

Chemical and Ionic Equilibrium - JEE

Main Questions

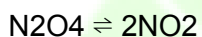
Multiple Choice Questions

1. At a given temperature, the equilibrium constant (K_c) for the reaction $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ is 0.0625. If the initial concentration of N_2O_4 is 2.0 M and initial concentration of NO_2 is zero, calculate the equilibrium concentration of NO_2 .

- a) 0.5 M
- b) 0.25 M
- c) 0.125 M
- d) 0.707 M

Solution:

Let x M of N_2O_4 dissociate at equilibrium



Initial: 2.0 0

Change: $-x$ $+2x$

Equilibrium: $(2-x)$ $2x$

$$K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]} = 0.0625$$

$$(2x)^2/(2-x) = 0.0625$$

$$\text{Solving: } x = 0.25$$

$$\text{Therefore, } [\text{NO}_2] = 2x = 0.5 \text{ M}$$

Answer: (a) 0.5 M

2. The pH of a 0.1 M CH_3COOH solution is 2.87. Calculate the ionization constant (K_a) of CH_3COOH .

- a) 1.8×10^{-5}
- b) 1.8×10^{-4}
- c) 1.8×10^{-3}
- d) 1.8×10^{-2}

Solution:

$$\text{pH} = 2.87$$

$$[\text{H}^+] = 10^{-2.87} = 1.35 \times 10^{-3} \text{ M}$$

$$[\text{CH}_3\text{COO}^-] = [\text{H}^+] = 1.35 \times 10^{-3} \text{ M}$$

$$[\text{CH}_3\text{COOH}]_{\text{equilibrium}} = 0.1 - 1.35 \times 10^{-3} \approx 0.1 \text{ M}$$

$$K_a = \frac{[\text{H}^+][\text{CH}_3\text{COO}^-]}{[\text{CH}_3\text{COOH}]}$$

$$K_a = \frac{(1.35 \times 10^{-3})^2}{0.1} = 1.8 \times 10^{-5}$$

Answer: (a) 1.8×10^{-5}

3. For the reaction $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$, $K_p = 1.8 \text{ atm}$ at 250°C . If the partial pressure of PCl_5 at equilibrium is 0.5 atm , what is the partial pressure of Cl_2 ?

- a) 0.95 atm
- b) 1.34 atm
- c) 0.85 atm
- d) 1.80 atm

Solution:

$$K_p = (\text{PCl}_3 \times \text{Cl}_2) / \text{PCl}_5 = 1.8$$

At equilibrium: $\text{PCl}_3 = \text{Cl}_2$ (from stoichiometry)

Let $x = \text{Cl}_2$

$$\text{Therefore: } (x \times x) / 0.5 = 1.8$$

$$x^2 = 0.9$$

$$x = 0.95$$

Answer: (a) 0.95 atm

4. Calculate the pH of a buffer solution prepared by mixing $0.2 \text{ M NH}_4\text{Cl}$ and $0.1 \text{ M NH}_4\text{OH}$.

Given: K_b for $\text{NH}_4\text{OH} = 1.8 \times 10^{-5}$

- a) 8.74
- b) 9.26
- c) 4.74
- d) 5.26

Solution:

$$\text{pOH} = -\log[\text{OH}^-] = -\log(K_b \times [\text{NH}_4\text{OH}] / [\text{NH}_4^+])$$

$$= -\log(1.8 \times 10^{-5} \times 0.1 / 0.2)$$

$$= -\log(9 \times 10^{-6})$$

$$= 5.26$$

$$\text{pH} = 14 - 5.26 = 8.74$$

Answer: (a) 8.74

5. The solubility product (K_{sp}) of AgCl is 1.8×10^{-10} . Calculate its solubility in 0.1 M NaCl solution.

- a) $1.8 \times 10^{-9} \text{ M}$
- b) $1.8 \times 10^{-10} \text{ M}$
- c) $1.8 \times 10^{-11} \text{ M}$
- d) $1.8 \times 10^{-8} \text{ M}$

Solution:

$$K_{sp} = [\text{Ag}^+][\text{Cl}^-] = 1.8 \times 10^{-10}$$

$[\text{Cl}^-]$ from $\text{NaCl} = 0.1 \text{ M}$

$$\text{Therefore: } [\text{Ag}^+] = 1.8 \times 10^{-10} / 0.1 = 1.8 \times 10^{-9} \text{ M}$$

This is the solubility in 0.1 M NaCl

Answer: (a) $1.8 \times 10^{-9} \text{ M}$

6. For the reaction $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$, what is the relationship between K_p and K_c ?

- a) $K_p = K_c(\text{RT})^2$
- b) $K_p = K_c(\text{RT})^{-2}$
- c) $K_p = K_c(\text{RT})$
- d) $K_p = K_c$

Solution:

$$K_p = K_c(\text{RT})^{\Delta n}$$

where Δn = moles of gaseous products - moles of gaseous reactants

$$\text{Here, } \Delta n = 2 - (1 + 3) = -2$$

$$\text{Therefore, } K_p = K_c(\text{RT})^{-2}$$

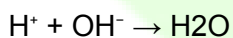
Answer: (b) $K_p = K_c(\text{RT})^{-2}$

7. A solution contains both NH_4Cl and NH_4OH . What happens to the pH when HCl is added?

- a) pH decreases significantly
- b) pH increases significantly
- c) pH decreases slightly
- d) pH remains almost constant

Solution:

This is a buffer solution. When HCl is added:



The added H^+ reacts with OH^- from NH_4OH



The equilibrium shifts right to maintain the ratio

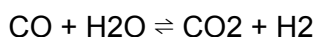
Buffer action maintains pH with small change

Answer: (c) pH decreases slightly

8. The value of K_c for the reaction $\text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + \text{H}_2(\text{g})$ is 4 at 300K. If 2 moles each of CO and H_2O are mixed in a 1L vessel, what is the equilibrium concentration of CO_2 ?

