ABBOTSLEIGH

2
Centre Number

Student Number

2025 **YEAR 12 ASSESSMENT TASK 1 - DEPTH STUDY**

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 90 minutes
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A formulae sheet, data sheet and Periodic Table are provided at the back of this paper

Total marks: 50

Section I – **25 marks** (pages 2 – 7)

- Attempt Questions 1–7
- Allow about 40 minutes for this section

Section II – **25 marks** (pages 10–17)

- Attempt Questions 8–14
- Allow about 50 minutes for this section

Section I

25 marks
Attempt Questions 1–7
Allow about 40 minutes for this part.

Multiple Choice Questions (3 marks)

Circle the correct option below for Questions 1 – 3.

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1 Which one of the following is an example of an equilibrium system?

A. Burning propane gas in a barbeque.

B. A saturated solution of sodium chloride.

C. The production of glucose by photosynthesis.

D. Reacting magnesium with oxygen in a Bunsen flame.

2 Which of the following statements is always true of a system at dynamic equilibrium?

A. The rates of the forward and reverse reactions are equal.

B. The concentration of reactants and products are equal.

C. The forward and reverse reactions are no longer occurring.

D. The concentration of reactants and products changes constantly.

3 You have modelled examples of static and dynamic equilibrium.

Which of the examples below is an example of a model of dynamic equilibrium?

A. Marbles rolling down a slope into a bucket.

B. Water evaporating from a swimming pool being replaced with water from a hose.

C. Water evaporating from a tree being replaced by water from the ground through the tree's roots.

D. Two groups of students lining up opposite each other across a basketball court swapping sides one at a time.

Short Answer Questions (22 marks)

Answer the questions in the spaces provided. These spaces provide guidance for the expected length of responses.

Show all relevant working in questions involving calculations.

Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Question 4 (4 marks)

Phosphorus pentachloride gas sets up an equilibrium with phosphorus trichloride and chlorine gas according to the following equation:

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

Initially 0.20 moles of PCl_5 were placed into a closed, 1.0 L container and allowed to come to equilibrium at constant temperature. The concentration of Cl_2 was measured to be 0.15 M once equilibrium had been established under these conditions.

(a) Write an expression for the equilibrium constant for this reaction. **1**

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(b) Calculate the equilibrium constant, K_{eq}, for this system under these conditions. **3**

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Question 5 (6 marks)

The equilibrium between aqueous ammonia molecules, $NH_3(aq)$ and ammonium ions, $NH_4^+(aq)$ in solution is shown below.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

This equilibrium mixture contains hydroxide ions, $OH^-(aq)$, high concentrations of these ions in solution makes it basic. Phenolphthalein indicator is used to detect the presence of OH^- in solution as the indicator turns pink in high concentrations of OH^-. The indicator will remain clear and colourless when lower concentrations of OH^- are in solution.

Equal volumes of a sample of this equilibrium mixture were added to two test tubes and two drops of Phenolphthalein indicator were added to each test tube. Different conditions were imposed on the equilibrium mixtures and the observations are recorded in the table below.

Test tube	*Initial colour of solution*	*Condition imposed on the equilibrium mixture*	*Final colour of solution*
1	Pink	Addition of 2.0 g $NH_4Cl(s)$	Clear and colourless
2	Pink	Addition of 2.0 g $NaCl(s)$	Pink

(a) Explain the observations observed in both test tubes with reference to Le Chatelier's principle. **3**

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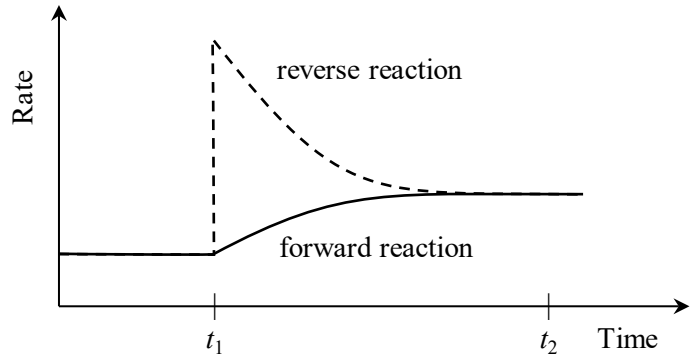
Question 5 continues on page 5

(b) The graph below shows the rate time graph for the forward and reverse reactions of the equilibrium system established in Test Tube 1. At time t_1 the change was imposed on the equilibrium system. **3**



Using collision theory, account for the shape of the rate-time graph below for the reverse reaction from time t_1 to t_2.

