

## **CHAPTER-7**

### **EQUILIBRIUM**

#### **ONE MARK QUESTIONS WITH ANSWERS.**

**CHAPTER WEIGHTAGE: 13**

**1.What is a reversible reaction?**

**Ans.** The reaction in which both forward and backward reaction takes place simultaneously is called as reversible reaction.

**2. Give an example for a reversible process.**

**Ans.**  $\text{H}_2\text{O(s)} \rightleftharpoons \text{H}_2\text{O(l)}$

**3.What is an irreversible process?**

**Ans.** It is a process in which the products obtained does not give back the reactants.

**4. Give an example for an irreversible process.**

**Ans.**  $\text{NaCl(aq)} + \text{AgNO}_3\text{(aq)} \rightleftharpoons \text{AgCl(s)} + \text{NaNO}_3\text{(aq)}$

**5. Define equilibrium state.**

**Ans.** It is a state in a reversible reaction at which both forward and backward reaction takes place in same rate.

**6.What is the freezing point of water?**

**Ans.** 273K or 0°C

**7. Give the boiling point of water at sea level.**

**Ans.** 373K or 100°C

**8. Write an example for solid-liquid equilibrium**

**Ans.**  $\text{H}_2\text{O(s)} \rightleftharpoons \text{H}_2\text{O(l)}$

**9. Give an example for liquid-gas equilibrium.**

**Ans.**  $\text{H}_2\text{O(l)} \rightleftharpoons \text{H}_2\text{O(g)}$

**10. Give an example for solid-gas equilibrium.**

**Ans.**  $\text{I}_2\text{(s)} \rightleftharpoons \text{I}_2\text{(g)}$

**11. State law of mass action.**

**Ans.** It states that "rate of a reaction is directly proportional to active masses of the reactants at constant temperature."

**12.What is equilibrium constant Kc?**

**Ans.** 
$$K_c = \frac{\text{Product of concentration of product at equilibrium}}{\text{Product of concentration of reactants at equilibrium}}$$

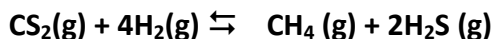
**13. Write the relationship between Kp and Kc.**

**Ans.**  $K_p = K_c(RT)^{\Delta n}$

**14. Given an example for a reaction in which Kp = Kc**

**Ans.**  $\text{H}_{2(g)} + \text{I}_{2(g)} \rightleftharpoons 2\text{HI(g)}$

15. Write the relationship between  $K_p$  and  $K_c$  for the reaction



Ans.  $n_p = 1 + 2 = 3$ ,  $n_R = 1 + 4 = 5$ ,  $\Delta n = n_p - n_R = 3 - 5 = -2$

$$\therefore K_p = K_c (\text{RT})^{\Delta n}, K_p = K_c (\text{RT})^{-2}$$

$$\therefore K_p = \frac{K_c}{(\text{RT})^2} \Rightarrow K_c > K_p$$

16. Write  $K_c$  expression for the reaction  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$

$$\text{Ans. } K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2] [\text{H}_2]^3}$$

17. The equilibrium constant for the reaction  $\text{A} + \text{B} \rightleftharpoons \text{C} + \text{D}$  is 10. If the initial concentration of A and B is doubled then what is the value of equilibrium constant?

Ans. It remains same.

18. Write  $K_p$  expression for the reaction  $2\text{SO}_3(\text{g}) \rightleftharpoons 2\text{SO}_2(\text{g}) + \text{O}_2(\text{g})$ .

$$\text{Ans. } K_p = \frac{P_{\text{SO}_2}^2 \times P_{\text{O}_2}}{P_{\text{SO}_3}^2}$$

19. What is the effect of catalyst on the equilibrium in a reversible reaction?

Ans. Catalyst has no effect.

20. What is reaction quotient?

$$\text{Ans. } Q_c = \frac{\text{Product of concentration of products}}{\text{Product of concentration of reactants}}$$

21. In a reversible reaction  $K = Q_c$ , what does it signify?

Ans. The reaction is at equilibrium.

22. In a reversible reaction  $Q_c > K$ , predict the direction in which the reaction proceeds?

Ans. Net reaction goes from right to left i.e., towards backward direction.

23. Give the relationship Gibb's free energy change and equilibrium constant

$$\text{Ans. } \Delta G^\circ = -2.303 \text{ RT} \log K$$

24. What happens to the rate of forward reaction when the pressure increases



Ans. Increase in pressure decreases the rate of forward reaction.

25. The rate constant values of a certain reaction is  $7.2 \times 10^{-10}$  and  $3.9 \times 10^{-7}$  at 600K and 800K. predict whether reaction is exothermic or endothermic?

Ans. Since rate constant values are increasing with temperature, the reaction is endothermic.

26. In a certain chemical reaction change in pressure does not influence the equilibrium state. What does it signify?

Ans. The number of moles of gaseous products and reactants are same in the reaction.

27. For the reaction  $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$   $\Delta H = -\text{qkJ}$ . State whether rate of forward reaction increases or decreases when temperature is decreased.

Ans. Rate of forward reaction increases.

**28. What happens to rate of forward reaction**

$\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}(\text{g}) \Delta H = +\text{qkJ}$ , when pressure is increased?

**Ans.** Rate of the reaction remains same.

**29. What is a strong electrolyte?**

**Ans.** It is an electrolyte which ionizes almost completely in aqueous solution.

**30. What is a weak electrolyte?**

**Ans.** It is an electrolyte which ionizes partially in an aqueous solution.

**31. Give two examples for a strong electrolyte.**

**Ans.** NaCl, HCl.

**32. Write two examples for a weak electrolyte.**

**Ans.**  $\text{CH}_3\text{COOH}$ ,  $\text{NH}_4\text{OH}$ .

**33. What is hydronium ion?**

**Ans.** Hydrated proton or  $\text{H}_3\text{O}^+$ .

**34. Give the conjugate acid of  $\text{H}_2\text{O}$ ,  $\text{CO}_3^{2-}$ ,  $\text{HSO}_4^-$ ,  $\text{O}^{2-}$  and  $\text{CH}_3\text{COO}^-$ .**

**Ans.** a)  $\text{H}_2\text{O}$  ----  $\text{H}_3\text{O}^+$   
b)  $\text{CO}_3^{2-}$  ----  $\text{HCO}_3^-$   
c)  $\text{HSO}_4^-$  ----  $\text{H}_2\text{SO}_4$   
d)  $\text{O}^{2-}$  ----  $\text{OH}^-$   
e)  $\text{CH}_3\text{COO}^-$  ----  $\text{CH}_3\text{COOH}$ .

