9 Which pair of values will **always** give a thermodynamically feasible reaction?

	Entropy change of the system	Enthalpy change of reaction
☒ **A**	negative	positive
☒ **B**	negative	negative
☒ **C**	positive	negative
☒ **D**	positive	positive

1 A homogeneous equilibrium is shown.

$$W + X \rightleftharpoons 2Y + Z$$

What is the K_c expression for this equilibrium?

☒ **A** $K_c = \dfrac{2[Y][Z]}{[W][X]}$

☒ **B** $K_c = \dfrac{[Y]^2[Z]}{[W][X]}$

☒ **C** $K_c = \dfrac{[W][X]}{2[Y][Z]}$

☒ **D** $K_c = \dfrac{[W][X]}{[Y]^2[Z]}$

(Total for Question 1 = 1 mark)

DO NOT WRITE IN THIS AREA

11 Some thermodynamic information is shown for four reactions, W, X, Y and Z, at 298 K.

Reaction	ΔH	$T\Delta S_{system}$
W	negative and with a larger negative value than $T\Delta S_{system}$	negative
X	negative	positive
Y	positive	positive and with a smaller positive value than ΔH
Z	positive	negative

Which of these reactions are feasible at 298 K?

- ☒ **A** X only
- ☒ **B** W and X only
- ☒ **C** Y only
- ☒ **D** W and Z only

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

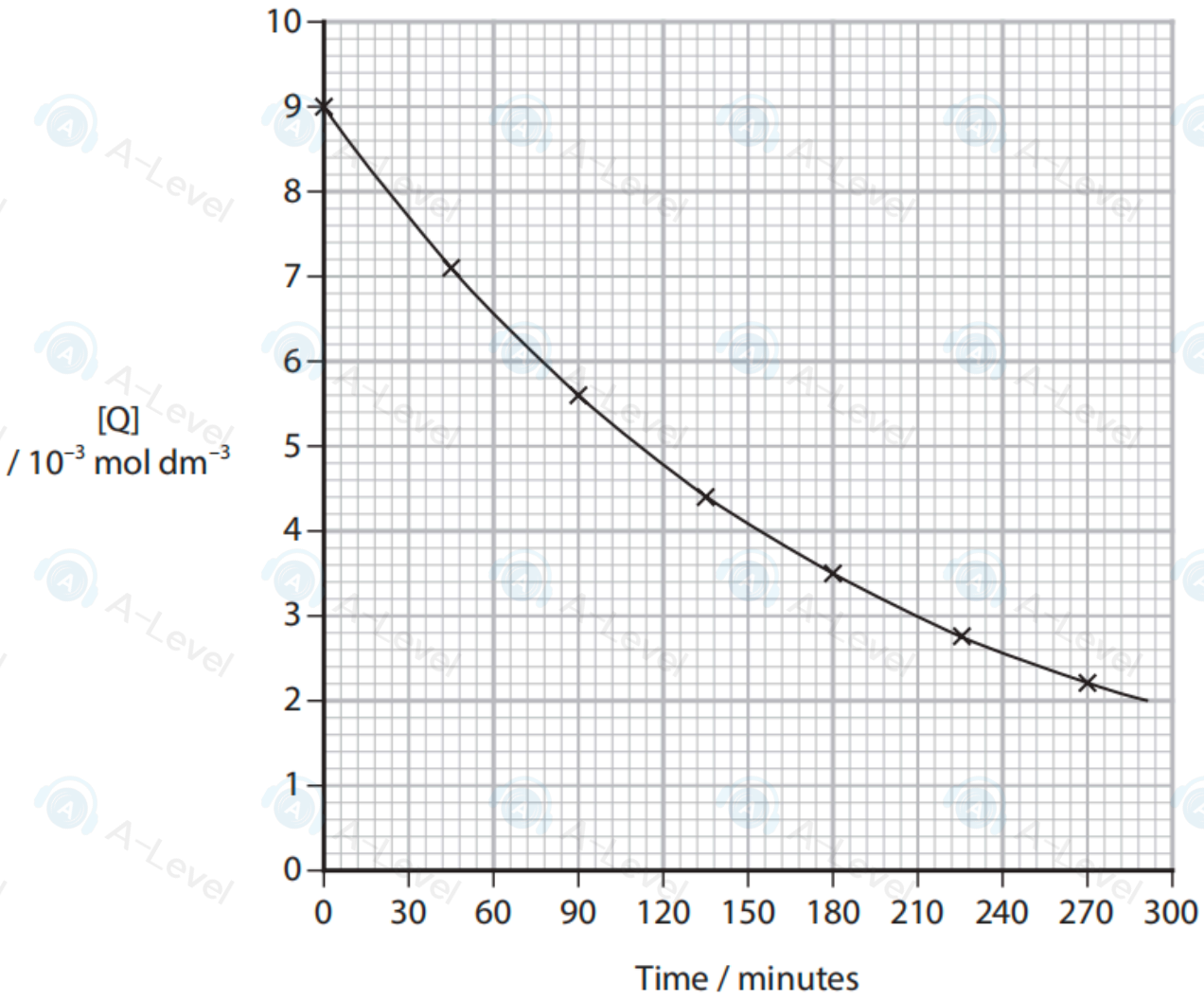
$$RCl + OH^- \rightarrow ROH + Cl^-$$

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** $(CH_3)_3CCH_2Cl$

15 A graph of the concentration of Q during decomposition is shown.



What is the half-life for this decomposition?

- ☒ **A** 93 minutes
- ☒ **B** 132 minutes
- ☒ **C** 146 minutes
- ☒ **D** 291 minutes

13: This question is about the equilibrium for the reaction shown.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -196\,kJ\,mol^{-1}$$

(a) Which is the expression for the equilibrium constant, K_p?

(1)

☒ **A** $K_p = \dfrac{2(pSO_3)}{2(pSO_2) \times (pO_2)}$

☒ **B** $K_p = \dfrac{[SO_3]^2}{[SO_2]^2 \times [O_2]}$

☒ **C** $K_p = \dfrac{(pSO_3)^2}{(pSO_2)^2 \times (pO_2)}$

☒ **D** $K_p = \dfrac{(pSO_2)^2 \times (pO_2)}{(pSO_3)^2}$

(b) Which statement about this equilibrium is correct?

