Chem

Chemical Equilibrium

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Chemical Equilibrium:

The chemical Equilibrium may be defined as the state of a reversible reaction when the two opposing reactions occur at the same time at a same rate and the concentration of reactants and products do not change with time.

Characteristics or condition of chemical equilibrium

① When a chemical Equilibrium is established in a closed vessel at constant temperature, concentration of the various species in the reaction mixture become constant.

② Equilibrium can not be attained in an open vessel.

③ When a catalyst is added to a system in equilibrium, it speeds up the rate of both the forward and the reverse reaction to an equal extent. Therefore a catalyst cannot change the equilibrium point except that it is achieved ... This enhance the rate of reaction.

e. you deter-
K_p, K_c, K_x from
equilibrium constant

Let us consider a reaction,

$$A \rightleftharpoons B$$

$A \rightarrow B$ forward reaction

$B \rightarrow A$ ~~B→A~~ Backward reaction.

rate of forward reaction,

$$r_f \propto C_A$$

$$\boxed{r_f = K_f C_A}$$

C_A = concentration of A
K_f = rate constant of forward reaction.

rate of backward reaction,

$$r_B \propto C_B$$

$$\boxed{r_b = K_b \times C_B}$$

C_B = concentration of B
K_b = rate constant of backward reaction

At equilibrium, rate of forward reaction = rate of backward reac.

$$r_f = r_b$$

$$K_f C_A = K_b C_B$$

$$\frac{K_f}{K_b} = \frac{C_B}{C_A}$$

$$\boxed{K = \frac{C_B}{C_A}}$$

where K is the equilibrium constant

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(i) When equilibrium constant is represented by pressure then it is known as K_P. $\boxed{K_P = \frac{P_B}{P_A}}$

(ii) When equilibrium constant is represented by concentration then it is known as K_C $\boxed{K_C = \frac{C_B}{C_A}}$

(iii) When equilibrium constant is represented by mole fraction then it is known as K_X. $\boxed{K_X = \frac{X_B}{X_A}}$

Let us consider a reaction.

$$aA + bB + \cdots \rightleftharpoons mM + nN + \cdots$$

for forward reaction,

$$r_f \propto C_A^a C_B^b$$

$$r_f = K_f C_A^a C_B^b \cdots$$

for backward reaction,

$$r_b \propto C_M^m C_N^n$$

$$r_b = K_b C_M^m C_N^n \cdots$$

At equilibrium, $r_f = r_b$

$$K_f \times C_A^a C_B^b \cdots = K_b \times C_M^m \times C_N^n \cdots$$

$$\frac{K_f}{K_b} = \frac{C_M^m \times C_N^n \cdots}{C_A^a \times C_B^b \cdots}$$

$$K_c = \frac{C_M^m \times C_N^n \ldots}{C_A^a \times C_B^b \ldots}$$

$$K_p = \frac{P_M^m \cdot P_N^n \ldots}{P_A^a \cdot P_B^b \ldots}$$

$$K_x = \frac{X_M^m \, X_N^n \ldots}{X_A^a \, X_B^b \ldots}$$

Determination of K_p, K_c, K_x from the equation. $N_2 + 3H_2 \rightleftharpoons 2NH_3$

$$K_p = \frac{P^2_{NH_3}}{P_{N_2} \times P^3_{H_2}}$$

$$K_c = \frac{C^2_{NH_3}}{C_{N_2} \times C^3_{H_2}} = \frac{[NH_3]^2}{[N_2]\,[H_2]^3}$$

$$K_x = \frac{X^2_{NH_3}}{X_{N_2} \times X^3_{H_2}}$$

Calculation of K_p, K_c and K_x for a given reaction.

$$PCl_5 \rightleftharpoons PCl_3 + Cl_2$$

The reaction occur in a closed vessel which volume is V and a constant temperature T and pressure P

$PCl_5 \rightleftharpoons$	$PCl_3 +$	Cl_2	
1	0	0	$t=0$
$1-\alpha$	α	α	$t=t$

Total moles $= 1-\alpha+\alpha+\alpha = 1+\alpha$

Now, $[PCl_5] = \dfrac{1-\alpha}{\cancel{1+\alpha}\,V}$ $\qquad [Cl_2] = \dfrac{\alpha}{V}$