**35. Write the conjugate base of  $\text{H}_2\text{O}$ ,  $\text{NH}_4^+$ ,  $\text{H}_2\text{CO}_3$ ,  $\text{HS}^-$ , HCl.**

**Ans.** a)  $\text{H}_2\text{O}$  ---  $\text{OH}^-$   
b)  $\text{NH}_4^+$  ---  $\text{NH}_3$   
c)  $\text{H}_2\text{CO}_3$  ---  $\text{HCO}_3^-$   
d)  $\text{HS}^-$  ---  $\text{S}^{2-}$   
e) HCl ---  $\text{Cl}^-$

**36.  $\text{OH}^-$  is a Lewis base. Why?**

**Ans.** Since it can donate a pair of electrons.

**37. What is the value of ionic product of water at 298K?**

**Ans.**  $10^{-14}(\text{mol/dm}^3)^2$ .

**38. What is the  $\text{P}^{\text{H}}$  of  $10^{-2} \text{ M}$  HCl solution?**

**Ans.**  $\text{P}^{\text{H}} = 2$ .

**39. The  $\text{pK}_a$  values of acids x, y and z are 4.2, 9.8 and 6.1 respectively. Which among the above acid is strongest?**

**Ans.** X

**40. An aqueous solution of  $\text{NH}_4\text{Cl}$  is acidic. Why?**

**Ans.**  $\text{NH}_4\text{Cl}$  upon hydrolysis gives ammonium hydroxide, a weak base and strong acid HCl.

**41. A small amount of  $\text{NH}_4\text{Cl}$  is added to  $\text{NH}_4\text{OH}$ , what happens to ionization of  $\text{NH}_4\text{OH}$ ?**

**Ans.** Ionisation of  $\text{NH}_4\text{OH}$  decreases.

**42. Write solubility product expression of  $\text{Ag}_2\text{CrO}_4$ .**

**Ans.**  $\text{Ag}_2\text{CrO}_4 \rightleftharpoons 2\text{Ag}^+(\text{aq}) + \text{CrO}_4^{2-}(\text{aq})$   
 $K_{sp} = (2s)^2 \times s \quad K_{sp} = 4s^3.$

**43. What is the effect of addition of noble gas on equilibrium?**

**Ans.** Equilibrium remains undisturbed.

**44. Define pH.**

**Ans.** It is defined as negative logarithm to the base 10 of molarity of hydrogen ion.  
i.e.,  $\text{pH} = -\log[\text{H}^+]$

**45. what is the significance of  $K_a/K_b$ ?**

**Ans.** At given temperature  $K_a/K_b$  is a measure of strength of acid/base. Larger the value of  $K_a/K_b$ , stronger is the acid/base.

**TWO MARKS QUESTIONS WITH ANSWERS.**

**1. Write any two characteristics of equilibrium?**

**Ans.** a) Equilibrium is possible only in a closed system at constant temperature.  
b) All measurable properties of the system remain constant.

**2. Explain solid –liquid equilibrium with an example?**

**Ans.** Solid –liquid equilibrium is a stage in a reversible reaction at which the rate of transfer of molecules from solid state to liquid state and rate of transfer of molecules from liquid state to solid state are equal at atmospheric pressure and at freezing point / melting point of the substance.

Example:  $\text{H}_2\text{O}(\text{s}) \rightleftharpoons \text{H}_2\text{O}(\text{l})$

**3) Explain liquid-vapour equilibrium with an example?**

**Ans.** Liquid –vapour equilibrium is a stage in a reversible reaction which rate of evaporation is equal to rate of condensation at the boiling point of liquid and at atmospheric pressure.

Example:  $\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{O}(\text{vap})$

**4) Explain solid –vapour equilibrium with an example?**

**Ans.** It is a stage at which rate of sublimation is equal to rate of condensation of a solid at given temperature

Example:  $\text{I}_2(\text{solid}) \rightleftharpoons \text{I}_2(\text{vap})$

**5) Explain solid –solution equilibrium with an example?**

**Ans.** It is a stage at which rate of dissolution of solid is equal to rate of crystallization of solid in a saturated solution at given temperature.

Example:  $\text{NaCl}(\text{s}) \rightleftharpoons \text{NaCl}(\text{in solution})$

**6) Explain gas –solution equilibrium with an example?**

**Ans.** It is a stage of equilibrium between the gas dissolved in solution and vapours of the gas above the liquid surface at given temperature.

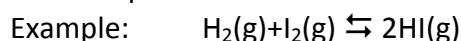
Example:  $\text{CO}_2(\text{g}) \rightleftharpoons \text{CO}_2(\text{in solution})$

**7) State Henry's law?**

**Ans.** It states that the mass of a gas dissolved in a given mass of solvent is proportional to pressure of the gas above the solvent at given temperature.

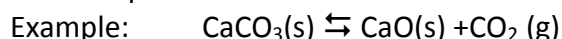
**8) What is homogeneous equilibrium? given an example**

**Ans.** It is an equilibrium in which all the reactants and products are in same phase.



**9) What is heterogeneous equilibrium? given an example**

**Ans.** It is an equilibrium in which reactants and products are in different phases.



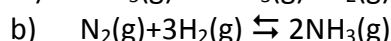
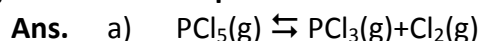
**10) State law of chemical equilibrium**

**Ans.** "The ratio of product of concentration of products to the product of concentration of reactants all the concentration terms are raised to respective stoichiometric co-efficient in the balanced chemical equation is a constant at given temperature" is called law of chemical equilibrium.

**11) Chemical equilibrium is dynamic. Explain**

**Ans.** At equilibrium the concentration of reactants and products remains constant, but rates of forward and backward reactions are equal. Hence the equilibrium said to be dynamic.