(1)

☒ **A** increasing the pressure increases the value of K_p

☒ **B** decreasing the pressure decreases the equilibrium yield of SO_3

☒ **C** adding a catalyst increases the equilibrium yield of SO_3

☒ **D** adding a catalyst increases the value of K_p

(c) What is the relationship between the equilibrium constant, K, and ΔS_{total}?

(1)

☒ **A** $\Delta S_{total} = R \ln K$

☒ **B** $\ln \Delta S_{total} = R K$

☒ **C** $\Delta S_{total} = R \log K$

☒ **D** $\log \Delta S_{total} = R K$

5 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.

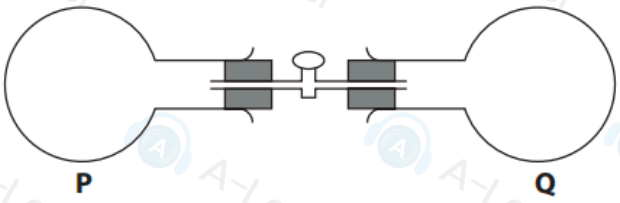
Which statement is true?

- ☒ **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

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

5 Two flasks, **P** and **Q**, are connected by a tube fitted with a tap.



Flask **P** contains argon gas and flask **Q** is in vacuum.
Assume argon behaves as an ideal gas and therefore has no intermolecular forces between its atoms.

How do the entropy and energy of the system change when the tap is opened and the argon fills both flasks?

	Entropy of the system	Energy of the system
☒ **A**	increases	decreases
☒ **B**	decreases	decreases
☒ **C**	increases	unchanged
☒ **D**	decreases	unchanged

(Total for Question 5 = 1 mark)

1 Two ways of writing an equation for the reaction between nitrogen monoxide and oxygen are shown.

$$2NO + O_2 \rightarrow 2NO_2 \qquad \text{Equation 1}$$

$$NO + \tfrac{1}{2}O_2 \rightarrow NO_2 \qquad \text{Equation 2}$$

(a) Which **pair** of rate equations could be correct for this reaction?

(1)

		Equation 1	Equation 2
☒	**A**	rate = $k[NO]^2[O_2]$	rate = $k[NO]^2[O_2]$
☒	**B**	rate = $k[NO]^2[O_2]$	rate = $k[NO][O_2]^{\frac{1}{2}}$
☒	**C**	rate = $k[NO_2]^2$	rate = $k[NO_2]^2$
☒	**D**	rate = $k[NO_2]^2$	rate = $k[NO_2]$

(b) Which two methods can be used for **continuous** monitoring of the progress of this reaction?

(1)

☒ **A** colorimetry and titration

☒ **B** colorimetry and volume change

☒ **C** mass change and volume change

☒ **D** mass change and titration

(Total for Question 1 = 2 marks)

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT W

10 This question is about the effect of changes on a system at equilibrium.

(a) The equation for the reaction between hydrogen and iodine is shown.

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

What is the effect, if any, of an **increase** in pressure on the appearance of the equilibrium mixture?

(1)

- ☒ **A** no change
- ☒ **B** the mixture becomes more purple
- ☒ **C** the mixture becomes more brown
- ☒ **D** the mixture becomes less brown

(b) The equation for the manufacture of ammonia by the Haber process is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H^{\ominus} = -92.2\,kJ\,mol^{-1}$$

(1)

$K_p = 6.76 \times 10^5\,atm^{-2}$ at 298 K

Which change(s), if any, will result in an **increase** in the value of K_p?

- ☒ **A** an increase in pressure only
- ☒ **B** a decrease in temperature only
- ☒ **C** an increase in pressure and an increase in temperature
- ☒ **D** no changes in pressure or temperature will affect the value of K_p

(c) The equation for the equilibrium between nitrogen dioxide and dinitrogen tetroxide is shown.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

A change in conditions results in K_p increasing from 0.115 atm to 3.89 atm.

What can be deduced about the change in position of the equilibrium?

(1)

- ☒ **A** the equilibrium position has shifted towards the products
- ☒ **B** the equilibrium position has shifted towards the reactants
- ☒ **C** the equilibrium position is unchanged
- ☒ **D** there is almost complete conversion of reactants into products

1 Which method would be most suitable to investigate the kinetics of the reactions shown?

(a) $(CH_3)_2C{=}CH_2(g) + HI(g) \rightarrow (CH_3)_3CI(g)$

(1)

- ☒ **A** colorimetry
- ☒ **B** measurement of change in volume
- ☒ **C** measurement of change in mass
- ☒ **D** quenching with ice-cold water followed by titrating with acid

(b) $HCOOCH_3(aq) + NaOH(aq) \rightarrow HCOONa(aq) + CH_3OH(aq)$

(1)

- ☒ **A** colorimetry
- ☒ **B** measurement of change in volume
- ☒ **C** measurement of change in mass
- ☒ **D** quenching with ice-cold water followed by titrating with acid

(Total for Question 1 = 2 marks)

DO NOT WRITE IN THIS AREA

3: Which of these substances would be expected to have the greatest standard molar entropy?

- ☒ **A** FeO
- ☒ **B** FeS
- ☒ **C** $FeCl_2$
- ☒ **D** $FeCl_3$

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

(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** $\frac{1}{16}$

9 The equation for the reaction between iron and steam is shown.

$$3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g) \qquad \Delta H = -151.2\,kJ\,mol^{-1}$$

(a) What is the equilibrium constant expression for this reaction?

(1)

☒ **A** $K_c = \dfrac{[Fe_3O_4] \times [H_2]^4}{[Fe]^3 \times [H_2O]^4}$

☒ **B** $K_c = \dfrac{[Fe_3O_4] \times [H_2]^4}{[H_2O]^4}$

☒ **C** $K_c = \dfrac{[H_2]^4}{[Fe]^3 \times [H_2O]^4}$

☒ **D** $K_c = \dfrac{[H_2]^4}{[H_2O]^4}$

(b) What is the effect on the equilibrium constant for this reaction if small pieces of iron are replaced by iron powder and if the temperature is increased?

