

1. 9701\_m17\_qp\_42 Q4

- 4 (a) Chlorine dioxide undergoes the following reaction in aqueous solution.



The initial rate of the reaction was measured at different initial concentrations of  $\text{ClO}_2$  and  $\text{OH}^-$ . The table shows the results obtained.

experiment	[ClO <sub>2</sub> ] /mol dm <sup>-3</sup>	[OH <sup>-</sup> ] /mol dm <sup>-3</sup>	initial rate /mol dm <sup>-3</sup> s <sup>-1</sup>
1	$1.25 \times 10^{-2}$	$1.30 \times 10^{-3}$	$2.33 \times 10^{-4}$
2	$2.50 \times 10^{-2}$	$1.30 \times 10^{-3}$	$9.34 \times 10^{-4}$
3	$2.50 \times 10^{-2}$	$2.60 \times 10^{-3}$	$1.87 \times 10^{-3}$

- (i) Use the data in the table to determine the rate equation, showing the order with respect to each reactant. Show your reasoning.

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rate equation = ..... [3]

- (ii) Calculate the value of the rate constant,  $k$ , using the data from experiment 2. State its units.

$k = \dots$  units  $\dots$  [2]

- (b) (i) Explain the difference between heterogeneous and homogeneous catalysts.

[1]

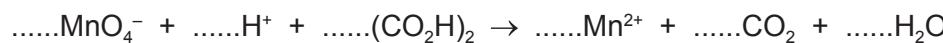
- (ii) Complete the table using ticks (✓) to indicate whether the catalyst used in the reaction is heterogeneous or homogeneous.

catalysed reaction	heterogeneous	homogeneous
manufacture of ammonia in the Haber process		
removal of nitrogen oxides from car exhausts		
oxidation of sulfur dioxide in the atmosphere		

[2]

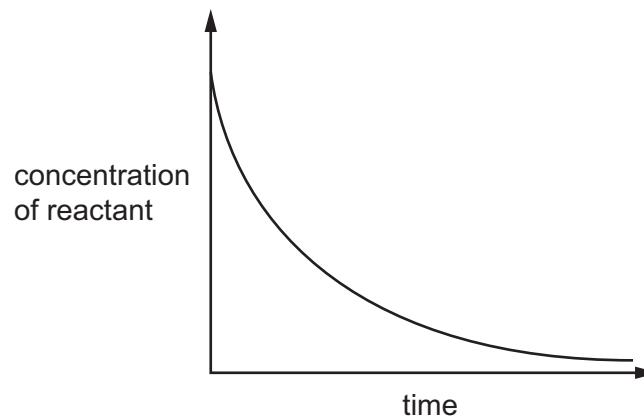
- (c) Some reactions are catalysed by one of the products of the reaction. This is called autocatalysis. An example of autocatalysis is the reaction between acidified manganate(VII) ions,  $\text{MnO}_4^-$ , and ethanedioic acid,  $(\text{CO}_2\text{H})_2$ .  $\text{Mn}^{2+}$  ions catalyse this reaction. The reaction is slow in the absence of a catalyst.

- (i) Balance the equation for this reaction.

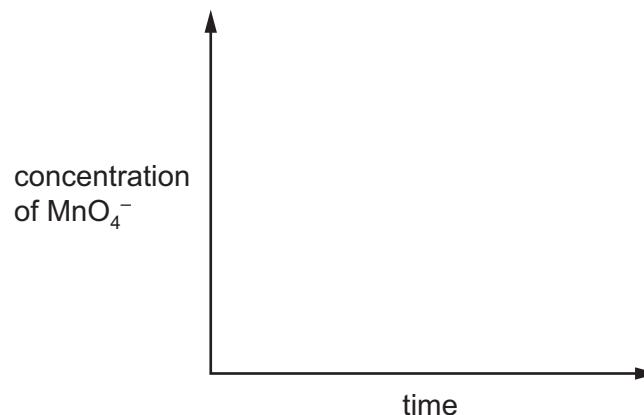


[2]

- (ii) The graph shown is a concentration-time graph for a typical reaction.



