Chemical and Ionic Equilibrium - JEE Main Questions

Multiple Choice Questions

1. At a given temperature, the equilibrium constant (Kc) for the reaction $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ 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
$N_2O_4 \rightleftharpoons 2NO_2$
Initial: 2.0 0
Change: -x +2x
Equilibrium: (2-x) 2x

$K_c = [NO_2]^2/[N_2O_4] = 0.0625$
$(2x)^2/(2-x) = 0.0625$
Solving: x = 0.25
Therefore, $[NO_2] = 2x = 0.5$ M
Answer: (a) 0.5 M

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

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

Solution:
pH = 2.87
$[H^+] = 10^{-2.87} = 1.35 \times 10^{-3}$ M
$[CH_3COO^-] = [H^+] = 1.35 \times 10^{-3}$ M
$[CH_3COOH]_{equilibrium} = 0.1 - 1.35 \times 10^{-3} \approx 0.1$ M
$K_a = [H^+][CH_3COO^-]/[CH_3COOH]$
$K_a = (1.35 \times 10^{-3})^2/0.1 = 1.8 \times 10^{-5}$
Answer: (a) 1.8×10^{-5}

3. For the reaction $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, Kp = 1.8 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:
$K_p = (P_{PCl_3} \times P_{Cl_2})/P_{PCl_5} = 1.8$
At equilibrium: $P_{Cl_3} = P_{Cl_2}$ (from stoichiometry)
Let $x = P_{Cl_2}$
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 M NH_4Cl and 0.1 M NH_4OH. Given: Kb for $NH_4OH = 1.8 \times 10^{-5}$

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

Solution:
$pOH = -\log[OH^-] = -\log(K_b \times [NH_4OH]/[NH_4^+])$
$= -\log(1.8 \times 10^{-5} \times 0.1/0.2)$
$= -\log(9 \times 10^{-6})$
$= 5.26$
$pH = 14 - 5.26 = 8.74$
Answer: (a) 8.74

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

a) 1.8×10^{-9} M
b) 1.8×10^{-10} M
c) 1.8×10^{-11} M
d) 1.8×10^{-8} M

Solution:
$K_{sp} = [Ag^+][Cl^-] = 1.8 \times 10^{-10}$
$[Cl^-]$ from NaCl = 0.1 M
Therefore: $[Ag^+] = 1.8 \times 10^{-10}/0.1 = 1.8 \times 10^{-9}$ M
This is the solubility in 0.1 M NaCl
Answer: (a) 1.8×10^{-9} M

6. For the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, what is the relationship between Kp and Kc?

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

Solution:
$K_p = K_c(RT)^{\Delta n}$
where Δn = moles of gaseous products - moles of gaseous reactants
Here, Δn = 2 - (1 + 3) = -2
Therefore, $K_p = K_c(RT)^{-2}$
Answer: (b) $K_p = K_c(RT)^{-2}$

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:
$H^+ + OH^- \rightarrow H_2O$
The added H^+ reacts with OH^- from NH_4OH
$NH_4OH \rightleftharpoons NH_4^+ + OH^-$
The equilibrium shifts right to maintain the ratio
Buffer action maintains pH with small change
Answer: (c) pH decreases slightly

8. The value of Kc for the reaction $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ 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:
$CO + H_2O \rightleftharpoons CO_2 + H_2$
Initial: 2 2 0 0
Change: -x -x +x +x
Equilibrium: 2-x 2-x x x

$K_c = [CO_2][H_2]/[CO][H_2O] = 4$
$x^2/(2-x)(2-x) = 4$

Solving quadratic: $x = 1.33$
Answer: (b) 1.33 M

9. The Ksp 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:
$Mg(OH)2 \rightleftharpoons Mg^{2+} + 2OH^-$
Let solubility = s
$Ksp = [Mg^{2+}][OH^-]^2 = s(2s)^2 = 4s^3$
$1.2 \times 10^{-11} = 4s^3$
$s = 1.44 \times 10^{-4}$
$[OH^-] = 2s = 2.88 \times 10^{-4}$
$pOH = -\log(2.88 \times 10^{-4}) = 3.54$
$pH = 14 - 3.54 = 10.32$
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, $H2O \rightleftharpoons H^+ + OH^-$, $Kw = 1.0 \times 10^{-14}$ at 25°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:
$pH = -\log[H^+]$
$8.5 = -\log[H^+]$
$[H^+] = 10^{-8.5} = 3.16 \times 10^{-9}$ M
Answer: (a) 3.16×10^{-9} M

12. What is the pH of a buffer solution containing 0.3 M CH_3COONa and 0.2 M CH_3COOH? (Ka for $CH_3COOH = 1.8 \times 10^{-5}$)

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

Solution:
pH = pKa + log([salt]/[acid])
pKa = $-\log(1.8 \times 10^{-5}) = 4.74$
pH = 4.74 + log(0.3/0.2)
= 4.74 + log(1.5)
= 4.74 + 0.18
= 4.93
Answer: (b) 4.93

13. The equilibrium constant for the reaction $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$ 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:
$\ln(K2/K1) = -(\Delta H/R)(1/T2 - 1/T1)$
$\ln(4) = -(\Delta H/R)(1/2T1 - 1/T1)$
$1.386 = (\Delta H/R)(1/2T1)$
ΔH = 23.08 kJ/mol
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:
pH = 3
$[H^+] = 10^{-3}$ M
[HA]initial = 0.1 M
Degree of ionization = $[H^+]$/[HA]initial × 100
= $(10^{-3}/0.1) \times 100$
= 1%

Answer: (b) 1%

15. For the reaction $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, the value of Kc 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: -0.5α +0.5α +0.5α
Equilibrium: 0.5(1-α) 0.5α 0.5α

$Kc = [PCl_3][Cl_2]/[PCl_5]$
$0.0419 = (0.5\alpha)(0.5\alpha)/0.5(1-\alpha)$
$0.0419 = 0.5\alpha^2/(1-\alpha)$
Solving: α = 0.25
Percentage = 25%
Answer: (a) 25%