



Question 11. A sample of HI (g) is placed in a flask at a pressure of 0.2 atm. At equilibrium partial pressure of HI (g) is 0.04 atm. What is  $K_p$  for the given equilibrium?

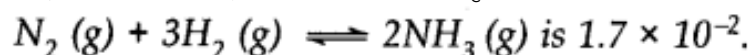


Answer:

$$p_{\text{HI}} = 0.04 \text{ atm}, p_{\text{H}_2} = 0.08 \text{ atm}; p_{\text{I}_2} = 0.08 \text{ atm}$$

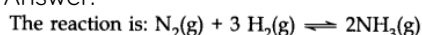
$$K_p = \frac{p_{\text{H}_2} \times p_{\text{I}_2}}{p_{\text{HI}}^2} = \frac{(0.08 \text{ atm}) \times (0.08 \text{ atm})}{(0.04 \text{ atm}) \times (0.04 \text{ atm})} = 4.0$$

Question 12. A mixture of 1.57 mol of  $\text{N}_2$ , 1.92 mol of  $\text{H}_2$  and 8.13 mol of  $\text{NH}_3$  is introduced into a 20 L reaction vessel at 500 K. At this temperature, the equilibrium constant  $K_c$  for the reaction



Is this reaction at equilibrium? If not, what is the direction of net reaction?

Answer:



$$\text{Concentration quotient (} Q_c) = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} = \frac{(8.13/20 \text{ mol L}^{-1})^2}{(1.57/20 \text{ mol L}^{-1}) \times (1.92/20 \text{ mol L}^{-1})^3} = 2.38 \times 10^3$$

The equilibrium constant ( $K_c$ ) for the reaction =  $1.7 \times 10^{-2}$

As  $Q_c \neq K_c$ ; this means that the reaction is not in a state of equilibrium.

Question 13. The equilibrium constant expression for a gas reaction is,

$$K_c = \frac{[\text{NH}_3]^4 [\text{O}_2]^5}{[\text{NO}]^4 [\text{H}_2\text{O}]^6}$$

Write the balanced chemical equation corresponding to this expression.

Answer: Balanced chemical equation for the reaction is 4



Question 14. If 1 mole of  $\text{H}_2\text{O}$  and 1 mole of  $\text{CO}$  are taken in a 10 litre vessel and heated to 725 K, at equilibrium point 40 percent of water (by mass) reacts with carbon monoxide according to equation.



Calculate the equilibrium constant for the reaction.

Answer:

Number of moles of water originally present = 1 mol

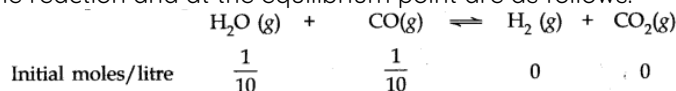
Percentage of water reacted = 40%

Number of moles of water reacted =  $1 \times 40/100 = 0.4 \text{ mol}$

Number of moles of water left =  $(1 - 0.4) = 0.6 \text{ mole}$

According to the equation, 0.4 mole of water will react with 0.4 mole of carbon monoxide to form 0.4 mole of hydrogen and 0.4 mole of carbon dioxide.

Thus, the molar conc, per litre of the reactants and products before the reaction and at the equilibrium point are as follows:



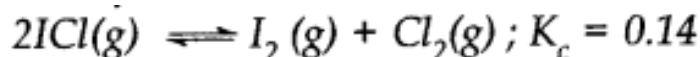
Mole/litre at the equilibrium point

$$\frac{1-0.4}{10} = \frac{0.6}{10} \quad \frac{1-0.4}{10} = \frac{0.6}{10} \quad \frac{0.4}{10} \quad \frac{0.4}{10}$$

