

# DPP-5: Calculations Related to Equilibrium

Chapter: Chemical Equilibrium — Complete Solution Key

Weird Chemist Style “Jo assignment tu kar raha hai... shayad tera dream college bhi usi ke peeche chhupa ho. — Weird Chemist.”

## Master Tools — ICE Table Technique

The ICE Table — Har Equilibrium Problem Ka Backbone:

	Reactant A	Reactant B	Product C
Initial conc. (M)	$[A]_0$	$[B]_0$	0
Change	$-x$	$-x$	$+x$
Equilibrium	$[A]_0 - x$	$[B]_0 - x$	$x$

Key formula:  $K_c = \frac{[\text{products}]^{\text{stoich. coeff.}}}{[\text{reactants}]^{\text{stoich. coeff.}}}$

For pressure:  $K_p = \frac{P_{\text{products}}^{\text{coeff}}}{P_{\text{reactants}}^{\text{coeff}}}$

Conversion:  $K_p = K_c(RT)^{\Delta n}$  where  $\Delta n = \text{moles gaseous products} - \text{moles gaseous reactants}$

Mole fraction to pressure:  $P_i = \chi_i \times P_{\text{total}}$

Shortcut for  $\Delta n = 0$ :  $K_p = K_c$  and volume cancels in  $K_c$  expression (sirf moles use karo!)

## GROUP-1: Equilibrium Constant Determination

### Explanation

**Q1.**  $A + 2B \rightleftharpoons 2C$ . Initially 2 mol A, 2 mol B in 10 L flask. At equilibrium 1 mol C formed. Find  $K_c$ .

ICE Table (moles  $\div$  10L = concentration):

	A	2B	2C
Initial (mol)	2	2	0
Change (mol)	-0.5	-1.0	+1.0
Equilibrium (mol)	1.5	1.0	1.0
Eq. conc. (M)	0.15	0.10	0.10

**How?** 1 mol C formed. Stoich: 2C forms per 1A and 2B. So 0.5 mol A and 1.0 mol B consumed.

$$K_c = \frac{[C]^2}{[A][B]^2} = \frac{(0.10)^2}{(0.15)(0.10)^2} = \frac{0.01}{0.15 \times 0.01} = \frac{0.01}{0.0015} = 6.67$$

### Approach & Common Mistakes

**Analogy — ICE table ek train schedule ki tarah hai:** I = train kahan se chali (initial), C = kitna safar kiya (change), E = kahan ruki (equilibrium).

#### Common Mistakes:

- Moles ko concentration mein convert karna bhoool jaana ( $\div$  volume!). Yahan divide by 10.
- Stoichiometry ignore karna: 2C bana toh 1A gaya aur 2B gaye (ratio 1:2:2 hai).
- Powers forget karna:  $[B]^2$  likhna hai, sirf  $[B]$  nahi.

### Answer

**Answer: (a)**  $K_c = 6.67 \approx 6.66$

### Explanation

**Q2.**  $A + B \rightleftharpoons C + D$ . Initially 1 mol each A and B. At equilibrium 0.4 mol each C and D formed. Find  $K$ .

$\Delta n = 0$  toh volume cancel ho jaata hai! Sirf moles se kaam chalega.

$$\text{A remaining} = 1 - 0.4 = 0.6 \text{ mol}$$

$$\text{B remaining} = 1 - 0.4 = 0.6 \text{ mol}$$

$$K_c = \frac{[C][D]}{[A][B]} = \frac{(0.4/V)(0.4/V)}{(0.6/V)(0.6/V)} = \frac{(0.4)^2}{(0.6)^2} = \frac{0.16}{0.36} = \frac{4}{9}$$

### Approach & Common Mistakes

**When  $\Delta n = 0$ :** Volume (V) cancels from  $K_c$  expression. Toh concentration ke jagah sirf moles ratio use kar sakte ho directly!

$$K_c = (0.4)^2 / (0.6)^2 = (4/6)^2 \times (1/1) = (2/3)^2 = 4/9$$

**Common Mistake:**  $(0.4 \times 0.4) / (0.6 \times 0.6) = 0.44$  likhna.  $0.16 / 0.36 = 4/9 \approx 0.444$ .

### Answer

**Answer: (d)**  $K = \frac{4}{9}$

### Explanation

**Q3.**  $A + B \rightleftharpoons C + D$ . Initially 4 mol each A and B. At equilibrium 2 mol C. Find  $K$ .

2 mol C formed  $\Rightarrow$  2 mol D formed, 2 mol A consumed, 2 mol B consumed.

$$[A]_{eq} = (4 - 2)/V = 2/V$$

$$[B]_{eq} = 2/V, \quad [C]_{eq} = 2/V, \quad [D]_{eq} = 2/V$$

$$K_c = \frac{(2/V)(2/V)}{(2/V)(2/V)} = 1$$

### Approach & Common Mistakes

**Shortcut:** Equal moles of all four species at equilibrium  $\Rightarrow K = 1$ ! Jab numerator aur denominator same hoon toh  $K = 1$ .

**Physical meaning:**  $K = 1$  means products aur reactants equally favored hain at equilibrium.

### Answer

**Answer: (b)**  $K_c = 1$

### Explanation

**Q4.**  $\text{Fe}^{3+} + \text{SCN}^- \rightleftharpoons \text{FeSCN}^{2+}$ . Initial: 3.1 mol  $\text{FeCl}_3$ , 3.2 mol  $\text{NH}_4\text{SCN}$  in 1L. At eq: 3.0 mol  $\text{FeSCN}^{2+}$ . Find  $K_c$ .

