SECTION 1   MULTIPLE CHOICE   (10 marks)

The next two questions refer to the following information.

CO and Cl_2 gases are mixed in a flask and they reach equilibrium according to the following equation. K = 248.

$$CO_{(g)} + Cl_{2(g)} \rightleftharpoons COCl_{2(g)} \qquad K=248$$

1.   When equilibrium is reached which of the statements below is correct?

    A.   The reaction has reached completion; no more products or reactants are being formed.
    B.   The concentration of CO and $COCl_2$ are equal.
    C.   The rates of both the forward and reverse reactions are equal.
    D.   There is 248 times more $COCl_{2(g)}$ than $CO_{(g)}$.

2.   For the above system at equilibrium, the volume of the system is halved. Once equilibrium is established, which one of the following statements is true about the system?

    A.   K has increased
    B.   K has increased and both the mass and concentration of Cl_2 have decreased.
    C.   The mass and concentration of Cl_2 have decreased.
    D.   The mass and concentration of $COCl_2$ have increased.

3.   Which of the following expressions for K is correct for the reaction?
$$2NO_{(g)} + Br_{2(g)} \rightleftharpoons 2NOBr_{(g)}$$
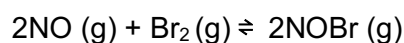
    A. $K = \dfrac{[NOBr]^2}{[NO]^2[Br_2]}$

    B. $K = \dfrac{[NO]^2[Br_2]}{[NOBr]^2}$

    C. $K = \dfrac{[NOBr]^2}{[NO]^2+[Br_2]}$

    D. $K = \dfrac{2[NO][Br_2]}{2[NOBr]}$

4. Consider the following system at equilibrium:

$$Co^{2+}(aq) + 6NH_3(aq) \rightleftharpoons Co(NH_3)_6^{2+}(aq)$$
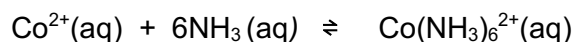
If $CoCl_2$ (s) is added and equilibrium is allowed to re-establish, how will the concentration of all species compare to their original concentrations?

	$[Co^{2+}](aq)$	$[NH3](aq)$	$[Co(NH3)_6^{2+}](aq)$
A.	same	lower	higher
B.	higher	lower	higher
C.	higher	higher	lower
D.	lower	lower	higher

The next two questions refer to the following information.

Bromine dissolves in water according to the following equilibrium equation;

$$Br_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + Br^-(aq) + HOBr(aq)$$
Red   **colourless**
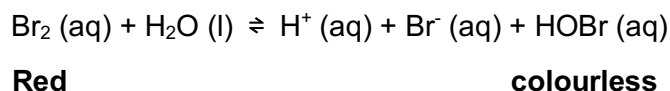
5. What observation would you expect if a few drops of concentrated acid such as hydrochloric acid was added to the system at equilibrium?

A. no observable change.
B. solution would become colourless.
C. solution would become more red.
D. solution would fade to become less red.

6. Which one of the following would NOT cause the equilibrium position to shift to the right?

A. Addition of NaBr (aq)
B. Adding concentrated NaOH (aq)
C. Adding Br_2 (aq)
D. Adding H_2O (l)

7.   The reaction below shows carbon and hydrogen reacting to form methane.

$$C (s) + 2H_2 (g) \rightleftharpoons CH_4 (g) \qquad\qquad \Delta H = -75kJ$$
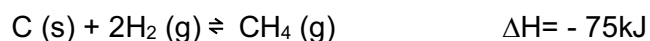
If the reaction has reached equilibrium, how could you increase the yield of methane?

A. Decrease the temperature
B. Increase the volume
C. Add a suitable catalyst
D. Both (a) and (c) above

8.   Consider a sealed system in which the following reaction is at equilibrium:

$$CaCO_3(s) \quad \rightleftharpoons \quad CaO(s) + \quad CO_2(g)$$

Now consider the following actions:

I   Add more $CO_2(g)$ to the system
II   Add more $CaCO_3(s)$ to the system
III   Decrease the volume of the system
IV   Increase the temperature of the system

Which of these leads to a change in $CO_2(g)$ concentration (after equilibrium is re-established).

A. All of them
B. Only II, III and IV
C. Only III and IV
D. Only IV

The next two questions refer to the following information.