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End of Question 5

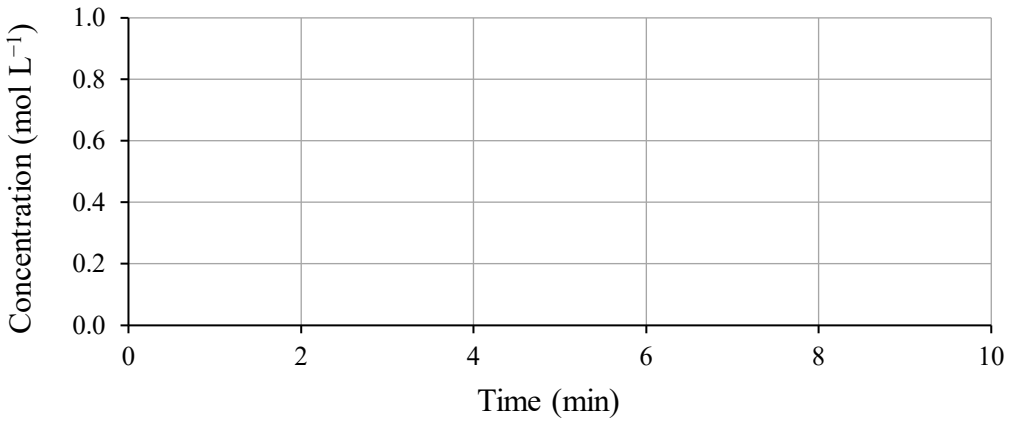
Question 6 (7 marks)

Sulfur trioxide, $SO_3(g)$, is made by the reaction of sulfur dioxide, $SO_2(g)$, and oxygen gas, $O_2(g)$, according to the following equation.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H^{\ominus} = -198 \text{ kJ mol}^{-1}$$

At time $t = 0$ min, $[SO_3(g)] = 0.4$ mol L^{-1} and the reaction mixture was at equilibrium. After 2 minutes, the volume of the reaction vessel was halved and at 4 minutes the system had reestablished equilibrium and $[SO_3(g)]$ had changed by 0.1 mol L^{-1}. At $t = 6$ min, $O_2(g)$ gas was removed from the system and equilibrium was reestablished at 8 minutes. While the system was reestablishing equilibrium, $[O_2(g)]$ was known to change by 0.1 mol L^{-1}. The new equilibrium position was maintained until 10 minutes.

(a) On the axes provided, sketch a graph to show how $[SO_3(g)]$ changes in the reaction vessel between $t = 0$ min and $t = 10$ min. **4**



(b) A manufacturer wishes to modify the reaction conditions of an industrial process that produces $SO_3(g)$ to maximise the production of this gas. **3**

Explain any changes the manufacturer could make to pressure and temperature to maximise yield of $SO_3(g)$.

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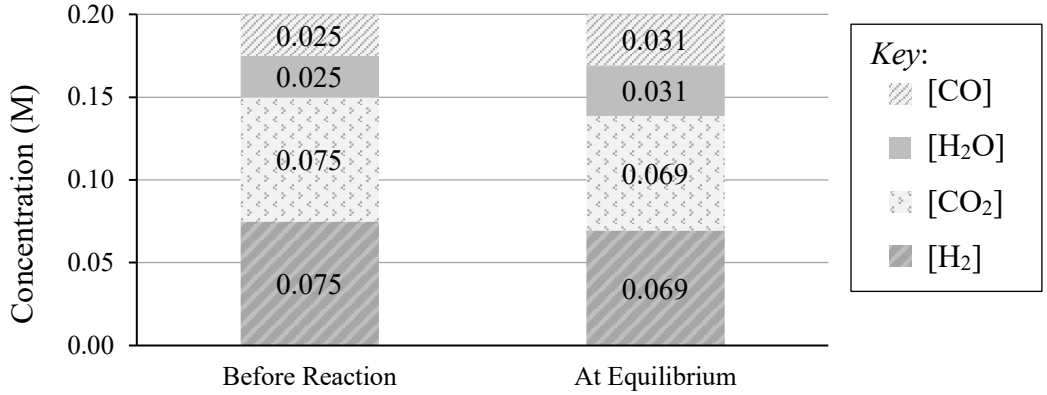
Question 7 (5 marks)