	$[\text{Fe}^{3+}]$ (M)	$[\text{SCN}^-]$ (M)	$[\text{FeSCN}^{2+}]$ (M)
Initial	3.1	3.2	0
Change	-3.0	-3.0	+3.0
Equilibrium	0.1	0.2	3.0

$$K_c = \frac{[\text{FeSCN}^{2+}]}{[\text{Fe}^{3+}][\text{SCN}^-]} = \frac{3.0}{(0.1)(0.2)} = \frac{3.0}{0.02} = 150$$

### Approach & Common Mistakes

**Note:**  $\text{FeCl}_3$  decomposes to  $\text{Fe}^{3+}$  in water (completely).  $\text{NH}_4\text{SCN}$  decomposes to  $\text{SCN}^-$ . Volume = 1L toh moles = concentration directly.

**Common Mistake:**  $K_c$  mein  $\text{FeCl}_3$  ya  $\text{NH}_4\text{SCN}$  ki concentration use karna. Only the ionic species ( $\text{Fe}^{3+}$ ,  $\text{SCN}^-$ ) go into  $K_c$  expression.

**High K (= 150):** Reaction strongly forward proceed karta hai — makes sense, blood red color intense hota hai!

### Answer

**Answer: (d)**  $K_c = 150$

### Explanation

**Q5.**  $\text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI}$ . Initially 2 mol each  $\text{H}_2$  and  $\text{I}_2$ . At eq 2 mol HI. Find  $K_p$ .

$\Delta n = 2 - 2 = 0$ , so  $K_p = K_c$ .

ICE (moles): let  $x$  mol react.

$$\text{HI at eq} = 2x = 2 \Rightarrow x = 1$$

$$[\text{H}_2]_{eq} = 2 - 1 = 1 \text{ mol}, \quad [\text{I}_2]_{eq} = 1 \text{ mol}, \quad [\text{HI}]_{eq} = 2 \text{ mol}$$

$$K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = \frac{(2/V)^2}{(1/V)(1/V)} = \frac{4}{1} = 4 = K_p$$

### Approach & Common Mistakes

**Key rule:**  $\Delta n = 0$  wali reactions mein  $K_p = K_c$  hamesha. Volume bhi cancel ho jaata hai.

$(2/V)^2 / (1/V \times 1/V) = 4V^2/V^2 = 4$  — V cancels! ✓

**Common Mistake:**  $(2)^2 / (1 \times 1) = 4$  par phir  $K_p$  ko  $K_c \cdot RT$  se adjust karna. Aisa mat karo jab  $\Delta n = 0$ .

### Answer

**Answer: (b)**  $K_p = 4$

### Explanation

**Q6.**  $H_2 + I_2 \rightleftharpoons 2HI$ . Initially 4.5 mol each in 10L. At eq 3 mol HI. Find  $K_c$ .

$2x = 3 \Rightarrow x = 1.5$  mol

$$[H_2]_{eq} = (4.5 - 1.5)/10 = 3/10 = 0.3 \text{ M}$$

$$[I_2]_{eq} = 0.3 \text{ M}, \quad [HI]_{eq} = 3/10 = 0.3 \text{ M}$$

$$K_c = \frac{(0.3)^2}{(0.3)(0.3)} = \frac{0.09}{0.09} = 1$$

### Approach & Common Mistakes

**Interesting result:** Jab  $H_2$ ,  $I_2$  aur HI sab equal concentration mein hoon, toh  $K_c = 1$ . Yahan sab 0.3M hain!

**Common Mistake:** Ye soचना ke  $K_c = (3)^2 / (3 \times 3) = 1$  moles se directly — yeh bhi sahi hai kyunki  $\Delta n = 0$ .

### Answer

**Answer: (a)**  $K_c = 1$

### Explanation

**Q7.**  $H_2 + I_2 \rightleftharpoons 2HI$ . Initially 1.50 mol each in 10L. At eq  $H_2 = I_2 = 1.25$  mol. Find  $K_c$ .

$H_2$  consumed =  $1.50 - 1.25 = 0.25$  mol  $\Rightarrow$  HI formed =  $2 \times 0.25 = 0.50$  mol

$$[H_2]_{eq} = 1.25/10 = 0.125 \text{ M}$$

$$[I_2]_{eq} = 0.125 \text{ M}$$

$$[HI]_{eq} = 0.50/10 = 0.05 \text{ M}$$

$$K_c = \frac{(0.05)^2}{(0.125)(0.125)} = \frac{0.0025}{0.015625} = 0.16$$

### Approach & Common Mistakes

**Check:**  $K_c = 0.16 < 1$  — matlab HI formation zyada favorable nahi is temperature pe. Ye kaafi low K hai.

**Common Mistake:** HI moles directly use karna without calculating from  $H_2$  consumption. Hame-

sha: HI formed =  $2 \times \text{H}_2$  consumed (stoichiometry!).

$$0.0025/0.015625 = 25/156.25 = 0.16 \checkmark$$

### Answer

**Answer: (b)**  $K_c = 0.16$

### Explanation

**Q8.**  $A + B \rightleftharpoons C + D$ . Equal initial A and B. At eq  $[D] = 2[A]$ . Find  $K_c$ .

Let initial  $[A] = [B] = a$ . Let change =  $x$ .

$$[A]_{eq} = a - x, \quad [B]_{eq} = a - x$$

$$[C]_{eq} = x, \quad [D]_{eq} = x$$

$$\text{Given: } [D] = 2[A] \Rightarrow x = 2(a - x) \Rightarrow x = 2a - 2x \Rightarrow 3x = 2a \Rightarrow x = \frac{2a}{3}$$

$$[A]_{eq} = a - \frac{2a}{3} = \frac{a}{3}$$

$$[C]_{eq} = [D]_{eq} = \frac{2a}{3}$$

$$K_c = \frac{[C][D]}{[A][B]} = \frac{(2a/3)^2}{(a/3)^2} = \left(\frac{2a/3}{a/3}\right)^2 = (2)^2 = 4$$

### Approach & Common Mistakes

**Algebraic approach:** Jab specific numbers nahi diye, variable ( $a$ ) lo. Condition use karo ( $[D] = 2[A]$ ) to find ratio of  $x$  to  $a$ . Phir  $K_c$  mein  $a$  cancel ho jaata hai.