When dilute hydrochloric acid is added to a solution of potassium chromate, a solution of potassium dichromate is produced and the following equilibrium is established.

$$2CrO_4{}^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7{}^{2-}(aq) + H_2O(l) \qquad \Delta H = -42 \text{ kJ}$$

yellow   **orange**

9. Which one of the following would NOT favour the rate of the forward reaction over the reverse?

   A.   Addition of more potassium chromate.

   B.   Increasing the concentration of hydrochloric acid.

   C.   Decreasing the temperature of the solution.

   D.   Addition of water.

10. What would you expect to happen to the colour of this solution if temperature was increased?

   A.   The solution would become more intensely orange due to the forward reaction being favoured more than the reverse.

   B.   The solution would become yellow due to the reverse reaction being favoured more than the forward.

   C.   The solution would remain orange due to the fact that no change is being made to a specific species in the reaction.

   D.   The solution would become colourless due to the forward reaction producing more water molecules.

SECTION 2 SHORT ANSWERS

Question 11   **1 mark**

Write the equilibrium expression for the following reaction

(a) $Ag^+_{(aq)}$ + $Cl^-_{(aq)}$ $\rightleftharpoons$ $AgCl_{(s)}$

K =

Question 12   **3 marks**

The decomposition of nitrosyl chloride (NOCl) is represented by the equation:

$$2\ NOCl_{(g)} \quad \rightleftharpoons \quad 2\ NO_{(g)} + Cl_{2(g)}$$
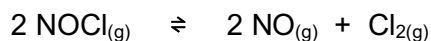
At 230 °C, K = 4.52 x 10^{-3}. At 465 °C, K = 9.29 x 10^{-2}

(a)   Is the forward reaction endothermic or exothermic?

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(1 mark)

(b)   Explain your answer in (a).

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(2 marks)

Question 13   **14 marks**

The reaction of the bromate ion with chromium (III) ion is in equilibrium with the bromide ion and the dichromate ion according to the following equation;

$$BrO_3^- \text{ (aq)} + 2Cr^{3+} \text{ (aq)} + 4H_2O \text{ (l)} \rightleftharpoons Br^- \text{ (aq)} + Cr_2O_7^{2-} \text{ (aq)} + 8H^+ \text{ (aq)}$$

(a) Complete the table with increase, decrease or no change for the following changes once equilibrium has been re-established.   (9 marks)

Change made	Rate of forward reaction	Effect on $[Cr_2O_7^{2-}]$ (increase, decrease or no change)	Effect on $[Cr^{3+}]$ (increase, decrease or no change)
A few drops of concentrated NaOH (aq) is added			
Adding $Cr(NO_3)_3$ (s)			
Increasing the volume by adding water			

(b) Using Collision Theory, explain the effect on the $[Cr_2O_7^{2-}]$ when concentrated NaOH (aq) is added.   (5 marks)

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Question 14　　　　　　　　　　　　　　　　　　　　　　　　　　**6 marks**

Two colourless gases, nitrogen trichloride and oxygen, react to produce brown nitrogen dioxide gas and green-yellow chlorine gas according to the following equation:

$$2\ NCl_3\,(g)\ +\ 2\ O_2\,(g)\ \rightleftharpoons\ 2\ NO_2\,(g)\ +\ 3\ Cl_2\,(g)\qquad \Delta H = -115kJ$$
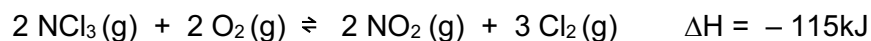
At 25°C the equilibrium mixture of these gases is a **pale brown colour** and the concentration of nitrogen trichloride and chlorine is 0.15 molL^{-1}.

(a) On the axes below, sketch a graph that depicts the change in <u>concentration</u> of NCl$_3$ and of Cl$_2$ as a result of the following changes in conditions of the equilibrium system. Use (———) for [NCl$_3$] and (- - - - -) for [Cl$_2$].

