2nd lecture

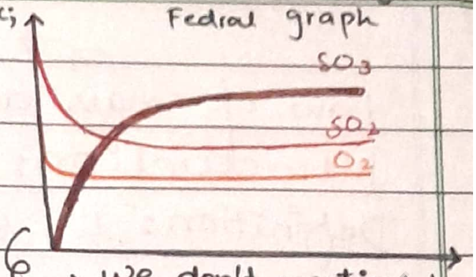
HD Pencil

Chemical Equilibrium

Date 24th/Oct/2023. Day Tuesday.

$$2SO_2 + O_2 \underset{450°C,\ 200\,atm}{\overset{V_2O_5}{\rightleftharpoons}} 2SO_3$$

Fedral graph



rate = product/time

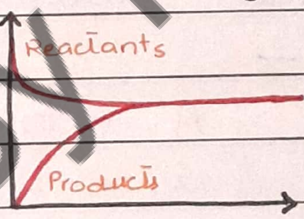
we don't mention moles in graph.

forward : $2SO_2 + O_2 \longrightarrow 2SO_3$

reverse : $2SO_3 \longrightarrow 2SO_2 + O_2$

Conditions: Temp, catalyst, Pressure

KPK graph



Chemical Equilibrium: "A state of chemical state in which forward and reverse reaction takes place at same rate."

Rate of forward = Rate of Reverse

~~SLOs Question~~ Self Assessments

Q write forward and reverse reaction of following expression.

$$2NO + O_2 \rightleftharpoons 2NO_2$$

forward: $2NO + O_2 \longrightarrow 2NO_2$

reverse : $2NO_2 \longrightarrow 2NO + O_2$

Date 25th/Oct/2023 Day Wednesday.

Theoratic Law

"Law of mass action:"

Introduction: C.M Guldberg and P.Waage

Definition: "It states that the rate at which a substance react is directly propotional to it's active mass.

The rate at which the reaction proceeds, is directly propotional to the product of active masses of the reactants."

* —

$$A + B \rightleftharpoons C + D$$

2	×	2	=	4
4	×	4	=	16
3	×	9	=	27

* Active Mass: Represents the concentration of reactants and products in $mol.dm^{-3}$

Representation: [ ]

Derivation: $aA + bB \rightleftharpoons cC + dD$

[rtn → reaction]

Rate of forward rtn $\propto [A]^a [B]^b$

Rate of forward rtn $= K_f [A]^a [B]^b$ ——→ i)

Rate of reverse rtn $\propto [C]^c [D]^d$

Rate of reverse rtn $= K_r [C]^c [D]^d$ ——→ ii)

At equilibrium:

rate of forward rtn = rate of reverse rtn.

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$$K_f [A]^a [B]^b = K_r [C]^c [D]^d$$

$$\frac{K_f}{K_r} = \frac{[C]^c [D]^d}{[A]^a [B]^a} \qquad \because \frac{K_f}{K_r} = K_c$$

$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

$$K_c = \frac{[Product]}{[Reactant]}$$ → Equilibrium constant expression

K_c → K_c is the ~~produ~~ ratio of product to reactant.

• $4HCl + O_2 \rightleftharpoons 2H_2O + 2Cl_2$

$$K_c = \frac{[Product]}{[Reactant]}$$

$$K_c = \frac{[H_2O]^2 [Cl_2]^2}{[HCl]^4 [O_2]}$$

• $2NO_2 \rightleftharpoons N_2O_4$

$$K_c = \frac{[N_2O_4]}{[NO_2]^2}$$

• $PCl_5 \rightleftharpoons PCl_3 + Cl_2$

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$$

Condition of Equilibruim

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(i) Container should be closed if any of reactants and Products are in gaseous state (Protects for external factors and vapourization).

(ii) Temperature of system should be constant. (Isolated system)

(iii) Pressure of system should be constant.