$[PCl_3] = \dfrac{\alpha}{\cancel{1+\alpha}\,V}$

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{\frac{\alpha}{V}\cdot\frac{\alpha}{V}}{\frac{1-\alpha}{V}} = \boxed{\frac{\alpha^2 \cancel{(1+\alpha)}}{V(1-\alpha)}}$$

when; $1 \gg \alpha$ $\qquad K_c = \dfrac{\alpha^2}{V}$

$\alpha^2 = K_c . V$

$\alpha = \sqrt{K_c . V}$

$\boxed{\alpha \propto \sqrt{V}}$

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Partial pressure, $P_{NO} = \frac{2(1-\alpha)}{3-\alpha}\cdot P$

$$P_{Cl_2} = \frac{1-\alpha}{3-\alpha}\cdot P$$

$$P_{NOCl} = \frac{2\alpha}{3-\alpha}\cdot P$$

$$K_P = \frac{\left\{\frac{2\alpha}{3-\alpha}P\right\}^2}{\left\{\frac{2(1-\alpha)}{3-\alpha}P\right\}^2 \times \frac{1-\alpha}{3-\alpha}P}$$

$$= \frac{4\alpha^2 P^2}{(3-\alpha)^2} \times \frac{(3-\alpha)^3}{4(1-\alpha)^3 P^3}$$

$$= \frac{\alpha^2(3-\alpha)}{(1-\alpha)^3 P}$$

$1 \gg \alpha$, $\quad K_P = \frac{3\alpha^2}{P}$

$$\alpha^2 = \frac{P K_P}{3}$$

$$\alpha = \frac{1}{\sqrt{3}}\sqrt{P}\sqrt{K_P}$$

$$\boxed{\alpha \propto \sqrt{P}}$$

$$k_x = \frac{x_{CO} \cdot x_{Cl_2}}{x_{COCl_2}} = \frac{\frac{\alpha}{1+\alpha} \cdot \frac{\alpha}{1+\alpha}}{\frac{1-\alpha}{1+\alpha}}$$

$$\boxed{k_x = \frac{\alpha^2}{1-\alpha^2}}$$

Determination of K_c, K_p, K_x of the following reaction.

$$2NO + Cl_2 \rightleftharpoons 2NOCl$$

1	1	0
$2(1-\alpha)$	$1-\alpha$	2α

Total moles $= 2-2\alpha+1-\alpha+2\alpha = 3-\alpha$

$$K_c = \frac{\left(\frac{2\alpha}{V}\right)^2}{\left\{\frac{2(1-\alpha)}{V}\right\}^2 \frac{1-\alpha}{V}} = \frac{4\alpha^2}{V^2} \times \frac{V^3}{4(1-\alpha)^3}$$

$$= \frac{\alpha^2 V}{(1-\alpha)^3}$$

$1 \gg \alpha$,

$$K_c = \alpha^2 V$$

$$\alpha^2 = \frac{1}{V} \cdot K_c \qquad \boxed{\alpha \propto \frac{1}{\sqrt{V}}}$$

$$\alpha = \frac{1}{\sqrt{V}} \cdot \sqrt{K_c}$$

Determination of Kp, Kc, Kx of the following reaction.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

The reaction is occur in a closed vessel which volume is v in a closed vessel in a constant temperature T and pressure P.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

$$\begin{array}{ccc} 1 & 1 & 0 \\ 2(1-\alpha) & 1-\alpha & 2\alpha \end{array}$$

Total moles $= 2-2\alpha+1-\alpha+2\alpha = 3-\alpha$

$[SO_2] = \dfrac{2(1-\alpha)}{V}$, $[O_2] = \dfrac{1-\alpha}{V}$, $[SO_3] = \dfrac{2\alpha}{V}$

$$K_c = \frac{\left(\frac{2\alpha}{V}\right)^2}{\left\{\frac{2(1-\alpha)}{V}\right\}^2 \times \frac{1-\alpha}{V}} = \frac{4\alpha^2}{V^2} \times \frac{V^2 \cdot V}{4(1-\alpha)^3}$$