(1)

	Iron powder used	Temperature increased
☒ **A**	K_c increases	K_c increases
☒ **B**	K_c unchanged	K_c increases
☒ **C**	K_c increases	K_c decreases
☒ **D**	K_c unchanged	K_c decreases

(Total for Question 9 = 2 marks)

3 Two chemicals, **E** and **F**, react to form products **G** and **H**.

$$\mathbf{E} + 2\mathbf{F} \rightarrow \mathbf{G} + \mathbf{H}$$

The mechanism for the reaction occurs in two steps via the formation of an intermediate **J**.

$$\mathbf{E} + \mathbf{F} \rightarrow \mathbf{J} \qquad \text{slow}$$

$$\mathbf{J} + \mathbf{F} \rightarrow \mathbf{G} + \mathbf{H} \qquad \text{fast}$$

What is the rate equation for the reaction?

☒ **A** rate = k[**E**][**F**]

☒ **B** rate = k[**E**][**F**]^2

☒ **C** rate = k[**F**][**J**]

☒ **D** rate = k[**E**][**F**]^2[**J**]

(Total for Question 3 = 1 mark)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NC

6 Heating copper(II) nitrate results in the equilibrium shown.

$$2Cu(NO_3)_2(s) \rightleftharpoons 2CuO(s) + 4NO_2(g) + O_2(g)$$

Which is the expression for K_p?

☒ **A** $K_p = \dfrac{2(pCuO) \times 4(pNO_2) \times (pO_2)}{2(pCu(NO_3)_2)}$

☒ **B** $K_p = \dfrac{(pCuO)^2 \times (pNO_2)^4 \times (pO_2)}{(pCu(NO_3)_2)^2}$

☒ **C** $K_p = 4(pNO_2) \times (pO_2)$

☒ **D** $K_p = (pNO_2)^4 \times (pO_2)$

(Total for Question 6 = 1 mark)

DO NOT WRITE IN THIS AREA

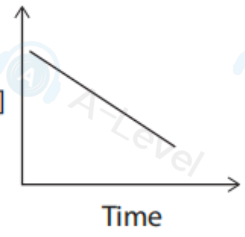
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

3 This question is about rates of chemical reactions.

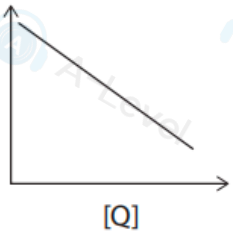
(a) Which graph shows a reaction that is zero order with respect to reactant Q?

(1)

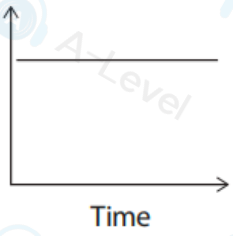
☒ **A**



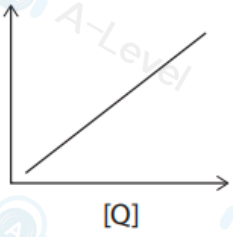
☒ **B**



☒ **C**



☒ **D**



(b) The equation for a gas phase reaction is shown.

$$A(g) \rightarrow B(g) + C(g)$$

The reaction is first order.
When the initial pressure of A is 2 atm the half-life of the reaction is 20 s.

What is the half-life of the reaction when the initial pressure of A is 4 atm?

(1)

☒ **A** 10 s

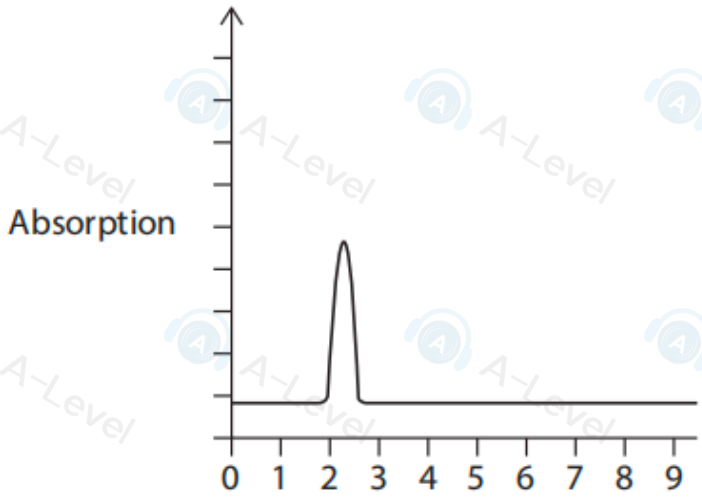
☒ **B** 20 s

☒ **C** 40 s

☒ **D** 400 s

(Total for Question 3 = 2 marks)

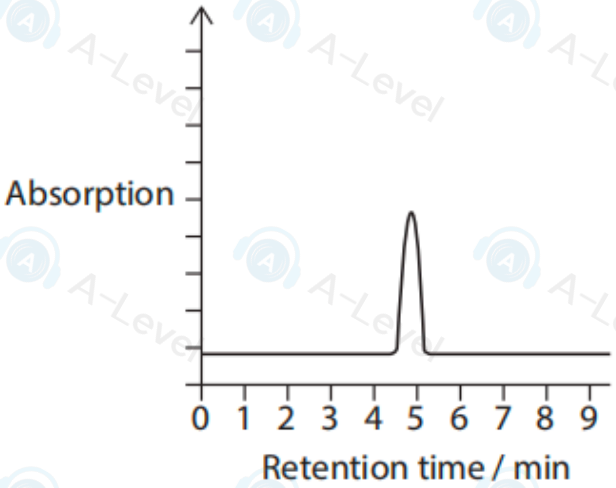
(c) A sample containing 2×10^{-9} g cm^{-3} of nandrolone was analysed using gas chromatography. The chromatogram produced is shown.



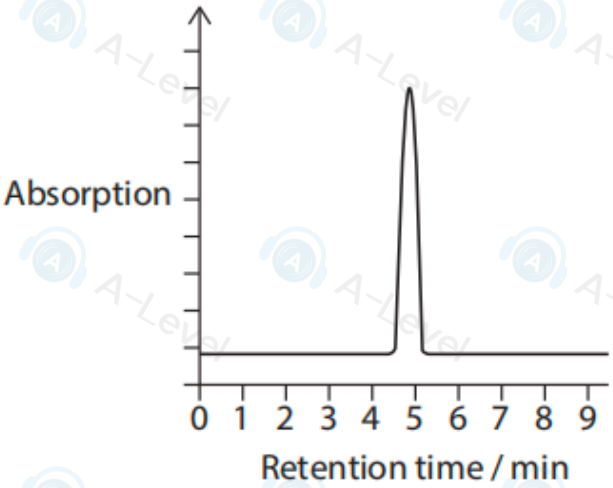
A second sample containing 4×10^{-9} g cm^{-3} of nandrolone was also analysed using gas chromatography, under the same conditions.

