
Calculate the total pressure exerted by equilibrated CoO and CoSO₄ at 1223 K

Given that

$$\text{CoO}(s) + \text{SO}_3(g) = \text{CoSO}_4(s), \Delta G^0 = -227,860 + 165.3 T$$
$$\text{SO}_2(g) + \frac{1}{2} \text{O}_2(g) = \text{SO}_3(g), \Delta G^0 = -94,600 + 89.37 T$$

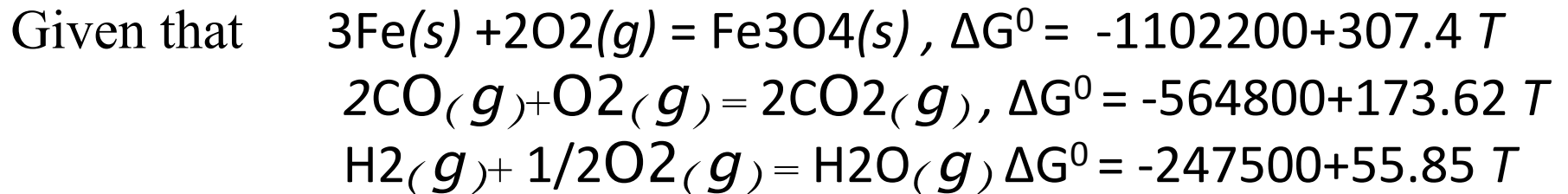
$$\begin{aligned}\Delta G^0(1223\text{K}) &= -25698 \text{ J} \\ &= 8.314 \times 1223 \times \ln P_{\text{SO}_3(\text{eq})}\end{aligned}$$

$$\begin{aligned}\Delta G^0(1223\text{K}) &= -14699 \text{ J} \\ &= 8.314 \times 1223 \times \ln(P_{\text{SO}_2(\text{eq})} \cdot P_{\text{O}_2}^{1/2} / P_{\text{SO}_3})\end{aligned}$$

$$P_{\text{SO}_2(\text{eq})} \cdot P_{\text{O}_2}^{1/2} / P_{\text{SO}_3} = 4.244 \qquad P_{\text{SO}_2(\text{eq})} \cdot (0.5P_{\text{SO}_2})^{1/2} / P_{\text{SO}_3} = 4.244$$

$$\begin{aligned}P_{\text{SO}_2} &= 0.612 \\ P_{\text{SO}_3} &= 0.0799 \\ P_{\text{O}_2} &= 0.306\end{aligned}$$

Magnetite (Fe_3O_4) is reduced to sponge iron (Fe) in a continuous reactor operating at 800 K using methane gas (CH_4) as the reducing agent. The gaseous reaction product leaving the reactor at a total pressure of 1 atm is a mixture of CO , CO_2 , H_2 , and H_2O with a negligible methane content. The gas is at equilibrium with the Fe – Fe_3O_4 mixture in the reactor. Calculate the consumption of methane as moles of methane used per mole of sponge iron produced.



All of the carbon and Hydrogen in the gas mixture is coming from Methane

$$\frac{n_C}{n_H} = \frac{1}{4} = \frac{P_{CO} + P_{CO_2}}{2P_{H_2} + 2P_{H_2O}}$$

The denominator has to be changed to 3PH₂ and PH₂O

$$2P_{CO} + 2P_{CO_2} = P_{H_2} + P_{H_2O}$$

All of the carbon comes from CH₄ = x moles

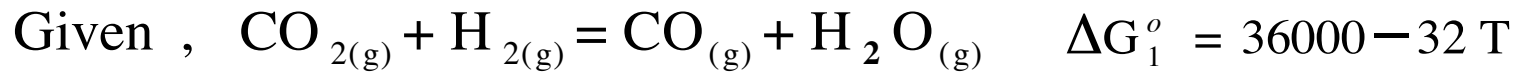
All of the oxygen comes from Fe₃O₄ = y moles

X moles of methane is used per 3/4y moles of Fe

Air at atmospheric pressure is blown over a Cu-rich copper–gold liquid solution at 1500 K. If only the copper is oxidized (to form pure solid Cu₂O), calculate the minimum activity of Cu which can be obtained in the solution.

Given that $\text{Cu}_{(l)} + \frac{1}{2} \text{O}_{2(g)} = \text{Cu}_2\text{O}_{(s)}, \Delta G^0 = -188300 + 88.48 T$

What is the equilibrium state of a CO–CO₂–H₂–H₂O gas mixture produced by mixing CO₂ and H₂ in the molar ratio 1:1 at 1000 K and a total pressure of 1 atm?



