SCHOOL OF INDIANA
HOME OF VISIONARIES

GRADE CHEMISTRY GRADE ELEVEN` MONDAY MAY 18 2020

Rules of writing the equilibrium constant expression for Homogeneous reactions

- ✓ Homogeneous reaction:- is a reaction in which all the reactants and the products are present in the same physical state.

  Rules

  1. The concentration of all the substances formed as products written in the numenator
  2. The concentrations of all the reactants are written in the domoniator.
  3. Each concentration terms is raised to the power by its respective coefficients as written in the balanced reaction

     ⇒ For a general reaction at equilibrium

     aA+ bB $\rightleftharpoons$ cM + dN

     kc = $\frac{[M]^c[N]^d}{[A]^a[B]^b}$

Note When all the reactants and products are in gaseous state, their concentrations can be written interms of partial pressures.

- ✓ In such cases, the equilibrium constant is denoted by kp.

  Kp = $\frac{(P_M)^c(P_N)^d}{(P_A)^a(P_B)^b}$

  Ex 1 For the formation of ammonia

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

  Kc = $\frac{[NH_3]^2}{[N_2][H_2]^3}$, Kp= $\frac{(PNH_3)^2}{(PN_2)(PH_2)^3}$

  Ex 2In the decomposition of hydrogen fluoride:

  $2HF_{(g)} \rightleftharpoons H_{2(g)} + F_{2(g)}$

  Kc= $\frac{[H_2][F_2]}{[HF]^2}$, Kp= $\frac{[PH_2][PF_2]}{[PHF]^2}$

Unit of Kc

- ✓ The unit of Kc of a reaction depends up on the number of moles of the reactants and products involved in the reaction.

Ex For the reaction

$NH_{3(g)} + CH_3COOH_{(aq)} \rightleftharpoons NH^{+}_{4(aq)} + CH_3COO^{-}_{(aq)}$

$$Kc[NH_4] = \frac{(mol\,L^{-1})(mol\,L^{-1})}{(mol\,L^{-1})(mol\,L^{-1})} = 1$$

Ex For the reaction

$2\,HF_{(g)} \rightleftharpoons H_{2(g)} + F_{2\,(g)}$

$$Kc = \frac{[H_2][F_2]}{[HF]^2} = \frac{(mol\,L^{-1})(mol\,L^{-1})}{(mol\,L^{-1})^2} = 1$$

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

$$Kc = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{[Mol\,L^{-1}]^2}{[mol\,L^{-1}]} = \frac{1}{[Mol\,L^{-1}]^2}$$

Unit of kp

- ✓ The unit of kp is decided by the units of pressure.
  - o If the partial pressure is expressed in atm, then the unit of kp will be:

$$Kp = \frac{(P_M)^c(P_N)^d}{(P_A)^a(P_B)^b} = \frac{(atm)^c(atm)^d}{(atm)^a(atm)^b} = (atm)\ (c+d) - (a+b)$$

  - o If the partial pressure is measured in kpa, then the unit of kp will be (kpa($^{(c+d)\ -(a+b)}$

Ex Kp units for the following reactions are shown

a. $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2\,NH_{3(g)}$, $Kp = \frac{(P_{NH3})^c}{(PN_2)(PH_2)^3} = \frac{atm^c}{atm.atm^3} = \frac{1}{atm^2}$

b. $H_{2(g)} + I_{2(g)} \rightleftharpoons 2\,HI(g)$, $Kp = \frac{(PHI)^c}{(PH_2)(PI_2)} = \frac{atm^c}{atm.atm} = 1$

c. $N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$, $Kp = \frac{(PNO_2)^c}{(PN_2O_4)} = \frac{atm^c}{atm} = atm$

Equilibrium constant for Heterogeneous Reactions

✓ In heterogeneous reactions, the reactants and products are presents in more than one physical state

Ex1 Thermal decomposition of calcium carbonate is an example of heterogeneous reaction.

$CaCO_{3\,(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$

Ex 2 other examples

$NH_4Cl_{(s)} \rightleftharpoons NH_{3(g)} + HCl_{(g)}$

$CO_{2(g)} + H_2O_{(l)} \rightleftharpoons H^{+¿¿}_{(aq)} + HCO^{-¿¿}_{3(aq)}$

Rules for writing the expression for heterogeneous reaction

1. The concentration terms of products are written in the numerator and the concentration terms of reactants are written in the denominator raised to the power of their respective coefficients in the balanced chemical equation.
2. While writing the expression for Kc, the molarities of gaseous reactants and products and species present in the solution are written.
3. Concentration terms of solids and pure liquids donot appear in the expression, as they are taken to be unity.
4. While writing the expression for kp, partial pressures of only the gaseous reactants and product are written in the expression for equilibrium constant.