On the axes below, sketch the curve you would expect for the autocatalysed reaction in (i).



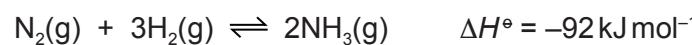
[2]

- (d) (i) Describe, with the aid of a reaction pathway diagram, the effect of a catalyst on a reversible reaction. Suggest why catalysts are used in industrial processes.

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.....  
.....

[3]

- (ii) The reaction for the Haber process to produce ammonia is shown.



At 500 °C, when pressure is measured in atmospheres, the numerical value of  $K_p$  for this equilibrium is  $1.45 \times 10^{-5}$ .

- Write the expression for  $K_p$  for this equilibrium.

$$K_p =$$

- Calculate the partial pressure of  $\text{NH}_3$  at equilibrium at 500 °C, when the partial pressure of  $\text{N}_2$  is 20 atm and that of  $\text{H}_2$  is 60 atm.

$$p_{\text{NH}_3} = \dots \text{ atm}$$

[2]

[Total: 17]

## 2. 9701\_s22\_qp\_43 Q1

- 1 (a) The solubility of the Group 2 sulfates decreases down the group.

Explain this trend.

.....  
.....  
.....  
.....

[3]

- (b) Describe what is observed when magnesium and barium are reacted separately with an excess of dilute sulfuric acid.

magnesium .....

barium .....

[1]

- (c) The solubility product,  $K_{\text{sp}}$ , of  $\text{BaSO}_4$  is  $1.08 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$  at 298 K.

Calculate the solubility of  $\text{BaSO}_4$  in g per  $100 \text{ cm}^3$  of solution.

solubility of  $\text{BaSO}_4$  = ..... g per  $100 \text{ cm}^3$  of solution

[2]

(d) (i) The equation for the formation of a gaseous sulfate ion is shown.



Calculate the standard enthalpy change of formation,  $\Delta H_f^\ominus$ , of  $SO_4^{2-}(g)$ . It may be helpful to draw a labelled energy cycle. Use relevant data from Table 1.1 in your calculations.

**Table 1.1**

energy change	value / kJ mol <sup>-1</sup>
lattice energy of barium sulfate, $BaSO_4(s)$	-2469
standard enthalpy change of formation of barium sulfate	-1473
standard enthalpy change of atomisation of barium	+180
first ionisation energy of barium	+503
second ionisation energy of barium	+965
standard enthalpy change of atomisation of sulfur	+279
standard enthalpy change for $S(g) \rightarrow S^{2-}(g)$	+440
standard enthalpy change for $O(g) \rightarrow O^{2-}(g)$	+657
$O=O$ bond energy	+496

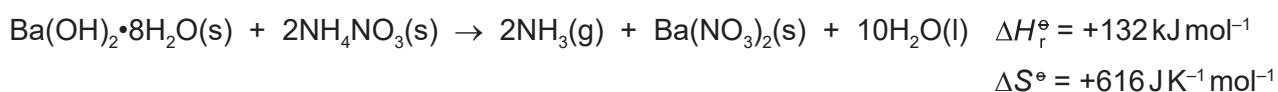
$$\Delta H_f^\ominus \text{ of } SO_4^{2-}(g) = \dots \text{ kJ mol}^{-1} \quad [3]$$

- (ii) Suggest how the lattice energy of  $\text{BaSO}_4(\text{s})$  differs from the lattice energy of  $\text{Cs}_2\text{SO}_4(\text{s})$ . Explain your answer.

.....  
.....  
..... [2]

- (e) The reaction of solid hydrated barium hydroxide,  $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ , with ammonium salts is endothermic.

- (i) Calculate the **minimum** temperature at which the reaction of  $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$  with  $\text{NH}_4\text{NO}_3$  becomes feasible. Show all your working.



$$\text{temperature} = \dots \text{ }^\circ\text{C} \quad [2]$$

- (ii) Barium hydroxide reacts readily with ammonium chloride on mixing at room temperature.



Some relevant standard entropies are given in Table 1.2.