$$= \frac{\alpha^2 V}{(1-\alpha)^3}$$

$1 >> \alpha$,

$K_c = \alpha^2 V$

$\alpha^2 = \frac{1}{V} \cdot K_c$ $\boxed{\alpha \propto \frac{1}{\sqrt{V}}}$

Partial pressure, $P_{SO_2} = \frac{2(1-\alpha)}{3-\alpha} \times P$

$$P_{O_2} = \frac{1-\alpha}{3-\alpha} \times P$$

$$P_{SO_3} = \frac{2\alpha}{3-\alpha} \times P$$

$$K_p = \frac{\left\{\frac{2\alpha}{3-\alpha} \cdot P\right\}^2}{\left\{\frac{2(1-\alpha)}{3-\alpha} \cdot P\right\}^2 \times \frac{1-\alpha}{3-\alpha} \cdot P}$$

$$= \frac{4\alpha^2 P^2}{(3-\alpha)^2} \times \frac{(3-\alpha)^2 \cdot (3-\alpha)}{4(1-\alpha)^2 P^2 (1-\alpha) \cdot P}$$

$$= \frac{4\alpha^2 P^2}{(3-\alpha)^2} \times \frac{(3-\alpha)^3}{4P^3 (1-\alpha)^3}$$

$$= \boxed{\frac{\alpha^2 (3-\alpha)}{P(1-\alpha)^3}}$$

when $1 \gg \alpha$, $K_p = \frac{3\alpha^2}{P}$

$$\alpha^2 = \frac{P}{3} K_p \qquad \boxed{\alpha \propto \sqrt{P}}$$

$$\alpha = \frac{1}{\sqrt{3}} \sqrt{P} \sqrt{K_p}$$

$$K_P = \frac{P_{N_2O_4}}{P_{NO_2}} = \frac{\frac{\alpha}{2-\alpha}\cdot P}{\left\{\frac{2(1-\alpha)}{2-\alpha}P\right\}^2}$$

$$= \frac{\alpha P}{2-\alpha} \times \frac{(2-\alpha)^2}{4(1-\alpha)^2 P^2}$$

$$= \boxed{\frac{\alpha(2-\alpha)}{4(1-\alpha)^2 P}}$$

when $1 \gg \alpha$, then.

$$K_P = \frac{2\alpha}{4P}$$

$$K_P = \frac{\alpha}{2P}$$

$$\alpha = 2P K_P$$

$$\boxed{\alpha \propto P}$$

$$K_X = \frac{\frac{\alpha}{2-\alpha}}{\left\{\frac{2(1-\alpha)}{2-\alpha}\right\}^2} = \boxed{\frac{\alpha(2-\alpha)}{4(1-\alpha)^2}}$$

Determination of K_c, K_p, K_x of the following reaction.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The reaction is occur in a closed vessel which volume is V in a constant temperature T and Pressure P.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

$$1 \quad 1 \quad 0$$

$$1-\alpha \quad 3(1-\alpha) \quad 2\alpha$$

Total mole $= 1-\alpha + 3 - 3\alpha + 2\alpha = 4 - 2\alpha = 2(2-\alpha)$

$$[N_2] = \frac{1-\alpha}{V}, \quad [H_2] = \frac{3(1-\alpha)}{V}, \quad [NH_3] = \frac{2\alpha}{V}$$

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{\left(\frac{2\alpha}{V}\right)^2}{\frac{1-\alpha}{V} \times \left\{\frac{3(1-\alpha)}{V}\right\}^3}$$

$$= \frac{\frac{4\alpha^2}{V^2}}{\frac{1-\alpha}{V} \times \frac{27(1-\alpha)^3}{V^3}}$$

$$= \frac{4\alpha^2}{V^2} \times \frac{V^4}{27(1-\alpha)^4}$$

$$\boxed{K_c = \frac{4\alpha^2 V^2}{27(1-\alpha)^4}}$$

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Relation between K_p, K_c, K_x

Show that, $K_p = K_c (RT)^{\Delta n} = K_x P^{\Delta n}$

let us consider a reaction

$$aA + bB + \cdots \rightleftharpoons mM + nN + \cdots$$

The reaction is occurred in a closed vessel which volume is V and a temperature T and pressure P

Now, $$K_p = \frac{P_M^m P_N^n}{P_A^a P_B^b} \quad \text{--- (1)}$$

We know that, $$PV = nRT$$
$$P = \frac{n}{V} RT$$
$$P = CRT \quad \left[\because C = \frac{n}{V}\right]$$

$\therefore$ $P_A = C_A RT, \quad P_B = C_B RT, \quad P_M = C_M RT, \quad P_N = C_N RT$