**Common Mistake:**  $[D] = 2[A]$  ko  $x = 2a$  maan lena (instead of  $x = 2(a - x)$ ).  $[A]$  jo bachi hai woh  $a - x$  hai,  $a$  nahi!

### Answer

**Answer: (d)**  $K_c = 4$

### Explanation

**Q9.**  $A(g) + B(g) \rightleftharpoons C(g)$ . Initially 1 mol each in 2L. 20% of A reacts. Find  $K_c$ .

20% of A reacts  $\Rightarrow 0.20 \times 1 = 0.2$  mol A reacts.

	A	B	C
Initial (mol)	1	1	0
Change (mol)	-0.2	-0.2	+0.2
Eq. (mol)	0.8	0.8	0.2
Eq. conc. (M)	0.4	0.4	0.1

$$K_c = \frac{[C]}{[A][B]} = \frac{0.1}{(0.4)(0.4)} = \frac{0.1}{0.16} = 0.625$$

### Approach & Common Mistakes

**Note:** Is reaction mein  $\Delta n = 0$  nahi hai! (reactants = 2 mol gas, products = 1 mol gas,  $\Delta n = -1$ ). Volume use karna zaroori hai.

$[A] = 0.8/2 = 0.4$  M,  $[C] = 0.2/2 = 0.1$  M.

**Common Mistake:** 20% of 2L soochna ya concentration calculate karna bhoolna.

### Answer

**Answer:** (c)  $K_c = 0.625$

### Explanation

**Q10.**  $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ . Initially 1 mol  $N_2O_4$  in 1L. At eq mole fraction of  $NO_2 = 1/2$ . Find  $K_c$ .

Let  $x$  mol  $N_2O_4$  dissociate.

$$N_2O_4 = 1 - x, \quad NO_2 = 2x, \quad \text{Total} = 1 + x$$

$$\text{Mole fraction of } NO_2 = \frac{2x}{1+x} = \frac{1}{2}$$

$$4x = 1 + x \Rightarrow 3x = 1 \Rightarrow x = \frac{1}{3}$$

At equilibrium (Volume = 1L):

$$[N_2O_4] = 1 - \frac{1}{3} = \frac{2}{3} \text{ M}$$

$$[NO_2] = 2 \times \frac{1}{3} = \frac{2}{3} \text{ M}$$

$$K_c = \frac{[NO_2]^2}{[N_2O_4]} = \frac{(2/3)^2}{2/3} = \frac{4/9}{2/3} = \frac{4}{9} \times \frac{3}{2} = \frac{2}{3}$$

### Approach & Common Mistakes

**Mole fraction step zaroori hai:** Seedha mole fraction nahi use kar sakte  $K_c$  mein — pehle moles find karo, phir concentration ( $\div$  volume) find karo.

**Analogy:** Mole fraction ek “slice of pie” bata raha hai (proportion), par  $K_c$  ko actual amount chahiye (concentration).

**Common Mistake:**  $K_c = (1/2)^2/(1/2) = 1/2$  directly likhna. Mole fraction  $\neq$  concentration!

### Answer

**Answer:** (c)  $K_c = \frac{2}{3}$

### GROUP-2: Equilibrium Calculations (find x from K)

### Explanation

**Q11.**  $A + B \rightleftharpoons C + D$ .  $K_c = 9$ . Initially 1 mol each A, B in 1L. Find amount of C at equilibrium. Let  $x =$  eq. concentration of C (= D).

$$K_c = \frac{x^2}{(1-x)^2} = 9 \Rightarrow \frac{x}{1-x} = \sqrt{9} = 3$$

$$x = 3(1-x) = 3 - 3x \Rightarrow 4x = 3 \Rightarrow x = \frac{3}{4} = 0.75 \text{ M}$$

### Approach & Common Mistakes

**Trick:** Jab  $K_c = \left(\frac{x}{a-x}\right)^2$  form mein aaye, **square root** lo dono sides ka! Quadratic solve karne ki zaroorat nahi.

$$\sqrt{K_c} = x/(1-x) \Rightarrow \sqrt{9} = 3 \Rightarrow x = 3/4$$

**Common Mistake:** Quadratic expand karna:  $x^2 = 9(1-x)^2 = 9 - 18x + 9x^2 \rightarrow 8x^2 - 18x + 9 = 0$ . Yeh kaam karta hai lekin time waste hai!

### Answer

**Answer:** (c) Amount of C = 0.75 mol

### Explanation

**Q12.**  $H_2 + CO_2 \rightleftharpoons H_2O + CO$ .  $K_p = 4.0$  at  $1660^\circ\text{C}$ . Initially 0.80 mol  $H_2$ , 0.80 mol  $CO_2$  in 5L. Find eq.  $[CO_2]$ .

$$\Delta n = 0 \Rightarrow K_p = K_c = 4.0. \text{ Initial } [H_2] = [CO_2] = 0.80/5 = 0.16 \text{ M.}$$

Let  $x$  react:

$$K_c = \frac{x^2}{(0.16-x)^2} = 4 \Rightarrow \frac{x}{0.16-x} = 2$$

$$x = 0.32 - 2x \Rightarrow 3x = 0.32 \Rightarrow x = \frac{0.32}{3} \approx 0.1067 \text{ M}$$

$$[CO_2]_{eq} = 0.16 - 0.1067 = 0.0533 \approx 0.0534 \text{ M}$$

### Approach & Common Mistakes

**Again use the square root trick!**  $K_c = 4 \Rightarrow \sqrt{K_c} = 2 \Rightarrow x/(0.16-x) = 2$ . Linear equation!

$K_p = K_c$  because:  $\Delta n = 2 - 2 = 0$  for this reaction.

### Answer

**Answer:** (b)  $[CO_2]_{eq} = 0.0534 \text{ M}$

### Explanation

**Q13.**  $CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$ .  $K_c = 4$ . Initially 4 mol each acid and alcohol. Find eq. concentration of acid.

