7. Equilibria

7.1 Chemical equilibria- reversible reactions, dynamic equilibrium

Paper 2

Question Paper

1 **(a)** Define Le Chatelier's principle.

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..... [2]

(b) Reaction 1 describes the reversible reaction between yellow $Fe^{3+}(aq)$ and colourless $SCN^{-}(aq)$ to produce red $FeSCN^{2+}(aq)$.

reaction 1 $Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$ $\Delta H = -x\ kJ\,mol^{-1}$

yellow colourless red

A mixture of $Fe^{3+}(aq)$, $SCN^{-}(aq)$ and $FeSCN^{2+}(aq)$ is at equilibrium at 20 °C.

The temperature of this mixture is then increased to 50 °C and allowed to reach equilibrium.

Deduce the changes that occur, if any, in the equilibrium mixture at 50 °C compared to the equilibrium mixture at 20 °C.

- change in appearance

  .....

- change in relative concentration of $FeSCN^{2+}(aq)$

  .....

- change in value of the equilibrium constant, K_c

  .....

[3]

(c) In another experiment, equimolar amounts of $Fe^{3+}(aq)$ and $SCN^{-}(aq)$ are mixed together and allowed to reach equilibrium. The total volume of the mixture is 25.0 cm^3.

reaction 1 $Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$

At equilibrium the mixture contains:

- $[SCN^{-}] = 1.30 \times 10^{-3}$ mol dm^{-3}
- $[FeSCN^{2+}] = 0.300 \times 10^{-3}$ mol dm^{-3}.

(i) Calculate the initial amount, in mol, of $Fe^{3+}(aq)$ added to $SCN^{-}(aq)$ to produce this mixture.

initial amount of $Fe^{3+}(aq)$ = ... mol [2]

(ii) Calculate K_c for reaction 1 and state its units.

Show your working.

K_c = ...

units .....

[2]

2 **(a)** Describe what is meant by dynamic equilibrium.

.....

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..... [2]

(b) Reaction 4 describes the reversible reaction between yellow $Fe^{3+}(aq)$ and colourless $SCN^{-}(aq)$ to produce red $FeSCN^{2+}(aq)$.

reaction 4 $Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$

yellow colourless red

An equilibrium mixture contains $Fe^{3+}(aq)$, $SCN^{-}(aq)$ and $FeSCN^{2+}(aq)$. A few colourless crystals of soluble KSCN(s) are added. The mixture is then left until it reaches equilibrium again. The temperature of both equilibrium mixtures is the same.

(i) Deduce the changes that occur, if any, in the equilibrium mixture after KSCN(s) is added compared to the original equilibrium mixture.

- change in appearance

  .....

- change in relative concentration of $Fe^{3+}(aq)$

  .....

- change in value of the equilibrium constant, K_c

  .....

[3]

(ii) The expression for the equilibrium constant, K_c, for reaction 4 is shown.

$$K_c = \frac{[FeSCN^{2+}(aq)]}{[Fe^{3+}(aq)] \times [SCN^{-}(aq)]}$$

5.00×10^{-5} mol of $Fe^{3+}(aq)$ and 5.00×10^{-5} mol of $SCN^{-}(aq)$ are added together and allowed to reach equilibrium. The total volume of the mixture is 25.0 cm^3.

At equilibrium the concentration of $FeSCN^{2+}(aq)$ is 4.23×10^{-4} mol dm^{-3}.

Calculate the equilibrium constant, K_c, for reaction 4.

Include the units in your answer.

K_c = ...

units .....

[4]

3 In industry, ethanol is made by reacting ethene with steam in the presence of H_3PO_4.

reaction 1 $C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$

(b) Reaction 1 reaches equilibrium at constant temperature and pressure.

Deduce what effect increasing the pressure will have on the amount of ethanol in the new equilibrium mixture. Use Le Chatelier's principle to explain your answer.

effect of increasing pressure .....

explanation .....

.....