Now from equation (1)

$$K_p = \frac{(C_M RT)^m (C_N RT)^n}{(C_A RT)^a (C_B RT)^b}$$

$$= \frac{C_M^m \times C_N^n \cdots}{C_A^a \times C_B^b \cdots} \times \frac{(RT)^{m+n+\cdots}}{(RT)^{a+b+\cdots}}$$

$$= K_c \times (RT)^{(m+n+\cdots) - (a+b+\cdots)}$$

when $1 \gg \alpha$ then, $K_c = \dfrac{4\alpha^2 V^2}{27}$

$$\alpha^2 = 27 K_c \times \frac{1}{4} \times \frac{1}{V^2}$$

$$\alpha = \frac{\sqrt{27}}{2} \times \frac{1}{V} \times \sqrt{K_c}$$

$$\boxed{\alpha \propto \frac{1}{V}}$$

Partial pressure, $P_{N_2} = \dfrac{1-\alpha}{2(2-\alpha)} \cdot P$

$$P_{H_2} = \frac{3(1-\alpha)}{2(2-\alpha)} P$$

$$P_{NH_3} = \frac{2\alpha}{2(2-\alpha)} P$$

$$K_p = \frac{P_{NH_3}^2}{P_{N_2} \times P_{H_2}^3}$$

$$= \frac{\left\{\frac{2\alpha}{2(2-\alpha)} P\right\}^2}{\left\{\frac{1-\alpha}{2(2-\alpha)} \cdot P\right\} \times \left\{\frac{3(1-\alpha)}{2(2-\alpha)} P\right\}^3}$$

$$= \frac{\frac{4\alpha^2 P^2}{4(2-\alpha)^2}}{\frac{(1-\alpha)P}{2(2-\alpha)} \times \frac{27(1-\alpha)^3 P^3}{8(2-\alpha)^3}}$$

$K_p = K_c \times (RT)^{\Delta n}$ [where, $\Delta n = (m+n+\cdots) - (a+b+\cdots)$

Again, we know that,

Partial pressure = mole fraction × total pressure

$P_A = X_A \cdot P$

$P_B = X_B \cdot P$

$P_M = X_M \cdot P$

$P_N = X_N \cdot P$

Now we can write from equation (1)

$$K_p = \frac{(X_M \cdot P)^m (X_N P)^n}{(X_A \cdot P)^a (X_B P)^b}$$

$$= \frac{X_M^m \cdot X_N^n \cdots}{X_A^a \, X_B^b \cdots} \times \frac{P^{m+n+\cdots}}{P^{a+b+\cdots}}$$

$$= K_x \times P^{(m+n)+\cdots-(a+b)\cdots}$$

$$= K_x \cdot P^{\Delta n}$$

$$\boxed{K_p = K_c (RT)^{\Delta n} = K_x P^{\Delta n}}$$

$$K_x = \frac{x^2_{NOCl}}{x^2_{NO} \times x_{Cl_2}} = \frac{\left(\frac{2\alpha}{3-\alpha}\right)^2}{\left\{\frac{2(1-\alpha)}{3-\alpha}\right\}^2 \left\{\frac{1-\alpha}{3-\alpha}\right\}}$$

$$= \frac{4\alpha^2}{(3-\alpha)^2} \times \frac{(3-\alpha)^3}{4(1-\alpha)^3}$$

become

$$= \boxed{\frac{\alpha^2(3-\alpha)}{(1-\alpha)^3}}$$

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$$K_x = \frac{X_{CO} \cdot X_{Cl_2}}{X_{COCl_2}} = \frac{\frac{\alpha}{1+\alpha} \cdot \frac{\alpha}{1+\alpha}}{\frac{1-\alpha}{1+\alpha}}$$

$$\boxed{K_x = \frac{\alpha^2}{1-\alpha^2}}$$

Determination of K_c, K_p, K_x of the following reaction.