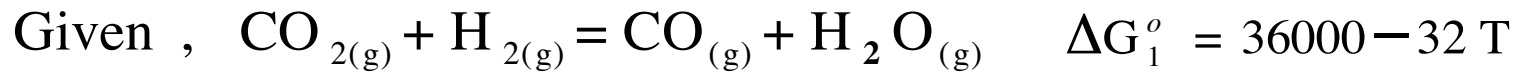
Sol : $\Delta G_1^\circ = -RT \ln K_{P1} \quad K_{P1} = \exp\left(-\frac{\Delta G_1^\circ}{RT}\right) = 0.618$

$$K_{P1} = \left(\frac{p_{\text{H}_2\text{O}} \cdot p_{\text{CO}}}{p_{\text{CO}_2} \cdot p_{\text{H}_2}} \right)$$

$$\therefore p_{\text{CO}} = p_{\text{H}_2\text{O}} \quad , \quad p_{\text{CO}_2} = p_{\text{H}_2}$$

$$\therefore P = 1 = p_{\text{H}_2\text{O}} + p_{\text{CO}} + p_{\text{CO}_2} + p_{\text{H}_2} = 2 (p_{\text{H}_2} + p_{\text{H}_2\text{O}})$$

What is the equilibrium state of a CO–CO₂–H₂–H₂O gas mixture produced by mixing CO₂ and H₂ in the molar ratio 1:1 at 1000 K and a total pressure of 1 atm?



Sol : $\Delta G_1^\circ = -RT \ln K_{p1} \quad K_{p1} = \exp\left(-\frac{\Delta G_1^\circ}{RT}\right) = 0.618$

$$K_{p1} = \left(\frac{p_{\text{H}_2\text{O}} \cdot p_{\text{CO}}}{p_{\text{CO}_2} \cdot p_{\text{H}_2}} \right)$$

$$\therefore p_{\text{CO}} = p_{\text{H}_2\text{O}} \quad , \quad p_{\text{CO}_2} = p_{\text{H}_2}$$

$$\therefore P = 1 = p_{\text{H}_2\text{O}} + p_{\text{CO}} + p_{\text{CO}_2} + p_{\text{H}_2} = 2 (p_{\text{H}_2} + p_{\text{H}_2\text{O}})$$

$$\therefore p_{\text{H}_2\text{O}} + p_{\text{H}_2} = 0.5 \quad \therefore p_{\text{H}_2\text{O}} = 0.5 - p_{\text{H}_2}$$

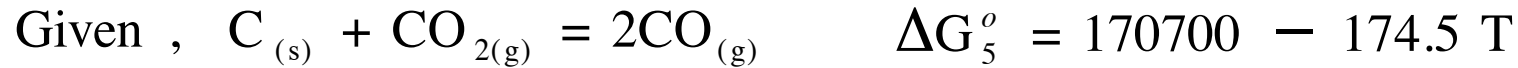
$$\therefore p_{\text{CO}} = p_{\text{H}_2\text{O}} = 0.5 - p_{\text{H}_2}$$

$$p_{\text{CO}_2} = p_{\text{H}_2}$$

$$\therefore K_{\text{P1}} = \left(\frac{(0.5 - p_{\text{H}_2}) \cdot (0.5 - p_{\text{H}_2})}{p_{\text{H}_2} \cdot p_{\text{H}_2}} \right) = \left(\frac{(0.5 - p_{\text{H}_2})^2}{p_{\text{H}_2}^2} \right)$$

$$\therefore \begin{cases} p_{\text{H}_2} = p_{\text{CO}_2} = 0.28 \text{ atm} \\ p_{\text{H}_2\text{O}} = 0.5 - p_{\text{H}_2} = 0.22 \text{ atm} = p_{\text{CO}} \end{cases}$$

What happens now if graphite is introduced to the system?



$$\text{Sol-3 : } K_5 = \exp\left(-\frac{\Delta G_5^\circ}{RT}\right) = 1.579 = \left(\frac{p_{\text{CO}}''^2}{p_{\text{CO}_2}''}\right)$$

In order to maintain equilibrium of (4)