Which is the chromatogram produced by this second sample?

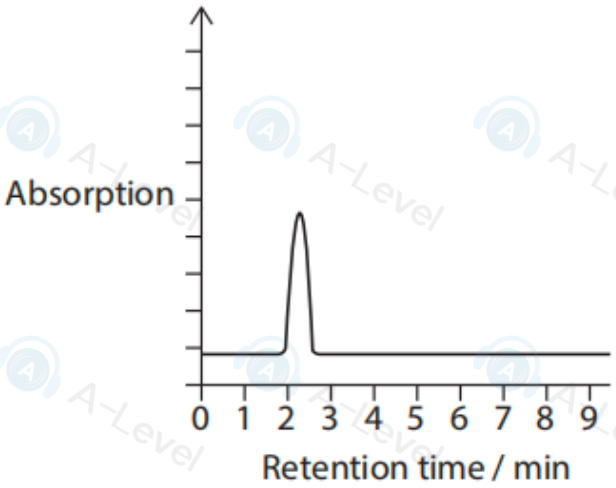
(1)



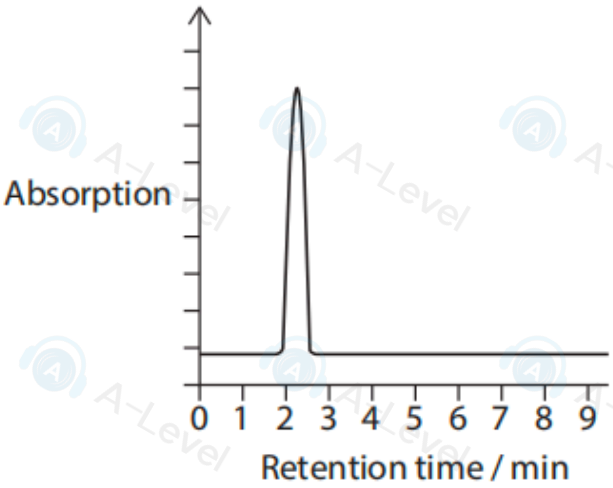
☒ **A**



☒ **B**



☒ **C**



☒ **D**

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

DO NOT WRITE IN THIS AREA

3 What are the units of K_p for the equilibrium shown?

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

☒ **A** atm^{-1}

☒ **B** atm

☒ **C** atm^{-2}

☒ **D** atm^2

(Total for Question 3 = 1 mark)

2 Nitrogen(V) oxide, N_2O_5, decomposes in a first order reaction.
At 45 °C, the half-life for this reaction is 1400 s.
In an experiment, the initial concentration of nitrogen(V) oxide is 1.0 mol dm^{-3}.

What is the concentration, in mol dm^{-3}, of nitrogen(V) oxide after 4200 s?

☒ **A** 0.875

☒ **B** 0.500

☒ **C** 0.250

☒ **D** 0.125

(Total for Question 2 = 1 mark)

DO NOT WRITE IN THIS AREA

6 Which equation represents the standard enthalpy change of atomisation of iodine?

- ☒ **A** $\frac{1}{2}I_2(s) \rightarrow I(g)$
- ☒ **B** $\frac{1}{2}I_2(g) \rightarrow I(g)$
- ☒ **C** $I_2(s) \rightarrow 2I(g)$
- ☒ **D** $I_2(g) \rightarrow 2I(g)$

10: The reaction shown is second order with respect to NO and first order with respect to O_2.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

If the concentration of NO is doubled and the concentration of O_2 is tripled, by what factor will the rate increase?

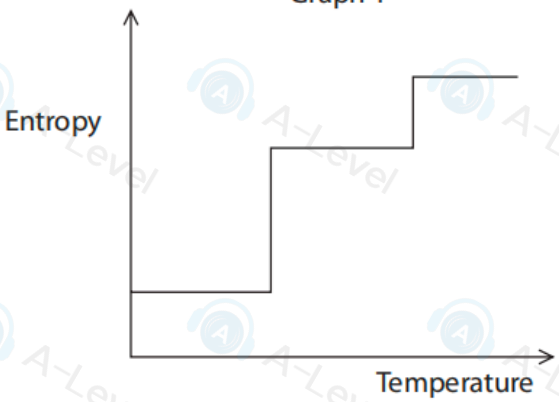
- ☒ **A** 6
- ☒ **B** 12
- ☒ **C** 18
- ☒ **D** 27

7 Which equation represents the second electron affinity of oxygen?

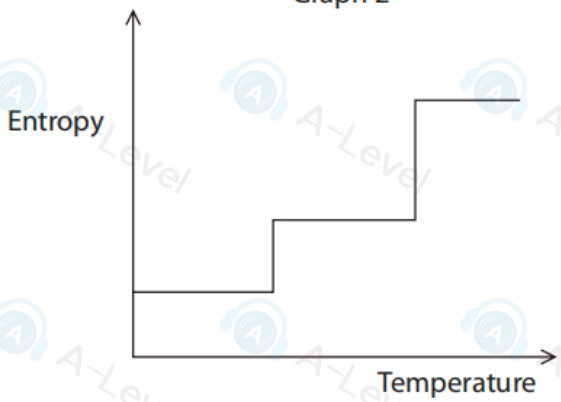
- ☒ **A** $O^-(g) + e^- \rightarrow O^{2-}(g)$
- ☒ **B** $O(g) + 2e^- \rightarrow O^{2-}(g)$
- ☒ **C** $O^+(g) \rightarrow O^{2+}(g) + e^-$
- ☒ **D** $O(g) \rightarrow O^{2+}(g) + 2e^-$