**12) Given an example for the reaction in which a)  $K_p > K_c$  b)  $K_p < K_c$**



**13) Write the significance of reaction quotient?**

- Ans.** 1. If  $Q_c < K_c$  net reaction goes from left to right (towards forward direction)  
2. If  $Q_c > K_c$  net reaction goes from right to left (towards backward direction)  
3. If  $Q_c = K_c$  no net reaction occurs (reaction is at equilibrium)

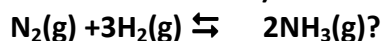
**14) State le Chatelier's principle?**

**Ans.** If a system under equilibrium is subjected to change in temperature, pressure or concentration then the equilibrium shifts itself in such a way so as to neutralize the effect of the change.

**15) Discuss the effect of increase in temperature on the rate an exothermic reversible reaction.**

**Ans.** Increase in temperature decrease the rate of forward reaction which is exothermic. The rate of backward reaction increases on increasing temperature since the reverse reaction is endothermic.

**16) What is the effect of a) addition of  $\text{NH}_3$  b) addition of  $\text{H}_2$  on the reaction**



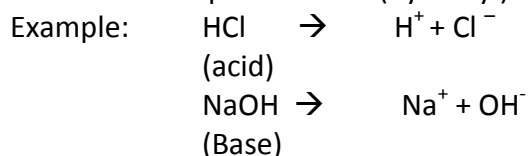
- Ans:** a) The increase in concentration of ammonia increases the rate of backward reaction.  
b) The increase in concentration of hydrogen increases the rate of forward reaction.

**17) Discuss the effect of pressure on the reaction  $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$**

**Ans.** Increase in pressure increases rate of backward reaction in which there is decrease in no. of gaseous components. Decrease in pressure increases rate of forward reaction in which there is increase in no. of moles of gaseous components.

**18) Explain Arrhenius concept of acid and base with an example?**

**Ans.** According to Arrhenius, acid is a substance that dissociates in water to give  $\text{H}^+$  ions and base is substance that produce  $\text{OH}^-$  (hydroxyl) ions.



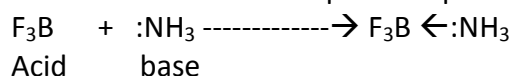
**19) With an example explain Bronsted Lowry concept of acid and base?**

**Ans.** Consider a reaction  $\text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_3^+\text{O}$

In the above example acetic acid donates a proton hence it is an acid and water accepts a proton and it is a base.

**20) Explain Lewis concept of acid and base with an example?**

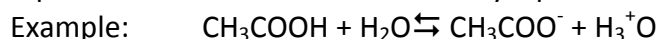
**Ans.** According to Lewis "acid is an electron pair acceptor and base is electron pair donor".



In the above example boron trifluoride is an acid and ammonia is a base

**21) What are conjugate acid-base pairs? Explain with an example.**

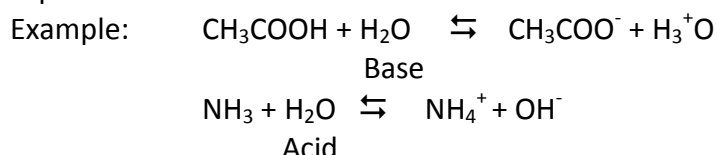
**Ans.** A pair of acid and base which differ by a proton is called conjugate acid-base pairs.



In the Above example acetic acid and acetate ion act as a pair of conjugate acid-base.

**22) Explain amphoteric substance with an example?**

**Ans.** Substance which act as acid in presence of a base and base in presence of an acid is called amphoteric substance.



**23) What is ionic product of water?**

**Ans.** It is the product of molar concentration of  $\text{H}^+$  and  $\text{OH}^-$  ions in water or in any aqueous solution is a constant at constant temperature. i.e.,  $K_w = [\text{H}^+][\text{OH}^-]$

**24) Show that  $\text{pH} + \text{pOH} = 14$  at 298K**

**Ans.** WKT,  $[\text{H}^+][\text{OH}^-] = 10^{-14}$  at 298K

Taking negative logarithm on both sides

$$-\log [\text{H}^+] - \log [\text{OH}^-] = -\log 10^{-14}$$

$$\text{pH} + \text{pOH} = -(-14)\log 10$$

$$\text{Therefore } \text{pH} + \text{pOH} = 14$$

**25) Explain common ion effect with an example.**

**Ans.** The suppression in degree of dissociation of a weak electrolyte by the addition of strong electrolyte having common ion is called common ion effect.

Example: the ionization of acetic acid [weak electrolyte] is suppressed by addition of sodium acetate [strong electrolyte] containing common acetate ion.

**26) Define solubility product.**

**Ans.** The product of molar concentrations of constituent ions, each raised to the power of its stoichiometric co-efficient in the equilibrium equation of the electrolyte at given temperature, is called as solubility product.

**27) What is a buffer solution? Give an Example.**

**Ans.** It is a solution that has ability to resist change in  $\text{p}^{\text{H}}$  upon addition of small amount of acid or base.

Example: Mixture of acetic acid and sodium acetate.

**28) Is  $\text{Cl}^-$  a strong base or weak base of conjugate acid HCl? Why?**

**Ans.** It is a weak base because HCl is a strong Bronsted acid its conjugate base is weak.

**29) What is hydrolysis of salt? Give an Example.**

**Ans.** The interaction of cations and anions of salt with water to give acidic or basic or neutral solution is called hydrolysis.

Example: when sodium acetate undergoes hydrolysis in water it gives basic solution due to formation of strong base NaOH and weak acid  $\text{CH}_3\text{COOH}$ .

**30) The aqueous solution of  $\text{K}_2\text{CO}_3$  is it acidic or basic or neutral? Explain.**

**Ans.**  $\text{K}_2\text{CO}_3$  is a salt obtained by neutralization of weak acid  $\text{H}_2\text{CO}_3$  and strong base KOH. Hence the aqueous solution of the salt has more  $\text{OH}^-$  than  $\text{H}^+$  ions and resultant solution is basic.

**31) An aqueous solution of  $\text{NH}_4\text{Cl}$  is acidic. Why?**

**Ans.**  $\text{NH}_4\text{Cl}$  is a salt obtained by neutralization of strong acid HCl and weak base  $\text{NH}_4\text{OH}$ . The aqueous solution of the salt has more  $\text{H}^+$  ions than  $\text{OH}^-$  hence the solution is acidic.