$$\therefore p_{\text{CO}_2}'' = p_{\text{CO}_2}' = 0.053 \text{ atm}$$

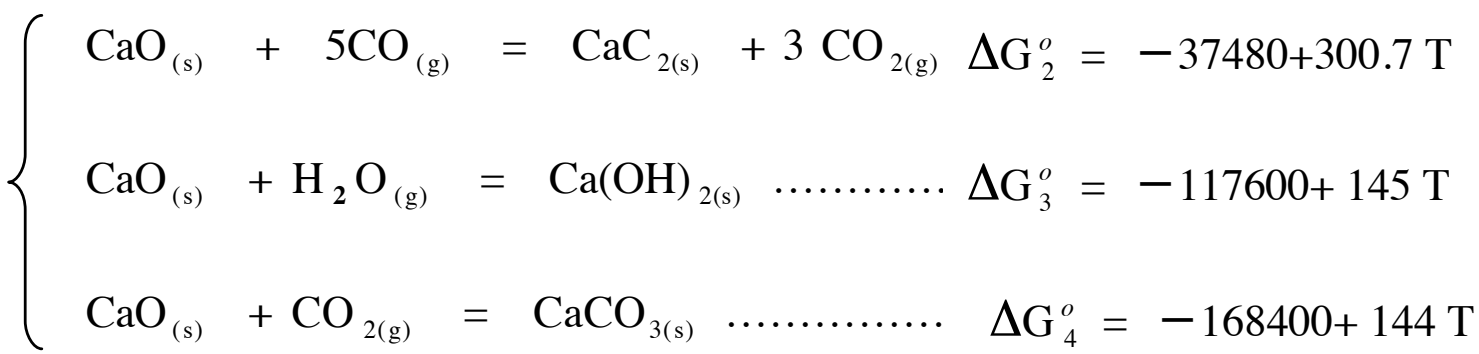
$$\therefore p_{\text{CO}}'' = (K_5 p_{\text{CO}_2}'')^{\frac{1}{2}} = (1.579 \times 0.053)^{\frac{1}{2}} = 0.289 \text{ atm}$$

However , $p_{\text{H}_2\text{O}}'' + p_{\text{H}_2}'' = 0.5 \text{ atm}$ (not changed !!)

$$\therefore K_{p1} = 0.618 = \left(\frac{p_{\text{H}_2\text{O}}'' \cdot p_{\text{CO}}''}{p_{\text{CO}_2}'' \cdot p_{\text{H}_2}''}\right) = \left(\frac{(0.5 - p_{\text{H}_2}'') \cdot 0.289}{p_{\text{H}_2}'' \cdot 0.053}\right)$$

$$\therefore \left\{ \begin{array}{l} p''_{\text{H}_2} = 0.449 \text{ atm} \\ p''_{\text{H}_2\text{O}} = (0.5 - 0.449) = 0.051 \text{ atm} \\ p''_{\text{CO}_2} = 0.053 \text{ atm} \\ p''_{\text{CO}} = 0.289 \text{ atm} \\ P = 0.842 \text{ atm} \end{array} \right.$$

Consider that this equilibrated gas is contained at 1 atm pressure and 1000 K in a rigid vessel of constant volume. What happens if some CaO is placed in the vessel?



Sol : T = 1000 K

If : Equilibrium (I) $K_2 = \exp\left(-\frac{\Delta G_2^o}{RT}\right) = \frac{p_{\text{CO}_2}'^3}{p_{\text{CO}}'^5} = 1.78 \times 10^{-14}$

substitute $\left\{ \begin{array}{l} p_{\text{CO}_2}' = 0.053 \text{ atm} \\ p_{\text{CO}}' = 152.9 \text{ atm} \quad \text{impossible !!} \end{array} \right.$

$$(II) \quad K_3 = 0.037 = \frac{1}{p'_{H_2O}}$$

$$\left\{ \begin{array}{l} p'_{H_2O} = 27.027 \text{ atm} \\ P \leq 1 \text{ atm} \end{array} \right. \quad \text{impossible !!}$$

$$(III) \quad K_4 = 18.82 = \frac{1}{p'_{CO_2}}$$

$$p'_{CO_2} = 0.053 \text{ atm} < p_{CO_2} = 0.28 \text{ atm} \quad \text{Yes !!}$$

∴ only reaction (4) is equilibrated .

$$\therefore p'_{CO_2} = 0.053 \text{ atm} (< p_{CO_2} = 0.28 \text{ atm})$$

∴ $CO_{2(g)}$ is consumed and (1) $P \downarrow$, (2) reaction (1) ←

at new equilibrium $p'_{\text{CO}} = p'_{\text{H}_2\text{O}}$

$$p'_{\text{H}_2\text{O}} + p'_{\text{H}_2} = 0.5 \text{ atm (not changed)}$$

$$\therefore K_{\text{p1}} = 0.618 = \left(\frac{p'_{\text{H}_2\text{O}} \cdot p'_{\text{CO}}}{p'_{\text{CO}_2} \cdot p'_{\text{H}_2}} \right) = \left(\frac{p'^2_{\text{H}_2\text{O}}}{(0.5 - p'_{\text{H}_2\text{O}}) \cdot 0.053} \right)$$

$$\therefore \begin{cases} p'_{\text{H}_2\text{O}} = 0.113 \text{ atm} = p'_{\text{CO}} \\ p'_{\text{H}_2} = (0.5 - 0.113) = 0.387 \text{ atm} \\ p'_{\text{CO}_2} = 0.053 \text{ atm} \\ P' = 0.666 \text{ atm} \end{cases}$$