4 Which graph shows the entropy of a substance as it changes state from solid to liquid to gas?

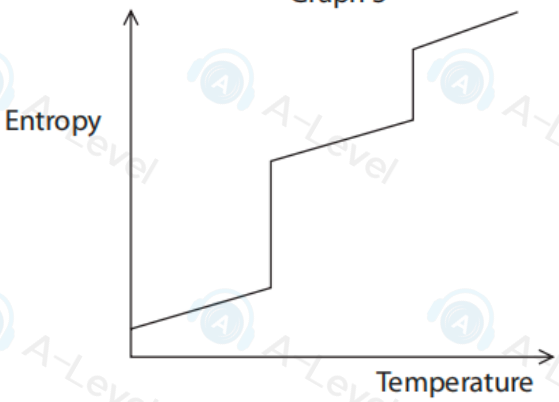
Graph 1



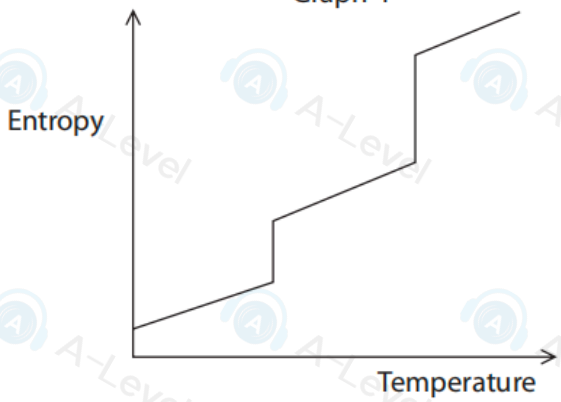
Graph 2



Graph 3



Graph 4



☒ **A** Graph 1

☒ **B** Graph 2

☒ **C** Graph 3

☒ **D** Graph 4

(Total for Question 4 = 1 mark)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO N

DO NOT WRITE IN TH

WRITE IN THIS AREA

7 The decomposition of hydrogen peroxide is catalysed by iodide ions.

$$2H_2O_2(aq) \xrightarrow{I^-} 2H_2O(l) + O_2(g)$$

The mechanism for this reaction is shown.

Step 1: $H_2O_2(aq) + I^-(aq) \rightleftharpoons IO^-(aq) + H_2O(l)$ fast

Step 2: $H_2O_2(aq) + IO^-(aq) \rightarrow I^-(aq) + H_2O(l) + O_2(g)$ slow

What is the rate equation for this reaction?

☒ **A** rate = $k[H_2O_2]^2[I^-]$

☒ **B** rate = $k[H_2O_2][I^-]$

☒ **C** rate = $k[H_2O_2]^2[I^-][IO^-]$

☒ **D** rate = $k[H_2O_2][IO^-]$

(Total for Question 7 = 1 mark)

1 The equation for a reaction is shown.

$$A(g) + 2B(g) \rightleftharpoons 3C(s) + 4D(g)$$

(a) Some collisions between reactant molecules do not lead to the formation of products.

What is the best explanation for this?

(1)

☒ **A** the reactant concentrations are too low

☒ **B** the collisions do not have sufficient energy

☒ **C** the reaction is at equilibrium

☒ **D** the molecules do not collide in the correct ratio

(b) What are the units of the equilibrium constant, K_p, for this reaction?

(1)

☒ **A** atm

☒ **B** atm^{-1}

☒ **C** atm^4

☒ **D** atm^{-4}

(Total for Question 1 = 2 marks)

IN THIS AREA

DO NOT WRITE IN THIS AREA

5 One of the stages in the manufacture of sulfuric acid involves the oxidation of sulfur dioxide to sulfur trioxide.
The equation for this reaction can be written in either of the two ways shown.

Equation **1** $2SO_2 + O_2 \rightleftharpoons 2SO_3$

Equation **2** $SO_2 + \frac{1}{2}O_2 \rightleftharpoons SO_3$

The value of K_p at 25°C using Equation **1** is $4.0 \times 10^{24}\,atm^{-1}$.

(a) What is the numerical value of K_p at 25°C using Equation **2**?

(1)

- ☒ **A** 2.0×10^{12}
- ☒ **B** 2.0×10^{22}
- ☒ **C** 2.0×10^{24}
- ☒ **D** 4.0×10^{24}

(b) The relationship between K_p and K_c is shown.

$$K_c = \frac{K_p}{(R \times T)^{\Delta n}}$$

where T is the temperature in kelvin,
R is the gas constant $0.082\,dm^3\,atm\,mol^{-1}\,K^{-1}$ and
Δn = moles of product – moles of reactants.

What is the value of K_c at 25°C for the equilibrium using Equation **1**?

(1)

- ☒ **A** 1.64×10^{23}
- ☒ **B** 1.95×10^{24}
- ☒ **C** 8.20×10^{24}
- ☒ **D** 9.77×10^{25}

6 What are the signs of the entropy changes at 373 K when water vapour condenses?

$$H_2O(g) \rightarrow H_2O(l)$$

		ΔS_{system}	$\Delta S_{surroundings}$
☒	**A**	positive	positive
☒	**B**	positive	negative
☒	**C**	negative	positive
☒	**D**	negative	negative

(Total for Question 6 = 1 mark)

3 Ammonia is produced by the reaction of nitrogen with hydrogen in the presence of an iron catalyst.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Which of the following statements about the catalyst is **not** correct?

(1)

☒ **A** it lowers the activation energy of the reaction

☒ **B** it has no effect on the equilibrium constant for the reaction

☒ **C** it alters the enthalpy change of the reaction

☒ **D** it reduces the energy cost of the reaction

(b) Which conditions favour the highest percentage of ammonia in an equilibrium mixture from identical amounts of nitrogen and hydrogen?

(1)

☒ **A** a temperature of 400 K and a pressure of 200 kPa

☒ **B** a temperature of 400 K and a pressure of 200 atm

☒ **C** a temperature of 400 °C and a pressure of 200 kPa

☒ **D** a temperature of 400 °C and a pressure of 200 atm

(Total for Question 3 = 2 marks)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

20 Nitrous oxide, N_2O, decomposes at high temperature to form nitrogen and oxygen.

$$N_2O(g) \rightleftharpoons N_2(g) + \tfrac{1}{2}O_2(g)$$

(a) (i) Some standard molecular entropy data are shown.

