane.
If iodine is added to a mixture of the two solvents, then the following equilibrium is set up.

$$I_2(aq) \rightleftharpoons I_2(hexane)$$

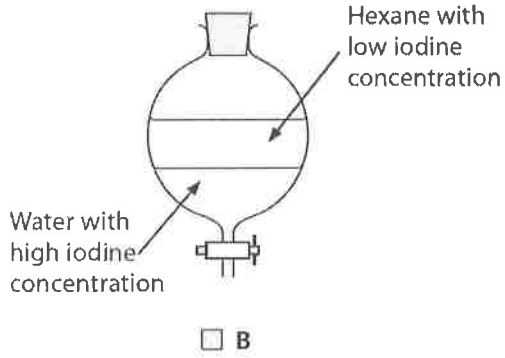
The equilibrium constant, known as the partition coefficient, is 85.

The density of hexane is 0.66 g cm^{-3}. The density of water is 1.00 g cm^{-3}.

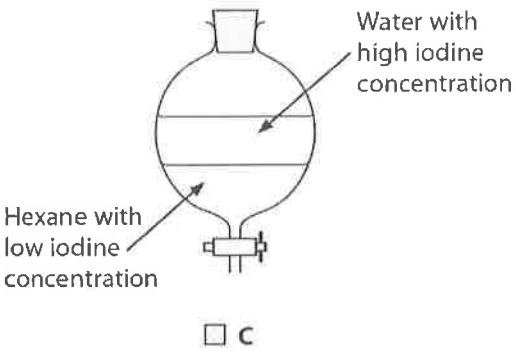
Which of the following diagrams is correct for this system at equilibrium?



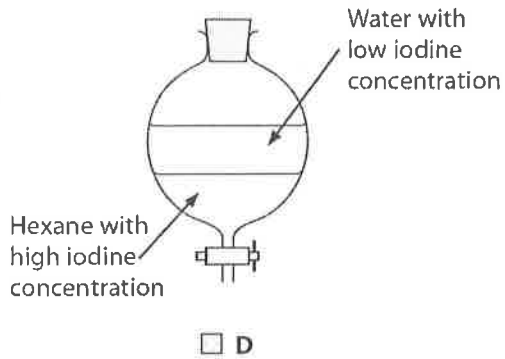
☐ A



☐ B



☐ C



☐ D

(Total for Question 3 = 1 mark)

4. The dihydrogenphosphate-hydrogenphosphate ion system is an important buffer in the human body.

$$H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+$$

In this system, there are two acid-base conjugate pairs. These are

	acid with its conjugate base	base with its conjugate acid
☐ **A**	$H_2PO_4^- / HPO_4^{2-}$	H_2O / H_3O^+
☐ **B**	H_2O / H_3O^+	$HPO_4^{2-} / H_2PO_4^-$
☐ **C**	H_3O^+ / H_2O	$H_2PO_4^- / HPO_4^{2-}$
☐ **D**	$H_2PO_4^- / HPO_4^{2-}$	H_3O^+ / H_2O

(Total for Question 4 = 1 mark)

5. The pH of a 1.5 $mol.dm^{-3}$ solution of hydrochloric acid, HCl(aq), is

☐ **A** –1.50
☐ **B** – 0.18
☐ **C** 0.18
☐ **D** 1.50

(Total for Question 5 = 1 mark)

6. Which of the following is **not** a reaction of a Bronsted-Lowry acid and base?

☐ **A** $CH_3Cl + OH^- \rightarrow CH_3OH + Cl^-$
☐ **B** $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$
☐ **C** $H_2O + HSO_4^- \rightarrow H_2SO_4 + OH^-$
☐ **D** $HCO_3^- + H_2O \rightarrow CO_3^{2-} + H_3O^+$

(Total for Question 6 = 1 mark)

7. Information about four samples of acid is shown below.

Sample 1: 1.0 $mol.dm^{-3}$ HCl
Sample 2: 1.0 $mol.dm^{-3}$ H_2SO_4
Sample 3: 0.1 $mol.dm^{-3}$ HCl
Sample 4: 0.1 $mol.dm^{-3}$ CH_3COOH

Which of the following lists shows the samples in order of increasing pH?

☐ **A** 1, 2, 3, 4
☐ **B** 4, 3, 2, 1
☐ **C** 2, 1, 3, 4
☐ **D** 4, 3, 1, 2

(Total for Question 7 = 1 mark)

8. A strong monoprotic acid, of concentration 0.0100 mol.dm^{-3}, has a pH = 2.0.

What is the **decrease** in pH if the concentration is increased to 0.0110 mol dm^{-3}?

☐ **A** 0.001
☐ **B** 0.04
☐ **C** 1.04
☐ **D** 1.96

(Total for Question 8 = 1 mark)

9. Which reaction has an enthalpy change equal to the enthalpy of hydration of the sodium ion?

☐ **A** $Na^+(g)$ + excess $H_2O(l) \rightarrow Na^+(aq)$
☐ **B** $Na^+(g)$ + 1 mol of $H_2O(l) \rightarrow Na^+(aq)$
☐ **C** $Na^+(s)$ + excess $H_2O(l) \rightarrow Na^+(aq)$
☐ **D** $Na^+(s)$ + 1 mol of $H_2O(l) \rightarrow Na^+(aq)$

(Total for Question 9 = 1 mark)

10. Which equation represents the standard enthalpy change of atomisation of bromine?

☐ **A** $\frac{1}{2}Br_2(s) \rightarrow Br(g)$
☐ **B** $\frac{1}{2}Br_2(l) \rightarrow Br(g)$
☐ **C** $Br_2(s) \rightarrow 2Br(g)$
☐ **D** $Br_2(l) \rightarrow 2Br(g)$

(Total for Question 10 = 1 mark)

11. Which equation represents the second electron affinity of oxygen?

☐ **A** $O^-(g) + e^- \rightarrow O^{2-}(g)$
☐ **B** $O(g) + 2e^- \rightarrow O^{2-}(g)$
☐ **C** $O^+(g) \rightarrow O^{2+}(g) + e^-$
☐ **D** $O(g) \rightarrow O^{2+}(g) + 2e^-$

(Total for Question 11 = 1 mark)

12. Which compound has the greatest covalent character?

☐ **A** $CaBr_2$
☐ **B** CaI_2
☐ **C** $MgBr_2$
☐ **D** MgI_2

(Total for Question 12 = 1 mark)

13. Magnesium nitrate decomposes on heating as shown.

$$Mg(NO_3)_2(s) \rightleftharpoons MgO(s) + 2NO_2(g) + \tfrac{1}{2}O_2(g)$$

What is the expression for the equilibrium constant, K_p, for this reaction?

☐ **A** $K_p = p(NO_2)^2\, p(O_2)^{\frac{1}{2}}$

☐ **B** $K_p = p(NO_2)^4\, p(O_2)$

☐ **C** $K_p = \dfrac{p(MgO)\, p(NO_2)^2\, p(O_2)^{\frac{1}{2}}}{p(Mg(NO_3)_2)}$

☐ **D** $K_p = \dfrac{p(MgO)^2\, p(NO_2)^4\, p(O_2)}{p(Mg(NO_3)_2)^2}$

(Total for Question 13 = 1 mark)

14. Which of these substances would be expected to have the greatest standard molar entropy?

☐ **A** FeO
☐ **B** FeS
☐ **C** $FeCl_2$
☐ **D** $FeCl_3$

(Total for Question 14 = 1 mark)

15. Which reaction has the most positive entropy change for the system, ΔS_{system}?

☐ **A** $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$
☐ **B** $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$
☐ **C** $C_2H_4(g) + HCl(g) \rightarrow C_2H_5Cl(l)$
☐ **D** $C_4H_{10}(g) \rightarrow C_2H_4(g) + C_2H_6(g)$

(Total for Question 15 = 1 mark)

16. For all chemical reactions, the equilibrium constant, K, is related to the total entropy change, ΔS_{total}, by the expression shown.

$$\Delta S_{total} = R \ln K$$

ΔS_{total} for a reaction is negative. Which statement is true?

- ☐ **A** the value of K is less than 1
- ☐ **B** the value of K is greater than 1
- ☐ **C** the value of K is negative
- ☐ **D** the position of equilibrium lies to the right

(Total for Question 16 = 1 mark)

17. Bromate(V) ions, BrO_3^-, react with bromide ions, Br^-, in aqueous acid.

$$BrO_3^- + 5Br^- + 6H^+ \rightarrow 3Br_2 + 3H_2O$$

The rate equation for the reaction is shown.

$$\text{rate} = k\,[BrO_3^-]\,[Br^-]\,[H^+]^2$$

(a) Which **continuous** monitoring method could be used to obtain kinetics data for this reaction?

(1)

- ☐ **A** colorimetry
- ☐ **B** mass change
- ☐ **C** titration with sodium thiosulfate
- ☐ **D** volume of gas evolved

(b) What are the units of the rate constant, k, for this reaction?

(1)

- ☐ **A** $mol.dm^{-3}.s^{-1}$
- ☐ **B** $dm^3.mol^{-1}.s^{-1}$
- ☐ **C** $dm^6.mol^{-2}.s^{-1}$
- ☐ **D** $dm^9.mol^{-3}.s^{-1}$

(c) The concentrations of **all** reactants are halved. By what factor does the rate of reaction change?

