Chemistry 2740 Spring 2021 Test 1 Solutions

1. (a) $\frac{1}{2}\mathrm{N}_{2(g)} + \frac{3}{2}\mathrm{H}_{2(g)} + \mathrm{H}^+_{(\mathrm{aq})} \longrightarrow \mathrm{NH}^+_{4(\mathrm{aq})}$

   (b)

$$\begin{aligned}
\Delta_f S^\circ(\mathrm{NH}^+_{4(\mathrm{aq})}) &= S^\circ(\mathrm{NH}^+_{4(\mathrm{aq})}) - \left[\frac{1}{2}S^\circ(\mathrm{N}_2) + \frac{3}{2}S^\circ(\mathrm{H}_2) + S^\circ(\mathrm{H}^+_{(\mathrm{aq})})\right] \\
&= 111.2 - \left[\frac{1}{2}(191.609) + \frac{3}{2}(130.680) + 0\right]\,\mathrm{J\,K^{-1}mol^{-1}} \\
&= -180.6\,\mathrm{J\,K^{-1}mol^{-1}}
\end{aligned}$$

2.

$$\begin{aligned}
S^\circ(\mathrm{Si}, 1473.15\,\mathrm{K}) &= S^\circ(\mathrm{Si}, 298.15\,\mathrm{K}) + \Delta S(298 \to 1473\,\mathrm{K}). \\
\Delta S(298 \to 1473\,\mathrm{K}) &= \int_{T_1}^{T_2} \frac{dq_{\mathrm{rev}}}{T} = \int_{T_1}^{T_2} \frac{C_{p,m}dT}{T} \\
&= \int_{298.15\,\mathrm{K}}^{1473.15} \frac{23.698 + 3.305\times10^{-3}T - \frac{4.354\times10^5}{T^2}}{T}\,dT \\
&= \int_{298.15\,\mathrm{K}}^{1473.15} \left(\frac{23.698}{T} + 3.305\times10^{-3} - \frac{4.354\times10^5}{T^3}\right)dT \\
&= \left[23.698\ln T + 3.305\times10^{-3}T + \frac{4.354\times10^5}{2T^2}\right]_{298.15\,\mathrm{K}}^{1473.15} \\
&= 23.698\ln\left(\frac{1473.15\,\mathrm{K}}{298.15\,\mathrm{K}}\right) + 3.305\times10^{-3}\,(1473.15 - 298.15\,\mathrm{K}) \\
&\qquad + 2.177\times10^5\left(\frac{1}{1473.15^2} - \frac{1}{298.15^2}\right) \\
&= 39.394\,\mathrm{J\,K^{-1}mol^{-1}}. \\
\therefore S^\circ(\mathrm{Si}, 1473.15\,\mathrm{K}) &= 18.82 + 39.394\,\mathrm{J\,K^{-1}mol^{-1}} \\
&= 58.21\,\mathrm{J\,K^{-1}mol^{-1}}.
\end{aligned}$$

3. (a)

$$\begin{aligned}
M_{\mathrm{NH_4NO3}} &= 2(14.01) + 4(1.01) + 3(16.00)\,\mathrm{g\,mol^{-1}} \\
&= 80.06\,\mathrm{g\,mol^{-1}}. \\
n_{\mathrm{NH_4NO3}} &= \frac{59\,\mathrm{g}}{80.06\,\mathrm{g\,mol^{-1}}} = 0.74\,\mathrm{mol}. \\
m_{\mathrm{H_2O}} &= (250\,\mathrm{cm^3})(0.9982\,\mathrm{g\,cm^{-3}}) \\
&= 250\,\mathrm{g} \equiv 0.250\,\mathrm{kg}.
\end{aligned}$$

$$\therefore m_{\mathrm{NH_4NO_3}} = \frac{0.74\,\mathrm{mol\ NH_4NO_3}}{0.250\,\mathrm{kg\,H_2O}}$$
$$= 3.0\,\mathrm{mol\,kg^{-1}}.$$

(b) $3.56\,\mathrm{J\,K^{-1}g^{-1}}$

(c) We need the total mass of the solution: $m_{\mathrm{soln}} = 59 + 250\,\mathrm{g} = 309\,\mathrm{g}$. We want to calculate the final temperature. The heat balance is as follows:

$$q = 0 = \left\{ \begin{array}{c} \text{heat of} \\ \text{reaction} \end{array} \right\} + \left\{ \begin{array}{c} \text{cooling of} \\ \text{solution} \end{array} \right\}$$
$$= n_{\mathrm{NH_4NO_3}} \Delta_r H_m + m_{\mathrm{soln}} c_p \Delta T.$$
$$\therefore \Delta T = \frac{-n_{\mathrm{NH_4NO_3}} \Delta_r H_m}{m_{\mathrm{soln}} c_p}$$
$$= \frac{-(0.74\,\mathrm{mol})(25.69 \times 10^3\,\mathrm{J\,mol^{-1}})}{(309\,\mathrm{g})(3.56\,\mathrm{J\,K^{-1}g^{-1}})}$$
$$= -17\,\mathrm{K}.$$

This would give a final temperature of $20 - 17\,^\circ\mathrm{C} = 3\,^\circ\mathrm{C}$. Not bad!

(d) A little more ammonium nitrate will result in a little more cooling.