Ex The equilibrium constant expression for some heterogeneous reaction are shown below.

a. $CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$, $kp = PCO_2$

b. $NH_4Cl_{(s)} \rightleftharpoons NH_{3(g)} + HCl_{(g)}$, $kp = (PNH_3)\,(PHCl)$

c. $CO_{2(g)} + H_2O_{(l)} \rightleftharpoons H^{+¿¿}_{(aq)} + HCO^{-¿¿}_{3(aq)}$, $Kp = ¿¿$

d. $Fe^{+3}_{(aq)} + 3\,OH^{-¿¿}_{(aq)} \rightleftharpoons Fe\,(OH)_{3(s)}$, $Kp = \frac{1}{\left[Fe^{+3}\right]¿¿¿}$

Relation between Kc and Kp

For the general reaction

$aA_{(g)} + bB_{(g)} \rightleftharpoons CM_{(g)} + dN_{(g)}$

$$Kc = \frac{[M]^c[N]^d}{[A]^a[B]^b} = \frac{C_M^c C_N^d}{C_A^c C_B^b}$$

$$Kp = \frac{[P_M]^c[P_N]^d}{[P_A]^a[P_B]^b}$$

Note – It is assumed that all the gaseous species behave like an ideal gas

$$P = \frac{nRT}{V} \text{ and } C = \frac{n}{V}$$

$$P_A = \frac{n_A RT}{V} = C_A RT$$

$$P_B = \frac{n_B RT}{V} = C_B RT$$

$$P_M = \frac{n_M RT}{V} = C_M RT$$

$$P_N = \frac{n_N RT}{V} = C_N RT$$

$$Kp = \frac{(C_M RT)^C (C_N RT)^d}{(C_A RT)^a (C_B RT)^b} = \frac{C_M^c C_N^d}{C_A^a C_B^b} (RT)^{\Delta n}$$

- $\Delta n = (c+d) - (a+b)$ for gaseous species

  $Kp = Kc\ (RT)^{\Delta n}$
- When the number of gaseous reactants and products are equal then,

  $a+b = c+d$
- $\Delta n = (c+d) - (a+b) = 0$

  Therefore, $\Delta n = 0$ and hence $Kp = Kc$

  Ex 1 The equilibrium constant for the reaction:

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

  is 1.8×10^{-3} kpa at 427^0C. Calculate Kc for the reaction at the same temperature.

  Soln

  Given $Kp = 1.8 \times 10^{-3}$ Kpa $= 1.8(\ Nm^{-2})$

  $R = 8.314\ MnK^{-1}\ mol^{-}$

  $T = 427^0C = 700k$

  $Kp = Kc\ (RT)^{\Delta n}$

For the given reaction, $\Delta n = (2+1)-2 = 3-2=1$

$\Delta n=1$

$Kp = Kc(RT) \Rightarrow Kc = \frac{K_P}{R_T}$

$Kc = \frac{1.8\,Nm^{-2}}{700k\,x\,8.14\,NmK^{-1}mol^{-1}}$

$Kc = 3.09\ mol\ m^{-3}$

Ex3. What are the values of Kp and Kc at 1000^0C for the reaction

$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$

If the pressure of CO_2 in equilibrium with $CaCO_3$ and CaO is 3.87 atm?

Soln

$Kp = PCO_2 = 3.87atm$

$Kc = \frac{K_P}{(RT)^{\Delta n}}$, n=1

$Kc = \frac{3.87\,atm}{0.082\,atm\,k^{-1}\,x\,1273\,k} = 0.0370$

Ex3. At 400^0C, Kc= 64 for the reaction

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

a. What is the value of Kp for this reaction?

b. If at equilibrium, the partial pressure of H_2 and I_2 in a container are 0.20 atm and 0.50atm respectively what is the partial pressure of HI in the mixture?

Soln

a. $Kp = Kc(RT)^{\Delta n}$

$\Delta n = 2-2 = 0$

Since, $\Delta n=0$, Kc and Kp are equal

$Kp = 64$

b. $Kp = \frac{(P_{HI})^2}{(P_{H2})(P_{I2})} \Rightarrow (P_{HI})^2 = Kp(P_{H2})\,(P_{I2})$

$P_{HI} = \sqrt{KP(P_{H2})(P_{I2})}$

$= \sqrt{64\,x\,0.2\,x\,0.5}$

$= 2.53atm$

$\therefore P_{HI} = 2.53atm$