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　　　　t_0　　　　System at equilibrium
　　　　t_1　　　　Volume halved
　　　　t_2　　　　System at equilibrium
　　　　t_3　　　　Temperature increases
　　　　t_4　　　　System at equilibrium

Concentration
(molL^{-1})

0.15

t_0　　　　　t_1　　　　　　　　　t_2　　　t_3　　　　　　　t_4

Time
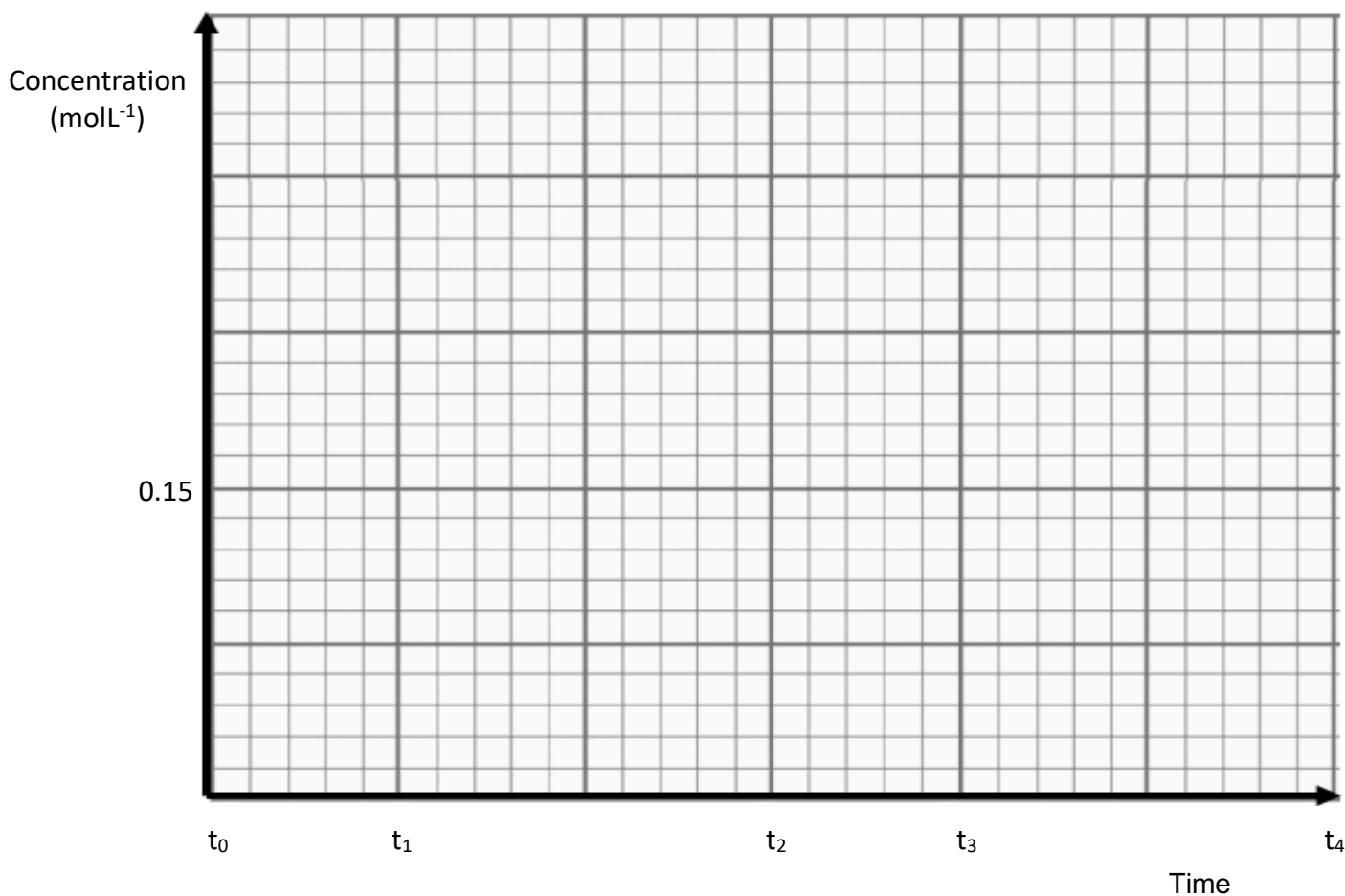
(b) Describe what you would expect to observe between T$_3$ and T$_4$.　　　(1 mark)

Question 15   **9 marks**

Hydrogen gas for use in the Haber Process can be produced by the steam reforming reaction of methane and water, according to the following equation:

$$CH_{4(g)} + H_2O_{(g)} \rightleftharpoons CO_{(g)} + 3\ H_{2(g)} \qquad \Delta H = +206kJ$$

The usual conditions for this reaction are a temperature of 750°C and a moderate pressure in the presence of a nickel catalyst.

Explain why these conditions are chosen for the steam reforming considering rate of reaction, yield and cost of operation.

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