**Table 1.2**

substance	$\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$	$\text{NH}_4\text{Cl}(\text{s})$	$\text{NH}_3(\text{g})$	$\text{BaCl}_2 \cdot 2\text{H}_2\text{O}(\text{s})$	$\text{H}_2\text{O}(\text{l})$
$S^\circ / \text{JK}^{-1} \text{ mol}^{-1}$	427	95	192	203	70

Calculate the standard Gibbs free energy change,  $\Delta G^\circ$ , for this reaction at 25 °C.

$$\Delta G^\circ = \dots \text{ kJ mol}^{-1} \quad [3]$$

[Total: 16]

## 3. 9701\_w18\_qp\_41 Q4

- 4 (a) The enthalpy change of solution,  $\Delta H_{\text{sol}}^{\circ}$ , of the Group 2 sulfates becomes more endothermic down the group.

State and explain the trend in the solubility of the Group 2 sulfates down the group.

.....  
 .....  
 .....  
 .....  
 ..... [3]

- (b) (i) Write the expression for  $K_w$ , the ionic product of water.

$$K_w =$$

[1]

- (ii) The numerical value of  $K_w$  increases with increasing temperature.

Place a tick (✓) in the appropriate column in each row to show the effect of increasing the temperature of water on the pH and on the ratio  $[\text{H}^+]:[\text{OH}^-]$ .

effect of increasing temperature of water	decrease	stay the same	increase
pH			
ratio $[\text{H}^+]:[\text{OH}^-]$			

[2]

- (c) An aqueous solution of sodium hydroxide has a pH of 13.25 at 298 K.

Calculate the concentration of this sodium hydroxide solution.

$$\text{concentration} = \dots \text{ mol dm}^{-3}$$

- (d) Buffer solutions are used to regulate the pH of a solution to keep its pH value within a narrow range.

Write **two** equations to describe how hydrogencarbonate ions,  $\text{HCO}_3^-$ , and carbonic acid,  $\text{H}_2\text{CO}_3$ , control the pH of blood.

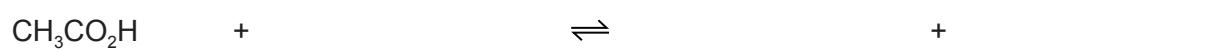
.....  
.....

[2]

- (e) The  $K_a$  for ethanoic acid is  $1.75 \times 10^{-5} \text{ mol dm}^{-3}$  at 298 K.

- (i) When ethanoic acid is dissolved in water, an equilibrium mixture containing two acid-base pairs is formed.

Write an equation for this equilibrium. In the boxes label each species acidic or basic to show its behaviour in this equilibrium.



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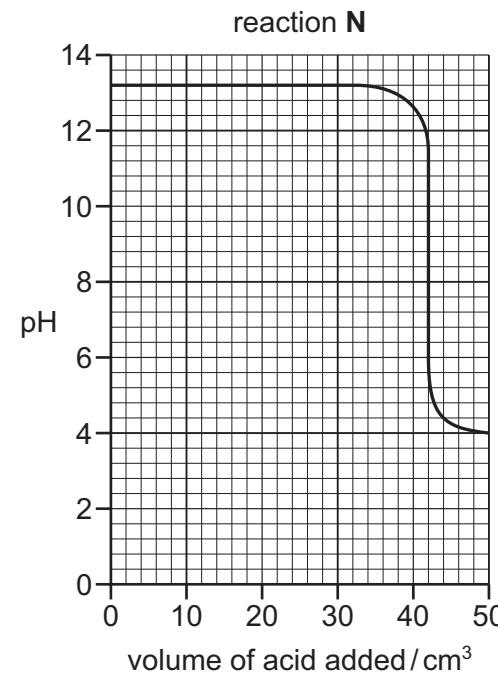
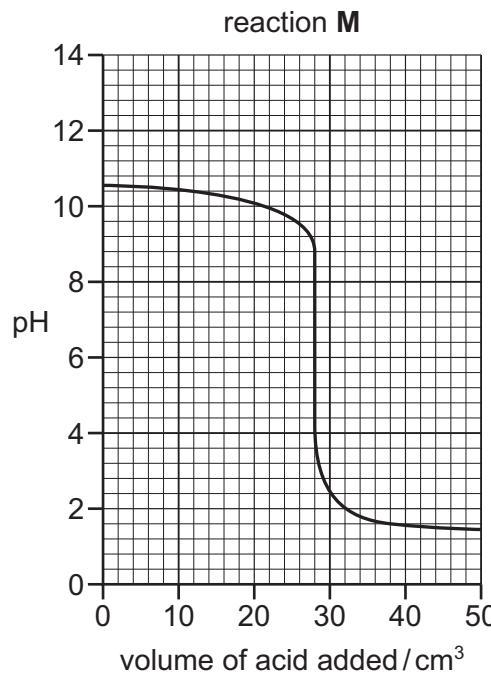
[2]