The water-gas shift reaction describes the reaction of carbon monoxide and water vapour (steam) at very high temperatures to form carbon dioxide and hydrogen.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

The concentrations of a reaction mixture are shown in the graph below before and after reaching equilibrium at 700 K.



(a) Using the data, calculate the value of K_{eq} for this reaction at 700 K. **2**

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(b) Calculate the reaction quotient before the reaction and use this to justify the direction in which the reaction will proceed to reach equilibrium. **3**

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End of Section I

Section I Extra writing space

If you use this space, clearly indicate which question you are answering.

2025 YEAR 12 TASK 1 – DEPTH STUDY

2
Centre Number

Student Number

Chemistry

Section II Answer Booklet

Analysis of the Cobalt chloride equilibrium system

25 marks
Attempt Questions 8–14
Allow about 50 minutes for this section

Instructions

- Write your Student Number at the top of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Please turn over

Use the following information to answer Questions 8 – 14.

Analysis of the Cobalt Complexation Equilibrium System

A solution of cobalt(II) ions in water appears maroon red in colour due to the formation of the complex ion $[Co(H_2O)_6]^{2+}(aq)$. When chloride ions in the form of hydrochloric acid are added to the solution, the colour changes due to the formation of a blue complex ion $[CoCl_4]^{2-}(aq)$.

This reaction is shown in the equation below.

Cobalt complexation:

$$\underset{\text{maroon red}}{[Co(H_2O)_6]^{2+}(aq)} + 4Cl^-(aq) \rightleftharpoons \underset{\text{blue}}{[CoCl_4]^{2-}(aq)} + 6H_2O(l)$$

The following methodology was carried out.

A stock solution of 0.0764 M $CoCl_2.6H_2O$ was prepared by accurately weighing the solid reagent on an analytical balance and then diluting to volume in a volumetric flask with distilled water.

The dissolution of this solid is shown below.

$$CoCl_2.6H_2O(s) \xrightarrow{H_2O} \underset{\text{maroon red}}{[Co(H_2O)_6]^{2+}(aq)} + 2Cl^-(aq)$$

A 25.00 mL aliquot of this solution was pipetted into a clean 50.00 mL volumetric flask, and the solution diluted to volume with concentrated (12.1 M) HCl.

The absorbance spectrum of this solution, along with a solvent blank, was collected at 5 different temperatures (10°C, 20°C, 30°C, 40°C, 50°C) using a spectrophotometer. Water baths were used for temperature control, and 5 minutes of equilibrium time was allotted between data collection.

The concentration of the blue complex $[CoCl_4]^{2-}(aq)$ was detected in the equilibrium solution at each temperature, by measuring its absorbance at 690 nm.

You may assume that under the conditions of this experiment, the only species present within the solution are those present in the equilibrium mentioned above, and that $[CoCl_4]^{2-}(aq)$ is the only species that absorbs at 690 nm.

Questions continue on page 11

Question 8 (2 marks)

Risk Assessment

Consider the following information from *RiskAssess.*

Hydrochloric acid, 10.0-12.1 M (32-37% w/w), concentrated HCl(aq)

Class: 8 **PG:** II **Training:** 1-5 UN: 1789 CAS: 7647-01-0

GHS data:

DANGER

Causes severe skin burns and eye damage
May cause respiratory irritation

Potential hazards
HIGHLY CORROSIVE TO EYES, LUNGS, GUT AND SKIN. Evolves highly lung-irritant HCl gas. Do not mix hydrochloric acid with formaldehyde solution, since highly carcinogenic bis(chloromethyl) ether is formed. Do not mix hydrochloric acid with acetone and hydrogen peroxide solution, since dangerously explosive acetone peroxide may be formed.