[2]

4 NO and NO_2 react at 25 °C to give N_2O_3 as shown in the equation.

$$NO(g) + NO_2(g) \rightleftharpoons N_2O_3(g) \qquad \Delta H = -7.2\,kJ\,mol^{-1}$$

The reaction is reversible and reaches equilibrium in a closed system.

(c) Table 2.1 shows the composition of an equilibrium mixture of NO(g), NO_2(g) and N_2O_3(g) at 101 kPa.

Table 2.1

gas	number of moles at equilibrium / mol
NO	0.605
NO_2	0.605
N_2O_3	0.390

Calculate K_p, the equilibrium constant with respect to partial pressures.

Deduce the units of K_p.

K_p = ... units .....
[3]

(b) State how the position of equilibrium changes, if at all, when the reaction takes place at 100 °C.

Explain your answer.

Assume the pressure remains constant.

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..... [2]

5 **(a)** 0.025 mol of HI(g) is added to a closed vessel and left to reach dynamic equilibrium. The total pressure of the vessel is 100 kPa.

equation **1** $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$

(i) Explain what is meant by dynamic equilibrium.

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..... [2]

(ii) Describe **one** difference in the initial appearance of the reaction mixture compared to the mixture at equilibrium.

..... [1]

(iii) Write an expression for K_p for the reaction described in equation **1**.

K_p =

[1]

(iv) At equilibrium the partial pressure of HI(g) is 86.4 kPa.

Calculate the amount of HI(g) present in the mixture at equilibrium. Show your working.

amount of HI(g) = ... mol [2]

(c) Describe the effect of increasing pressure on the value of K_p for the decomposition of HI(g).

..... [1]

6 Hydrogen iodide, HI, is a colourless gas at room temperature.

(c) HI(g) can be formed by reacting $H_2(g)$ with $I_2(g)$. The reaction is reversible, and an equilibrium forms quickly at high temperatures.

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

(i) Construct an expression for the equilibrium constant, K_p, for the reaction of $H_2(g)$ and $I_2(g)$ to form HI(g).

$K_p =$

[1]

(ii) The equilibrium partial pressures of the gases at 200 °C are as follows.

$$p_{H_2(g)} = 895\,Pa$$
$$p_{I_2(g)} = 895\,Pa$$
$$p_{HI(g)} = 4800\,Pa$$

Calculate K_p for this reaction.

K_p = ... [1]

(iii) State how the value of K_p would change, if at all, if the reaction were carried out at 100 °C rather than 200 °C.

Explain your answer.

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..... [2]

7 Phosphorus, sulfur and chlorine can all react with oxygen to form oxides.

(d) Chlorine forms several oxides, including Cl_2O, ClO_2 and Cl_2O_6.

(iii) $Cl_2O_6(g)$ is produced by the reaction of $ClO_2(g)$ with $O_3(g)$.

$$2ClO_2(g) + 2O_3(g) \rightleftharpoons Cl_2O_6(g) + 2O_2(g) \qquad \Delta H = -216\,kJ\,mol^{-1}$$

The reaction takes place at 500 K and 100 kPa.

State and explain the effect on the yield of $Cl_2O_6(g)$ when the experiment is carried out:

- at 1000 K and 100 kPa

.....

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.....

- at 500 K and 500 kPa.

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.....

[4]

8 Methylpropane, $(CH_3)_2CHCH_3$, is an isomer of butane, $CH_3(CH_2)_2CH_3$.

(b) When a sample of butane is heated to 373 K, in the presence of a catalyst, and allowed to reach equilibrium the following reaction occurs.

$$CH_3(CH_2)_2CH_3(g) \rightleftharpoons (CH_3)_2CHCH_3(g) \qquad \Delta H = -8.0\,kJ\,mol^{-1}$$

State and explain the effect on the composition of this equilibrium mixture when the temperature is increased to 473 K.