(1)

☐ **A** $\frac{1}{2}$

☐ **B** $\frac{1}{4}$

☐ **C** $\frac{1}{8}$

☐ **D** $\frac{1}{16}$

(d) The first four steps in the reaction mechanism are shown.

Step 1 $BrO_3^- + H^+ \rightarrow BrO_3H$

Step 2 $BrO_3H + H^+ \rightarrow BrO_3H_2^+$

Step 3 $BrO_3H_2^+ + Br^- \rightarrow Br_2O_2 + H_2O$

Step 4 $Br_2O_2 + Br^- \rightarrow BrO_2^- + Br_2$

Which is the rate-determining step?

(1)

☐ **A** Step 1

☐ **B** Step 2

☐ **C** Step 3

☐ **D** Step 4

(Total for Question 17 = 4 marks)

18. A chloroalkane, RCl, undergoes hydrolysis according to the equation shown.

$$RCl + OH^- \rightarrow ROH + Cl^-$$

The rate equation is rate = k[RCl]

Which chloroalkane is most likely to be RCl?

☐ **A** CH_3CH_2Cl

☐ **B** $(CH_3)_3CCl$

☐ **C** $CH_3CHClCH_3$

☐ **D** $(CH_3)_3CCH_2Cl$

(Total for Question 18 = 1 mark)

19. Propanone reacts with iodine in acidic solution as shown in the equation below.

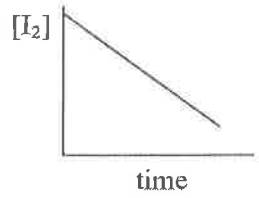
$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)$$

The rate equation for the reaction is

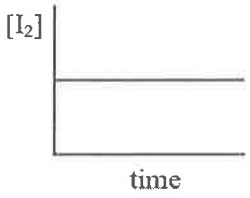
$$\text{Rate} = k[CH_3COCH_3(aq)][H^+(aq)]$$

The reaction is carried out using a large excess of both propanone and acid.
Which of the graphs below shows the change of iodine concentration with time?

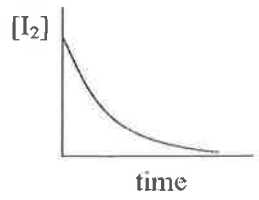
☐ **A**



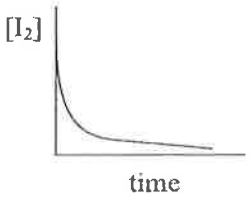
☐ **B**



☐ **C**

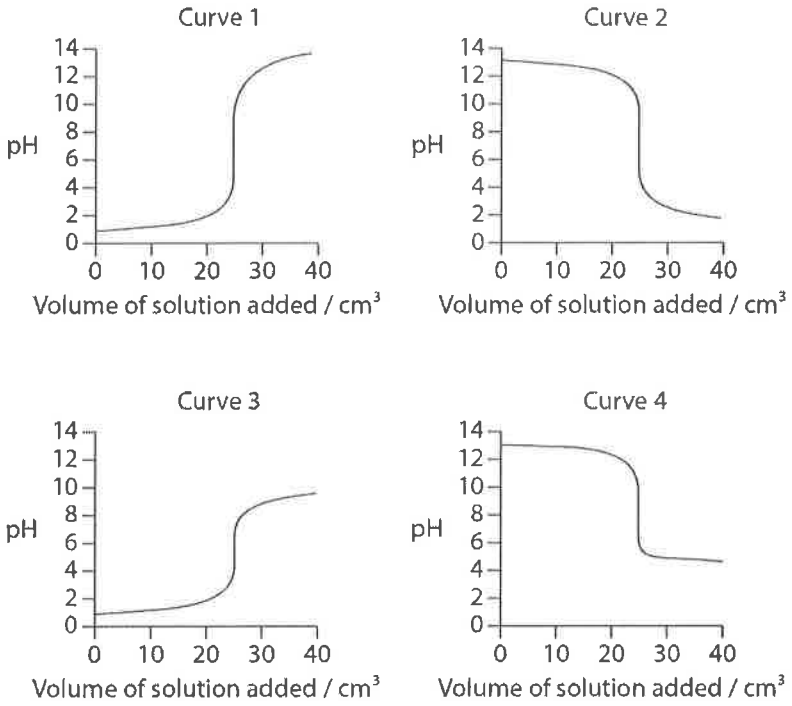


☐ **D**



(Total for Question 19 = 1 mark)

20. This question is about the titration curves obtained by reacting different acids and alkalis of the same concentration.



(a) Which curve is produced by adding ammonia to 25cm³ of hydrochloric acid?

(1)

- ☐ **A** Curve 1
- ☐ **B** Curve 2
- ☐ **C** Curve 3
- ☐ **D** Curve 4

(b) Which of these indicators would be **most** suitable to determine the end-point for the titration that gives Curve 4?

(1)

	Indicator	pH range
☐ **A**	Congo red	3.0 – 5.0
☐ **B**	Bromocresol purple	5.2 – 6.8
☒ **C**	Thymol blue (base)	8.0 – 9.6
☐ **D**	Alizarin yellow R	10.1 – 13.0

(Total for Question 20 = 2 marks)

TOTAL FOR SECTION A = 25 MARKS

SECTION B

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

21. This question is about ionic compounds.

(a) Complete the table below by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

(1)

Energy change	Always positive	Always negative	Can be either negative or positive
Lattice energy			
Enthalpy change of hydration			
Enthalpy change of solution			

(b) Define lattice energy.

(2)

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(c) The table below shows various energy changes which can be used in the following questions.

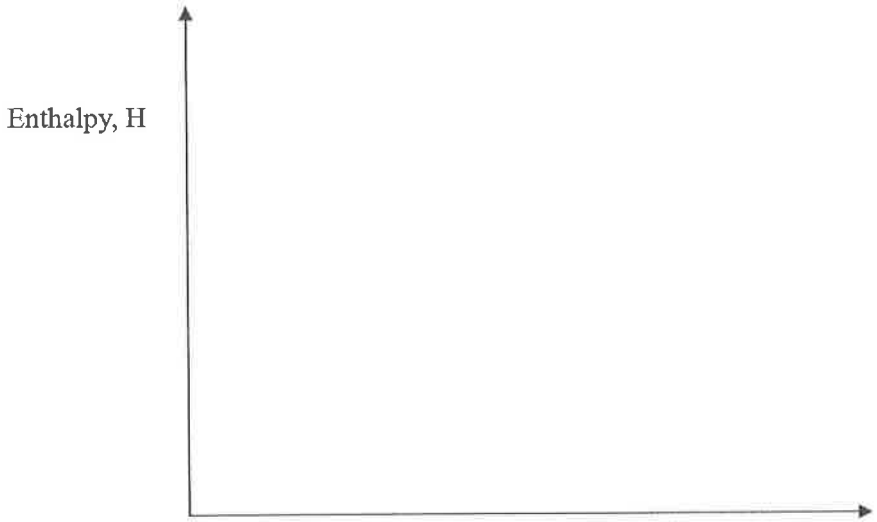
Energy change	Value / $kJ.mol^{-1}$
standard enthalpy change of atomisation of calcium	+178.2
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1145
standard enthalpy change of atomisation of bromine	+111.9
Br–Br bond energy	+192.9
standard enthalpy change of solution of calcium bromide, $CaBr_2(s)$	–103.1
standard enthalpy change of formation of calcium bromide, $CaBr_2(s)$	–682.8
standard enthalpy change of hydration of Ca^{2+}	–1579
first electron affinity of bromine	–324.6
first ionisation energy of bromine	+1140

(i) Construct a labelled Born-Haber Cycle for the formation of $CaBr_2(s)$, and use it to calculate lattice energy of $CaBr_2(s)$.

(4)

(ii) Using the enthalpy changes given in the table above, sketch the enthalpy level diagram to show the relationship between the enthalpy change of solution, lattice energy and enthalpies of hydration for the dissolving of calcium bromide in water.
Fully label your diagram.

(3)



(iii) Calculate the enthalpy change of hydration of bromide ion, Br^-.
If lattice energy value were not found in (c)(i), then use -2200 $kJ.mol^{-1}$.

(2)

(iv) The enthalpy change of hydration of the Br^- ion is more negative than the enthalpy change of hydration of the I^- ion. Explain why.

(2)

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(Total for Question 21 = 14 marks)

22.(a) Aqueous acidified iodate(V) ions, IO_3^-, react with iodide ions, as shown.

$$IO_3^- + 6H^+ + 5I^- \rightarrow 3I_2 + 3H_2O$$

The initial rate of this reaction is investigated. The results obtained are shown below.

Experiment	$[IO_3^-]$ / mol.dm^{-3}	$[H^+]$ / mol.dm^{-3}	$[I^-]$ / mol.dm^{-3}	Initial rate / mol.dm^{-3} min^{-1}
1	0.0400	0.0150	0.0250	4.20×10^{-2}
2	0.120		0.0125	7.09×10^{-2}

The rate equation for this reaction is rate = $k [IO_3^-][H^+]^2[I^-]^2$.