$$2NO + Cl_2 \rightleftharpoons 2NOCl$$

$$1 \qquad 1 \qquad 0$$

$$2(1-\alpha) \qquad 1-\alpha \qquad 2\alpha$$

Total moles $= 2 - 2\alpha + 1 - \alpha + 2\alpha = 3 - \alpha$

$$K_c = \frac{\left(\frac{2\alpha}{V}\right)^2}{\left\{\frac{2(1-\alpha)}{V}\right\}^2 \frac{1-\alpha}{V}} = \frac{4\alpha^2}{V^2} \times \frac{V^3}{4(1-\alpha)^3}$$

$$= \frac{\alpha^2 V}{(1-\alpha)^3}$$

$1 \gg \alpha$,

$$K_c = \alpha^2 V$$

$$\alpha^2 = \frac{1}{V} \cdot K_c \qquad \boxed{\alpha \propto \frac{1}{\sqrt{V}}}$$

$$\alpha = \frac{1}{\sqrt{V}} \cdot \sqrt{K_c}$$

$$= \frac{4\alpha^2 P^2}{4(2-\alpha)^2} \times \frac{16(2-\alpha)^4}{27P^4(1+\alpha)^4}$$

$$K_P = \boxed{\frac{16\alpha^2(2-\alpha)^2}{27P^2(1+\alpha)^4}}$$

$1 \gg \alpha$, $\quad K_P = \frac{16\alpha^2 \cdot 2^2}{27P^2}$

$$\alpha^2 = \frac{27P^2 K_P}{64}$$

$$\alpha = \frac{\sqrt{27}}{8} P\sqrt{K_P}$$

$$\boxed{\alpha \propto P}$$

$$K_X = \frac{\left[\frac{2\alpha}{2(2-\alpha)}\right]^2}{\left[\frac{1-\alpha}{2(2-\alpha)}\right]\left[\frac{3(1+\alpha)}{2(2-\alpha)}\right]^3} = \boxed{\frac{16\alpha^2(2-\alpha)^2}{27(1+\alpha)^4}}$$

$1 \gg \alpha$, $\quad K_X = \frac{16\alpha^2 \cdot 4}{27}$

$$\alpha^2 = \frac{27}{64} K_X$$

$$\alpha = \frac{27}{8}\sqrt{K_X}$$

Partial pressure, $P_{NO} = \frac{2(1-\alpha)}{3-\alpha}\cdot P$

$$P_{Cl_2} = \frac{1-\alpha}{3-\alpha}\cdot P$$

$$P_{NOCl} = \frac{2\alpha}{3-\alpha}\cdot P$$

$$K_p = \frac{\left\{\frac{2\alpha}{3-\alpha}P\right\}^2}{\left\{\frac{2(1-\alpha)}{3-\alpha}P\right\}^2 \times \frac{1-\alpha}{3-\alpha}P}$$

$$= \frac{4\alpha^2P^2}{(3-\alpha)^2} \times \frac{(3-\alpha)^3}{4(1-\alpha)^3P^3}$$

$$= \frac{\alpha^2(3-\alpha)}{(1-\alpha)^3P}$$

$1 \gg \alpha$, $\quad K_p = \frac{3\alpha^2}{P}$

$$\alpha^2 = \frac{PK_p}{3}$$

$$\alpha = \frac{1}{\sqrt{3}}\sqrt{P}\sqrt{K_p}$$

$$\boxed{\alpha \propto \sqrt{P}}$$

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Determination of K_c, K_p, K_x of the following reaction.

$$2NO_2 \rightleftharpoons N_2O_4$$

$$1 \qquad 0$$

$$2(1-\alpha) \qquad \alpha$$

Total moles $= 2-2\alpha+\alpha = 2-\alpha$

$$[NO_2] = \frac{2(1-\alpha)}{V}, \quad [N_2O_4] = \frac{\alpha}{V}$$

$$K_c = \frac{[N_2O_4]}{[NO_2]^2} = \frac{\frac{\alpha}{V}}{\left[\frac{2(1-\alpha)}{V}\right]^2} = \frac{\alpha}{V} \times \frac{V^2}{4(1-\alpha)^2}$$

$$= \boxed{\frac{\alpha V}{4(1-\alpha)^2}}$$

$1 \gg \alpha$,

$$K_c = \frac{\alpha V}{4}$$

$$\alpha = \frac{4K_c}{V}$$

$$\boxed{\alpha \propto \frac{1}{V}}$$

Partial pressure, $P_{NO_2} = \frac{2(1-\alpha)}{2-\alpha} \cdot P$

$$P_{N_2O_4} = \frac{\alpha}{2-\alpha} \cdot P$$

$1 \gg \alpha$, $K_c = \frac{\alpha^2}{V}$

$\alpha^2 = V K_c$

$\alpha = \sqrt{V}\sqrt{K_c}$

$\boxed{\alpha \propto \sqrt{V}}$

Partial pressure, $P_{COCl_2} = \frac{1-\alpha}{1+\alpha} P$

$P_{CO} = \frac{\alpha}{1+\alpha} \cdot P$

$P_{Cl_2} = \frac{\alpha}{1+\alpha} \cdot P$

$$K_P = \frac{\frac{\alpha}{1+\alpha} \cdot P \times \frac{\alpha}{1+\alpha} \cdot P}{\frac{1-\alpha}{1+\alpha} \cdot P}$$