- (ii) A buffer solution was prepared by adding  $30.0 \text{ cm}^3$  of  $0.25 \text{ mol dm}^{-3}$  ethanoic acid, an excess, to  $20.0 \text{ cm}^3$  of  $0.15 \text{ mol dm}^{-3}$  sodium hydroxide.

Calculate the pH of the buffer solution formed at 298 K. Give your answer to **one** decimal place.

pH = ..... [4]

- (f) Titration curves for two different acid-base reactions, **M** and **N**, are shown.



- (i) Use the titration curve for reaction **M** to deduce the volume of acid added at the end-point for this titration.

volume of acid added at the end-point = ..... cm<sup>3</sup> [1]

- (ii) The table shows some acid-base indicators.

name of indicator	pH range of colour change
malachite green	0.2–1.8
bromocresol green	3.8–5.4
bromothymol blue	6.0–7.6
thymolphthalein	9.3–10.6

Name a suitable indicator for each of the acid-base titrations **M** and **N**. Explain your answers.

reaction **M** ..... reaction **N** .....

explanation .....

[2]

[Total: 19]

## 4. 9701\_w20\_qp\_41 Q4

- 4 (a) (i) Give the mathematical expression for each of the terms pH and  $K_w$ .

pH = .....

$K_w$  = ..... [2]

- (ii) Calculate the pH of 0.027 mol dm<sup>-3</sup> NaOH(aq).

pH = ..... [1]

- (b) The  $K_a$  value of chloric(I) acid, HClO, is  $3.72 \times 10^{-8}$  mol dm<sup>-3</sup>.

Calculate the pH of 0.010 mol dm<sup>-3</sup> HClO(aq).

pH = ..... [1]

- (c) Water and octan-1-ol form two layers when mixed.

Ethanamide is more soluble in water than it is in octan-1-ol. When 1.00 g of ethanamide is added to 50.0 cm<sup>3</sup> of water and this is then shaken with 50.0 cm<sup>3</sup> of octan-1-ol, it is found that the water layer contains 0.935 g of ethanamide at equilibrium.

- (i) Calculate the partition coefficient,  $K_{pc}$ , for ethanamide in water and octan-1-ol.

$K_{pc}$  = ..... [1]

- (ii) The 50.0 cm<sup>3</sup> of water containing 0.935 g of ethanamide is then shaken with 100.0 cm<sup>3</sup> of pure octan-1-ol under the same conditions.

Calculate the mass of ethanamide that is dissolved in the 100.0 cm<sup>3</sup> of octan-1-ol at equilibrium.

mass of ethanamide = ..... g  
[2]

[Total: 7]

## 5. 9701\_m19\_qp\_42 Q2

- 2 (a) The following table lists the solubilities of the hydroxides and carbonates of some of the Group 2 elements, M, at 25 °C.

element M	solubility / mol dm <sup>-3</sup>	
	M(OH) <sub>2</sub>	MCO <sub>3</sub>
Mg	$2.0 \times 10^{-4}$	$1.5 \times 10^{-3}$
Ca	$1.5 \times 10^{-2}$	$1.3 \times 10^{-4}$
Sr	$3.4 \times 10^{-2}$	$7.4 \times 10^{-5}$
Ba	$1.5 \times 10^{-1}$	$9.1 \times 10^{-5}$

- (i) Explain why the solubility of the Group 2 hydroxides, M(OH)<sub>2</sub>, increases down the group.