(i) Explain what is meant by order of reaction.

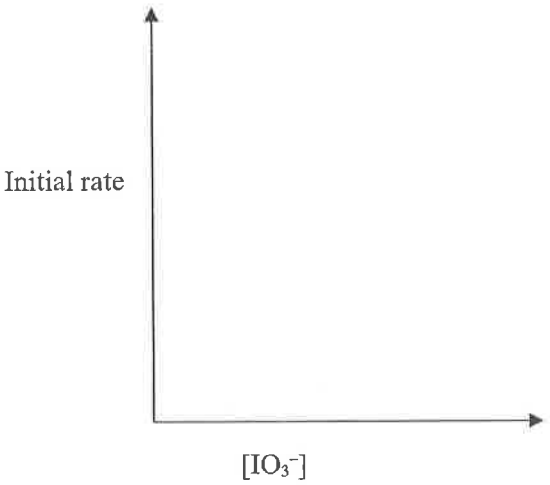
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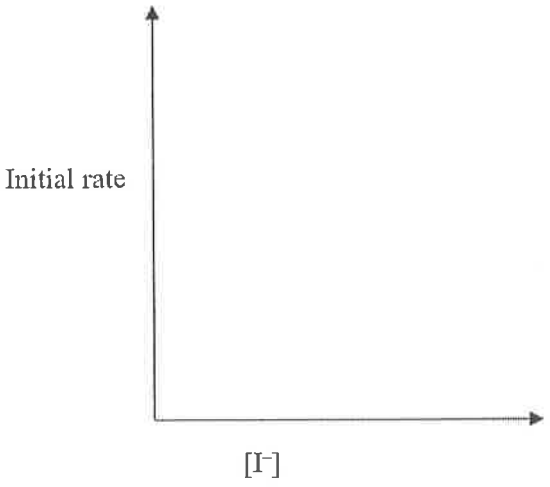
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(ii) Use the rate expression to sketch lines to show the relationship between the initial rates and the concentrations of $[IO_3^-]$ and $[I^-]$.

(2)





(iv) Use data from the table to calculate the rate constant, k, for this reaction.
Include the units of k.

(2)

(v) Calculate the concentration of hydrogen ions, $[H^+]$, in experiment 2.

(1)

(vi) This reaction is repeated in two separate experiments. The experiments are carried out at the same temperature and with the same concentrations of I^- and IO_3^-.
One experiment takes place at pH 1.0 and the other experiment takes place at pH 2.0.
Calculate the value of $\frac{rate\ at\ pH\ 1.0}{rate\ at\ pH\ 2.0}$.

(1)

$\frac{rate\ at\ pH\ 1.0}{rate\ at\ pH\ 2.0}$ = ...

(b) In aqueous solution, iron(III) ions react with iodide ions, as shown.

$$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$$

The initial rate of reaction is first order with respect to Fe^{3+} and second order with respect to I^-.

The mechanism for this reaction has **three** steps.

Each step involves **only** two ions reacting together.

Given that FeI^{2+} and I_2^- were intermediates formed in steps 1 and 2 respectively, suggest equations for the **three** steps of this mechanism. Identify the rate-determining step.

(3)

step 1 .....

step 2 .....

step 3 .....

rate-determining step = ...

(Total for Question 22 = 10 marks)

23.* Halogenoalkanes are hydrolysed by aqueous alkali to form alcohols.

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

The rate equations for these reactions with two halogenoalkanes are shown.

1-bromobutane	rate = $k[CH_3CH_2CH_2CH_2Br][OH^-]$
2-bromo-2-methylpropane	rate = $k[(CH_3)_3CBr]$

Explain how these rate equations can be used to deduce the different reaction mechanisms of the reaction of hydroxide ions with these halogenoalkanes.

(6)

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(Total for Question 23 = 6 marks)

24. This question is about some compounds of silicon and entropy changes.

(a) Silicon dioxide and magnesium react when heated strongly.

Reaction **1** $SiO_2(s) + 4Mg(s) \rightarrow Mg_2Si(s) + 2MgO(s)$

(i) Complete the table, indicating the type of bonding in the reactants and products of this reaction.

(2)

Substance	SiO_2	Mg	Mg_2Si	MgO
Bonding type			covalent	

(ii) The entropy change of the system, ΔS_{system}, for Reaction **1** is $-43.8\ J.K^{-1}.mol^{-1}$.

Suggest, with reference to the equation, why ΔS_{system} for this reaction is negative.

(2)

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(iii) The enthalpy change, ΔH, for Reaction **1** is $-370\ kJ.mol^{-1}$.

Calculate the entropy change of the surroundings, $\Delta S_{surroundings}$, in $J.K^{-1}.mol^{-1}$, for Reaction **1** at 23.0 °C.

(2)

(iv) Calculate the total entropy change, ΔS_{total} , for Reaction **1** at 23.0°C.

Give your answer to an appropriate number of significant figures, and in units of $J.K^{-1}.mol^{-1}$.

(2)

(v) Reaction **1** does not occur at room temperature due to its very high activation energy. Suggest why the activation energy for Reaction **1** is very high.

(1)

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(b) Magnesium silicide, Mg_2Si, reacts with hydrochloric acid forming silane, SiH_4, and magnesium chloride.

(i) Write an equation for this reaction. State symbols are not required.

(1)

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(ii) Silane has a molecular structure similar to methane.
Complete the table, giving the shape of a molecule of SiH_4 and its bond angle.

(2)

Name of shape	
Bond angle	

(c) Silane spontaneously **combusts** in air at room temperature.

Reaction **2** $SiH_4(g) + 2O_2(g) \rightarrow SiO_2(s) + 2H_2O(l)$

Entropy data for this reaction are shown.

Species	$SiH_4(g)$	$O_2(g)$	$SiO_2(s)$	$H_2O(l)$
$S^\ominus$ / $J.K^{-1}.mol^{-1}$	204.5	205.0	41.8	69.9

(i) Calculate the entropy change of the system, ΔS_{system}, in $J.K^{-1}.mol^{-1}$, for Reaction **2**.

(2)

(ii) State why the entropy change of the surroundings for Reaction **2** is highly positive, in terms of the bond strengths of the reactants and products.

(1)

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(d) The values of total entropy change and equilibrium constant of a reaction are related by the following equation.

$$\Delta S^{\ominus}_{total} = R \ln K$$

The equation for the dissolving of barium hydroxide is

$$Ba(OH)_2(s) + aq \rightarrow Ba^{2+}(aq) + 2OH^-(aq) \qquad \Delta S^{\ominus}_{total} = 44 \text{ J.mol}^{-1}\text{K}^{-1}$$

(i) Calculate the value of the equilibrium constant, K, for this equation at 298 K.
$R = 8.31 \text{ J.mol}^{-1}.\text{K}^{-1}$

(1)

(ii) What does the value of the equilibrium constant suggest about the solubility of barium hydroxide? Justify your answer.

(1)

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(iii) For the dissolving of calcium hydroxide, the value of the total entropy change is $-106 \text{ J.mol}^{-1}.\text{K}^{-1}$
Compare the values of the total entropy changes for these two hydroxides and show that they are consistent with the trend in the solubility of Group 2 hydroxides.

(2)

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(Total for Question 24 = 19 marks)

25. Ethanoic acid can be manufactured by the following reaction, which is carried out between 150 °C and 200 °C.

$$CH_3OH(g) + CO(g) \rightleftharpoons CH_3COOH(g)$$

(a) A mixture of 50.0 mol of methanol and 50.0 mol of carbon monoxide reaches equilibrium at a pressure of 32.0 atm.
At 175°C, the equilibrium partial pressure of ethanoic acid is 22.2 atm.

(i) Write the expression for the equilibrium constant in terms of pressure, K_p, for this reaction.

(1)

(ii) Calculate the partial pressures of methanol and carbon monoxide at equilibrium.

(2)

(iii) Calculate the value of K_p for this reaction at 175 °C.
Include a unit in your answer and give your answer to three significant figures.

(2)

(b) Another sample of 50.0 mol of methanol and 50.0 mol of carbon monoxide was allowed to reach equilibrium at the same pressure of 32.0 atm, but at a lower temperature. 93.6 % of the methanol was converted at equilibrium.

(i) Complete the table below to show the number of moles of each species in the equilibrium mixture.

(2)

	CH_3OH	CO	CH_3COOH
Number of moles at start	50.0	50.0	0
Number of moles at equilibrium			

(ii) Calculate the partial pressure of ethanoic acid in the equilibrium mixture.

(1)

(iii) Is the reaction exothermic or endothermic? Explain your answer.

(1)

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.....

(c) How, if at all, does the addition of methanol to the equilibrium mixture affect the following? Justify your answers.

$$CH_3OH(g) + CO(g) \rightleftharpoons CH_3COOH(g)$$

(i) The equilibrium constant for the formation of ethanoic acid.

(1)

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(ii) The equilibrium yield of ethanoic acid.

(1)

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(d) In industry, catalysts are used even though they are often expensive.

State and explain **ONE** benefit to the **environment** resulting from the use of catalysts in industrial processes.