- a) 1.17 M
- b) 1.33 M
- c) 1.50 M
- d) 1.67 M

Solution:



Initial: 2 2 0 0

Change: -x -x +x +x

Equilibrium: 2-x 2-x x x

$$K_c = \frac{[\text{CO}_2][\text{H}_2]}{[\text{CO}][\text{H}_2\text{O}]} = 4$$

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

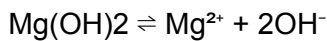
Solving quadratic: $x = 1.33$

Answer: (b) 1.33 M

9. The K_{sp} of $Mg(OH)_2$ is 1.2×10^{-11} . What is the pH of a saturated solution of $Mg(OH)_2$?

- a) 9.97
- b) 10.32
- c) 10.68
- d) 11.03

Solution:



Let solubility = s

$$K_{sp} = [Mg^{2+}][OH^-]^2 = s(2s)^2 = 4s^3$$

$$1.2 \times 10^{-11} = 4s^3$$

$$s = 1.44 \times 10^{-4}$$

$$[OH^-] = 2s = 2.88 \times 10^{-4}$$

$$pOH = -\log(2.88 \times 10^{-4}) = 3.54$$

$$pH = 14 - 3.54 = 10.32$$

Answer: (b) 10.32

10. In which of the following cases will the equilibrium constant NOT change?

- a) Change in temperature
- b) Addition of catalyst
- c) Change in pressure
- d) Change in concentration

Solution:

Equilibrium constant depends only on temperature

Catalyst speeds up both forward and reverse reactions equally

Pressure and concentration changes shift equilibrium but don't change K

Answer: (b) Addition of catalyst

11. For the dissociation of water, $H_2O \rightleftharpoons H^+ + OH^-$, $K_w = 1.0 \times 10^{-14}$ at $25^\circ C$. What is $[H^+]$ in a solution of $pH = 8.5$?

- a) 3.16×10^{-9} M
- b) 3.16×10^{-8} M
- c) 3.16×10^{-7} M
- d) 3.16×10^{-6} M

Solution:

$$pH = -\log[H^+]$$

$$8.5 = -\log[H^+]$$

$$[H^+] = 10^{-8.5} = 3.16 \times 10^{-9} \text{ M}$$

Answer: (a) 3.16×10^{-9} M

12. What is the pH of a buffer solution containing 0.3 M CH₃COONa and 0.2 M CH₃COOH? (K_a for CH₃COOH = 1.8 × 10⁻⁵)

- a) 4.43
- b) 4.93
- c) 5.43
- d) 5.93

Solution:

$$\begin{aligned}\text{pH} &= \text{pK}_a + \log\left(\frac{[\text{salt}]}{[\text{acid}]}\right) \\ \text{pK}_a &= -\log(1.8 \times 10^{-5}) = 4.74 \\ \text{pH} &= 4.74 + \log(0.3/0.2) \\ &= 4.74 + \log(1.5) \\ &= 4.74 + 0.18 \\ &= 4.93\end{aligned}$$

Answer: (b) 4.93

13. The equilibrium constant for the reaction N₂(g) + O₂(g) ⇌ 2NO(g) is K₁ at temperature T₁. If the temperature is doubled to T₂, the new equilibrium constant K₂ is found to be 4K₁. What is the activation energy of the reaction? (R = 8.314 J/mol·K)

- a) 11.54 kJ/mol
- b) 23.08 kJ/mol
- c) 34.62 kJ/mol
- d) 46.16 kJ/mol

Solution:

Using van't Hoff equation:

$$\begin{aligned}\ln(K_2/K_1) &= -(\Delta H/R)(1/T_2 - 1/T_1) \\ \ln(4) &= -(\Delta H/R)(1/2T_1 - 1/T_1) \\ 1.386 &= (\Delta H/R)(1/2T_1) \\ \Delta H &= 23.08 \text{ kJ/mol}\end{aligned}$$

Answer: (b) 23.08 kJ/mol

14. A 0.1 M solution of a weak acid HA has pH = 3. What is its degree of ionization?

- a) 0.1%
- b) 1%
- c) 10%
- d) 100%

Solution:

$$\begin{aligned}\text{pH} &= 3 \\ [\text{H}^+] &= 10^{-3} \text{ M} \\ [\text{HA}]_{\text{initial}} &= 0.1 \text{ M} \\ \text{Degree of ionization} &= [\text{H}^+]/[\text{HA}]_{\text{initial}} \times 100 \\ &= (10^{-3}/0.1) \times 100 \\ &= 1\%\end{aligned}$$

Answer: (b) 1%

15. For the reaction $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$, the value of K_c is 0.0419 at 250°C . What is the percentage dissociation of PCl_5 if initial concentration is 0.5 M?

- a) 25%
- b) 50%
- c) 75%
- d) 100%

Solution:

Let α = fraction dissociated

Initial: 0.5 0 0

Change: -0.5 α +0.5 α +0.5 α

Equilibrium: 0.5(1- α) 0.5 α 0.5 α

$$K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]}$$

$$0.0419 = \frac{(0.5\alpha)(0.5\alpha)}{0.5(1-\alpha)}$$

$$0.0419 = \frac{0.5\alpha^2}{(1-\alpha)}$$

$$\text{Solving: } \alpha = 0.25$$

$$\text{Percentage} = 25\%$$

Answer: (a) 25%