(iv) Volume of system should remain unchanged

(v) Catalyst if used in system remain unchanged

(vi) Conc; of reactants and products should remain constant.

Ways to Regognise Equi

(i) Physical Methods: spectroscopy, Refactrometry, polarimetry.

(ii) Chemical Method: titration.

Equilibrium Contants & unit

Kc may or may not have units. In Kc expression each reactant and product is shown in square brackets [] which is equal to $mol \cdot dm^{-3}$.

Condition 1: when moles of reactant = Mole of product, then Kc will have no unit.

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- $H_2 + I_2 \rightleftharpoons 2HI$

$$K_c = \frac{[Product]}{[Reactant]}$$

$$K_c = \frac{[HI]^2}{[H_2][I_2]} \Rightarrow K_c = \frac{[mol.dm^{-3}]^2}{[mol.dm^{-3}][mol.dm^{-3}]} = 1 \text{ No unit.}$$

- $H_2 + CO_2 \rightleftharpoons H_2O + CO$

$$K_c = \frac{[H_2O][CO]}{[H_2][CO_2]}$$

$$K_c = \frac{[mol.dm^{-3}][mol.dm^{-3}]}{[mol.dm^{-3}][mol.dm^{-3}]} = 1 \text{ (No unit)}$$

Condition: 2 when moles of reactant ≠ to moles of product, then Kc will have unit.

- $N_2 + 3H_2 \rightleftharpoons 2NH_3$

★ → $mol.dm^{-3}$

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

$$K_c = \frac{[★]^2}{[★][★]^3} = \frac{1}{[★]^2} = mol^{-2}.dm^6$$

lecture: 5

First three point

Date 27/Oct/2023. Importance of Kc. Day Friday.

Value of Kc helps us predict:

① Dirrection of Reaction.

- ~~ratio~~ $Q_c < K_c$

then [R] > [P] and rxn will move in forward direction. When the ratio of product/reactant is less than Kc. The system is not at Equilibrium and more products are required to reach/aquire equilibrium.

- $Q_c > K_c$ [R] < [P], reverse.
- $Q_c = K_c$ Equilibrium is attained.

② Extend of Chemical Reaction.

- Kc is very small: when value of Kc is very small/low, [R] > [P]. Reaction is at initial stage. $K_c < 1$. It should proceed more in forward direction.

- Kc is very large: when [R] < [P], equilibrium mixture will entirely consist of product and small amount of reactant will be present. ~~This~~ The reaction will now proceed in reverse direction. $K_c > 1$

- when Kc is neither large or small: The [R] = [P]. Equilibrium is maintain $K_c = 1$

HW: Practice Example 9.4.

Peshwar Board.

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Example 9.3

$H_2 + I_2 \rightleftharpoons 2HI$

Given data:

$[H_2] = 0.04\ mol.dm^{-3}$

$[I_2] = 0.04\ mol.dm^{-3}$

$[HI] = 0.08\ mol.dm^{-3}$

Required = K_c

Formula: $K_c = \frac{[Product]}{[Reactant]}$

Solution: $K_c = \frac{[HI]^2}{[H_2][I_2]}$

$K_c = \frac{[0.08]^2}{[0.04][0.04]} \Rightarrow K_c = 4$

Result: So, the value of K_c is 4.

Example 9.4:

$CO + H_2O \rightleftharpoons CO_2 + H_2$

Given: $[CO] = 0.0600\ mol.dm^{-3}$

$[H_2O] = 0.120\ mol.dm^{-3}$

$[CO_2] = 0.150\ mol.dm^{-3}$

$[H_2] = 0.300\ mol.dm^{-3}$

Required: K_c Formula: $K_c = [P]/[R]$

Solution: $K_c = \frac{[0.150][0.300]}{[0.06][0.12]}$

$K_c = 6.25$

Result: So, the value of K_c is 6.25.

Date 30/Oct/2023. Importance of Kc (last point) Day Monday.