(2)

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(Total for Question 25 = 13 marks)

TOTAL FOR SECTION B = 62 MARKS

SECTION C

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

26. This question is about acids and bases.

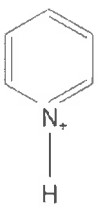
(a) Some K_a and pK_a values for several weak acids are shown.

Weak acid	K_a / mol.dm^{-3}	pK_a
$C_5H_5NH^+$		5.25
CH_3CH_2COOH	1.3×10^{-5}	4.88
$HCOOH$	1.8×10^{-4}	3.75
$CH_2ClCOOH$	1.4×10^{-3}	2.85
$CHCl_2COOH$	4.5×10^{-2}	

(i) Complete the table.

(2)

(ii) The structure of $C_5H_5NH^+$ is shown.



Write the K_a expression for this weak acid.

(1)

(iii) When methanoic acid is added to propanoic acid, an equilibrium is set up containing two acid-base pairs.
Complete the equilibrium, labelling the acid-base pairs as **A1**, **B1** and **A2**, **B2**.

(2)

$CH_3CH_2COOH + HCOOH \rightleftharpoons$ ..... + ...

....

(b) A student calculated the pH of a 0.050 mol.dm^{-3} of $CH_2ClCOOH$ solution.
He used the following set of assumptions:

- $[H^+]_{equilibrium} = [A^-]_{equilibrium}$
- $[HA]_{equilibrium} = [HA]_{initial}$

Justify these assumptions, and calculate the pH value.

(3)

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(c) A student was given 50.0 cm^3 of a solution of sodium hydroxide.
The pH of this solution was 12.43.

The student was asked to adjust the pH to 12.00, by dilution with deionised water.
The student did **not** have access to a pH meter.

Calculate the volume of deionised water, **in cm^3**, the student should add to the original solution.
Given: $K_W = 10^{-14} mol^2 . dm^{-6}$

(5)

(Total for Question 26 = 13 marks)
TOTAL FOR SECTION C = 13 MARKS
TOTAL FOR PAPER = 100 MARKS

The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8)
							1.0 H hydrogen 1										(18) 4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									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	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(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 darmstactium 110	[272] Rg roentgenium 111							

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

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
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

* Lanthanide series

* Actinide series

SECTION A

Answer ALL the questions in this section.
You should aim to spend no more than 25 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 Ostwald Process is a method for making nitric acid.
The equation for the first stage of this process is

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905 \text{ kJ mol}^{-1}$$

(a) The equilibrium yield of nitrogen monoxide, NO, is **increased** by

(1)

- ☐ **A** increasing both the pressure and the temperature.
- ☒ **B** decreasing both the pressure and the temperature.
- ☐ **C** decreasing the pressure and increasing the temperature.
- ☐ **D** increasing the pressure and decreasing the temperature.

(b) For this stage of the process, the catalyst is an alloy of platinum and rhodium.
A pressure of between 4 and 10 atm and a temperature of 1150 K are used.
Unreacted reactants are recycled.

Which one of the following changes will affect the value of the equilibrium constant, K_p?

(1)

- ☐ **A** Changing the composition of the platinum-rhodium catalyst.
- ☐ **B** Increasing the pressure above 10 atm.
- ☒ **C** Decreasing the temperature below 1150 K.
- ☐ **D** Not recycling unreacted reactants.

(Total for Question 1 = 2 marks)

2. The reaction between carbon monoxide and hydrogen reaches a dynamic equilibrium.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Which of these statements about a dynamic equilibrium is **not** true?

- ☐ **A** The forward rate of reaction is equal to the backward rate of reaction.
- ☐ **B** The concentrations of the products and reactants do not change.
- ☒ **C** The concentrations of the products and reactants are equal.
- ☐ **D** The equilibrium can be approached from either direction.

(Total for Question 2 = 1 mark)

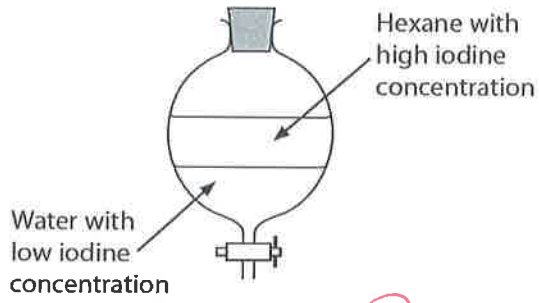
3. Iodine is soluble in both water and hexane.
If iodine is added to a mixture of the two solvents, then the following equilibrium is set up.

$$I_2(aq) \rightleftharpoons I_2(hexane)$$

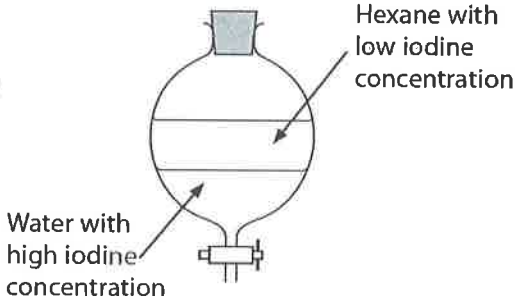
The equilibrium constant, known as the partition coefficient, is 85.

The density of hexane is 0.66 g cm^{-3}. The density of water is 1.00 g cm^{-3}.

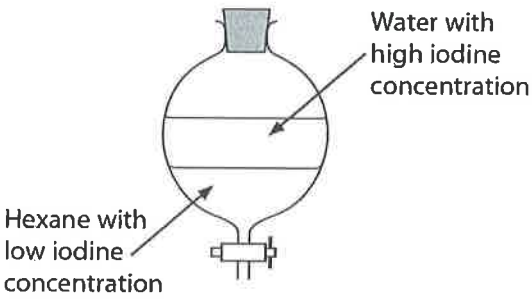
Which of the following diagrams is correct for this system at equilibrium?



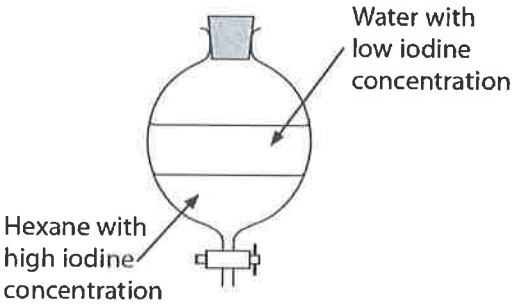
☒ A ✓ (1)



☒ B



☒ C



☒ D

(Total for Question 3 = 1 mark)

4. The dihydrogenphosphate-hydrogenphosphate ion system is an important buffer in the human body.

$$H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+$$

In this system, there are two acid-base conjugate pairs. These are

	acid with its conjugate base	base with its conjugate acid
☒ **A**	$H_2PO_4^- / HPO_4^{2-}$	H_2O / H_3O^+
☒ **B**	H_2O / H_3O^+	$HPO_4^{2-} / H_2PO_4^-$
☒ **C**	H_3O^+ / H_2O	$H_2PO_4^- / HPO_4^{2-}$
☒ **D**	$H_2PO_4^- / HPO_4^{2-}$	H_3O^+ / H_2O

(Total for Question 4 = 1 mark)

5. The pH of a 1.5 $mol.dm^{-3}$ solution of hydrochloric acid, HCl(aq), is

☒ **A** –1.50
☒ **B** – 0.18
☒ **C** 0.18
☒ **D** 1.50

(Total for Question 5 = 1 mark)

6. Which of the following is **not** a reaction of a Bronsted-Lowry acid and base?

☒ **A** $CH_3Cl + OH^- \rightarrow CH_3OH + Cl^-$
☒ **B** $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$
☒ **C** $H_2O + HSO_4^- \rightarrow H_2SO_4 + OH^-$
☒ **D** $HCO_3^- + H_2O \rightarrow CO_3^{2-} + H_3O^+$

(Total for Question 6 = 1 mark)

7. Information about four samples of acid is shown below.

Sample 1: 1.0 $mol.dm^{-3}$ HCl
Sample 2: 1.0 $mol.dm^{-3}$ H_2SO_4
Sample 3: 0.1 $mol.dm^{-3}$ HCl
Sample 4: 0.1 $mol.dm^{-3}$ CH_3COOH

Which of the following lists shows the samples in order of increasing pH?

☒ **A** 1, 2, 3, 4
☒ **B** 4, 3, 2, 1
☒ **C** 2, 1, 3, 4
☒ **D** 4, 3, 1, 2

(Total for Question 7 = 1 mark)

8. A strong monoprotic acid, of concentration 0.0100 mol.dm^{-3}, has a pH = 2.0.

What is the **decrease** in pH if the concentration is increased to 0.0110 mol dm^{-3}?