Substance	Standard molecular entropy $S^{\ominus}$ / $JK^{-1}mol^{-1}$
nitrogen, N_2	192
oxygen, O_2	205
nitrous oxide, N_2O	220

Calculate the standard entropy change of the system for the decomposition shown.
Include a sign and units in your answer.

(2)

(ii) The standard enthalpy change of the forward reaction is $-82\,kJ\,mol^{-1}$.

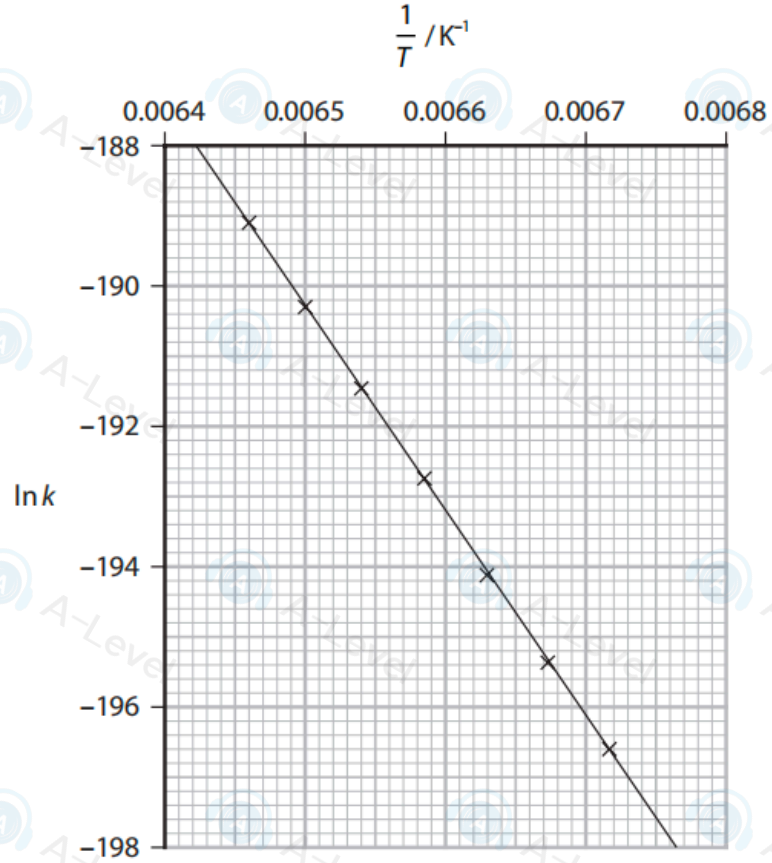
Calculate the entropy change of the surroundings at 2048 K.
Include a sign and units in your answer.

(2)

(iii) Calculate the total entropy change of the reaction at 2048 K.
Include a sign and units in your answer.

(1)

(b) Rate experiments on the decomposition of nitrous oxide produced the following graph.



Calculate the activation energy for the reaction in kJ mol^{-1}.
Include the value of the gradient.

$$\ln k = -\frac{E_a}{R}\frac{1}{T} + \text{constant}$$

$R = 8.31\ \text{JK}^{-1}\ \text{mol}^{-1}$

(2)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

(c) Explain whether or not this reaction occurs at 2048 K by considering the values calculated in (a) and (b).

(2)

.....

.....

.....

.....

(Total for Question 20 = 9 marks)

14: This question is about nitrosyl chloride, NOCl, which is a yellow gas.
Nitrosyl chloride decomposes into yellow-green chlorine, Cl_2, and colourless nitric oxide, NO, as shown.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

(a) A mixture of nitrosyl chloride, chlorine and nitric oxide was placed in a sealed container and allowed to reach equilibrium.

Explain what you would expect to **see** when the pressure of the equilibrium mixture is increased.

(2)

.....

.....

.....

.....

.....

(b) 0.250 mol of nitrosyl chloride in a 500 cm^3 sealed container was heated to 200 °C. At equilibrium there was 0.016 mol of chlorine in the mixture.

(i) Write the expression for the equilibrium constant K_c.

(1)

(ii) Complete the table using the equilibrium equation and the data.

(2)

Substance	NOCl	NO	Cl_2
Initial mol	0.250	0	0
Equilibrium mol			0.016
Concentration / mol dm^3			

(iii) Using your answers from (b)(i) and (b)(ii), calculate the equilibrium constant, K_c.
Give your answer to an appropriate number of significant figures and include units.

(3)

(iv) When the temperature is reduced, the value of the equilibrium constant, K_c, becomes smaller.

Explain what can be deduced about the nature of the reaction.

(2)

15 This question is about some compounds of silicon.

(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)

.....

.....

.....

.....

.....

(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 $JK^{-1}\,mol^{-1}$.

(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)

.....

.....

.....

(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)

(ii) Silane has a molecular structure.

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

(i) Calculate the entropy change of the system, ΔS_{system}, in $JK^{-1}mol^{-1}$, 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)

.....

.....

.....

.....

19 Many effervescent products such as vitamin tablets are solids which contain citric acid, $C_6H_8O_7$, and sodium hydrogencarbonate. Only when these tablets are added to water is fizzing observed. The equation for the reaction is shown.

$$C_6H_8O_7 + 3NaHCO_3 \rightarrow 3H_2O + 3CO_2 + Na_3C_6H_5O_7$$

(a) Give **two** reasons why this reaction is thermodynamically feasible when considering the entropy of the system.

(2)

(b) Describe, in terms of the particles involved, why the reaction does not occur until the tablets are dissolved in water.

(3)

(c) For the reaction at 25°C, the standard entropy change of the surroundings, $\Delta S^{\ominus}_{surroundings} = -234.9\,J\,K^{-1}\,mol^{-1}$.

Calculate the enthalpy change of the reaction.
Include a sign and units in your answer.

(2)

(d) The enthalpy change of solution, $\Delta_{sol}H$, of sodium hydrogencarbonate is $+18.6\,kJ\,mol^{-1}$.

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 sodium hydrogencarbonate in water.

Fully label your diagram.

(3)

20 Cracking reactions are used to obtain more useful compounds from the alkanes found in crude oil. An equation for the cracking of butane is shown.

$$C_4H_{10}(g) \rightarrow C_2H_6(g) + C_2H_4(g)$$

Thermodynamic data for the compounds in this reaction are given in the table.