**32) Write applications of equilibrium constant .**

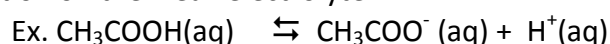
**Ans.** 1) If the value of  $K_c$  is very large [ $>10^3$ ] the reaction proceeds nearly to completion.

2) If the value of  $K_c$  is small [ $<10^{-3}$ ] the reaction proceeds rarely.

3) If the value of  $K_c$  is in range of  $10^{-3}$  to  $10^3$ , the appreciable concentrations of both reactants and products are present.

**33) Explain ionic equilibrium with an example.**

**Ans.** It is the equilibrium established between ions and unionized molecules in an aqueous solution of the weak electrolyte.

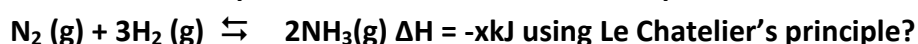


**34)  $K_{a1}$  of polyprotic acid is higher than  $K_{a2}$ . Why?**

**Ans.**  $K_{a1}$  of polyprotic acid is higher than  $K_{a2}$  because it is difficult to remove an  $\text{H}^+$  ion from a negative ion due to electrostatic forces of attraction.

**4 Marks questions with answers**

**1) Explain the Effect of pressure concentration and temperature on reaction**



**Ans.** a) Effect of pressure: increase in pressure increases rate of forward reaction since it is accompanied by decrease in no. of gaseous moles; hence equilibrium shifts to right side decrease in pressure increases rate of backward reaction.

b) Effect of concentration: Increase in concentration of reactants increase rate of forward reaction. Addition of ammonia or decrease in concentration of reactants increase rate of backward reaction.

c) Effect of temperature: Increase in temperature increases rate of endothermic reaction that is backward reaction. Decrease in temperature increases rate of exothermic reaction that is forward reaction.

**2) For the equilibrium  $4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightleftharpoons 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g})$  Discuss the effect of**

a) Addition of  $\text{NH}_3$

b) Addition of oxygen

c) Addition of  $\text{H}_2\text{O}$

d) Removal of  $\text{H}_2\text{O}$

**Ans.** a) Addition of  $\text{NH}_3$ : Addition of ammonia (reactant) increases the concentration of product that is rate of forward reaction increases.

b) Addition of oxygen: Addition of oxygen increases the concentration of product that is rate of forward reaction increases.

c) Addition of water: Addition of water (product) increases the concentration of reactant that is rate of backward reaction increases.

d) Removal of water: Removal of water (product) decreases the concentration of reactant i.e. rate of forward reaction increases.

**3) Mention four conditions by which the concentration of sulphur trioxide can be increased in the following reaction.  $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) + \text{heat}$ .**

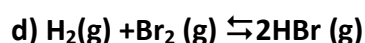
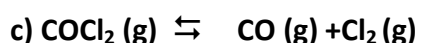
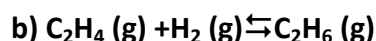
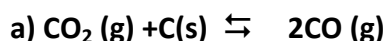
**Ans.** a) Addition of any of the reactants  $\text{SO}_2$  or  $\text{O}_2$  increases the concentration of products

b) Removal of sulphur trioxide increases the rate of forward reaction. i.e. Product concentration increases.

c) Increase of pressure increases concentration of  $\text{SO}_3$ , because forward reaction is accompanied by decrease in no. of moles.

d) Decrease of temperature increases the rate of forward reaction hence the product concentration.

**4) Which of the following reactions is affected by increase in pressure? Also mention the change in direction of equilibrium.**



**Ans.** a) Increase in pressure increases rate of backward reaction because  $n_p(2) > n_R(1)$

b) Increase in pressure increases rate of forward reaction because  $n_R(2) > n_p(1)$

c) Increase in pressure increases rate of backward reaction because  $n_p(2) < n_R(1)$

d) Increase in pressure has no effect on effect on the reaction because  $n_p(2) = n_R(2)$

**5) Write conjugate acid and base for following amphoteric species**



**Ans.**

Conjugate acid	Species	Conjugate base
$\text{H}_3\text{O}^+$	$+\text{H}^+ \leftarrow \text{H}_2\text{O} \rightarrow -\text{H}^+$	$\text{OH}^-$
$\text{NH}_4^+$	$+\text{H}^+ \leftarrow \text{NH}_3 \rightarrow -\text{H}^+$	$\text{H}_2\text{N}^-$
$\text{H}_2\text{SO}_4$	$+\text{H}^+ \leftarrow \text{HSO}_4^- \rightarrow -\text{H}^+$	$\text{SO}_4^{2-}$
$\text{H}_2\text{CO}_3$	$+\text{H}^+ \leftarrow \text{HCO}_3^- \rightarrow -\text{H}^+$	$\text{CO}_3^{2-}$

**6) Write any four characteristics of equilibrium constants  $K_c/K_p$ .**

**Ans.** a) The value of equilibrium constant is independent of initial concentrations of reactants and products

b) Equilibrium constant depends on temperature. It is constant for a given reaction at constant temperature.

c) The equilibrium constant for the reverse reaction is equal to inverse of equilibrium constant for the forward reaction is  $K_{\text{rev}} = 1/K_c$

d) Equilibrium constant is applicable only when concentrations of reactants and products have attained equilibrium.



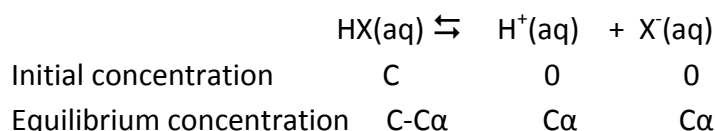
## 7) Explain the factors affecting acidic strength of acids.

**Ans.** The important factors affecting acidic strengths are

- 1) The bond strength of H-A: The strength of H-A bond is weak in case of strong acids hence cleavage of bond becomes easier, whereas the strength of H-A bond is high in case of weak acids.
- 2) Polarity of H-A bond: In case of strong acids the electronegativity difference between H and A is large, hence H-A bond become more polar therefore cleavage of bond becomes easier, where as polarity of H-A bond is less in case of weak acids.