- ☒ **A** 0.001
- ☒ **B** 0.04
- ☒ **C** 1.04
- ☒ **D** 1.96

(Total for Question 8 = 1 mark)

9. Which reaction has an enthalpy change equal to the enthalpy of hydration of the sodium ion?

- ☒ **A** $Na^+(g)$ + excess $H_2O(l) \rightarrow Na^+(aq)$
- ☒ **B** $Na^+(g)$ + 1 mol of $H_2O(l) \rightarrow Na^+(aq)$
- ☒ **C** $Na^+(s)$ + excess $H_2O(l) \rightarrow Na^+(aq)$
- ☒ **D** $Na^+(s)$ + 1 mol of $H_2O(l) \rightarrow Na^+(aq)$

(Total for Question 9 = 1 mark)

10. Which equation represents the standard enthalpy change of atomisation of bromine?

- ☐ **A** $\frac{1}{2}Br_2(s) \rightarrow Br(g)$
- ☒ **B** $\frac{1}{2}Br_2(l) \rightarrow Br(g)$
- ☐ **C** $Br_2(s) \rightarrow 2Br(g)$
- ☐ **D** $Br_2(l) \rightarrow 2Br(g)$

(Total for Question 10 = 1 mark)

11. Which equation represents the second electron affinity of oxygen?

- ☒ **A** $O^-(g) + e^- \rightarrow O^{2-}(g)$
- ☒ **B** $O(g) + 2e^- \rightarrow O^{2-}(g)$
- ☒ **C** $O^+(g) \rightarrow O^{2+}(g) + e^-$
- ☒ **D** $O(g) \rightarrow O^{2+}(g) + 2e^-$

(Total for Question 11 = 1 mark)

12. Which compound has the greatest covalent character?

- ☐ **A** $CaBr_2$
- ☐ **B** CaI_2
- ☐ **C** $MgBr_2$
- ☒ **D** MgI_2

(Total for Question 12 = 1 mark)

13. Magnesium nitrate decomposes on heating as shown.

$$Mg(NO_3)_2(s) \rightleftharpoons MgO(s) + 2NO_2(g) + \tfrac{1}{2}O_2(g)$$

What is the expression for the equilibrium constant, K_p, for this reaction?

(1) ☒ **A** $K_p = p(NO_2)^2\, p(O_2)^{\frac{1}{2}}$

☒ **B** $K_p = p(NO_2)^4\, p(O_2)$

☒ **C** $K_p = \dfrac{p(MgO)\, p(NO_2)^2\, p(O_2)^{\frac{1}{2}}}{p(Mg(NO_3)_2)}$

☒ **D** $K_p = \dfrac{p(MgO)^2\, p(NO_2)^4\, p(O_2)}{p(Mg(NO_3)_2)^2}$

(Total for Question 13 = 1 mark)

14. Which of these substances would be expected to have the greatest standard molar entropy?

☒ **A** FeO
☒ **B** FeS
☒ **C** $FeCl_2$
(1) ☒ **D** $FeCl_3$

(Total for Question 14 = 1 mark)

15. Which reaction has the most positive entropy change for the system, ΔS_{system}?

☐ **A** $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$
☐ **B** $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$
☐ **C** $C_2H_4(g) + HCl(g) \rightarrow C_2H_5Cl(l)$
(1) ☒ **D** $C_4H_{10}(g) \rightarrow C_2H_4(g) + C_2H_6(g)$

(Total for Question 15 = 1 mark)

16. For all chemical reactions, the equilibrium constant, K, is related to the total entropy change, ΔS_{total}, by the expression shown.

$$\Delta S_{total} = R \ln K$$

ΔS_{total} for a reaction is negative. Which statement is true?

(1)

- ☒ **A** the value of K is less than 1
- ☒ **B** the value of K is greater than 1
- ☒ **C** the value of K is negative
- ☒ **D** the position of equilibrium lies to the right

(Total for Question 16 = 1 mark)

17. Bromate(V) ions, BrO_3^-, react with bromide ions, Br^-, in aqueous acid.

$$BrO_3^- + 5Br^- + 6H^+ \rightarrow 3Br_2 + 3H_2O$$

The rate equation for the reaction is shown.

$$\text{rate} = k\,[BrO_3^-]\,[Br^-]\,[H^+]^2$$

(a) Which **continuous** monitoring method could be used to obtain kinetics data for this reaction?

(1)

- ☒ **A** colorimetry
- ☒ **B** mass change
- ☒ **C** titration with sodium thiosulfate
- ☒ **D** volume of gas evolved

(b) What are the units of the rate constant, k, for this reaction?

(1)

- ☒ **A** $mol.dm^{-3}.s^{-1}$
- ☒ **B** $dm^3.mol^{-1}.s^{-1}$
- ☒ **C** $dm^6.mol^{-2}.s^{-1}$
- ☒ **D** $dm^9.mol^{-3}.s^{-1}$

(c) The concentrations of **all** reactants are halved. By what factor does the rate of reaction change?

(1)

- ☒ **A** $\frac{1}{2}$
- ☒ **B** $\frac{1}{4}$
- ☒ **C** $\frac{1}{8}$
- ☒ **D** $\frac{1}{16}$

(d) The first four steps in the reaction mechanism are shown.

Step **1** $BrO_3^- + H^+ \rightarrow BrO_3H$

Step **2** $BrO_3H + H^+ \rightarrow BrO_3H_2^+$

Step **3** $BrO_3H_2^+ + Br^- \rightarrow Br_2O_2 + H_2O$

Step **4** $Br_2O_2 + Br^- \rightarrow BrO_2^- + Br_2$

Which is the rate-determining step?

(1)

- ☒ **A** Step **1**
- ☒ **B** Step **2**
- ☒ **C** Step **3**
- ☒ **D** Step **4**

(Total for Question 17 = 4 marks)

18. A chloroalkane, RCl, undergoes hydrolysis according to the equation shown.

$$RCl + OH^- \rightarrow ROH + Cl^-$$

The rate equation is rate = k[RCl]

Which chloroalkane is most likely to be RCl?

- ☒ **A** CH_3CH_2Cl
- ☒ **B** $(CH_3)_3CCl$
- ☒ **C** $CH_3CHClCH_3$
- ☒ **D** $(CH_3)_3CCH_2Cl$

(Total for Question 18 = 1 mark)

19. Propanone reacts with iodine in acidic solution as shown in the equation below.

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)$$

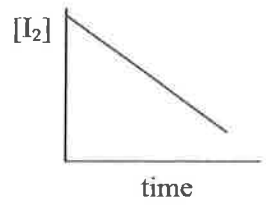
The rate equation for the reaction is

$$\text{Rate} = k[CH_3COCH_3(aq)][H^+(aq)]$$

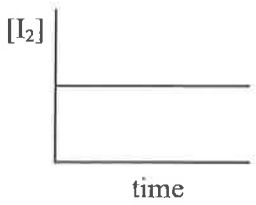
The reaction is carried out using a large excess of both propanone and acid.
Which of the graphs below shows the change of iodine concentration with time?

(1)

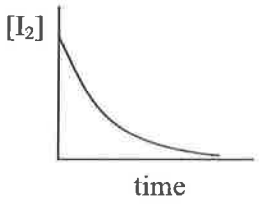
☒ **A**



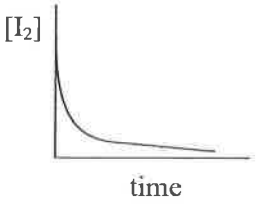
☒ **B**



☒ **C**

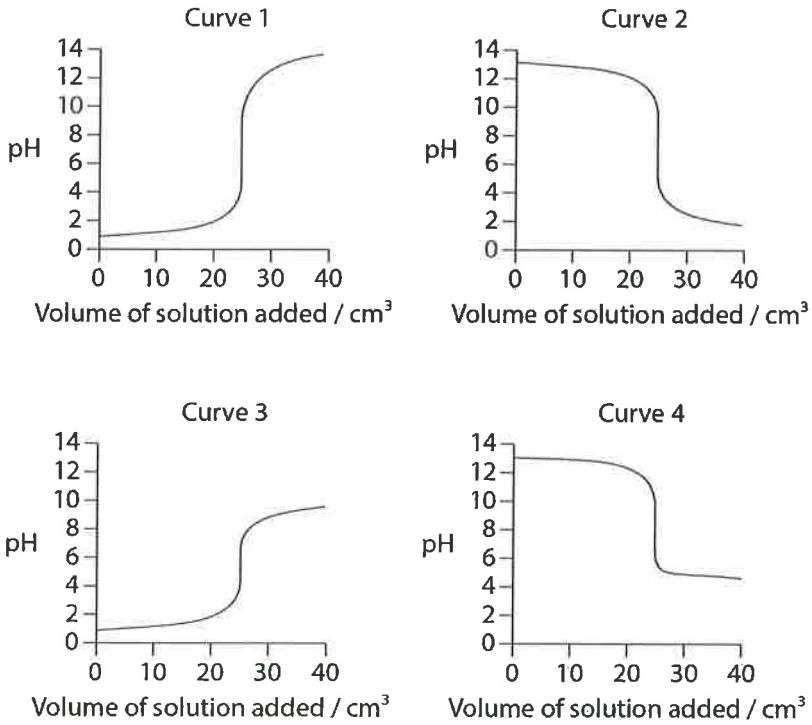


☒ **D**



(Total for Question 19 = 1 mark)

20. This question is about the titration curves obtained by reacting different acids and alkalis of the same concentration.



(a) Which curve is produced by adding ammonia to 25cm³ of hydrochloric acid?

(1)

- ☐ **A** Curve 1
- ☐ **B** Curve 2
- ☒ **C** Curve 3
- ☐ **D** Curve 4

(b) Which of these indicators would be **most** suitable to determine the end-point for the titration that gives Curve 4?