Standard handling procedures
Avoid inhalation of vapour or skin contact. Handle in a fume cupboard if possible; otherwise a well-ventilated area. Do not breathe vapour. Avoid splashes in eyes or on skin. Use sulfuric acid rather than hydrochloric acid as a catalyst for the preparation of urea-formaldehyde polymer.

Disposal
Retain for collection by a waste service or <10 mL/day may be poured, with stirring, into 100 times the volume of water, then poured down the drain. Residues should be placed in an Acid waste container.

Identify ONE risk associated with the use of concentrated hydrochloric acid solution (12.1 M HCl) and explain how a named safety precaution would minimise this risk. **2**

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Question 9 (3 marks)

Chemicals used to prepare equilibrium mixture

Consider the solution preparation details given in the methodology on page 10.

(a) Calculate the initial concentration of $[Co(H_2O)_6]^{2+}(aq)$ in the $CoCl_2.6H_2O$/HCl stock solution after dilution. **1**

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(b) Calculate the initial total concentration of $Cl^-(aq)$ in the $CoCl_2.6H_2O$/HCl stock solution after dilution. Be sure to consider both sources of chloride ions. **2**

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Question 10 (4 marks)

Hypothesis

Refer to the equation below as you answer this question.

$$\underset{\text{maroon red}}{[Co(H_2O)_6]^{2+}}(aq) + 4Cl^-(aq) \rightleftharpoons \underset{\text{blue}}{[CoCl_4]^{2-}}(aq) + 6H_2O(l)$$

Across the limited range of temperatures investigated within this experiment, $\Delta S^{\ominus}$ values are reasonably small and positive while $\Delta G^{\ominus}$ values are reasonably large and positive.

(a) Predict the sign of the enthalpy change ($\Delta H^{\ominus}$) for this complexation reaction. **2**

Provide an explanation for your prediction.

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(b) Predict any changes to the colour of the solution that would be observed as the temperature of the equilibrium mixture increases. **2**

Justify these observations with reference to Le Chatelier's principle.

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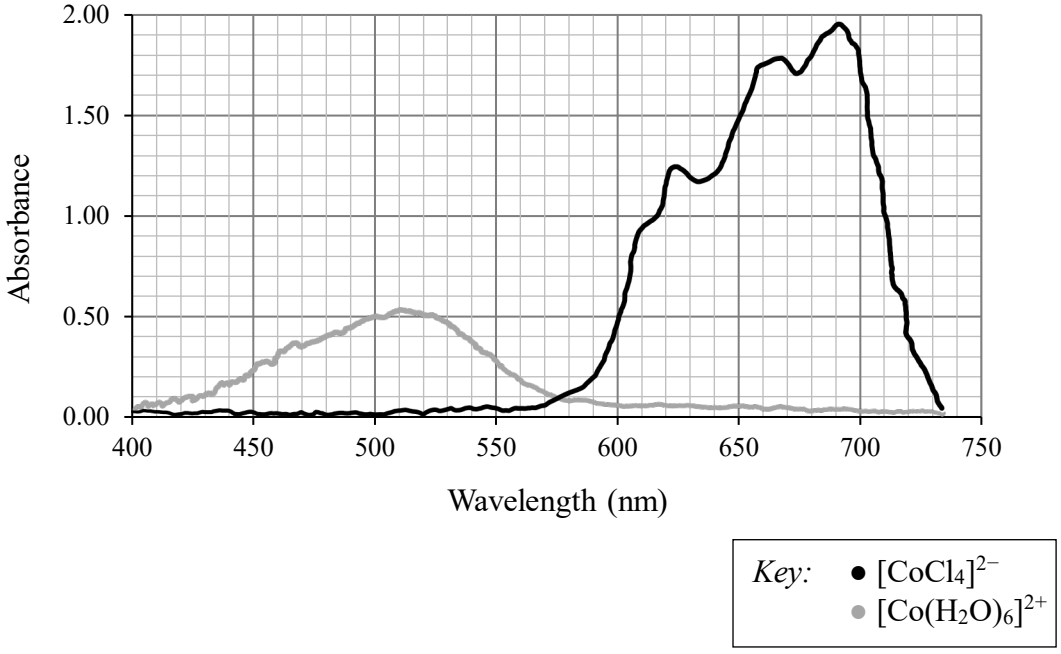
Question 11 (2 marks)

Assessing the validity of measuring absorbance at 690 nm

In the equilibrium mixture analysed in this investigation there are two coloured cobalt species present, $[Co(H_2O)_6]^{2+}(aq)$ and $[CoCl_4]^{2-}(aq)$. You may assume these are the only coloured ions present in solution.

