Chemistry 2740 Spring 2020 Test 1 Solutions

1. (a) I like to think of problems like these in terms of heat balances. In this case,

$$\left\{\begin{array}{l}\text{heat of}\\ \text{reaction}\end{array}\right\}+\left\{\begin{array}{l}\text{heat gained}\\ \text{by polymer}\end{array}\right\}=\left\{\begin{array}{l}\text{excess}\\ \text{heat}\end{array}\right\}.$$

The excess heat is the heat that will have to be removed. Symbolically,

$$q_{\text{excess}} = n\Delta_r H_m + nC_{p,m}\Delta T.$$

Number of moles of monomers consumed per hour:

$$n = \frac{30\,000 \times 10^3\,\text{g}}{28.054\,\text{g/mol}} = 1.07 \times 10^6\,\text{mol}.$$

Going back to the heat balance now,

$$\begin{aligned} q_{\text{excess}} &= (1.07 \times 10^6\,\text{mol})(-96.7 \times 10^3\,\text{J/mol}) \\ &\quad + (1.07 \times 10^6\,\text{mol})(46.2\,\text{J}\,\text{K}^{-1}\text{mol}^{-1})(50 - 25\,\text{K}) \\ &= -1.02 \times 10^{11}\,\text{J}. \end{aligned}$$

Note that I was careful to convert all quantities to joules. The negative sign indicates that this is heat that has to be removed from the reactor.

This isn't the only way to set up a heat balance for this problem, by the way. The interpretation of the sign will differ depending on the details of how you set up the problem.

(b) The heat removed from the polymer has to be taken up by the water, so

$$\begin{aligned} -q_{\text{excess}} &= mc_p\Delta T \\ \therefore m &= \frac{-q_{\text{removed}}}{c_p\Delta T} \\ &= \frac{1.02 \times 10^{11}\,\text{J}}{(4.184\,\text{J}\,\text{K}^{-1}\text{g}^{-1})(120 - 30\,\text{K})} \\ &= 2.71 \times 10^8\,\text{g} \\ &\equiv 2.71 \times 10^5\,\text{kg}. \end{aligned}$$

So 2.71×10^5 kg/h (271 t/h) of water have to circulate through the heat exchanger. Note that it is not necessary to have quite this much water in the system since the water can be circulated to a chiller and then circulated back to the heat exchanger. Often, the "waste" heat removed by the water is used in other chemical processes, or in heating the building during the cold months.

2. (a) $T_{\text{fp}} = 231\,\text{K}$
   (b) $T_{\text{bp}} = 358\,\text{K}$
   (c) $\Delta_{\text{fus}}S^\circ = 171 - 122 = 49\,\text{J}\,\text{K}^{-1}\text{mol}^{-1}$
   (d) $\Delta_{\text{vap}}S^\circ = 322 - 234 = 88\,\text{J}\,\text{K}^{-1}\text{mol}^{-1}$
   (e) $206\,\text{J}\,\text{K}^{-1}\text{mol}^{-1}$ (liquid)
   (f) From part (b), we have the boiling point, and from part (d), we have the entropy of vaporization. Since

$$\begin{aligned}\Delta_{\text{vap}}S &= \frac{\Delta_{\text{vap}}H}{T},\\ \Delta_{\text{vap}}H &= T\Delta_{\text{vap}}S\\ &= (358\,\text{K})(88\,\text{J}\,\text{K}^{-1}\text{mol}^{-1})\\ &= 32\,\text{kJ/mol}.\end{aligned}$$

3. (a) $2\,\text{Li}_{(\text{s})} + \text{C}_{(\text{s})} + \frac{3}{2}\,\text{O}_{2(\text{g})} \longrightarrow \text{Li}_2\text{CO}_{3(\text{s})}$
   (b)

$$\begin{aligned}\Delta_f S^\circ(\text{Li}_2\text{CO}_3) &= S^\circ(\text{Li}_2\text{CO}_3) - \left[2S^\circ(\text{Li}) + S^\circ(\text{C}) + \frac{3}{2}S^\circ(\text{O}_2)\right]\\ &= 90.31 - \left[2(29.09) + 5.74 + \frac{3}{2}(205.152)\right]\ \text{J}\,\text{K}^{-1}\text{mol}^{-1}\\ &= -281.34\,\text{J}\,\text{K}^{-1}\text{mol}^{-1}.\end{aligned}$$

   (c)

$$\begin{aligned}\Delta_f G^\circ(\text{Li}_2\text{CO}_3) &= \Delta_f H^\circ(\text{Li}_2\text{CO}_3) - T\Delta_f S^\circ(\text{Li}_2\text{CO}_3)\\ &= -1216.04\,\text{kJ}\,\text{mol}^{-1} - (298.15\,\text{K})(-281.34\times10^{-3}\,\text{kJ}\,\text{K}^{-1}\text{mol}^{-1})\\ &= -1132.16\,\text{kJ}\,\text{mol}^{-1}.\end{aligned}$$

   (d) For the reaction as written,

$$\begin{aligned}\Delta_r G^\circ_m &= 2\Delta_f G^\circ(\text{Li}_2\text{CO}_3) - 3\Delta_f G^\circ(\text{CO}_2)\\ &= 2(-1132.16\,\text{kJ}\,\text{mol}^{-1}) - 3(-394.37)\,\text{kJ}\,\text{mol}^{-1})\\ &= -1081.21\,\text{kJ}\,\text{mol}^{-1}.\\ \Delta_r G_m &= \Delta_r G^\circ + RT\ln Q\\ &= \Delta_r G^\circ + RT\ln\left(\frac{1}{(a_{\text{CO}_2})^3}\right)\\ &= -1081.21\,\text{kJ}\,\text{mol}^{-1} + (8.314\,472\times10^{-3}\,\text{kJ}\,\text{K}^{-1}\text{mol}^{-1})(298.15\,\text{K})\ln\left(\frac{1}{(1.2^3)}\right)\\ &= -1082.56\,\text{kJ}\,\text{mol}^{-1}.\end{aligned}$$

The reaction was written with 4 equivalents of lithium, so the maximum work is

$$w_{\max} = \frac{1}{4}\left(1082.56\,\mathrm{kJ\,mol^{-1}}\right) = 270.64\,\mathrm{kJ\,mol^{-1}}.$$

(I dropped the sign on the basis that we normally think of maximum work as a positive quantity.)