Haber's Process:

$$N_{2(g)} + 3H_{2(g)} \underset{400°C,\ 200\ atm}{\overset{Fe}{\rightleftharpoons}} 2NH_{3(g)}$$

400°C, 200 atm ⟶ 33% NH_3

~~Faster~~ lower temperature, higher pressure ⟶ 98% NH_3

Contact Process:

- $S_{(s)} + O_{2(g)} \rightleftharpoons 2SO_{2(g)}$
- $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$

$2SO_{3(g)} + H_2O \rightleftharpoons H_2SO_{4(g)}$

Le-Chatellier's: If you impose a change in concentration, temperature or pressure on a chemical system at equilibrium, the system responds in a way that opposes the change

Examples: Haber's process, Contact process.

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Date ____________ Homework Day ____________

Self Assessment Ex : 9.3.

Q1 $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$

Solution:

$$K_c = \frac{[NO]^2}{[N_2][O_2]} \Rightarrow K_c = \frac{[mol.dm^{-3}]^2}{[mol.dm^{-3}][mol.dm^{-3}]} \Rightarrow K_c = \text{No unit}$$

Q2 $H_2 + CO_2 \rightleftharpoons H_2O + CO$

Solution:

$$K_c = \frac{[H_2O][CO]}{[H_2][CO_2]} \Rightarrow K_c = \frac{[mol.dm^{-3}][mol.dm^{-3}]}{[mol.dm^{-3}][mol.dm^{-3}]} \Rightarrow K_c = \text{No unit}$$

Q3 $PCl_5 \rightleftharpoons PCl_3 + Cl_2$

Solution:

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]} \Rightarrow K_c = \frac{[mol.dm^{-3}][mol.dm^{-3}]}{[mol.dm^{-3}]} \Rightarrow K_c = mol.dm^{-3}$$

Q4. $CO + 2H_2 \rightleftharpoons CH_3OH$

Solution:

$$K_c = \frac{[CH_3OH]}{[CO][H_2]^2} \Rightarrow K_c = \frac{[mol.dm^{-3}]}{[mol.dm^{-3}][mol.dm^{-3}]^2} \Rightarrow K_c = dm^6 . mol^{-2}$$

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Date Homework Day

Self Assessment Ex: 9.2

Q1 Derive Kc of:

$$3O_{2(g)} \rightleftharpoons 2O_{3(g)}$$

Forward Reaction:

$$3CO_2 \longrightarrow 2O_3$$

Reverse Reaction:

$$2O_3 \longrightarrow 3O_2$$

Rate of Forward Reaction $\propto [CO_2]^3$

Rate of Forward Reaction $= K_f [CO_2]^3$

Rate of Reverse Reaction $\propto [O_3]^2$

Rate of Reverse Reaction $= K_r [O_3]^2$

At Equilibrium:

Rate of Forward Reaction = Rate of Reverse Reaction

$$K_f [CO_2]^3 = K_r [O_3]^2$$

$$\frac{K_f}{K_r} = \frac{[O_3]^2}{[CO_2]^3}$$

$$\boxed{K_c = \frac{[O_3]^2}{[CO_2]^3}} \quad \because K_c = \frac{K_f}{K_r}$$

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→ Write Kc. (Self A. Ex: 9.2)

Q2 (a) $4HCl + O_2 \rightleftharpoons 2H_2O + 2Cl_2$

Solution:

$$K_c = \frac{[H_2O]^2[Cl_2]^2}{[HCl]^4[O_2]}$$

(b) $CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$

Solution:

$$K_c = \frac{[CH_3COOC_2H_5][H_2O]}{[CH_3COOH][C_2H_5OH]}$$

(c) $2HF \rightleftharpoons H_2 + F_2$

Solution:

$$K_c = \frac{[H_2][F_2]}{[HF]^2}$$

(d) $2NO_2 \rightleftharpoons N_2O_4$

Solution:

$$K_c = \frac{[N_2O_4]}{[NO_2]^2}$$

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Review Excercise:

Q4 $CO + 3H_2 \rightleftharpoons CH_4 + H_2O$

(i) **Solution:**

Forward Reaction: $CO + 3H_2 \longrightarrow CH_4 + H_2O$

Reverse Reaction: $CH_4 + H_2O \longrightarrow CO + 3H_2$

(ii) **Solution:**

Forward Reaction: $CO + 3H_2 \longrightarrow CH_4 + H_2O$

Reverse Reaction: $CH_4 + H_2O \longrightarrow CO + 3H_2$

Rate of Forward Reaction: $\propto [CO][H_2]^3$

$= K_f [CO][H_2]^3$

Rate of Reverse Reaction: $\propto [CH_4][H_2O]$

$= K_r [CH_4][H_2O]$

At Equilibrium State:

Rate of Forward Reaction = Rate of Reverse Reaction

$K_f [CO][H_2]^3 = K_r [CH_4][H_2O]$

$$\frac{K_f}{K_r} = \frac{[CH_4][H_2O]}{[CO][H_2]^3}$$

$$K_c = \frac{[CH_4][H_2O]}{[CO][H_2]^3} \quad \because K_c = \frac{K_f}{K_r}$$

(iii) Unit of Kc

$$K_c = \frac{[mol.dm^{-3}][mol.dm^{-3}]}{[mol.dm^{-3}][mol.dm^{-3}]^{3/2}}$$

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$$K_c = dm^6.mol^{-2}$$

write Equilibrium constant

Q5 (i) $H_2O \rightleftharpoons H_2 + \frac{1}{2}O_2$

Solution:

$$K_c = \frac{[H_2][O_2]^{1/2}}{[H_2O]}$$

(ii) $CO + 2H_2 \rightleftharpoons CH_3OH$

Solution:

$$K_c = \frac{[CH_3OH]}{[CO][H_2]^2}$$

(iii) $COCl_2 \rightleftharpoons CO + Cl_2$

Solution:

$$K_c = \frac{[CO][Cl_2]}{[COCl_2]}$$

(iv) $4HCl + O_2 \rightleftharpoons 2Cl_2 + 2H_2O$

Solution:

$$K_c = \frac{[Cl_2]^2[H_2O]^2}{[HCl]^4[O_2]}$$

units of Kc

Q6 (i) $COCl_2 \rightleftharpoons 2CO + Cl_2$

Solution:

$$K_c = \frac{[CO]^2[Cl_2]}{[COCl_2]} \Rightarrow K_c = \frac{[mol.dm^{-3}]^2[mol.dm^{-3}]}{[mol.dm^{-3}]} \Rightarrow K_c = dm^6.mol^{-2}$$

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

Solution:

$K_c = \frac{[HI]^2}{[H_2][I_2]} \Rightarrow K_c = \frac{[mol.dm^{-3}]^2}{[mol.dm^{-3}][mol.dm^{-3}]} \Rightarrow K_c = \text{No unit.}$

(iii) $2H_2 + O_2 \rightleftharpoons 2H_2O$

Solution:

$K_c = \frac{[H_2O]^2}{[H_2]^2[O_2]} \Rightarrow K_c = \frac{[mol\,dm^{-3}]^2}{[mol.dm^{-3}]^2[mol\,dm^{-3}]} \Rightarrow K_c = dm^3.mol^{-1}$

(iv) $N_2 + 2O_2 \rightleftharpoons 2NO_2$

Solution:

$K_c = \frac{[NO_2]^2}{[N_2][O_2]^2} \Rightarrow K_c = \frac{[mol.dm^{-3}]^2}{[mol.dm^{-3}][mol.dm^{-3}]^2} \Rightarrow K_c = dm^6.mol^{-2}$

"THINK TANK"

Q1 Bromine chloride (BrCl) decomposes to form chlorine and bromine.