The graph below shows the visible spectra for each of the cobalt species in solution at 25°C in aqueous solution.

Visible spectra for the cobalt species at 25°C



During this investigation, the concentration of $[CoCl_4]^{2-}(aq)$ was determined by measuring the absorbance at 690 nm. **2**

Using the graph above to support your answer, justify on the validity of this step.

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Question 12 (6 marks)

Preparation of a calibration curve to determine the concentration of $[CoCl_4]^{2-}(aq)$

Use the following data collected from the experiment to answer this question.

A series of solutions containing known concentrations of $[CoCl_4]^{2-}(aq)$ were prepared and their absorbances measured at 690 nm.

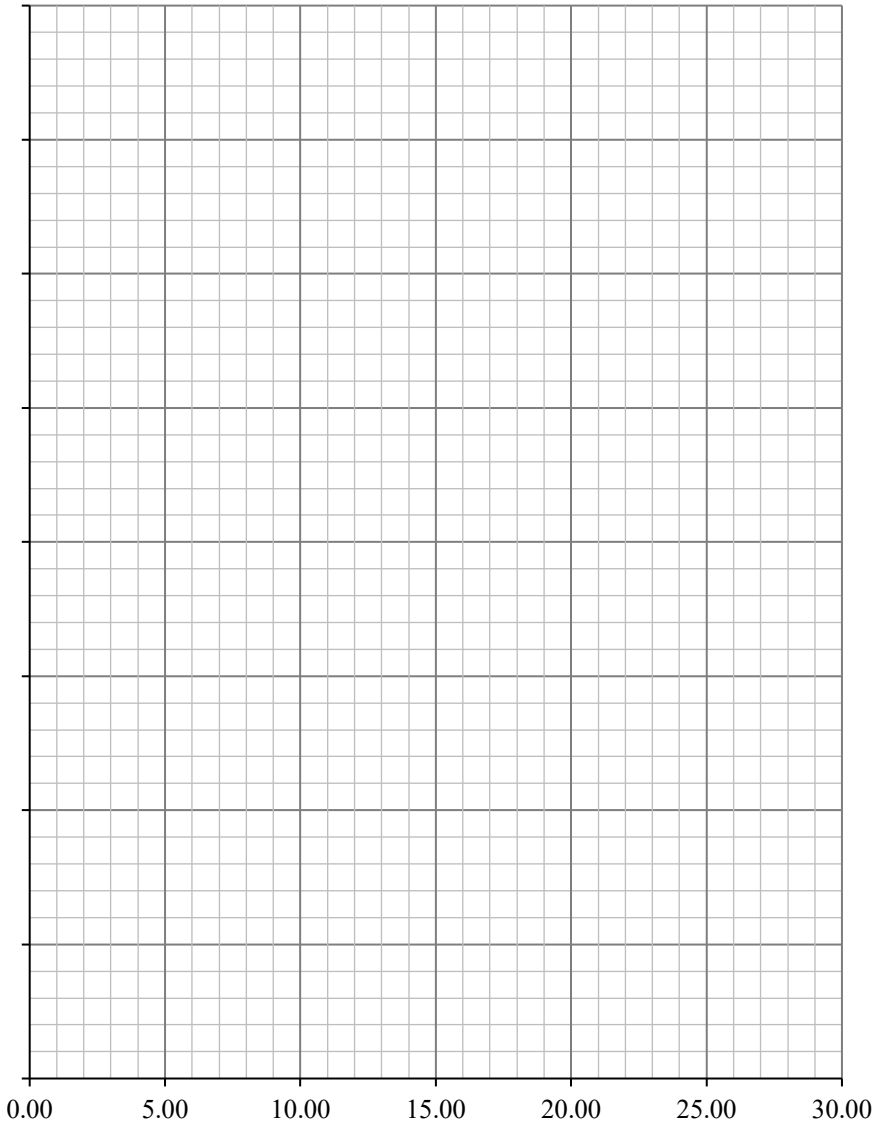
Concentration of $[CoCl_4]^{2-}(aq)$ ($\times 10^{-4}$ M at 25°C)	*Absorbance at* 690 nm
0.00	0.00
5.00	0.29
10.0	0.58
15.0	0.86
20.0	1.15
25.0	1.44

The absorbance of the equilibrium solution at 10°C was 0.236.