$\Delta n = 0 \Rightarrow$  volume cancels. Work with moles directly.

Let  $x$  mol react:

$$K_c = \frac{x \cdot x}{(4 - x)^2} = 4 \Rightarrow \frac{x}{4 - x} = 2$$

$$x = 8 - 2x \Rightarrow 3x = 8 \Rightarrow x = \frac{8}{3}$$

$$\text{Acid remaining} = 4 - x = 4 - \frac{8}{3} = \frac{12 - 8}{3} = \frac{4}{3} \text{ mol}$$

Concentration (in volume  $V$ ):  $[\text{acid}]_{eq} = \frac{4/3}{V}$ . If  $V = 1 \text{ L}$ ,  $= \frac{4}{3} \text{ M}$ .

### Approach & Common Mistakes

**Esterification:** Ye reaction reversible hai, incomplete hogi.  $K = 4$  matlab  $2/3$  reaction complete hogi.

$x = 8/3 \approx 2.67$  mol reacts out of 4 mol. Acid left  $= 4 - 8/3 = 4/3$  mol.

**Common Mistake:**  $K_c = 4$  likhne ke baad  $4 - x = x/4 = 1$  maan lena. Nahi! Quadratic/linear equation solve karna hai.

### Answer

**Answer: (b)**  $[\text{acid}]_{eq} = \frac{4}{3} \text{ M (or mol)}$

### Explanation

**Q14.**  $\text{PCl}_5 \rightleftharpoons \text{PCl}_3 + \text{Cl}_2$ . Need 0.1 mol/L  $\text{Cl}_2$ .  $K_c = 0.04$ . Find initial  $[\text{PCl}_5]$ .

At equilibrium:  $[\text{Cl}_2] = 0.1 \text{ M} \Rightarrow [\text{PCl}_3] = 0.1 \text{ M}$  (stoichiometry).

Let initial  $[\text{PCl}_5] = a$ .

$$[\text{PCl}_5]_{eq} = a - 0.1$$

$$K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = \frac{(0.1)(0.1)}{a - 0.1} = 0.04$$

$$a - 0.1 = \frac{0.01}{0.04} = 0.25 \Rightarrow a = 0.35 \text{ mol/L}$$

### Approach & Common Mistakes

**Reverse approach:** Yahan equilibrium moles diye hain, initial find karna hai. Seedha  $K_c$  expression mein plug in karo aur  $a$  solve karo.

**Verify:**  $K_c = (0.1)(0.1)/(0.35 - 0.1) = 0.01/0.25 = 0.04 \checkmark$

### Answer

**Answer: (c)** Initial  $[\text{PCl}_5] = 0.35 \text{ mol/L}$

### Explanation

**Q15.**  $\text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI}$ . 0.5 mol each in 10L.  $K_c = 49$ . Find  $[\text{HI}]/[\text{I}_2]$ .

Initial  $[\text{H}_2] = [\text{I}_2] = 0.05 \text{ M}$ .

Since  $[\text{H}_2] = [\text{I}_2]$  initially and stoichiometry is symmetric,  $[\text{H}_2]_{eq} = [\text{I}_2]_{eq}$  always.

$$K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = \frac{[\text{HI}]^2}{[\text{I}_2]^2} = \left(\frac{[\text{HI}]}{[\text{I}_2]}\right)^2 = 49$$

$$\frac{[\text{HI}]}{[\text{I}_2]} = \sqrt{49} = 7$$

### Approach & Common Mistakes

**Elegant shortcut!** Jab  $\text{H}_2$  aur  $\text{I}_2$  equal initial concentrations mein hoon, toh  $[\text{H}_2]_{eq} = [\text{I}_2]_{eq}$  hamesha. Isliye:

$$K_c = \frac{[\text{HI}]^2}{[\text{I}_2]^2} \Rightarrow \frac{[\text{HI}]}{[\text{I}_2]} = \sqrt{K_c} = \sqrt{49} = 7$$

No need to find actual concentrations!

**Common Mistake:** ICE table se  $x$  solve karna aur phir ratio lena — works but longer.

### Answer

**Answer: (a)**  $[\text{HI}]/[\text{I}_2] = 7$

### Explanation

**Q16.**  $\text{A} + \text{B} \rightleftharpoons \text{C} + \text{D}$  in 1L at  $250^\circ\text{C}$ . Initial  $[\text{A}] = 3n$ ,  $[\text{B}] = n$ . At eq  $[\text{C}]_{eq} = [\text{B}]_{eq}$ . Find  $[\text{D}]_{eq}$ .

Let change =  $x$  (mol/L).

$$\begin{aligned} [\text{A}]_{eq} &= 3n - x, & [\text{B}]_{eq} &= n - x \\ [\text{C}]_{eq} &= x, & [\text{D}]_{eq} &= x \end{aligned}$$

Condition:  $[\text{C}]_{eq} = [\text{B}]_{eq} \Rightarrow x = n - x \Rightarrow 2x = n \Rightarrow x = n/2$

$$[\text{D}]_{eq} = x = \frac{n}{2}$$

### Approach & Common Mistakes

**Simple algebra:** Condition diya hai ( $[\text{C}] = [\text{B}]$ ), use it to find  $x = n/2$ . Phir  $[\text{D}] = x = n/2$ .

**Check:**  $[\text{A}]_{eq} = 3n - n/2 = 5n/2$ ,  $[\text{B}]_{eq} = n/2 = [\text{C}]_{eq}$  ✓

### Answer

**Answer: (a)**  $[\text{D}]_{eq} = \frac{n}{2}$

### Explanation

**Q17.**  $\text{X}_2 + \text{Y}_2 \rightleftharpoons 2\text{XY}$ . 1 mol  $\text{X}_2$  in 1L, 2 mol  $\text{Y}_2$  in 2L flasks. Flasks combined (total  $V = 3\text{L}$ ).  $[\text{XY}]_{eq} = 0.6$  mol/L. Find eq. conc. of  $\text{X}_2$  and  $\text{Y}_2$ .