(1)

	Indicator	pH range
☐ **A**	Congo red	3.0 – 5.0
☐ **B**	Bromocresol purple	5.2 – 6.8
☒ **C**	Thymol blue (base)	8.0 – 9.6
☐ **D**	Alizarin yellow R	10.1 – 13.0

(Total for Question 20 = 2 marks)

TOTAL FOR SECTION A = 25 MARKS

SECTION B

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

21. This question is about ionic compounds.

(a) Complete the table below by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

(1)

Energy change	Always positive	Always negative	Can be either negative or positive
Lattice energy		✓	
Enthalpy change of hydration		✓	
Enthalpy change of solution			✓

(b) Define lattice energy.

(2)

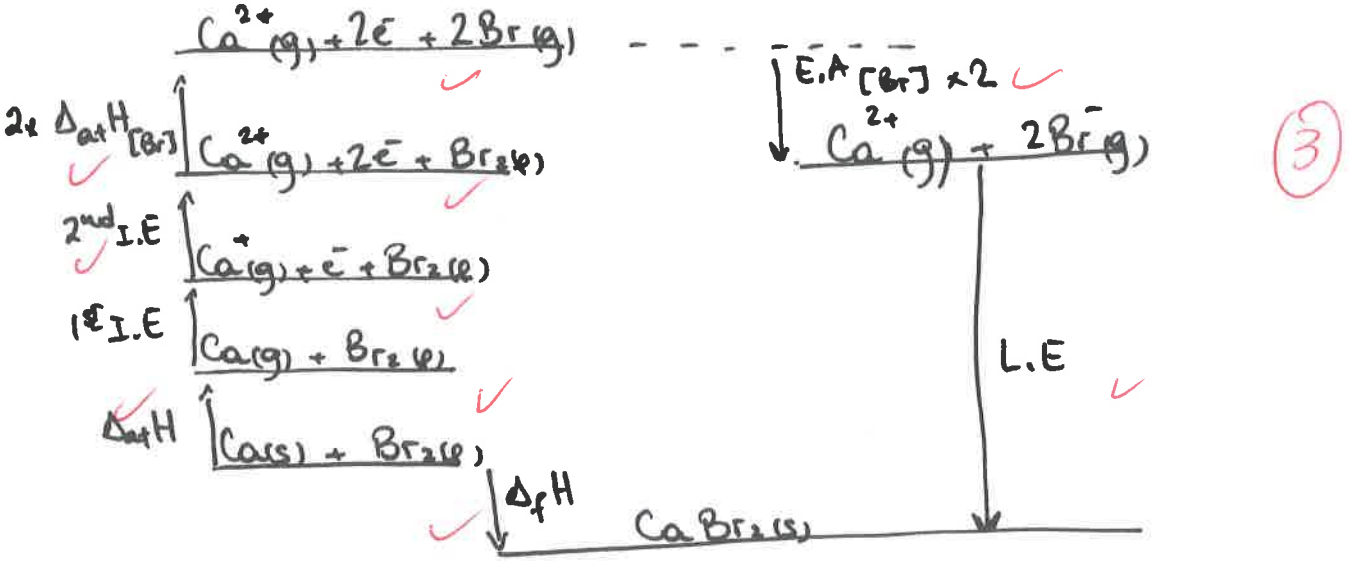
Enthalpy change when one mole of an ionic compound is formed from its ions in their gaseous state

(c) The table below shows various energy changes which can be used in the following questions.

Energy change	Value / kJ.mol^{-1}
standard enthalpy change of atomisation of calcium	+178.2
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1145
standard enthalpy change of atomisation of bromine	+111.9
Br–Br bond energy	+192.9
standard enthalpy change of solution of calcium bromide, $CaBr_2(s)$	–103.1
standard enthalpy change of formation of calcium bromide, $CaBr_2(s)$	–682.8
standard enthalpy change of hydration of Ca^{2+}	–1579
first electron affinity of bromine	–324.6
first ionisation energy of bromine	+1140

(i) Construct a labelled Born-Haber Cycle for the formation of $CaBr_2(s)$, and use it to calculate lattice energy of $CaBr_2(s)$.

(4)



(3)

$$\Delta_f H_{[CaBr_2]} = \Delta_{at}H + 1^{st}\ I.E + 2^{nd}\ I.E + \Delta_{at}H \times 2 + 2 \times E.A + L.E$$

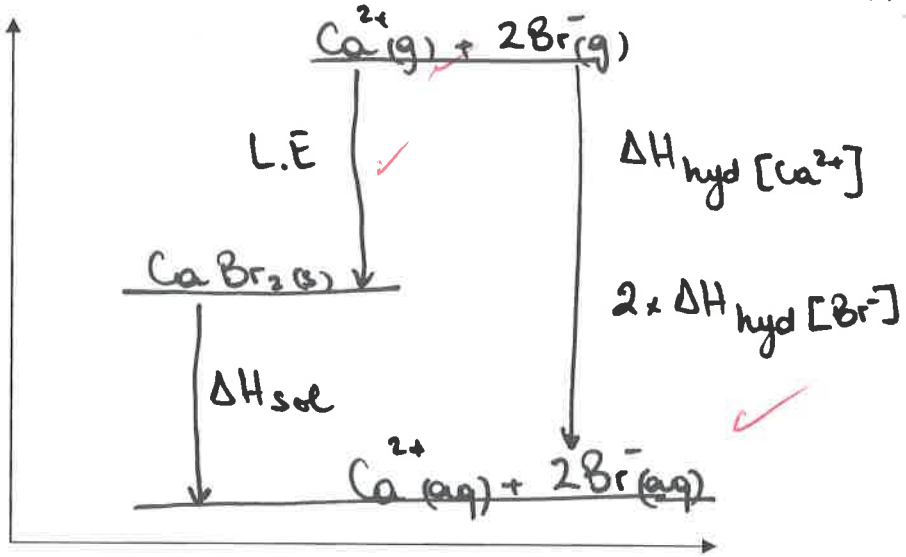
$$\Rightarrow L.E = -682.8 - [178.2 + 590 + 1145 + 2 \times 119 + 2 \times (-324.6)]$$

$$L.E = -2184.8\ kJ.mol^{-1}$$

(1)

(ii) Using the enthalpy changes given in the table above, sketch the enthalpy level diagram to show the relationship between the enthalpy change of solution, lattice energy and enthalpies of hydration for the dissolving of calcium bromide in water.
Fully label your diagram.

(3)



correct species + labelling : (2)

correct leveling : (1)

(iii) Calculate the enthalpy change of hydration of bromide ion, Br^-.
If lattice energy value were not found in (c)(i), then use -2200 kJ.mol^{-1}.

(2)

$$\Delta H_{hyd}[Br^-] = \frac{L.E + \Delta H_{sol} - \Delta H_{hyd}[Ca^{2+}]}{2}$$ (1)

$$= \frac{-2184.6 - 103.1 - (-1579)}{2} = -354.4 \text{ kJ.mol}^{-1}$$ (1)

(iv) The enthalpy change of hydration of the Br^- ion is more negative than the enthalpy change of hydration of the I^- ion. Explain why.

(2)

I.R $[Br^-]$ < I.R $[I^-]$ (1)

=> attraction between the nucleus of Br^- and the dipole of H_2O would be greater than that with I^- (1), leading to a more negative value.

(Total for Question 21 = 14 marks)

22.(a) Aqueous acidified iodate(V) ions, IO_3^-, react with iodide ions, as shown.

$$IO_3^- + 6H^+ + 5I^- \rightarrow 3I_2 + 3H_2O$$

The initial rate of this reaction is investigated. The results obtained are shown below.

Experiment	$[IO_3^-]$ / mol.dm^{-3}	$[H^+]$ / mol.dm^{-3}	$[I^-]$ / mol.dm^{-3}	Initial rate / mol.dm^{-3} min^{-1}
1	0.0400	0.0150	0.0250	4.20×10^{-2}
2	0.120		0.0125	7.09×10^{-2}

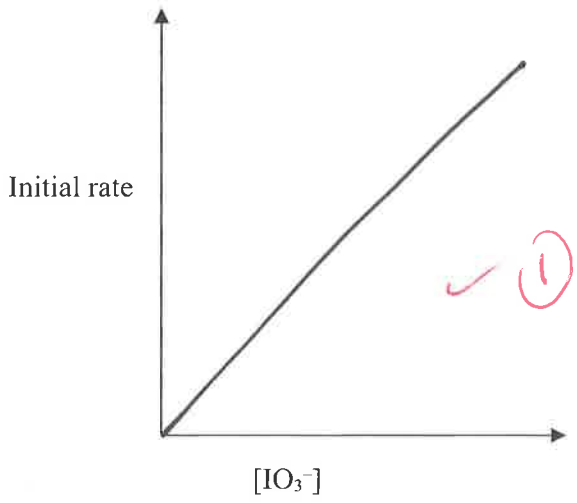
The rate equation for this reaction is rate = k $[IO_3^-][H^+]^2[I^-]^2$.

(i) Explain what is meant by order of reaction.