Question 12 continues on page 16

Question 12 (continued)

(a) Plot a calibration curve to show the relationship between concentration of $[CoCl_4]^{2-}(aq)$ and absorbance at 690 nm. **4**



(b) Use the calibration curve and the average absorbance measured at 10°C to determine the equilibrium concentration of $[CoCl_4]^{2-}(aq)$ at this temperature. **2**

Show working on your graph and state your answer with units correct to 2 decimal places.

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End of Question 12

Question 13 (4 marks)

Determination of K_{eq} at 10°C

(a) Write an expression for K_{eq} for the cobalt complexation equilibrium system. **1**

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(b) Complete the table below using values from Question 9(a), 9(b) and 12(b). **2**

	$[Co(H_2O)_6]^{2+}(aq)$	+	$4Cl^-(aq)$	$\rightleftharpoons$	$[CoCl_4]^{2-}(aq)$	+	$H_2O\ (l)$
Initial Concentration (mol/L)							
Change in Concentration (mol/L)							
Equilibrium Concentration (mol/L)							

(c) Determine K_{eq} at 10°C. **1**

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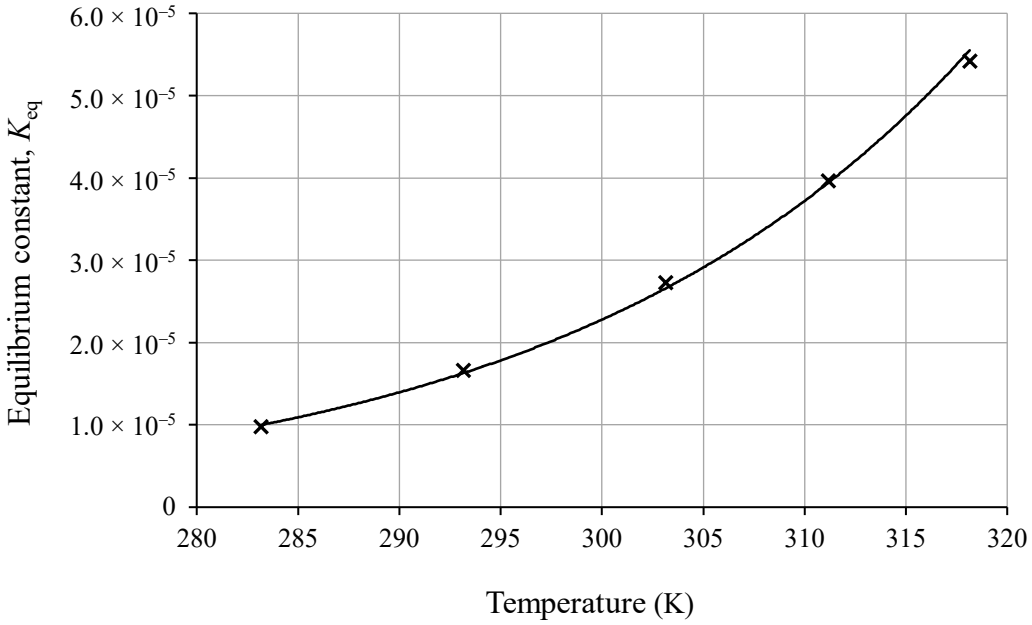
Question 14 (4 marks)

The effect of Increasing Temperature on K_{eq}

The K_{eq} values determined for the remaining temperatures studied within this investigation are shown in the graph below.

Refer to the information provided to answer this question.



Explain, with reference to the composition of the reaction mixture, whether the cobalt complexation equilibrium system is endothermic or exothermic in the forward direction. **4**

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End of Assessment

Section II Extra writing space

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