After combining, initial concentrations in 3L:

$$[X_2]_0 = \frac{1}{3} \text{ M}, \quad [Y_2]_0 = \frac{2}{3} \text{ M}$$

$[XY]_{eq} = 0.6 \text{ M}$ . From stoichiometry: 2 mol XY formed from 1 mol  $X_2$  + 1 mol  $Y_2$ .

$$\text{change} = x = 0.6/2 = 0.3 \text{ M reacted}$$

$$[X_2]_{eq} = \frac{1}{3} - 0.3$$

$$[Y_2]_{eq} = \frac{2}{3} - 0.3$$

### Approach & Common Mistakes

**Key step:** Dono flasks combine hote hain, toh total volume = 1 + 2 = 3L. Initial conc. recalculate karo!

$$[XY] = 0.6 = 2x \Rightarrow x = 0.3 \text{ M consumed.}$$

**Common Mistake:** Volumes separate rakhna ya initial conc. galat calculate karna.

### Answer

$$\text{Answer: (a)} \quad [X_2]_{eq} = \left(\frac{1}{3} - 0.3\right) \text{ M}, \quad [Y_2]_{eq} = \left(\frac{2}{3} - 0.3\right) \text{ M}$$

### GROUP-3: Pressure-based Equilibrium ( $P$ , $P_{total}$ )

#### Explanation

**Q18.**  $C(s) + S_2(g) \rightleftharpoons CS_2(g)$ . Initially 12g C, 64g  $S_2$ , 76g  $CS_2$  in 13L vessel at  $1027^\circ\text{C}$ . Find total pressure.

Moles: C =  $12/12 = 1 \text{ mol}$  (**solid — no pressure contribution!**)

$S_2 = 64/64 = 1 \text{ mol}$  (gas),  $CS_2 = 76/76 = 1 \text{ mol}$  (gas)

Total gaseous moles = 1 + 1 = 2 mol.  $T = 1027 + 273 = 1300 \text{ K}$ ,  $V = 13 \text{ L}$ .

$$P = \frac{n_{gas}RT}{V} = \frac{2 \times R \times 1300}{13} = \frac{2600R}{13} = 200R$$

**Note:** This is the initial (pre-equilibrium) pressure. Since no  $K_c$  given, question asks initial gas pressure.

### Approach & Common Mistakes

**Rule:** Solids (C yahan) pressure mein contribute nahi karte. Sirf gases count karo.

**Ideal gas law:**  $PV = nRT \Rightarrow P = nRT/V$ .  $T = \text{Celsius} + 273!$

**Common Mistake:** C ko bhi gaseous maan lena ( $n = 3$  instead of 2).

### Answer

**Answer: (a)** Total pressure =  $200R$  (initial gas pressure)

### Explanation

**Q19.**  $\text{PCl}_5 \rightleftharpoons \text{PCl}_3 + \text{Cl}_2$ . Mole fraction:  $\chi(\text{PCl}_5) = 0.4$ ,  $\chi(\text{Cl}_2) = 0.3$ . Find  $\chi(\text{PCl}_3)$ .

Sum of all mole fractions = 1 (always!):

$$\chi(\text{PCl}_5) + \chi(\text{PCl}_3) + \chi(\text{Cl}_2) = 1$$

$$0.4 + \chi(\text{PCl}_3) + 0.3 = 1 \Rightarrow \chi(\text{PCl}_3) = 0.3$$

### Approach & Common Mistakes

**Fastest question in DPP!** Mole fractions ka sum hamesha 1 hota hai. Baki sab subtract karo.

Also note:  $\chi(\text{PCl}_3) = \chi(\text{Cl}_2) = 0.3$  — makes sense since they're produced in equal amounts from  $\text{PCl}_5$  decomposition!

### Answer

**Answer: (a)**  $\chi(\text{PCl}_3) = 0.3$

### Explanation

**Q20.**  $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$ .  $K_p = 0.66$ .  $P_{\text{total}} = 0.5$  atm. Find  $P(\text{N}_2\text{O}_4)$ .

Let  $P(\text{N}_2\text{O}_4) = p_1$ ,  $P(\text{NO}_2) = p_2$ .

$$p_1 + p_2 = 0.5 \Rightarrow p_2 = 0.5 - p_1 \quad \text{(i)}$$

$$K_p = \frac{p_2^2}{p_1} = 0.66 \quad \text{(ii)}$$

Substitute (i) into (ii):

$$\frac{(0.5 - p_1)^2}{p_1} = 0.66 \Rightarrow 0.25 - p_1 + p_1^2 = 0.66p_1$$

$$p_1^2 - 1.66p_1 + 0.25 = 0$$

$$p_1 = \frac{1.66 \pm \sqrt{1.66^2 - 4(0.25)}}{2} = \frac{1.66 \pm \sqrt{1.756}}{2} = \frac{1.66 \pm 1.325}{2}$$

Taking smaller root ( $p_1 < 0.5$ ):  $p_1 = \frac{1.66 - 1.325}{2} = \frac{0.335}{2} \approx 0.168$  atm

### Approach & Common Mistakes

**Pressure type questions mein:** Always write two equations: (i) sum of partial pressures = total pressure, (ii)  $K_p$  expression. Then solve.

**Two roots of quadratic:** Lena woh root jo physically possible ho ( $p_1 < P_{\text{total}} = 0.5$  atm). Larger root = 1.49 atm — physically impossible!

**Common Mistake:** Both roots try karna without checking physical validity.

### Answer

**Answer: (a)**  $P(\text{N}_2\text{O}_4) \approx 0.168 \text{ atm}$

### Explanation

**Q21.**  $\text{C}(\text{s}) + \text{CO}_2(\text{g}) \rightleftharpoons 2\text{CO}(\text{g})$ .  $K_p = 63 \text{ atm}$ . At eq  $P(\text{CO}) = 10 P(\text{CO}_2)$ . Find total pressure.