	$C_4H_{10}(g)$	$C_2H_6(g)$	$C_2H_4(g)$
Standard molar entropy $S^{\ominus}$ / $JK^{-1}mol^{-1}$	310.1	229.5	219.5
Standard molar enthalpy change of formation $\Delta_f H^{\ominus}$ / $kJ\,mol^{-1}$	−126.5	−84.7	+52.2

(a) (i) Calculate the entropy change in the system, $\Delta S^{\ominus}_{system}$, for the cracking of butane.
Include a sign and units with your answer.

(2)

(ii) Calculate the enthalpy change of reaction, $\Delta_r H^{\ominus}$, for the cracking of butane.
Include a sign and units with your answer.

(2)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

(iii) Calculate the entropy change in the surroundings, $\Delta S^{\ominus}_{\text{surroundings}}$, at 298 K for the cracking of butane, using your answer to (a)(ii).
Include a sign and units with your answer.

(2)

(iv) Calculate the total entropy change, $\Delta S^{\ominus}_{\text{total}}$, at 298 K for the cracking of butane, using your answers to (a)(i) and (a)(iii).
Include a sign and units with your answer.

(1)

(v) Calculate the temperature at which the cracking reaction becomes feasible.

(2)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

(b) 5 mol of butane is cracked at 750 K. At equilibrium, 4.45 mol of ethene is formed and the total pressure is 1.20 atm.

$$C_4H_{10}(g) \rightleftharpoons C_2H_6(g) + C_2H_4(g)$$

(i) Give the expression for the equilibrium constant, K_p, for this reaction.

(1)

(ii) Calculate the value of K_p, including units if required.

(5)

(Total for Question 20 = 15 marks)

DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA
DO NOT WRITE IN THIS AREA

20 This question is about Group 2 compounds.

(a) Barium carbonate, $BaCO_3$, decomposes at high temperatures as shown.

$$BaCO_3(s) \rightarrow BaO(s) + CO_2(g)$$

(i) Calculate the standard entropy change for the system, $\Delta S^{\ominus}_{system}$.

Compound	Standard molar entropy / $J\,K^{-1}\,mol^{-1}$
$BaCO_3$	112.1
BaO	70.4
CO_2	213.6

(2)

(ii) The lowest temperature at which barium carbonate, $BaCO_3$, decomposes is 712 °C.

Use this information and your answer from (a)(i) to calculate the standard enthalpy change of the reaction, in $kJ\,mol^{-1}$.
Give your answer to an appropriate number of significant figures.

(3)

(b) Magnesium chloride, $MgCl_2(s)$, is used in the manufacture of tofu from soya milk.

An experiment was carried out to determine the enthalpy change of solution, $\Delta_{sol}H$, of anhydrous magnesium chloride, $MgCl_2(s)$.
4.26 g of anhydrous magnesium chloride was added to 200 cm^3 of deionised water in a polystyrene cup. The mixture was stirred to ensure all the solid dissolved to form a solution.
The temperature of the solution rose by 6.8 °C.

Calculate the enthalpy change of solution, $\Delta_{sol}H$, of anhydrous magnesium chloride, $MgCl_2(s)$.
Include a sign and units with your answer.

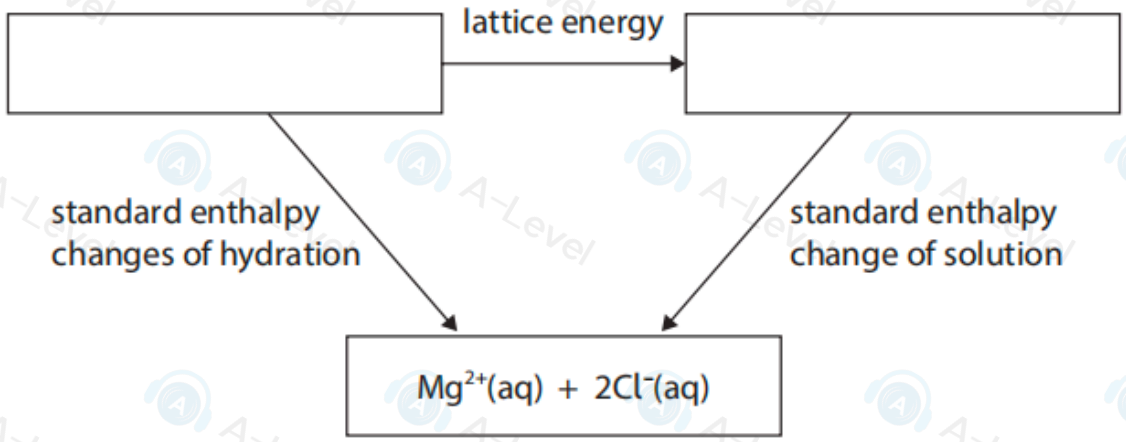
[Specific heat capacity of the solution = 4.18 $J\,g^{-1}\,°C^{-1}$]

(3)

(c) The standard enthalpy change of solution, $\Delta_{sol}H^{\ominus}$, of anhydrous $MgCl_2(s)$, can also be determined using a Hess Cycle.

(i) Complete the Hess Cycle shown by adding appropriate formulae, with state symbols, to the empty boxes.

(1)



[Lattice energy = −2526 kJ mol^{-1}
Standard enthalpy change of hydration of magnesium ions = −1920 kJ mol^{-1}]

(ii) Calculate the standard enthalpy change of hydration of chloride ions, $\Delta_{hyd}H^{\ominus}[Cl^-(g)]$, using the cycle and data in (c)(i) and your answer to (b).

[If you did not obtain a final answer to (b) use a value of $-155\ kJ\,mol^{-1}$. This is not the correct value.]

(3)

(d) The theoretical lattice energy for magnesium chloride, $MgCl_2(s)$, is $-2326\ kJ\,mol^{-1}$.

(i) Give **two** assumptions used in theoretical calculations of lattice energy.

(2)

.....

.....

.....

.....

.....

(ii) Explain the difference between the theoretical and experimental values for the lattice energy of magnesium chloride, $MgCl_2(s)$.