## 8) Derive an expression for ionization constant $K_a$ of weak acid.

**Ans.** Consider a weak acid HX which partially ionizes in aqueous solution as



Where C is the initial concentration in mol/L of the acid,  $\alpha$  is the extent of ionization. The ionization constant of the acid is given by

$$K_a = \frac{[\text{H}^+][\text{X}^-]}{[\text{HX}]} = \frac{C\alpha \cdot C\alpha}{C - C\alpha}$$
$$K_a = \frac{C\alpha^2}{1 - \alpha}$$

The above expression is called as mathematical form of Ostwald's dilution law.

## 2 Marks Problems

### 1) The $K_c$ for a certain reaction is $4.5 \times 10^7$ at 750K, what is $K_c$ for the reverse reaction?

**Ans.**  $K_c^{-1} = 1/K_c = 1/4.5 \times 10^7 = 0.2222 \times 10^{-7}$   
 $K_c^{-1} = 2.222 \times 10^{-8}$

### 2) For a reversible reaction $\text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g})$ $K_c$ is 3.0 at $270^\circ\text{C}$ find the value of $K_p$ ?

**Ans.** Given

$$t = 270^\circ\text{C}$$

$$T = t + 273$$

$$= 270 + 273 = 543\text{K}$$

$$R = 0.0831 \text{ bar litre / mol K}$$

$$K_c = 3.0$$

For the above reaction

$$n_p = 1, n_R = 2$$

$$\Delta n = n_p - n_R = 1 - 2 = -1$$

$$\text{W.K.T } K_p = K_c(RT)^{\Delta n}$$

$$K_p = 3.0 \times (0.0831 \times 543)^{-1}$$

$$K_p = 3.0 / 0.0831 \times 543 = 0.06648$$

### 3) For the synthesis of ammonia $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$ the $K_p$ value is 41 at 400K. Calculate $K_c$ for the reaction?

**Ans.** Given

$$K_p = 41$$

$$T = 400\text{K}$$

$$R = 0.0831 \text{ bar litre / mol K}$$

For the above reaction

$$n_p = 2, n_R = 4$$

$$\Delta n = n_p - n_R = 2 - 4 = -2$$

$$\text{W.K.T } K_p = K_c(RT)^{\Delta n}$$

$$K_c = K_p / (RT)^{\Delta n} = 41 / (0.0831 \times 400)^{-2}$$

$$K_c = 41 \times (0.0831 \times 400)^2 = 45300.8$$

### 4) For the reaction $2\text{NOCl}(\text{g}) \rightleftharpoons 2\text{NO}(\text{g}) + \text{Cl}_2(\text{g})$ , The equilibrium constant is $3.75 \times 10^{-6}$ at 1069K. What is equilibrium constant for the reaction $2\text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2\text{NOCl}(\text{g})$ ?

**Ans.** Given  $K_c = 3.75 \times 10^{-6}$

$$\text{W.K.T } K_c^{-1} = 1/K_c = 1/3.75 \times 10^{-6}$$

$$= 0.2666 \times 10^6 = 2.666 \times 10^5$$

5) The equilibrium concentrations of ammonia, hydrogen and Nitrogen for synthesis of ammonia are  $1.2 \times 10^{-2} \text{M}$ ,  $3 \times 10^{-2} \text{M}$  and  $1.5 \times 10^{-2} \text{M}$  respectively, at given temperature calculate equilibrium constant  $K_c$ .

Ans. Given  $[\text{NH}_3] = 1.2 \times 10^{-2} \text{M}$   $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3(\text{g})$   
 $[\text{H}_2] = 3 \times 10^{-2} \text{M}$   $K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}$   
 $[\text{N}_2] = 1.5 \times 10^{-2} \text{M}$   $= \frac{(1.2 \times 10^{-2})^2}{(1.5 \times 10^{-2}) \times (3 \times 10^{-2})^3}$   
 $= 0.03556 \times 10^{-4+2+6}$   
 $= 0.03556 \times 10^{-4} = 3.556 \times 10^{-2}$

6) The equilibrium concentrations of hydrogen iodide and hydrogen for the reaction  $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$  are  $5.86 \times 10^{-2} \text{M}$  and  $0.86 \times 10^{-2} \text{M}$  respectively. At given temperature calculate equilibrium constant  $K_c$ .

Ans. Given  $[\text{HI}] = 5.86 \times 10^{-2}$   $K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$   
 $[\text{H}_2] = [\text{I}_2] = 0.86 \times 10^{-2}$   $= \frac{(5.86 \times 10^{-2})^2}{0.86 \times 10^{-2} \times 0.86 \times 10^{-2}}$   
 $= 42.43 \times 10^{-4+2+2} = 42.43$

7) For the reaction  $2\text{NO}(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{NOBr}(\text{g})$  the equilibrium concentrations of Nitric oxide, bromine and nitrosyl bromide are  $0.0352 \text{M}$ ,  $0.0178 \text{M}$  and  $0.0518 \text{M}$  respectively at constant temperature, calculate equilibrium constant  $K_c$ .

Ans. Given  $[\text{NO}] = 0.0352$   $K_c = \frac{[\text{NOBr}]^2}{[\text{NO}]^2[\text{Br}_2]}$   
 $[\text{Br}_2] = 0.0178$   $K_c = \frac{(0.0518)^2}{(0.0352)^2(0.0178)}$   
 $[\text{NOBr}] = 0.0518$   $= 121.66$

8) The equilibrium partial pressure of HI,  $\text{H}_2$  and  $\text{I}_2$  for the reaction  $2\text{HI}(\text{g}) \rightleftharpoons \text{I}_2(\text{g}) + \text{H}_2(\text{g})$  are  $0.04 \text{ atm}$ ,  $0.08 \text{ atm}$  and  $0.08 \text{ atm}$  respectively, Calculate equilibrium constant  $K_p$  for the reaction.

Ans. Given  $P_{\text{HI}} = 0.04 \text{ atm}$   $K_p = \frac{P_{\text{H}_2} P_{\text{I}_2}}{P_{\text{HI}}^2}$   
 $P_{\text{I}_2} = 0.08 \text{ atm}$   $= \frac{0.08 \times 0.08}{(0.04)^2}$   
 $P_{\text{H}_2} = 0.08 \text{ atm}$   $= 0.16$

9) For the reaction  $\text{A} + 3\text{B} \rightleftharpoons 4\text{C}$ , the partial pressure of B and C are  $0.8 \text{ atm}$  and  $0.4 \text{ atm}$  respectively. The equilibrium constant  $K_p$  for the reaction is 24, what is the partial pressure of A at equilibrium?