Applying law of chemical equilibrium,

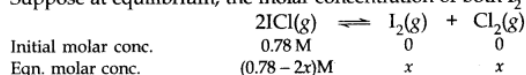
$$\begin{aligned} \text{Equilibrium constant } (K_c) &= \frac{[\text{H}_2(\text{g})][\text{CO}_2(\text{g})]}{[\text{H}_2\text{O}(\text{g})][\text{CO}(\text{g})]} = \frac{\left(\frac{0.4}{10} \text{ mol L}^{-1}\right) \times \left(\frac{0.4}{10} \text{ mol L}^{-1}\right)}{\left(\frac{0.6}{10} \text{ mol L}^{-1}\right) \times \left(\frac{0.6}{10} \text{ mol L}^{-1}\right)} \\ &= \frac{0.16}{0.36} = 0.44 \end{aligned}$$

Question 15. What is the equilibrium concentration of each of the substances in the equilibrium when the initial concentration of ICl was 0.78 M?



Answer:

Suppose at equilibrium, the molar concentration of both  $\text{I}_2(\text{g})$  and  $\text{Cl}_2(\text{g})$  is  $x \text{ mol L}^{-1}$ .



$$K_c = \frac{[\text{I}_2(\text{g})][\text{Cl}_2(\text{g})]}{[\text{ICl}(\text{g})]^2} = \frac{(x) \times (x)}{(0.78 - 2x)^2}$$

$$\frac{x}{(0.78 - 2x)} = (0.14)^{1/2} = 0.374 \quad \text{or} \quad x = 0.374 (0.78 - 2x)$$

$$x = 0.292 - 0.748x \quad \text{or} \quad 1.748x = 0.292; x = \frac{0.292}{1.748} = 0.167$$

$$[\text{ICl}] = (0.78 - 2 \times 0.167) = (0.78 - 0.334) = 0.446 \text{ M}$$

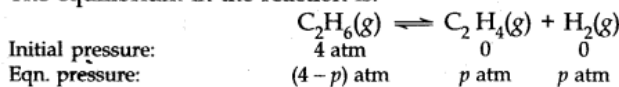
$$[\text{I}_2] = 0.167 \text{ M}; [\text{Cl}_2] = 0.167 \text{ M}$$

Question 16.  $K = 0.04 \text{ atm}$  at 898 K for the equilibrium shown below. What is the equilibrium concentration of  $\text{C}_2\text{H}_6$  when it is placed in a flask at 4 atm pressure, and allowed to come to equilibrium.



Answer:

The equilibrium in the reaction is:



$$K_p = \frac{p_{\text{C}_2\text{H}_4} \times p_{\text{H}_2}}{p_{\text{C}_2\text{H}_6}} \quad \text{or} \quad 0.04 = \frac{p^2}{(4 - p)}$$

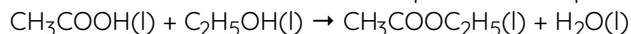
$$p^2 = 0.04 (4 - p) \quad \text{or} \quad p^2 + 0.04 p - 0.16 = 0$$

$$p = \frac{(-0.04) \pm \sqrt{0.0016 - 4(-0.16)}}{2}$$

$$= \frac{(-0.04) \pm 0.8}{2} = \frac{0.76}{2} = 0.38$$

Equilibrium pressure or concentration of  $\text{C}_2\text{H}_6 = (4 - 0.38) = 3.62 \text{ atm}$ .

Question 17. The ester, ethyl acetate is formed by the reaction of ethanol and acetic acid and the equilibrium is represented as:



(i) Write the concentration ratio (concentration quotient)  $Q$  for this

reaction. Note that water is not in excess and is not a solvent in this reaction.

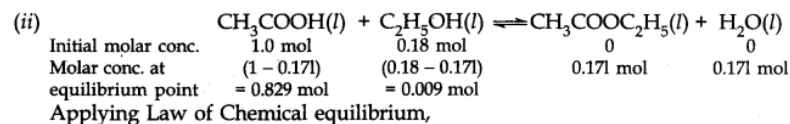
(ii) At 293 K, if one starts with 1.000 mol of acetic acid and 0.180 mol of ethanol, there is 0.171 mol of ethyl acetate in the final equilibrium mixture. Calculate the equilibrium constant.