(3)

(e) Hydrated barium chloride is a soluble, toxic salt. It can be formed from the reaction of barium carbonate with hydrochloric acid as shown.

$$BaCO_3 + 2HCl + nH_2O \rightarrow BaCl_2 \cdot nH_2O + CO_2 + H_2O$$

A 5.00 g sample of barium carbonate reacted with 120 cm^3 of 0.500 mol dm^{-3} hydrochloric acid.

(i) Show that the hydrochloric acid is in excess in this reaction.

(2)

(ii) All of the barium carbonate reacted and produced 6.19 g of hydrated barium chloride.

Calculate the relative formula mass of $BaCl_2 \cdot nH_2O$ and hence deduce the value of n.

(3)

19: This question is about some copper compounds.

(a) Crystals of hydrated copper(II) sulfate, $CuSO_4 \cdot 5H_2O$, lose water when heated, forming anhydrous copper(II) sulfate, $CuSO_4$.

$$CuSO_4 \cdot 5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(l)$$

Substance	$CuSO_4 \cdot 5H_2O(s)$	$CuSO_4(s)$	$H_2O(l)$
Standard enthalpy of formation, $\Delta_f H^{\ominus}$ / kJ mol^{-1}	−2279.6	−771.4	−285.8
Standard molar entropy, $S^{\ominus}$ / J K^{-1} mol^{-1}	300.4	109.0	69.9

(i) Using the data in the table, calculate the standard enthalpy change, $\Delta_r H^{\ominus}$, for this reaction.

(2)

(ii) Using the data in the table, calculate the standard molar entropy change, $\Delta S^{\ominus}_{system}$, for this reaction.

(2)

(iii) Using your answers from (a)(i) and (a)(ii), calculate the **lowest** temperature at which hydrated copper(II) sulfate will decompose.

(3)

(b) Hydrated copper(II) sulfate is soluble in water. A student carried out an experiment to determine its enthalpy change of solution.

100 g of distilled water was placed in a polystyrene cup and the temperature recorded.

21.36 g of hydrated copper sulfate was added to the distilled water, the mixture stirred, and the minimum temperature recorded.

Using this data, the student's calculated enthalpy change of solution was $+12.3\ kJ\ mol^{-1}$.

Calculate the temperature change in this experiment.

[specific heat capacity of the solution is $3.7\ J\ g^{-1}\ °C$
total mass of solution = 121.36 g
molar mass of $CuSO_4 \cdot 5H_2O = 249.6\ g\ mol^{-1}$]

(4)

(b) Hydrated copper(II) sulfate is soluble in water. A student carried out an experiment to determine its enthalpy change of solution.

100 g of distilled water was placed in a polystyrene cup and the temperature recorded.

21.36 g of hydrated copper sulfate was added to the distilled water, the mixture stirred, and the minimum temperature recorded.

Using this data, the student's calculated enthalpy change of solution was +12.3 kJ mol^{-1}.

Calculate the temperature change in this experiment.

[specific heat capacity of the solution is 3.7 $Jg^{-1}°C$
total mass of solution = 121.36 g
molar mass of $CuSO_4 \cdot 5H_2O$ = 249.6 g mol^{-1}]

(4)

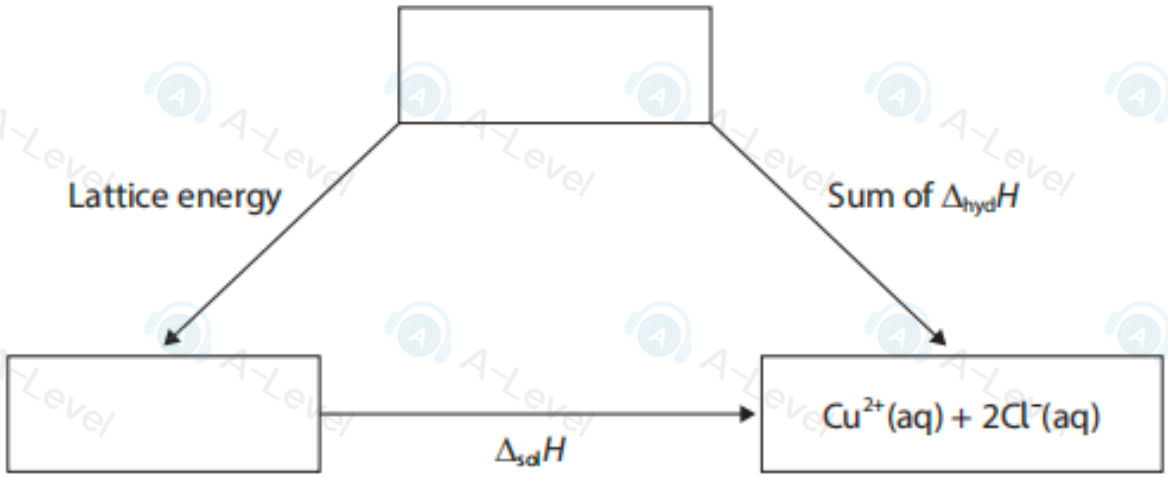
(c) Copper(II) chloride, $CuCl_2$, is another copper compound that is soluble in water. It is possible to calculate the enthalpy change of solution, $\Delta_{sol}H$, using a Hess cycle and the lattice energy and enthalpy changes of hydration, $\Delta_{hyd}H$.

(i) Explain what is meant by the term **enthalpy change of hydration**.

(2)

(ii) Complete the Hess cycle by filling in the empty boxes.

(1)



(iii) Complete the expression for the enthalpy change of solution using the enthalpy changes of hydration and lattice energy.

(1)

$\Delta_{sol}H =$

(iv) The lattice energy of copper(II) chloride is $-2811\ kJ\ mol^{-1}$.
Use this value, the data in the table, and your expression in (c)(iii) to calculate the enthalpy change of solution.

(2)

Ion	Enthalpy change of hydration / $kJ\ mol^{-1}$
Cu^{2+}	−2100
Cl^{-}	−378

(v) The enthalpy change of hydration of Cu^+ is $-593\ kJ\ mol^{-1}$.
Explain why the hydration enthalpy of Cu^+ is much less exothermic than Cu^{2+}.

(2)

(Total for Question 19 = 19 marks)

TOTAL FOR SECTION C = 19 MARKS
TOTAL FOR PAPER = 90 MARKS