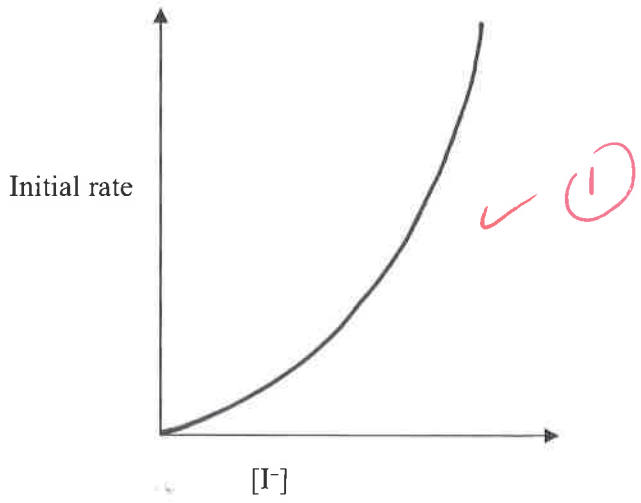
The sum of partial orders. ✓1 (1)

(ii) Use the rate expression to sketch lines to show the relationship between the initial rates and the concentrations of $[IO_3^-]$ and $[I^-]$.

(2)



✓1



✓1

(iv) Use data from the table to calculate the rate constant, k, for this reaction.
Include the units of k.

(2)

$$k = \frac{4.20 \times 10^{-2}}{0.04 \times (0.015)^2 \times (0.025)^2}$$ ✓ (1)

$k = 7.47 \times 10^6$ or 7.5×10^6 $mol^{-4} . dm^{12} . min^{-1}$ ✓ ✓ (1)

(v) Calculate the concentration of hydrogen ions, $[H^+]$, in experiment 2.

(1)

$$[H^+] = \sqrt{\frac{k}{[IO_3^-][I^-]^2}} = \sqrt{\frac{7.5 \times 10^6}{(0.120)(0.0125)^2}} = 2.25 \times 10^{-2}$$ $mol . dm^{-3}$ ✓ ✓ (1)

(vi) This reaction is repeated in two separate experiments. The experiments are carried out at the same temperature and with the same concentrations of I^- and IO_3^-.
One experiment takes place at pH 1.0 and the other experiment takes place at pH 2.0.
Calculate the value of $\frac{rate\ at\ pH\ 1.0}{rate\ at\ pH\ 2.0}$.

(1)

$$\frac{r_1}{r_2} = \frac{k[IO_3^-](10^{-1})^2[I^-]^2}{k[IO_3^-](10^{-2})^2[I^-]^2}$$ ✓

$$\Rightarrow \frac{r_1}{r_2} = \frac{10^{-2}}{10^{-4}} = \frac{1}{10^{-2}} = 100$$ ✓ (1)

$\frac{rate\ at\ pH\ 1.0}{rate\ at\ pH\ 2.0}$ = ... 100 ✓

(b) In aqueous solution, iron(III) ions react with iodide ions, as shown.

$$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$$

The initial rate of reaction is first order with respect to Fe^{3+} and second order with respect to I^-.

The mechanism for this reaction has **three** steps.

Each step involves **only** two ions reacting together.

Given that FeI^{2+} and I_2^- were intermediates formed in steps 1 and 2 respectively, suggest equations for the **three** steps of this mechanism. Identify the rate-determining step.

(3)

step 1 $Fe^{3+} + I^- \rightarrow FeI^{2+}$ (1)

step 2 $FeI^{2+} + I^- \rightarrow I_2^- + Fe^{2+}$

step 3 $Fe^{3+} + I_2^- \rightarrow Fe^{2+} + I_2$ (1)

rate-determining step = Step 2 (1)

(Total for Question 22 = 10 marks)

23.* Halogenoalkanes are hydrolysed by aqueous alkali to form alcohols.

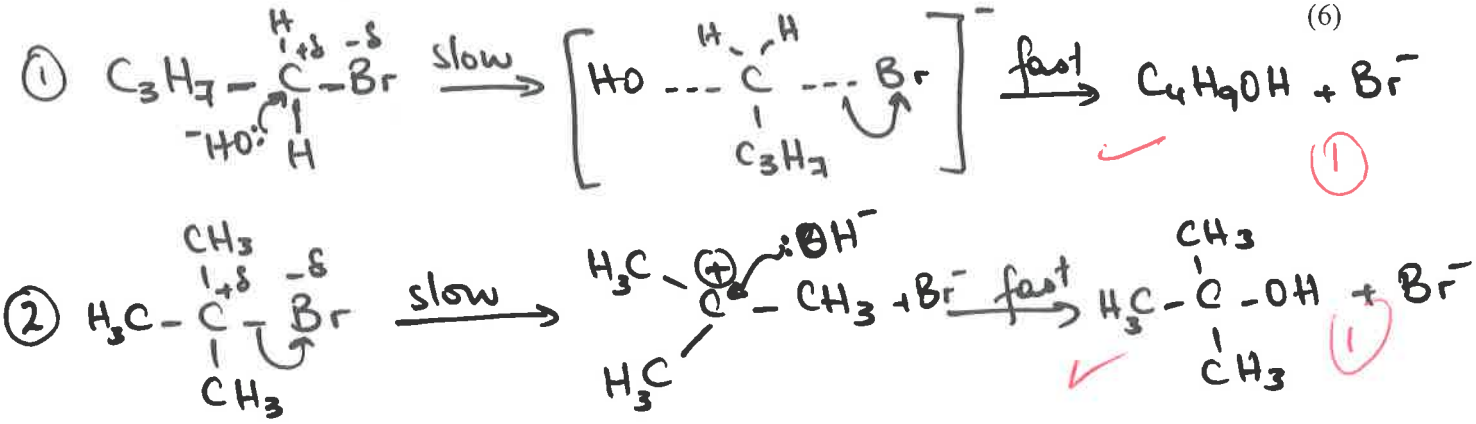
$$RX + OH \rightarrow ROH + X$$

The rate equations for these reactions with two halogenoalkanes are shown.

1-bromobutane	rate = $k[CH_3CH_2CH_2CH_2Br][OH^-]$
2-bromo-2-methylpropane	rate = $k[(CH_3)_3CBr]$

Explain how these rate equations can be used to deduce the different reaction mechanisms of the reaction of hydroxide ions with these halogenoalkanes.

(6)



A rate equation gives the molecularity of species uptill the slow rate-determining step. ✓ (1)

For 1-bromobutane, the rate expression shows a partial order of 1 with respect to each of the ~~the~~ reagents, hence it's a substitution reaction where both are present uptill the rate-determining step (slow step) as shown in mechanism number (1) ✓ (1)

As for 2-bromo-2-methylpropane, the rate expression shows a partial order of 1 with respect to RBr only, hence the slow step is independent of the nucleophile, which is consistent with mechanism number 2. ✓ (1)

The molecularity of the reaction of 1-bromobutane is 2, hence it's S_N2.

the molecularity of the reaction of 2-bromo-2-methylpropane is 1, hence it's S_N1.

(1): for proper english language.

(Total for Question 23 = 6 marks)

24. This question is about some compounds of silicon and entropy changes.

(a) Silicon dioxide and magnesium react when heated strongly.

Reaction **1** $SiO_2(s) + 4Mg(s) \rightarrow Mg_2Si(s) + 2MgO(s)$

(i) Complete the table, indicating the type of bonding in the reactants and products of this reaction.

(2)

Substance	SiO_2	Mg	Mg_2Si	MgO
Bonding type	covalent	metallic	covalent	ionic

(2)

(ii) The entropy change of the system, ΔS_{system}, for Reaction **1** is $-43.8\ J.K^{-1}.mol^{-1}$.

Suggest, with reference to the equation, why ΔS_{system} for this reaction is negative.

(2)

There is a decrease in number of particles (5 → 3) (2)

(iii) The enthalpy change, ΔH, for Reaction **1** is $-370\ kJ.mol^{-1}$.

Calculate the entropy change of the surroundings, $\Delta S_{surroundings}$, in $J.K^{-1}.mol^{-1}$, for Reaction **1** at 23.0 °C.

(2)

$$\Delta S_{surroundings} = -\frac{-370 \times 10^3}{296} = +1250\ J.mol^{-1}.K^{-1}$$

(1) (1)

(iv) Calculate the total entropy change, ΔS_{total}, for Reaction **1** at 23.0°C.

Give your answer to an appropriate number of significant figures, and in units of $J.K^{-1}.mol^{-1}$.

(2)

$\Delta S_T = -43.8 + 1250$ ✓ (1)

$= +1210$ $J.mol^{-1}.K^{-1}$ ✓ (1)

(v) Reaction **1** does not occur at room temperature due to its very high activation energy. Suggest why the activation energy for Reaction **1** is very high.

(1)

Both reactants are solid ✓ (1)

(b) Magnesium silicide, Mg_2Si, reacts with hydrochloric acid forming silane, SiH_4, and magnesium chloride.

(i) Write an equation for this reaction. State symbols are not required.

(1)

$Mg_2Si + 4HCl \longrightarrow SiH_4 + 2MgCl_2$ ✓ (1)

(ii) Silane has a molecular structure similar to methane. Complete the table, giving the shape of a molecule of SiH_4 and its bond angle.