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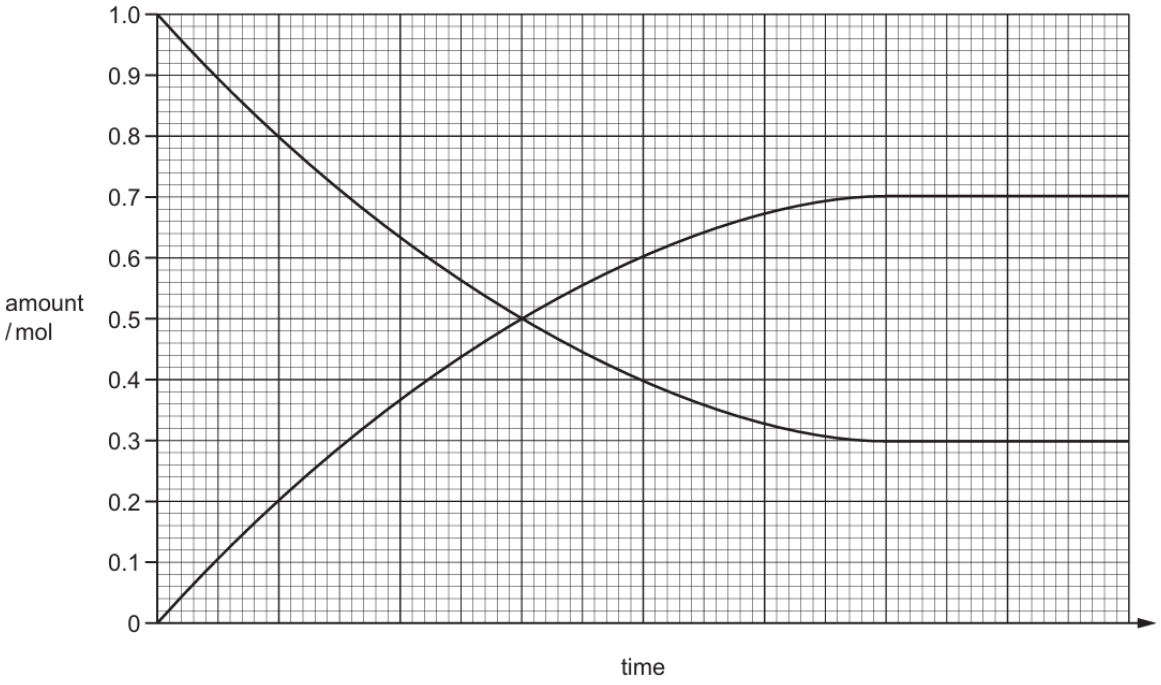
..... [2]

(c) 1 mole of butane gas was added to a 1 dm^3 closed system, at a constant temperature and pressure. The amount of butane and methylpropane was measured at regular time intervals.



(i) Label the graph with a *t* to show the time taken to reach dynamic equilibrium. [1]

(ii) Use the graph to find the concentration of butane and methylpropane in the mixture at equilibrium.

concentration of butane = ... mol dm^{-3}

concentration of methylpropane = ... mol dm^{-3}

[1]

(iii) Write an expression for K_c for this reaction.

[1]

(iv) Calculate a value for K_c and state its units.

K_c = ... units = ... [2]

9 In the Periodic Table, the p block contains elements whose outer electrons are found in the p subshell.

(d) SO_2 can react with ozone, O_3, to form SO_3 in two different reactions.

(i) In one reaction, SO_2 reacts with O_3 until a dynamic equilibrium is established.

$$SO_2(g) + O_3(g) \rightleftharpoons SO_3(g) + O_2(g)$$

State and explain the effect of an increase in pressure on the composition of the equilibrium mixture.

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..... [2]

(ii) In the other reaction, a different equilibrium is established at 300 K as shown.

$$3SO_2(g) + O_3(g) \rightleftharpoons 3SO_3(g) \qquad \Delta H = +462.3\,kJ\,mol^{-1}$$

Suggest a temperature needed to increase the yield of SO_3 at equilibrium.

Explain your answer.

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..... [2]