(iii) Starting with 0.50 mol of ethanol and 1.0 mol of acetic acid and maintaining it at 293 K, 0.214 mol of ethyl acetate is found after some time. Has equilibrium been reached?

Answer:

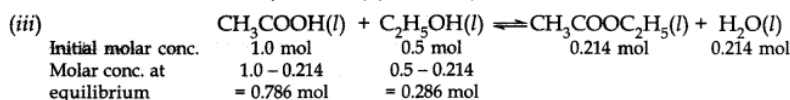
(i) The concentration ratio (Concentration quotient)  $Q_c$  for the reaction is:

$$Q_c = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5(l)][\text{H}_2\text{O}(l)]}{[\text{CH}_3\text{COOH}(l)][\text{C}_2\text{H}_5\text{OH}(l)]}$$



$$K_c = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5(l)][\text{H}_2\text{O}(l)]}{[\text{CH}_3\text{COOH}(l)][\text{C}_2\text{H}_5\text{OH}(l)]}$$

$$= \frac{(0.171 \text{ mol}) \times (0.171 \text{ mol})}{(0.829 \text{ mol})(0.009 \text{ mol})} = 3.92$$



$$Q_c = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5(l)][\text{H}_2\text{O}(l)]}{[\text{CH}_3\text{COOH}(l)][\text{C}_2\text{H}_5\text{OH}(l)]}$$

$$= \frac{(0.214 \text{ mol}) \times (0.214 \text{ mol})}{(0.786 \text{ mol})(0.286 \text{ mol})} = 0.204$$

Since  $Q_c$  is less than  $K_c$  this means that the equilibrium has not been reached. The reactants are still taking part in the reaction to form the products.

Question 18. A sample of pure  $\text{PCl}_5$  was introduced into an evacuated vessel at 473 K. After equilibrium was reached, the concentration of  $\text{PCl}_5$  was found to be  $0.5 \times 10^{-1} \text{ mol L}^{-1}$ . If  $K_c$  is  $8.3 \times 10^{-3}$  what are the concentrations of  $\text{PCl}_3$  and  $\text{Cl}_2$  at equilibrium?

Answer:

Let the initial molar concentration of  $\text{PCl}_5$  per litre =  $x \text{ mol}$

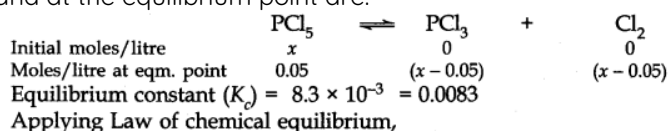
Molar concentration of  $\text{PCl}_5$  at equilibrium =  $0.05 \text{ mol}$

$\therefore$  Moles of  $\text{PCl}_5$  decomposed =  $(x - 0.05) \text{ mol}$

Moles of  $\text{PCl}_3$  formed =  $(x - 0.05) \text{ mol}$

Moles of  $\text{Cl}_2$  formed =  $(x - 0.05) \text{ mol}$

The molar conc./litre of reactants and products before the reaction and at the equilibrium point are:



Applying Law of chemical equilibrium,

$$K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]}; \quad 0.0083 = \frac{(x - 0.05) \times (x - 0.05)}{0.05}$$

$$(x - 0.05)^2 = 0.0083 \times 0.05 = 4.15 \times 10^{-4}$$

$$(x - 0.05) = (4.15 \times 10^{-4})^{1/2} = 2.037 \times 10^{-2} = 0.02 \text{ moles}$$

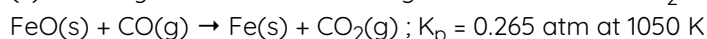
$$x = 0.05 + 0.02 = 0.07 \text{ mol}$$

The molar concentration per litre of  $\text{PCl}_3$  at eqm. =  $0.07 - 0.05 = 0.02 \text{ mol}$

The molar concentration per litre of  $\text{Cl}_2$  at eqm. =  $0.07 - 0.05 = 0.02 \text{ mol}$ .