$$= \frac{\alpha^2 P^2}{(1+\alpha)^2} \times \frac{1+\alpha}{P(1-\alpha)}$$

$$= \frac{\alpha^2 P}{1-\alpha^2}$$

$1 \gg \alpha$, $K_P = \alpha^2 P$

$\alpha^2 = \frac{1}{P} \cdot K_P$

$\boxed{\alpha \propto \frac{1}{\sqrt{P}}}$

Partial pressure $P_{PCl_3} = \frac{1-\alpha}{2-\alpha} \cdot P$

$P_{Cl_2} = \frac{1-\alpha}{2-\alpha} \cdot P$

$P_{PCl_5} = \frac{\alpha}{2-\alpha} \cdot P$

$$K_p = \frac{P_{PCl_5}}{P_{PCl_3} \times P_{Cl_2}} = \frac{\frac{\alpha}{2-\alpha} \cdot P}{\frac{1-\alpha}{2-\alpha} \cdot P \times \frac{1-\alpha}{2-\alpha} \cdot P}$$

$$= \frac{\alpha P}{2-\alpha} \times \frac{(2-\alpha)^2}{(1-\alpha)^2 P^2}$$

$$= \boxed{\frac{\alpha(2-\alpha)}{P(1-\alpha)^2}}$$

when, $1 \gg \alpha$,
$$K_p = \frac{\alpha \cdot 2}{P}$$

$$\alpha = \frac{1}{2} K_p \times P$$

$$\boxed{\alpha \propto P}$$

$$K_x = \frac{\frac{\alpha}{2-\alpha}}{\frac{1-\alpha}{2-\alpha} \times \frac{1-\alpha}{2-\alpha}} = \boxed{\frac{\alpha(2-\alpha)}{(1-\alpha)^2}}$$

$1 \gg \alpha$,
$$\boxed{K_x = 2\alpha}$$

∴ Partial pressure $P_{PCl_5} = \frac{1-\alpha}{1+\alpha} \cdot P$ [mole fraction × total pressure]

$$P_{PCl_3} = \frac{\alpha}{1+\alpha} P$$

$$P_{Cl_2} = \frac{\alpha}{1+\alpha} \cdot P$$

$$K_p = \frac{P_{PCl_3} \times P_{Cl_2}}{P_{PCl_5}} = \frac{\frac{\alpha}{1+\alpha} \cdot P \times \frac{\alpha}{1+\alpha} \cdot P}{\frac{1-\alpha}{1+\alpha} \cdot P}$$

$$= \frac{\alpha^2}{(1+\alpha)^2} P^2 \times \frac{1+\alpha}{(1-\alpha) P}$$

$$\boxed{K_p = \frac{\alpha^2 P}{(1+\alpha)(1-\alpha)}} = \boxed{\frac{\alpha^2 P}{1-\alpha^2}}$$

$1 \gg \alpha$, then, $K_p = \alpha^2 P$

$$\alpha^2 = K_p \times \frac{1}{P}$$

$$\alpha = \sqrt{K_p} \times \frac{1}{\sqrt{P}}$$

$$\boxed{\alpha \propto \frac{1}{\sqrt{P}}}$$

mole fraction, $X_{PCl_5} = \frac{1-\alpha}{1+\alpha}$, $X_{PCl_3} = \frac{\alpha}{1+\alpha}$, $X_{Cl_2} = \frac{\alpha}{1+\alpha}$

$$K_x = \frac{X_{PCl_3} \times X_{Cl_2}}{X_{PCl_5}} = \frac{\frac{\alpha}{1+\alpha} \cdot \frac{\alpha}{1+\alpha}}{\frac{1-\alpha}{1+\alpha}} = \boxed{\frac{\alpha^2}{1-\alpha^2}}$$