Ans. Given  $K_p = 24$   $K_p = \frac{P_{\text{C}}^4}{P_{\text{A}} P_{\text{B}}^3}$   
 $P_{\text{B}} = 0.8 \text{ atm}$   $P_{\text{A}} = \frac{P_{\text{C}}^4}{K_p P_{\text{B}}^3}$   
 $P_{\text{C}} = 0.4 \text{ atm}$   $= \frac{(0.4)^4}{24 \times (0.8)^3}$   
 $P_{\text{A}} = ?$   $P_{\text{A}} = 0.00208 \text{ atm}$

10) The equilibrium constant  $K_c$  for a reaction is  $1.3 \times 10^2$  at  $300 \text{K}$ . Calculate standard free energy change for the reaction. State whether the reaction is spontaneous or non-spontaneous.

Ans. Given  $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$   $\Delta G^0 = -2.303RT \log K_c$   
 $T = 300 \text{K}$   $= -2.302 \times 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 300 \text{K} \log 1.3 \times 10^2$   
 $K_c = 1.3 \times 10^2$   $= -5744.14(2 + \log 1.3)$   
 $\Delta G^0 = -12142.54 \text{ J mol}^{-1}$

Since  $\Delta G^0$  is negative the reaction is spontaneous

**11) standard free energy change for a reaction is 12 KJ at 300K. Calculate equilibrium constant for the reaction at same temperature.**

**Ans.** Given  $\Delta G^0 = 12\text{KJ} = 12 \times 10^3\text{J}$        $\Delta G^0 = -2.303RT \log K_c$   
 $T = 300\text{K}$        $\log K_c = -\Delta G^0 / 2.303RT$   
 $R = 8.314\text{Jmol}^{-1}\text{K}^{-1}$        $\log K_c = -12000\text{J} / 2.303 \times 8.314\text{Jmol}^{-1}\text{K}^{-1} \times 300\text{K}$   
 $\log K_c = -2.0891$   
 $K_c = \text{antilog}[+1-2.0891]$   
 $\quad = \text{antilog}[3.9109]$   
 $K_c = 8.145 \times 10^{-3}$

**12) Calculate the pH of  $10^{-3}\text{M}$  NaOH solution at 298K**

**Ans.**  $[\text{OH}^-] = 10^{-3}\text{M}$   
 $\text{pOH} = -\log[\text{OH}^-]$   
 $\text{pOH} = -\log 10^{-3} = -(-3\log 10) = 3$   
W.K.T  $\text{pH} + \text{pOH} = 14$  at 298K  
 $\text{pH} = 14 - 3 = 11$

**13) Find the pH of 0.025M HCl solution.**

**Ans.**  $[\text{H}^+] = 0.025 = 25 \times 10^{-3}$   
 $\text{pH} = -\log[\text{H}^+]$   
 $\text{pH} = -\log[25 \times 10^{-3}]$   
 $\quad = -[\log 25 - 3\log 10] = +3 - 1.3979$   
 $\text{pH} = 1.6021$

**14) Calculate pH of 0.02M  $\text{H}_2\text{SO}_4$  solution.**

**Ans.** Since  $\text{H}_2\text{SO}_4$  is a dibasic acid  $[\text{H}^+] = 2 \times 0.02 = 0.04 = 4 \times 10^{-2}$   
 $\text{pH} = -\log[\text{H}^+]$   
 $\text{pH} = -\log[4 \times 10^{-2}]$   
 $\quad = -[\log 4 - 2\log 10] = +2 - 0.6021$   
 $\text{pH} = 1.3979$

**15) Calculate the hydrogen ion concentration of a sample of milk of pH 6.4.**

**Ans.**  $\text{pH} = -\log[\text{H}^+]$   
 $6.4 = -\log[\text{H}^+]$   
 $[\text{H}^+] = \text{Antilog}[-6.4]$   
 $[\text{H}^+] = \text{Antilog}[-6.4 + 1 - 1]$   
 $\quad = \text{Antilog}[7.6]$   
 $[\text{H}^+] = 3.982 \times 10^{-7}\text{M}$

**16) Calculate the hydroxyl ion concentration of a sample of soft drink of pH 3.2 at 298K.**

**Ans.**  $\text{pOH} = 14 - \text{pH} = 14 - 3.2 = 11.8$   
 $\text{pOH} = -\log[\text{OH}^-]$   
 $11.8 = -\log[\text{OH}^-]$   
 $[\text{OH}^-] = \text{Antilog}[-11.8]$   
 $[\text{OH}^-] = \text{Antilog}[+1 - 1 - 11.8]$   
 $\quad = \text{Antilog}[12.2]$   
 $[\text{OH}^-] = 1.585 \times 10^{-12}$

17) The ionization constant 0.05M propanoic acid is  $1.3 \times 10^{-5}$ . Calculate degree of ionization.

Ans. Given  $K_a = 1.3 \times 10^{-5}$   
 $C = 0.05M$

$$\alpha = \sqrt{K_a / C} = \sqrt{1.3 \times 10^{-5} / 0.05} = \sqrt{26 \times 10^{-6}}$$

$$= \sqrt{2.6 \times 10^{-4}}$$

$$\alpha = 1.61 \times 10^{-2} = 0.0161$$

18) calculate the percentage of ionization of 0.05M ammonia solution if ionization constant is  $1.75 \times 10^{-5}$

Ans. Given  $K_b = 1.75 \times 10^{-5}$   $C = 0.05M$

$$\alpha = \sqrt{K_b / C} = \sqrt{1.75 \times 10^{-5} / 0.05} = \sqrt{35 \times 10^{-6}}$$

$$\alpha = \sqrt{3.5 \times 10^{-4}} = 1.87 \times 10^{-2}$$

Percentage of ionization is  $1.87 \times 10^{-2} \times 100 = 1.87$

19) Hydrogen ion concentration of a solution is  $4.5 \times 10^{-6}$  mol/L, what is the hydroxyl ion concentration at 298K.