.....  
 .....  
 .....  
 .....  
 ..... [3]

- (ii) Suggest a reason for the general decrease in the solubility of the Group 2 carbonates, MCO<sub>3</sub>, down the group.

..... [1]

- (iii) When carbon dioxide is passed through a saturated solution of calcium hydroxide (limewater), a white precipitate of calcium carbonate is formed.

Use the data in the table to deduce, for **each** of Mg, Sr and Ba, whether or not a saturated solution of its hydroxide could also be used to test for carbon dioxide.  
 Explain your answer. No calculations are required.

.....  
 .....  
 .....  
 .....  
 ..... [2]

- (b) (i) Calculate the value of the solubility product,  $K_{\text{sp}}$ , of magnesium hydroxide at 25 °C.

$$K_{\text{sp}} = \dots \quad [2]$$

- (ii) State what would be observed if a few drops of a saturated solution of barium hydroxide are added to a saturated solution of barium carbonate. Explain your answer.

observation .....

explanation .....

.....  
[2]

- (c) The equation for the formation of the gaseous hydroxide ion is shown.



Use data in the table and from the *Data Booklet* to calculate  $\Delta H_f^\circ(\text{OH}^-(\text{g}))$ . You might find it useful to construct a Born-Haber cycle.

enthalpy change	$\Delta H^\circ / \text{kJ mol}^{-1}$
atomisation of Mg(s)	+148
formation of Mg(OH) <sub>2</sub> (s)	-925
lattice energy of Mg(OH) <sub>2</sub> (s)	-2993

$$\Delta H_f^\circ(\text{OH}^-(\text{g})) = \dots \text{ kJ mol}^{-1} \quad [3]$$

[Total: 13]

**6. 9701\_m18\_qp\_42 Q1**

- 1 (a) (i) State how the solubilities of the hydroxides of the Group 2 elements vary down the group.

..... [1]

- (ii) Explain the factors that are responsible for this variation.

.....  
.....  
.....  
.....

..... [3]

- (b) The solubility of  $\text{Sr}(\text{OH})_2$  is  $3.37 \times 10^{-2} \text{ mol dm}^{-3}$  at  $0^\circ\text{C}$ .

- (i) Write an expression for the solubility product of  $\text{Sr}(\text{OH})_2$ .

$$K_{\text{sp}} =$$

[1]

- (ii) Calculate the value of  $K_{\text{sp}}$  at  $0^\circ\text{C}$ . Include units in your answer.

$$K_{\text{sp}} = \dots \text{ units} = \dots$$

[2]

(c) Metal peroxides contain the  $\text{-O-O-}$  ion.

The peroxides of the Group 2 elements,  $\text{MO}_2$ , decompose on heating to produce a single gas and the solid oxide,  $\text{MO}$ , only.

(i) Write an equation for the thermal decomposition of strontium peroxide,  $\text{SrO}_2$ .

..... [1]

(ii) Suggest how the temperature at which thermal decomposition of  $\text{MO}_2$  occurs varies down Group 2.

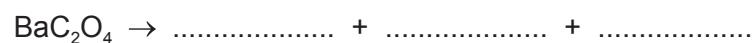
Explain your answer.

.....  
.....  
.....  
.....

..... [3]

(d) (i) The ethanedioates of the Group 2 elements,  $\text{MC}_2\text{O}_4$ , decompose on heating to produce a mixture of two different gases and the solid oxide,  $\text{MO}$ , only.

Complete the equation for the thermal decomposition of barium ethanedioate.



[1]

(ii) Describe **two** observations you would make during the reaction when ethanedioic acid,  $\text{H}_2\text{C}_2\text{O}_4$ , is warmed with acidified manganate(VII) ions.

.....  
.....  
.....  
.....