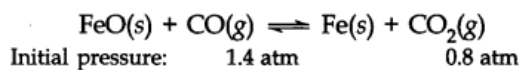
Question 19. One of the reactions that takes place in producing steel from iron ore is the reduction of iron

(II) oxide by carbon monoxide to give iron metal and  $\text{CO}_2$



What are the equilibrium partial pressures of CO and  $\text{CO}_2$  at 1050 K if the initial pressures are:  $P_{\text{CO}} = 1.4 \text{ atm}$  and  $P_{\text{CO}_2} = 0.80 \text{ atm}$ ?

Answer:



$$Q_p = \frac{p_{\text{CO}_2}}{p_{\text{CO}}} = \frac{(0.8 \text{ atm})}{(1.4 \text{ atm})} = 0.571$$

Since  $Q_p > K_p(0.265)$ , this means that the reaction will move in the backward direction to attain the equilibrium. Therefore, partial pressure of  $\text{CO}_2$  will decrease while that of  $\text{CO}$  will increase so that the equilibrium may be attained again. Let  $p$  atm be the decrease in the partial pressure of  $\text{CO}_2$ . Therefore, the partial pressure of  $\text{CO}$  will increase by the same magnitude i.e.,  $p$  atm.

$$p_{\text{CO}_2} = (0.8 - p) \text{ atm}; p_{\text{CO(g)}} = (1.4 + p) \text{ atm}$$

$$\text{At equilibrium, } K_p = \frac{p_{\text{CO}_2}}{p_{\text{CO}}} = \frac{(0.8 - p) \text{ atm}}{(1.4 + p) \text{ atm}} = \frac{(0.8 - p)}{(1.4 + p)}$$

$$\text{or } 0.265 = \frac{(0.8 - p)}{(1.4 + p)}$$

$$0.371 + 0.265 p = 0.8 - p \quad \text{or} \quad 1.265 p = 0.8 - 0.371 = 0.429$$

$$p = 0.429/1.265 = 0.339 \text{ atm}$$

$$(p_{\text{CO}})_{\text{eq}} = (1.4 + 0.339) = \mathbf{1.739 \text{ atm}}$$

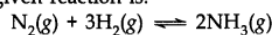
$$(p_{\text{CO}_2})_{\text{eq}} = (0.8 - 0.339) = \mathbf{1.461 \text{ atm}}$$

Question 20.

Equilibrium constant  $K_c$  for the reaction,  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$  at 500 K is 0.061. At particular time, the analysis shows that the composition of the reaction mixture is:  $3.0 \text{ mol L}^{-1}$  of  $\text{N}_2$ ;  $2.0 \text{ mol L}^{-1}$  of  $\text{H}_2$ ;  $0.50 \text{ mol L}^{-1}$  of  $\text{NH}_3$ . Is the reaction at equilibrium? If not, in which direction does the reaction tend to proceed to reach the equilibrium?

Answer:

The given reaction is:



According to available data.

$$\text{N}_2 = [3.0]; \text{H}_2 = [2.0]; \text{NH}_3 = [0.50]$$

$$Q_c = \frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})][\text{H}_2(\text{g})]^3} = \frac{[0.50]^2}{[3.0][2.0]^3} = \frac{0.25}{24} = \mathbf{0.0104}.$$

Since the value of  $Q_c$  is less than that of  $K_c$  (0.061), the reaction is not in a state of equilibrium. It will proceed in the **forward direction** till  $Q_c$  becomes the same as  $K_c$ .

\*\*\*\*\* END \*\*\*\*\*