(i) $2BrCl \rightleftharpoons Br_2 + Cl_2$

(ii) **Solution:**

$K_c = \frac{[Br_2][Cl_2]}{[BrCl]^2}$

(iii) K_c = No unit.

Q2) **Reactant:** $[N_2O_4]$

Product: $[NO_2]^2$

Unit: $Kc = \frac{[mol \cdot dm^{-3}]^2}{[mol \cdot dm^{-3}]}$

$Kc = [mol \cdot dm^{-3}]$

Q3 The first reaction is an irreversible reaction while the second one is the reversible reaction. Since only reversible reaction reaction goes to completion, that's why in the second reaction, both reactants and products will be found.

Q4 Yes, we can use cobalt chloride ($CoCl_3$) as an experiment to test for water. In Anhyderous state, it is blue but when water is added, it turns pink.

KPK Board:

Practise Problem 9.4:

Given:

$[N_2] = 6.4 \times 10^{-3}$ mol dm^{-3}.

$[O_2] = 1.7 \times 10^{-3}$ mol. dm^{-3}.

$[NO] = 1.1 \times 10^{-5}$ mol. dm^{-3}.

Reaction: $N_2 + O_2 \rightleftharpoons 2NO$

Required: $K_c = ?$

Calculation: $K_c = \frac{[NO]^2}{[N_2][O_2]}$

$$K_c = \frac{[1.1 \times 10^{-5}]^2}{[6.4 \times 10^{-3}][1.7 \times 10^{-3}]}$$

$$K_c = 1.1121 \times 10^{-5}.$$

Review Questions

HW

1. Encircle the correct answer.

(i) Which is true about the equilibrium state?

(a) The forward reaction stops.

(b) The reverse reaction stops.

(c) Both forward and reverse reactions stop.

(d) Both forward and reverse reactions continue at the same rate.

(ii) When a mixture of H_2 and I_2 is sealed in a flask and temperature is kept at 25°C, following equilibrium is established.

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

Which substance or substances will be present in the equilibrium mixture?

(a) H_2 and I_2

(b) HI only

(c) H_2 only

(d) H_2, I_2 and HI

(iii) What are the units for

$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{2(g)}$

(a) mol.dm^{-3}

(b) mol^2. dm^{-6}

(c) dm^3.mol^{-1}

(d) No units

(iv) Which of the following reaction will not have any units for K_c?

(a) $H_{2(g)} + CO_{2(g)} \rightleftharpoons H_2O_{(g)} + CO_{(g)}$

(b) $N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$

(c) $2A_{(g)} + B_{(g)} \rightleftharpoons 3AC_{(g)}$

(d) All of these

(v) Concentration of reactants and products at equilibrium remains unchanged if

(a) concentration of any reactant or product is not changed.

(b) temperature of the reaction is not changed.

(c) pressure or volume of the system is not changed.

(d) all of the above are observed

(vi) Which of the following does not happen, when a system is at equilibrium state?

(a) forward and reverse reactions stop.

(b) forward and reverse rates become equal.

(c) concentration of reactants and products stop changing.

(d) reaction continues to occur in both the directions.

(vii) For which reaction, Kc has units of mol.dm^{-3}.

(a) $2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$

(b) $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

(c) $PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}$

(d) $2ICl_{(g)} \rightleftharpoons I_{2(g)} + Cl_{2(g)}$

(viii) In an irreversible reaction equilibrium is

(a) established quickly

(b) established slowly

(c) never established

(d) established when reaction stops.

(ix) Active mass means

(a) total mass of reactants

(b) total mass of products

(c) total mass of reactants and products

(d) mass of substance in moles per dm^3 in a dilute solution

(x) For a reversible reaction

$$K_c = \frac{[C]^2}{[A][B]}$$

Which substance is product of the reaction?

(a) A

(b) B

(c) Both A and B

(d) C