[2]

[Total: 14]

**7. 9701\_w19\_qp\_43 Q5**

**5** Silver sulfide,  $\text{Ag}_2\text{S}$ , is very insoluble in water.

(a) (i) Write an expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Ag}_2\text{S}(\text{s})$ .

$$K_{\text{sp}} =$$

[1]

(ii) The solubility of  $\text{Ag}_2\text{S}(\text{s})$  in water at 298 K is  $1.16 \times 10^{-17} \text{ mol dm}^{-3}$ .

Calculate the numerical value of the solubility product,  $K_{\text{sp}}$ , of  $\text{Ag}_2\text{S}(\text{s})$  at 298 K.

$$K_{\text{sp}} = \dots \quad [2]$$

(iii) Calculate the minimum volume of water needed to dissolve 1.00 g of  $\text{Ag}_2\text{S}(\text{s})$  under standard conditions.

$$\text{volume} = \dots \text{ dm}^3 \quad [2]$$

(b) Bromic(I) acid, HOBr(aq), is a weak acid. Its  $K_a$  is  $2.0 \times 10^{-9} \text{ mol dm}^{-3}$ .

(i) Calculate the pH of  $0.20 \text{ mol dm}^{-3}$  HOBr(aq).

pH = ..... [2]

(ii)  $5.0 \text{ cm}^3$  of  $0.20 \text{ mol dm}^{-3}$  potassium hydroxide, KOH, are added to  $20.0 \text{ cm}^3$  of  $0.20 \text{ mol dm}^{-3}$  HOBr(aq).

Calculate the pH of the buffer solution produced.

pH = ..... [2]

[Total: 9]

## 8. 9701\_w18\_qp\_42 Q4

- 4 (a) Calcium nitride,  $\text{Ca}_3\text{N}_2$ , reacts readily with water to form a white precipitate suspended in an alkaline solution. The oxidation number of nitrogen does not change during the reaction.

Construct an equation for the reaction of  $\text{Ca}_3\text{N}_2$  with water.

..... [2]

- (b) The enthalpy changes of solution,  $\Delta H_{\text{sol}}^{\ominus}$ , of the hydroxides of the Group 2 elements become less endothermic down the group.

State and explain the trend in the solubilities of the Group 2 hydroxides.

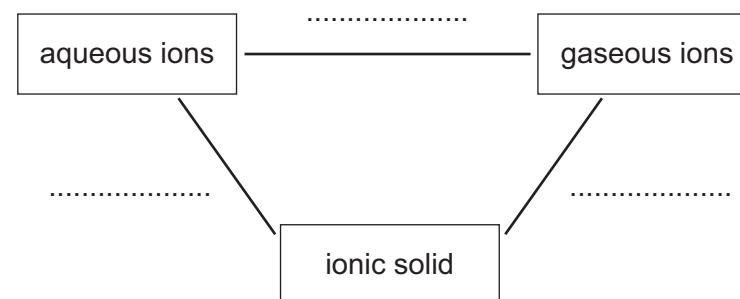
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.....  
.....

..... [3]

- (c) Complete the energy cycle to show the enthalpy changes that occur in the transformations between aqueous ions, gaseous ions and an ionic solid.

On your diagram label each enthalpy change with its appropriate symbol; lattice energy,  $\Delta H_{\text{latt}}^{\ominus}$ , enthalpy change of hydration,  $\Delta H_{\text{hyd}}^{\ominus}$ , or enthalpy change of solution,  $\Delta H_{\text{sol}}^{\ominus}$ .

Complete the three arrows showing the correct direction of each enthalpy change.



[3]

(d) The numerical value of the solubility product,  $K_{\text{sp}}$ , of  $\text{CaF}_2$  is  $3.45 \times 10^{-11}$  at 298 K.

(i) Write an expression for the solubility product of  $\text{CaF}_2$ . Include its units.

$$K_{\text{sp}} =$$

units = .....

[2]

(ii) Calculate the solubility of  $\text{CaF}_2$  at 298 K.

solubility = ..... mol dm<sup>-3</sup> [1]

[Total: 11]

**9. 9701\_w17\_qp\_42 Q2**

- 2 (a) When water is added to magnesium nitride,  $\text{Mg}_3\text{N}_2$ , the products are a white suspension of  $\text{Mg}(\text{OH})_2$  and an alkaline gas.