Ans. W.K.T  $[H^+][OH^-] = 10^{-14}$  at 298K  
 $[OH^-] = 10^{-14} / [H^+] = 10^{-14} / 4.5 \times 10^{-6}$   
 $[OH^-] = 0.2222 \times 10^{-14+6} = 0.2222 \times 10^{-8} \text{ mol/L}$

20) The  $pK_a$  of acetic acid and  $pK_b$  of ammonium hydroxide are 5.75 and 5.70 respectively. Calculate the pH of ammonium acetate solution.

Ans.  $pH = 7 + \frac{1}{2}[pK_a + pK_b] = 7 + \frac{1}{2}[5.75 - 5.70]$   
 $= 7 + \frac{1}{2} \times 0.05 = 7 + 0.025 = 7.025$

21) The solubility of  $A_2X$  in water is  $1.1 \times 10^{-5}$  mol/L calculate the solubility product of the electrolyte.

Ans.  $S = 1.1 \times 10^{-5}$

$$A_2X \rightarrow 2A^+ + X^{2-}$$

$$K_{sp} = [A^+]^2[X^{2-}] = (2s)^2 \cdot s = 4s^3$$

$$= 4 \times (1.1 \times 10^{-5})^3$$

$$= 5.324 \times 10^{-15} (\text{mol/L})^3$$

22) The solubility product of silver bromide is  $5.0 \times 10^{-13}$  at 298K. find its solubility.

Ans.  $K_{sp} = 5 \times 10^{-13}$

$$AgBr \rightarrow Ag^+ + Br^-$$

$$K_{sp} = [Ag^+][Br^-]$$

$$K_{sp} = s \cdot s$$

$$5 \times 10^{-13} = s^2$$

$$s = \sqrt{5 \times 10^{-13}} = 0.7071 \times 10^{-6} \text{ mol/L}$$

### 3 Marks Problems

1) For the reaction  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$ , The partial pressures of  $\text{N}_2$  and  $\text{H}_2$  are 0.8 and 0.4 atmosphere respectively at equilibrium. The total pressure of the system is 2.80 atmospheres. What is  $K_p$  for the above reaction?

Ans. Given  $P_{\text{N}_2} = 0.8\text{atm}$   $P_{\text{N}_2} + P_{\text{H}_2} + P_{\text{NH}_3} = P$   
 $P_{\text{H}_2} = 0.4\text{atm}$   $0.8 + 0.4 + P_{\text{NH}_3} = 2.8$   
 $P = 2.8\text{atm}$   $P_{\text{NH}_3} = 2.8 - 1.2 = 1.6\text{atm}$   
 $K_p = P_{\text{NH}_3}^2 / P_{\text{N}_2} \cdot P_{\text{H}_2}^3 = (1.6)^2 / 0.8 \times (0.4)^3 = 50$

2) The equilibrium constant at 298K for the reaction  $\text{Cu}(\text{s}) + 2\text{Ag}^+(\text{aq}) \rightleftharpoons \text{Cu}^{2+}(\text{aq}) + 2\text{Ag}(\text{s})$  is  $2.0 \times 10^{15}$ . The concentration of  $\text{Cu}^{2+}$  and  $\text{Ag}^+$  in solution are  $1.8 \times 10^{-2} \text{ mol/L}$  and  $3.0 \times 10^{-9} \text{ mol/L}$  respectively. Predict the direction in which reaction proceed.

Ans. Given  $[\text{Cu}^{2+}] = 1.8 \times 10^{-2} \text{ mol/L}$   $Q_c = [\text{Cu}^{2+}(\text{aq})][\text{Ag}(\text{s})] / [\text{Cu}(\text{s})][\text{Ag}^+(\text{aq})]^2$   
 $[\text{Ag}^+] = 3.0 \times 10^{-9} \text{ mol/L}$   $= 1.8 \times 10^{-2} / (3.0 \times 10^{-9})^2$   
 $K_p = 2.0 \times 10^{15}$   $= 0.2 \times 10^{-2+18} = 2 \times 10^{15}$

By convention  $[\text{Ag}(\text{s})] = 1$  and  $[\text{Cu}(\text{s})] = 1$

$Q_c = K_p = 2 \times 10^{15}$ , hence reaction is at equilibrium

3) 2 moles of  $\text{N}_2\text{O}_4$  taken in a flask of 10L capacity is heated to 350K. At equilibrium 50% of  $\text{N}_2\text{O}_4$  was found to be dissociated to give  $\text{NO}_2$ . Find the equilibrium constant for the reaction.

Ans. Initial concentration of  $\text{N}_2\text{O}_4 = 2/10 \text{ mol/L}$   
 50% of  $2\text{N}_2\text{O}_4$  is dissociated implies,  $x = 50/100 = 0.5$

	$\text{N}_2\text{O}_4$	$\rightleftharpoons$	$2\text{NO}_2$
Initial concentration	2/10		0
Equilibrium concentration	$2(1-x)/10$		$2(2x)/10$
	$2(1-0.5)/10 = 0.1$		$2(2 \times 0.5)/10 = 0.2$

$K_c = [\text{NO}_2]^2 / [\text{N}_2\text{O}_4]$   
 $= (0.2)^2 / 0.1 = 0.4$

4) Calculate the  $\text{pK}_a$  value of 0.1M weak mono basic acid whose degree of ionisation  $1.52 \times 10^{-2}$

Ans. Given  $\alpha = 1.52 \times 10^{-2}$   $K_a = C\alpha^2$   
 $C = 0.1\text{M}$   $= 0.1 \times (1.52 \times 10^{-2})^2 = 0.2310 \times 10^{-4}$   
 $= 2.310 \times 10^{-5}$

$\text{pK}_a = -\log K_a$   
 $= -\log[2.310 \times 10^{-5}] = -[\log 2.310 - (5)\log 10]$   
 $= +5 - \log 2.310 = +5 - 0.3636 = 4.6364$

5) Calculate the hydrogen ion concentration of 0.1M weak mono basic acid whose dissociation constant is  $4 \times 10^{-10}$  at 298K.