(2)

Name of shape	tetrahedral ✓ (1)
Bond angle	109.5° ✓ (1)

(c) Silane spontaneously **combusts** in air at room temperature.

Reaction **2** $SiH_4(g) + 2O_2(g) \rightarrow SiO_2(s) + 2H_2O(l)$

Entropy data for this reaction are shown.

Species	$SiH_4(g)$	$O_2(g)$	$SiO_2(s)$	$H_2O(l)$
$S^\ominus$ / $J.K^{-1}.mol^{-1}$	204.5	205.0	41.8	69.9

(i) Calculate the entropy change of the system, ΔS_{system} , in $J.K^{-1}.mol^{-1}$, for Reaction **2**.

(2)

$\Delta S_{sys} = (41.8 + 2 \times 69.9) - (204.5 + 205 \times 2)$

$= 181.6 - 614.5$

$= -432.9 \ J.mol^{-1}.K^{-1}$ (2)

(ii) State why the entropy change of the surroundings for Reaction **2** is highly positive, in terms of the bond strengths of the reactants and products.

(1)

E(bonds broken) < E(bonds formed)

reactants have simple structure (1)

products have giant structure

(d) The values of total entropy change and equilibrium constant of a reaction are related by the following equation.

$$\Delta S^{\ominus}_{total} = R \ln K$$

The equation for the dissolving of barium hydroxide is

$$Ba(OH)_2(s) + aq \rightarrow Ba^{2+}(aq) + 2OH^-(aq) \qquad \Delta S^{\ominus}_{total} = 44 \text{ J.mol}^{-1}\text{K}^{-1}$$

(i) Calculate the value of the equilibrium constant, K, for this equation at 298 K.
$R = 8.31 \text{ J.mol}^{-1}.\text{K}^{-1}$

(1)

$K = e^{\frac{\Delta S_T}{R}}$

$K = 199$ ✓ (1)

(ii) What does the value of the equilibrium constant suggest about the solubility of barium hydroxide? Justify your answer.

(1)

$K > 0$ => Barium hydroxide is soluble in H_2O ✓ (1)

(iii) For the dissolving of calcium hydroxide, the value of the total entropy change is $-106 \text{ J.mol}^{-1}.\text{K}^{-1}$
Compare the values of the total entropy changes for these two hydroxides and show that they are consistent with the trend in the solubility of Group 2 hydroxides.

(2)

$\Delta S_T < 0$ => K is small => the dissolution of $Ca(OH)_2$ is less feasible than that of $Ba(OH)_2$, which is consistent with the solubility of group (II) hydroxide. ✓ (2)

(Total for Question 24 = 19 marks)

25. Ethanoic acid can be manufactured by the following reaction, which is carried out between 150 °C and 200 °C.

$$CH_3OH(g) + CO(g) \rightleftharpoons CH_3COOH(g)$$

(a) A mixture of 50.0 mol of methanol and 50.0 mol of carbon monoxide reaches equilibrium at a pressure of 32.0 atm.
At 175°C, the equilibrium partial pressure of ethanoic acid is 22.2 atm.

(i) Write the expression for the equilibrium constant in terms of pressure, K_p, for this reaction.

(1)

$$K_p = \frac{P_{CH_3COOH}}{P_{CO} \times P_{CH_3OH}} \quad @ \text{ eqm.} \quad (1)$$

(ii) Calculate the partial pressures of methanol and carbon monoxide at equilibrium.

(2)

At eqm : $P_{CO} = P_{CH_3OH}$ (1)

$\Rightarrow P_T = \Sigma P_i$

$\Rightarrow 32 = P_{CH_3COOH} + P_{CO} + P_{CH_3OH}$

$\Rightarrow P_{CH_3OH} = \frac{32 - 22.2}{2} = 4.9 \text{ atm.}$ (1)

(iii) Calculate the value of K_p for this reaction at 175 °C.
Include a unit in your answer and give your answer to three significant figures.

(2)

$$K_p = \frac{22.2}{(4.9)^2} = 0.925 \text{ atm}^{-1}$$ (1) (1)

(b) Another sample of 50.0 mol of methanol and 50.0 mol of carbon monoxide was allowed to reach equilibrium at the same pressure of 32.0 atm, but at a lower temperature. 93.6 % of the methanol was converted at equilibrium.

(i) Complete the table below to show the number of moles of each species in the equilibrium mixture.

(2)

	CH_3OH	CO	CH_3COOH
Number of moles at start	50.0	50.0	0
Number of moles at equilibrium	3.2	3.2	46.8

(1) (1)

(ii) Calculate the partial pressure of ethanoic acid in the equilibrium mixture.

(1)

$$P_{CH_3COOH} = \frac{46.8}{53.2} \times 32 = 28.15 \text{ atm}$$ (1)

(iii) Is the reaction exothermic or endothermic? Explain your answer.

The degree of conversion (1) increased (1)
at lower temperature, then the
reaction is exothermic. (1)

(c) How, if at all, does the addition of methanol to the equilibrium mixture affect the following? Justify your answers.

$$CH_3OH(g) + CO(g) \rightleftharpoons CH_3COOH(g)$$

(i) The equilibrium constant for the formation of ethanoic acid.

(1)

It has no effect ✓ (1)
K is constant as long as temperature is constant

(ii) The equilibrium yield of ethanoic acid.

(1)

The yield increases as the equilibrium shifts forward ✓ in order to consume the additional methanol ✓ (1)

(d) In industry, catalysts are used even though they are often expensive.

State and explain **ONE** benefit to the **environment** resulting from the use of catalysts in industrial processes.

(2)

Catalysts help reduce the temperature needed for an optimum yield ✓ which will eventually affect the consumption of fuel.
Hence, less CO_2 emitted ✓ (1)

(1)

(Total for Question 25 = 13 marks)

TOTAL FOR SECTION B = 62 MARKS

SECTION C

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

26. This question is about acids and bases.

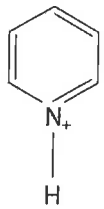
(a) Some K_a and pK_a values for several weak acids are shown.

Weak acid	K_a / mol.dm^{-3}	pK_a
$C_5H_5NH^+$	5.6×10^{-6} (1)	5.25
CH_3CH_2COOH	1.3×10^{-5}	4.88
HCOOH	1.8×10^{-4}	3.75
$CH_2ClCOOH$	1.4×10^{-3}	2.85
$CHCl_2COOH$	4.5×10^{-2}	1.35 ✓ (1)

(i) Complete the table.

(2)

(ii) The structure of $C_5H_5NH^+$ is shown.



Write the K_a expression for this weak acid.

(1)

$$K_a = \frac{[H^+][C_5H_5N]}{[C_5H_5NH^+]}$$ @ eqm. (1)

(iii) When methanoic acid is added to propanoic acid, an equilibrium is set up containing two acid-base pairs.
Complete the equilibrium, labelling the acid-base pairs as **A1**, **B1** and **A2**, **B2**.

(2)

$CH_3CH_2COOH + HCOOH \rightleftharpoons$ $CH_3CH_2COOH_2^+$ + $HCOO^-$

B2 A1 A2 B1 (1) (1)

(b) A student calculated the pH of a 0.050 mol.dm^{-3} of $CH_2ClCOOH$ solution.
He used the following set of assumptions:

- $[H^+]_{equilibrium} = [A^-]_{equilibrium}$
- $[HA]_{equilibrium} = [HA]_{initial}$

Justify these assumptions, and calculate the pH value. (3)

The dissociation of H_2O is too small compared to that of the acid ✓ (1)
therefore $[H^+]_{H_2O} <<< [H^+]_{acid}$ ✓

hence $[H^+]_{eqm} = [A^-]_{eqm}$ ✓ (1)

HA is a weak acid, and its degree of conversion is too small / negligible, hence ✓ (1)

$[HA]_{eqm} = [HA]_0$ ✓

(c) A student was given 50.0 cm^3 of a solution of sodium hydroxide.
The pH of this solution was 12.43.

The student was asked to adjust the pH to 12.00, by dilution with deionised water.
The student did **not** have access to a pH meter.

Calculate the volume of deionised water, **in cm^3**, the student should add to the original solution.
Given: $K_w = 10^{-14} mol^2 . dm^{-6}$

(5)

Original solution : $[H^+] = 10^{-12.43}$

$\Rightarrow [OH^-] = \frac{10^{-14}}{10^{-12.43}} = 10^{-1.57}$ mol.dm^{-3} (1)

$\Rightarrow n_{OH^-} = 1.346 \times 10^{-3}$ mol (1)

Final solution : $[OH^-] = \frac{10^{-14}}{10^{-12}} = 10^{-2}$ mol.dm^{-3} (1)

$\Rightarrow V_{final} = \frac{1.346 \times 10^{-3}}{10^{-2}} = 0.1346$ dm^3 (1)

$\Rightarrow V_{(H_2O\ added)} = 134.6 - 50.0$

$= 84.6$ cm^3 . (1)

(Total for Question 26 = 13 marks)
TOTAL FOR SECTION C = 13 MARKS
TOTAL FOR PAPER = 100 MARKS

The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8)
							1.0 H hydrogen 1										(18) 4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									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	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(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