Let  $P(\text{CO}_2) = p$ , then  $P(\text{CO}) = 10p$ .

$$K_p = \frac{P(\text{CO})^2}{P(\text{CO}_2)} = \frac{(10p)^2}{p} = \frac{100p^2}{p} = 100p = 63$$

$$p = 0.63 \text{ atm}$$

$$P_{\text{total}} = P(\text{CO}_2) + P(\text{CO}) = 0.63 + 6.3 = 6.93 \text{ atm}$$

### Approach & Common Mistakes

**C is solid!** So  $K_p$  has no term for C.  $K_p = P(\text{CO})^2/P(\text{CO}_2)$  only.

**Condition use karo:**  $P(\text{CO}) = 10p$  given. Substituting directly simplifies the expression beautifully.

$P(\text{CO}) = 10 \times 0.63 = 6.3 \text{ atm}$ . Total =  $0.63 + 6.3 = 6.93 \text{ atm}$ . ✓

### Answer

**Answer: (c)**  $P_{\text{total}} = 6.93 \text{ atm}$

### Explanation

**Q22.**  $\text{A}(\text{g}) \rightleftharpoons \text{B}(\text{g})$ . Initial pressure = 1 atm.  $K_p = 4$ . Find  $P_B$  at equilibrium.

Let  $P_B = x$  at equilibrium. Then  $P_A = 1 - x$  (since  $\Delta n = 0$ , total P = 1 atm).

Wait:  $\Delta n = 1 - 1 = 0$  but... let me check. Initially only A. As A converts to B:  $P_A = 1 - x$ ,  $P_B = x$ .

$$K_p = \frac{P_B}{P_A} = \frac{x}{1-x} = 4 \Rightarrow x = 4 - 4x \Rightarrow 5x = 4 \Rightarrow x = \frac{4}{5} \text{ atm}$$

### Approach & Common Mistakes

**Simple 1-step:**  $K_p = P_B/P_A = 4$  and  $P_A + P_B = 1$  (total pressure constant since  $\Delta n = 0$ ).

$P_B = 4/5 = 0.8 \text{ atm}$ ,  $P_A = 1/5 = 0.2 \text{ atm}$ . Check:  $0.8/0.2 = 4 = K_p$  ✓

**Common Mistake:** Thinking total pressure changes because reaction occurs.  $\Delta n = 0$  means total moles (and pressure) unchanged!

### Answer

**Answer: (c)**  $P_B = \frac{4}{5} \text{ atm}$

### Explanation

**Q23.**  $2\text{AB}(\text{g}) \rightleftharpoons 2\text{A}(\text{g}) + \text{B}_2(\text{g})$ . Initial  $P(\text{AB}) = 500$  mm.  $P_{\text{total, eq}} = 625$  mm. Find  $K_p$ .

Let  $2y$  mm of AB dissociate (2 moles react per reaction):

	2AB	2A	B <sub>2</sub>
Initial (mm)	500	0	0
Change (mm)	-2y	+2y	+y
Equilibrium (mm)	500 - 2y	2y	y

$$\text{Total} = 500 - 2y + 2y + y = 500 + y = 625 \Rightarrow y = 125 \text{ mm}$$

$$P(\text{AB}) = 250 \text{ mm}, \quad P(\text{A}) = 250 \text{ mm}, \quad P(\text{B}_2) = 125 \text{ mm}$$

$$K_p = \frac{P(\text{A})^2 \cdot P(\text{B}_2)}{P(\text{AB})^2} = \frac{(250)^2 \times 125}{(250)^2} = 125 \text{ mm Hg}$$

### Approach & Common Mistakes

**Pressure ICE table:** Concentrations ki jagah pressures (mm Hg) use karo. Ek change variable  $y$  lo.

Total pressure change:  $500 \rightarrow 625$ , difference = 125 mm = extra B<sub>2</sub> formed. So  $y = 125$  mm.

**Beautiful cancellation:**  $P(\text{A})^2 / (P(\text{AB}))^2 = (250)^2 / (250)^2 = 1$ . So  $K_p = P(\text{B}_2) = 125$  mm Hg.

### Answer

**Answer: (b)**  $K_p = 125$  mm Hg

### Explanation

**Q24 & Q25. [Identical question!]**  $\text{C}(\text{s}) + \text{CO}_2(\text{g}) \rightleftharpoons 2\text{CO}(\text{g})$ . Initial  $P(\text{CO}_2) = 0.5$  atm.  $P_{\text{total, eq}} = 0.8$  atm. Find  $K_p$ .

Let  $x$  atm CO<sub>2</sub> reacts. Then  $2x$  atm CO forms.

$$P(\text{CO}_2)_{\text{eq}} = 0.5 - x$$

$$P(\text{CO})_{\text{eq}} = 2x$$

$$\text{Total: } (0.5 - x) + 2x = 0.5 + x = 0.8 \Rightarrow x = 0.3 \text{ atm}$$

$$P(\text{CO}_2)_{\text{eq}} = 0.5 - 0.3 = 0.2 \text{ atm}$$

$$P(\text{CO})_{\text{eq}} = 0.6 \text{ atm}$$

$$K_p = \frac{P(\text{CO})^2}{P(\text{CO}_2)} = \frac{(0.6)^2}{0.2} = \frac{0.36}{0.2} = 1.8 \text{ atm}$$

### Approach & Common Mistakes

**Flag:** Q24 aur Q25 same question hain! Both have identical data and options.

**C is solid:**  $K_p$  mein C ka koi term nahi. Only gaseous species.

**Units of  $K_p$ :** Is reaction mein  $\Delta n = +1$ , so  $K_p$  has units of atm.

Verify:  $K_p = 1.8 \text{ atm}$  ✓

### Answer

**Answer (Q24 & Q25): (c)  $K_p = 1.8 \text{ atm}$**

### Explanation

**Q26.**  $A_2(g) \rightleftharpoons 2A(g)$ . At equilibrium 20% by volume of A atoms.  $P_{\text{total}} = 1 \text{ atm}$ . Find  $K_p$ .  
“20% by volume” = 20% mole fraction (ideal gas mein volume fraction = mole fraction).