Ans. Given  $C = 0.1\text{M}$   $\alpha = \sqrt{K_a / C} = \sqrt{4 \times 10^{-10} / 0.1} = 6.324 \times 10^{-5}$

$K_a = 4 \times 10^{-10}$

Wkt  $[\text{H}^+] = C\alpha = 0.1 \times 6.324 \times 10^{-5} = 0.6324 \times 10^{-5} \text{M}$

6) Find the pH of 0.05M acid which is 10% ionised at 298K.

Ans. Given  $c = 0.05$

$$\alpha = 10\% = 10/100 = 0.1$$

$$\text{wkt } [H^+] = C\alpha = 0.05 \times 0.1 = 0.005 = 5 \times 10^{-3}M$$

$$pH = -\log [H^+] = -\log 5 \times 10^{-3}$$

$$= -[\log 5 - 3\log 10] = [3 - 0.6990]$$

$$pH = 2.301$$

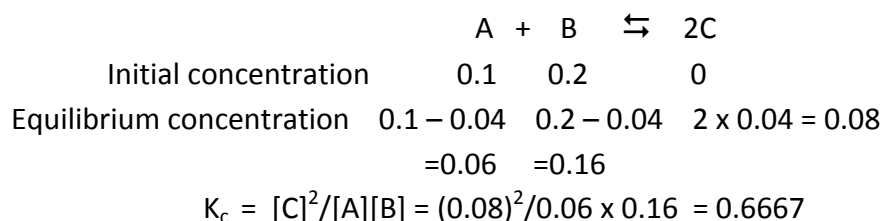
## 4 Marks Problems

1) The initial molar concentration of reactants A and B are 0.1 M and 0.2M respectively in the reaction  $A + B \rightleftharpoons 2C$  at equilibrium. The concentration of A in the mixture was found to be 0.06m. Calculate the equilibrium constant.

Ans. Initial concentration of A = 0.1M

Concentration of A at equilibrium = 0.06M

Concentration of A reacted =  $0.1 - 0.06m = 0.04M$



$$K_c = [C]^2/[A][B] = (0.08)^2/0.06 \times 0.16 = 0.6667$$

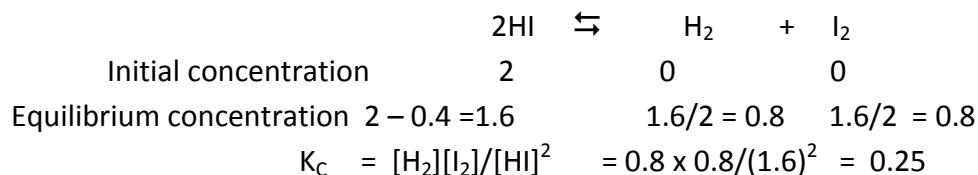
2) 2 moles of HI when heated in a closed container, at equilibrium 20% of HI found to be dissociated. Calculate the equilibrium constant for the reaction  $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$

Ans. Initial concentration of HI = 2 moles

20 moles of HI are dissociated out of 100 moles at equilibrium

$\Rightarrow$  ? moles of HI are dissociated out of 2 moles

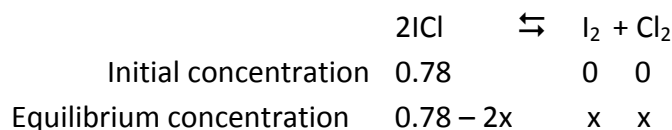
Concentration of dissociated HI =  $2 \times 20/100 = 4/10 = 0.4$  moles



$$K_c = [H_2][I_2]/[HI]^2 = 0.8 \times 0.8/(1.6)^2 = 0.25$$

3) What is the equilibrium concentration of each of the substances in equilibrium when the initial concentration of ICl was 0.78M for the reaction  $2ICl \rightleftharpoons I_2 + Cl_2$ ,  $K_c = 0.14$ .

Ans. Let x mol be the equilibrium concentration of I<sub>2</sub> and Cl<sub>2</sub>



$$K_c = [I_2][Cl_2]/[ICl]^2$$

$$0.14 = X \cdot X/(0.78 - 2X)^2$$

$$0.14[0.78 - 2X]^2 = X^2$$

Taking the square root both sides

$$[0.14]^{1/2}[0.78 - 2X] = X$$

$$0.374 \times 0.78 - 0.374 \times 2X = X$$

$$0.2917 = X + 0.748X$$

$$0.2917 = 1.748X$$

$$X = 0.2917/1.748 = 0.1668$$

$$[Cl_2] = [I_2] = X = 0.1668M$$

$$[ICl] = 0.78 - 2X = 0.78 - 2 \times 0.1668$$

$$[ICl] = 0.78 - 0.3336 = 0.446M$$

4) Calculate the degree of ionisation and  $K_a$  of 0.025M ammonia solution, if the ionisation constant of ammonia is  $1.77 \times 10^{-5}$  at 298K.

Ans. Given  $K_b = 1.77 \times 10^{-5}$   $\alpha = \sqrt{K_b/C}$

$$C = 0.025 \quad = \sqrt{1.77 \times 10^{-5}/0.025}$$

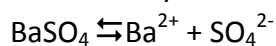
$$\alpha = 2.66 \times 10^{-2}$$

$$\text{WKT, } K_a \times K_b = K_w$$

$$K_a = K_w/K_b = 10^{-14}/1.77 \times 10^{-5} = 0.5649 \times 10^{-9}$$

5) The  $K_{sp}$  values of  $BaSO_4$  and  $PbSO_4$  are  $1.1 \times 10^{-10}$  and  $1.6 \times 10^{-8}$  respectively. Which salt is more soluble?

Ans. Let solubility of  $BaSO_4$  is  $s_1$  and solubility of  $PbSO_4$  is  $s_2$



$$K_{sp} = [Ba^{2+}][SO_4^{2-}]$$

$$1.1 \times 10^{-10} = s_1 \cdot s_1$$

$$s_1 = \sqrt{1.1 \times 10^{-10}} = 1.0489 \times 10^{-5} \text{ mol/L}$$



$$K_{sp} = [Pb^{2+}][SO_4^{2-}]$$

$$1.6 \times 10^{-8} = s_2 \cdot s_2$$

$$s_2 = \sqrt{1.6 \times 10^{-8}} = 1.2649 \times 10^{-4} \text{ mol/L}$$

$s_2 > s_1$  hence  $PbSO_4$  is more soluble than  $BaSO_4$