Solution 7.1

Hot liquid sodium at 400C flows through a solid plutonium pipe, also at 400C. Naturally, one should worry about the amount of plutonium that can be dissolved in liquid sodium. Assume that the system is at 1 atm pressure and that the sodium is virtually insoluble in solid plutonium; but, plutonium forms an ideal solution with liquid sodium. Find a thermodynamic estimate of the maximum composition of plutonium in the liquid sodium.

Sodium is virtually insoluble in solid plutonium - this shows

$$\mu^{solid}_{plutonium} = \mu^{solid}_{plutonium,0} + RTlnX^{solid}_{plutonium} \quad (1)$$
$$\bar{G}^{solid}_{plutonium} = \bar{G}^{solid}_{plutonium,0} \quad (2)$$

where $\bar{G}^{solid}_{plutonium,0}$ is the reference state. However with sodium, liquid forms ideal solution,

$$\mu^{liquid}_{plutonium} = \mu^{liquid}_{plutonium,0} + RTlnX^{liquid}_{plutonium} \quad (3)$$
$$\bar{G}^{liquid}_{plutonium} = \bar{G}^{liquid}_{plutonium,0} + RTlnX^{liquid}_{plutonium} \quad (4)$$

For the equilibrium, $\mu^{solid}_{plutonium} = \mu^{liquid}_{plutonium}$ or $\bar{G}^{liquid}_{plutonium} = \bar{G}^{solid}_{plutonium}$. This leads to,

$$\bar{G}^{liquid}_{plutonium,0} - \bar{G}^{solid}_{plutonium,0} = RTlnX^{*}_{plutonium} \quad (5)$$

where $X^{*}_{plutonium}$ is the equilibrium composition.

This quantity $\Delta G_0 = \bar{G}^{liquid}_{plutonium,0} - \bar{G}^{solid}_{plutonium,0}$ at 400C can be obtained from Problem Set 5.1. $\bar{G}_{plutonium,0} = \bar{G}^{\gamma}_{plutonium,0} = -10138 cal/mole$. Extrapolating the expressions for $\bar{H}^{liquid}_{plutonium,0}$ and $\bar{S}^{liquid}_{plutonium,0}$ down to 673K gives $\bar{G}^{liquid}_{plutonium,0} = -10089 cal/mole$.

Using $\Delta G_0 = 49 cal/mole$ at 673K, the equilibrium concentration X^* can be calculated as

$$X^* = exp(-\Delta G_0/(RT)) = exp\left[\frac{-49}{1.987 \cdot 673}\right] = 0.964 \quad (6)$$

Therefore, almost all of the liquid is plutonium and only a small fraction, less than 5%, is sodium.