$$\chi(A) = 0.20 \Rightarrow P(A) = 0.20 \times 1 = 0.20 \text{ atm}$$

$$\chi(A_2) = 0.80 \Rightarrow P(A_2) = 0.80 \times 1 = 0.80 \text{ atm}$$

$$K_p = \frac{P(A)^2}{P(A_2)} = \frac{(0.20)^2}{0.80} = \frac{0.04}{0.80} = 0.05 = 5 \times 10^{-2} \text{ atm}$$

### Approach & Common Mistakes

**Volume fraction = Mole fraction** for ideal gases at constant T and P. Avogadro's law!

**Note:**  $\Delta n = +1$ , so  $K_p$  has units of atm.

**Common Mistake:**  $K_p = (0.20)^2 / (0.80) = 0.05$  not  $0.04 / 0.80 = 0.05$ . Same, OK! But don't forget to square  $P(A)$ .

### Answer

**Answer: (a)  $K_p = 5 \times 10^{-2} \text{ atm}$**

### Explanation

**Q27.**  $N_2 + 3H_2 \rightleftharpoons 2NH_3$ . Initial  $N_2 : H_2 = 1 : 3$ . Initial pressure = 100 atm. 20% mixture reacts. Final total pressure?

Initial: 1 mol  $N_2$  + 3 mol  $H_2$  = 4 mol total. Initial pressure = 100 atm.

**20% of mixture reacts:**  $0.20 \times 4 = 0.8 \text{ mol}$  total reacts. Since ratio  $N_2:H_2 = 1:3$  matches stoichiometry (perfect stoichiometric mix):

$$N_2 \text{ consumed} = 0.20 \times 1 = 0.20 \text{ mol}$$

$$H_2 \text{ consumed} = 0.20 \times 3 = 0.60 \text{ mol}$$

$$NH_3 \text{ formed} = 0.20 \times 2 = 0.40 \text{ mol}$$

**Moles at equilibrium:**  $N_2 = 0.80$ ,  $H_2 = 2.40$ ,  $NH_3 = 0.40$ , Total = 3.60 mol

At constant  $T$  and  $V$ :  $P \propto n$

$$P_{eq} = P_{\text{initial}} \times \frac{n_{eq}}{n_{\text{initial}}} = 100 \times \frac{3.6}{4} = 90 \text{ atm}$$

### Approach & Common Mistakes

**Moles se pressure nikalo:** At constant T and V, pressure  $\propto$  moles. Moles 4 se 3.6 ho gaye (10% reduction), so pressure bhi 10% reduce: 100  $\rightarrow$  90 atm.

**Why decrease?**  $N_2 + 3H_2 \rightarrow 2NH_3$ : 4 moles  $\rightarrow$  2 moles. Moles decrease karte hain  $\rightarrow$  pressure decrease.

**Common Mistake:** Moles ke change ko alag-alag calculate karna galat method se.

### Answer

**Answer: (b)**  $P_{\text{total}} = 90$  atm

### Explanation

**Q28.**  $PCl_5 \rightleftharpoons PCl_3 + Cl_2$ .  $\chi(PCl_3) = 0.25$ .  $P_{\text{total}} = 2.0$  atm. Find  $P(Cl_2)$ .

Ye reaction mein  $PCl_3$  aur  $Cl_2$  **equal moles mein produce** hote hain (1:1 stoichiometry).

$\therefore \chi(Cl_2) = \chi(PCl_3) = 0.25$

$$P(Cl_2) = \chi(Cl_2) \times P_{\text{total}} = 0.25 \times 2.0 = 0.5 \text{ atm}$$

### Approach & Common Mistakes

**Symmetry argument:**  $PCl_5 \rightarrow PCl_3 + Cl_2$  — ek  $PCl_3$  ke saath ek  $Cl_2$  banta hai hamesha. Toh unke moles (and mole fractions) equal rahenge.

**Also note:**  $\chi(PCl_5) = 1 - 0.25 - 0.25 = 0.50$ .  $K_p = (0.25)(0.25) \times 2^2 / ((0.5)(2)) = 0.5$  atm.

### Answer

**Answer: (c)**  $P(Cl_2) = 0.5$  atm

### Explanation

**Q29.**  $N_2 + 3H_2 \rightleftharpoons 2NH_3$ . Initial ratio  $N_2:H_2 = 1:3$ . At eq 50% reacted. Eq. pressure =  $p$ . Find  $P(NH_3)$ .

Initial (basis):  $N_2 = 1$  mol,  $H_2 = 3$  mol, Total = 4 mol.

50% reacts (ratio 1:3 matches stoichiometry perfectly):

$$N_2 \text{ consumed} = 0.5 \text{ mol}, \quad H_2 \text{ consumed} = 1.5 \text{ mol}$$

$$NH_3 \text{ formed} = 2 \times 0.5 = 1.0 \text{ mol}$$

Equilibrium moles:  $N_2 = 0.5$ ,  $H_2 = 1.5$ ,  $NH_3 = 1.0$ . Total = 3.0 mol.

$$\chi(NH_3) = \frac{1.0}{3.0} = \frac{1}{3}$$

$$P(NH_3) = \frac{1}{3} \times p = \frac{p}{3}$$

### Approach & Common Mistakes

**Steps:** (1) Moles find karo after 50% reaction. (2) Mole fraction nikalo. (3)  $P_i = \chi_i \times P_{\text{total}}$ .

Total moles:  $0.5 + 1.5 + 1.0 = 3.0$  mol.  $\text{NH}_3$  fraction =  $1/3$ .

