Chemistry 2720 Fall 2001 Assignment 3 Solutions

1. The heat of condensation of steam is very large. Each gram of steam releases 2257 J of heat on condensing. On the other hand, a gram of liquid water at 100°C which comes to equilibrium with skin at a temperature of 37°C only releases

   $$m\tilde{C}_P\Delta T = (1\,\text{g})(4.184\,\text{J}\,\text{K}^{-1}\text{g}^{-1})(37-100)\,\text{K} = -264\,\text{J}.$$

   In other words, condensing steam can deliver over eight times more heat than an equivalent amount of liquid water.

2. The melting temperature is the easiest thing to get, so let's start there. It's the flat part of the diagram. The temperature initially drops below the melting temperature. That's supercooling. Anyway, by making a few measurements on the graph, I found that the melting temperature is 1242 K.

   The heat balance for the calorimetry experiment is

   $$\begin{aligned} q &= \left\{\begin{array}{c}\text{cool}\\ \text{sample}\end{array}\right\} + \left\{\begin{array}{c}\text{warm}\\ \text{calorimeter}\end{array}\right\} = 0. \\ \therefore 0 &= (518.05\,\text{g})\tilde{C}_P(24.33-100.0^\circ\text{C}) + (8403\,\text{J/K})(24.33-22.04^\circ\text{C}). \\ \therefore \tilde{C}_P &= \frac{19.2\times10^3\,\text{J}}{39.2\times10^3\,\text{g}\,\text{K}} = 0.491\,\text{J}\,\text{K}^{-1}\text{g}^{-1} \end{aligned}$$

3. The steam (converted to water) and liquid water reach the same final temperature at equilibrium. The heat balance is

   $$q = \left\{\begin{array}{c}\text{8 g steam}\\ \text{cooled}\\ \text{from 115°C}\\ \text{to 100°C}\end{array}\right\} + \left\{\begin{array}{c}\text{8 g steam}\\ \text{condensed}\end{array}\right\} + \left\{\begin{array}{c}\text{8 g water}\\ \text{cooled}\\ \text{from 100°C}\\ \text{to } T_f\end{array}\right\} + \left\{\begin{array}{c}\text{300 g water}\\ \text{warmed}\\ \text{from 20°C}\\ \text{to } T_f\end{array}\right\} = 0.$$

   Note that writing down in words what will happen also allows you to organize your data, which makes it easier to solve the problem. In fact, now all we have to do is to write down in mathematical form what we wrote in English above, with only one slight problem, namely that the specific heat capacity of steam is only given in Appendix C on a molar basis.

   $$\begin{aligned} \tilde{C}_P &= \frac{33.76\,\text{J}\,\text{K}^{-1}\text{mol}^{-1}}{18.015\,\text{g/mol}} = 1.874\,\text{J}\,\text{K}^{-1}\text{g}^{-1}. \\ q = 0 &= (8\,\text{g})(1.874\,\text{J}\,\text{K}^{-1}\text{g}^{-1})(-15\,\text{K}) + (8\,\text{g})(-2257\,\text{J/g}) \\ &\quad + (8\,\text{g})(4.184\,\text{J}\,\text{K}^{-1}\text{g}^{-1})(T_f-100^\circ\text{C}) + (300\,\text{g})(4.184\,\text{J}\,\text{K}^{-1}\text{g}^{-1})(T_f-20^\circ\text{C}). \\ \therefore 1289T_f &= 46732. \\ \therefore T_f &= 36^\circ\text{C}. \end{aligned}$$

Note that because we used degrees Celsius consistently in this calculation, the answer came out in these units. If we had used Kelvin, we would have obtained an answer in Kelvin. We can get away with using degree Celsius in this case because the formulas only involve *differences* in temperatures. Since the Kelvin and Celsius scales are identical except for the choice of zero, they are interchangeable when only differences in temperature are involved.

4. A Watt is a Joule per second, so the reactor puts out $7.14 \times 10^8\,\mathrm{J/s}$. All we have to do is to calculate how many moles of sodium per second are required to carry this energy away, then we can convert to tonnes per hour.

   We know that heat is connected to heat capacity by

$$q = n\bar{C}\Delta T.$$

   It follows that

$$\begin{aligned} n &= \frac{q}{C\Delta T} \\ &= \frac{7.14 \times 10^8\,\mathrm{J/s}}{(29.26\,\mathrm{J\,K^{-1}mol^{-1}})(529-397)\,\mathrm{K}} \\ &= 1.85 \times 10^5\,\mathrm{mol/s} \\ &\equiv (1.85 \times 10^5\,\mathrm{mol/s})\frac{(22.9898\,\mathrm{g/mol})(3600\,\mathrm{s/h})}{10^6\,\mathrm{g/t}} \\ &= 15\,300\,\mathrm{t/h} \end{aligned}$$

   In the MONJU reactor, this is accomplished by using three pumps, each with a pumping rate of 5100 t/h.