(i) Write an equation for this reaction.

..... [1]

- (ii) A 2.52 g sample of  $\text{Mg}_3\text{N}_2$  is added to an excess of water.

Calculate the mass of  $\text{Mg}(\text{OH})_2$  formed.

mass of  $\text{Mg}(\text{OH})_2$  = ..... g [2]

- (b) State and explain how the solubility of the Group 2 hydroxides varies down the group.

.....  
.....  
.....  
.....  
..... [4]

- (c) Magnesium hydroxide is sparingly soluble in water. The concentration of its saturated solution at 298 K is  $1.7 \times 10^{-4} \text{ mol dm}^{-3}$ .

(i) Write an expression for the solubility product,  $K_{\text{sp}}$ , of  $\text{Mg}(\text{OH})_2$ .

$$K_{\text{sp}} =$$

[1]

- (ii) Calculate the value of  $K_{\text{sp}}$  for  $\text{Mg}(\text{OH})_2$  at 298 K and state its units.

$$K_{\text{sp}} = \dots \text{ units} \dots [2]$$

- (d) The temperature at which the Group 2 hydroxides and carbonates start to decompose increases down the group.

Suggest an explanation for this trend in the decomposition temperature of the Group 2 hydroxides.

.....  
.....  
.....

[2]

[Total: 12]

## 10. 9701\_s19\_qp\_41 Q5

- 5 (a) Chlorate(I) ions undergo the following reaction under aqueous conditions.



A series of experiments was carried out at different concentrations of  $\text{ClO}^-$  and  $\text{NH}_3$ .

The table shows the results obtained.

experiment	$[\text{ClO}^-]$ /mol dm <sup>-3</sup>	$[\text{NH}_3]$ /mol dm <sup>-3</sup>	initial rate /mol dm <sup>-3</sup> s <sup>-1</sup>
1	0.200	0.100	0.256
2	0.400	0.200	2.05
3	0.400	0.400	8.20

- (i) Use the data in the table to determine the order with respect to each reactant,  $\text{ClO}^-$  and  $\text{NH}_3$ .

Show your reasoning.

.....  
 .....  
 .....  
 .....  
 .....  
 .....  
 .....  
 .....  
 ..... [2]

- (ii) Write the rate equation for this reaction.

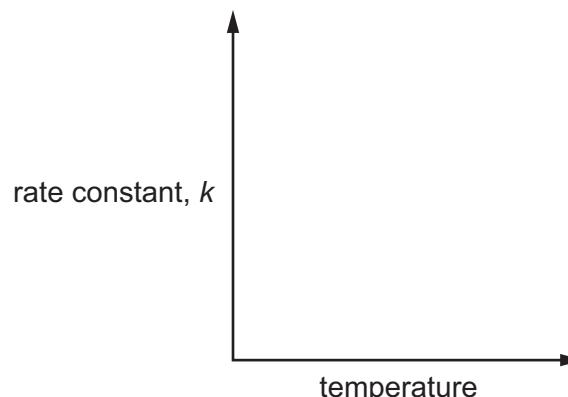
$$\text{rate} = \dots \quad [1]$$

- (iii) Use the results of experiment 1 to calculate the rate constant,  $k$ , for this reaction. Include the units of  $k$ .

$$k = \dots$$

$$\text{units} = \dots \quad [2]$$

- (iv) On the axes sketch a graph to show how the value of  $k$  changes as temperature is increased.



[1]

- (b) In another experiment, the reaction between chlorate(I) ions and iodide ions in aqueous alkali was investigated.

A solution of iodide ions in aqueous alkali was added to a large excess of chlorate(I) ions and  $[I^-]$  was measured at regular intervals.

- (i) Describe how the results of this experiment can be used to confirm that the reaction is first-order with respect to  $[I^-]$ .

.....  
.....  
.....

[2]

A three-step mechanism for this reaction is shown.



- (ii) Use this mechanism to deduce the overall equation for this reaction.

..... [1]

- (iii) Identify a step that involves a redox reaction. Explain your answer.

.....  
.....

[1]

[Total: 10]