**Common Mistake:**  $\text{NH}_3$  ke mole fraction ko  $2/4 = 1/2$  maan lena (initial proportion se). Equilibrium moles calculate karne ke baad karo!

### Answer

**Answer: (a)**  $P(\text{NH}_3) = \frac{p}{3}$

### GROUP-4: Miscellaneous

#### Explanation

**Q30.**  $\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$ . In 20L vessel: initially 1 mol each CO,  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ . No  $\text{H}_2$  initially. Which is true?

$Q = ?$  at initial conditions:

$$Q = \frac{[\text{CO}_2][\text{H}_2]}{[\text{CO}][\text{H}_2\text{O}]} = \frac{(0.05)(0)}{(0.05)(0.05)} = 0$$

Since  $Q = 0 < K$  (for any  $K > 0$ ), reaction **goes forward**.

#### Direction of change:

- CO: decreases ( $< 1$  mol) ✓
- $\text{H}_2\text{O}$ : decreases ( $< 1$  mol) ✓
- $\text{CO}_2$ : increases ( $> 1$  mol) ✓
- $\text{H}_2$ : increases from 0 (but  $< 1$  mol max, since limited by  $\text{H}_2\text{O}$  available)

So: **CO,  $\text{H}_2\text{O}$ ,  $\text{H}_2$  are all less than 1 mole.** (CO and  $\text{H}_2\text{O}$  decrease;  $\text{H}_2$  starts from 0 and goes up but cannot exceed 1)

### Approach & Common Mistakes

**Q vs K approach:** Jab koi reactant/product zero hota hai,  $Q = 0 < K$  hamesha. Reaction forward jaayega.

**Why  $\text{H}_2 < 1$ ?** Reaction agar complete bhi ho toh max 1 mol  $\text{H}_2$  ban sakta hai (limited by 1 mol  $\text{H}_2\text{O}$ ). Lekin it's reversible, so even less than 1 mol  $\text{H}_2$  will form.

**Common Mistake:**  $\text{CO}_2$  increases  $\rightarrow$  " $\text{CO}_2$  and  $\text{H}_2\text{O}$  both increase" soochna. Nahi!  $\text{H}_2\text{O}$  toh reactant hai, woh decrease karega.

### Answer

**Answer: (b)** CO,  $\text{H}_2\text{O}$ ,  $\text{H}_2$  all less than 1 mole

#### Explanation

**Q31.**  $2\text{P}(\text{g}) + \text{Q}(\text{g}) \rightleftharpoons 3\text{R}(\text{g}) + \text{S}(\text{g})$ . Initially 2 mol each P and Q in 1L. Which is true at equilibrium?

Stoichiometric ratio needed for reaction: P:Q = 2:1.

But initial P:Q = 2:2 = 1:1. **Q is in excess**, P is limiting.

Let reaction extent =  $x$  (mol/L):

$$[P]_{eq} = 2 - 2x$$

$$[Q]_{eq} = 2 - x$$

$$[R]_{eq} = 3x, \quad [S]_{eq} = x$$

For any  $x > 0$ :  $2 - 2x < 2 - x$  (since subtracting more from P's column).

$\therefore [P] < [Q]$  **always at equilibrium!**

### Approach & Common Mistakes

**Analogy:** Reaction mein P aur Q ka ratio 2:1 chahiye. Lekin tum 2:2 = 1:1 ratio mein liye. Matlab P ki "per unit of Q" bhi zyada use ho rahi hai. Isliye P, Q se pehle khatam hoga —  $P < Q$  at equilibrium.

**Mathematically:**  $[P]_{eq} = 2 - 2x$  vs  $[Q]_{eq} = 2 - x$ . Since  $2x > x$  for  $x > 0$ :  $[P] < [Q]$ . ✓

**Common Mistake:** Option (c):  $[Q] = [R]$  tabhi hoga jab  $2 - x = 3x \Rightarrow x = 0.5$ . Ye specific K ke liye hoga, hamesha nahi.

### Answer

**Answer: (a)**  $[P] < [Q]$  at equilibrium (always, for any  $x > 0$ )

## Quick Answer Key — DPP-5

Q	Ans	Key value	Q	Ans	Key value	Q	Ans	Key value
1	(a)	$K_c = 6.66$	12	(b)	$[\text{CO}_2] = 0.0534 \text{ M}$	23	(b)	$K_p = 125 \text{ mm}$
2	(d)	$K = 4/9$	13	(b)	$[\text{acid}] = 4/3$	24	(c)	$K_p = 1.8 \text{ atm}$
3	(b)	$K = 1$	14	(c)	$0.35 \text{ mol/L}$	25	(c)	Same as Q24
4	(d)	$K_c = 150$	15	(a)	ratio = 7	26	(a)	$5 \times 10^{-2} \text{ atm}$
5	(b)	$K_p = 4$	16	(a)	$[D] = n/2$	27	(b)	90 atm
6	(a)	$K_c = 1$	17	(a)	$(1/3 - 0.3), (2/3 - 0.3)$	28	(c)	0.5 atm
7	(b)	$K_c = 0.16$	18	(a)	200R	29	(a)	$p/3$
8	(d)	$K_c = 4$	19	(a)	0.3	30	(b)	$\text{CO}, \text{H}_2\text{O}, \text{H}_2 < 1$
9	(c)	$K_c = 0.625$	20	(a)	0.168 atm	31	(a)	$[P] < [Q]$
10	(c)	$K_c = 2/3$	21	(c)	6.93 atm			
11	(c)	$[C] = 0.75$	22	(c)	$P_B = 4/5 \text{ atm}$			

**Note:** Q24 and Q25 are **identical questions** in the original paper.

**Key shortcuts:** (1)  $\Delta n = 0 \Rightarrow K_p = K_c$ , volume cancels. (2) Square root trick:  $K_c = x^2/(a-x)^2 \Rightarrow \sqrt{K_c} = x/(a-x)$ . (3) For pressure problems: two equations — sum of partial pressures +  $K_p$  expression.