Chem 3321 homework #4 – due Feb. 20, 2023

Problem 1, 10 marks – Carnot cycle

We learned in class that a heat engine has a maximum efficiency of $\eta = 1 - T_C/T_H$ where T_C and T_H are the temperatures (in Kelvin) of the cold and hot reservoirs, respectively. Although it is not possible in practice to design an engine with this efficiency, there is a hypothetical engine that does achieve it. The cycle this hypothetical engine follows is called the Carnot cycle. Work through the details of this Carnot cycle engine and prove that its efficiency is $\eta = 1 - T_C/T_H$. You may use my Chapter 20 lecture notes on the course web page but make sure you can do all the calculations on your own.

Problem 2, 10 marks – refrigerator

An electric motor is used to operate a Carnot refrigerator with an interior temperature of 0.00 °C. Liquid water at 0.00 °C is placed into the refrigerator and transformed to ice at 0.00 °C. If the room temperature is 300. K, what mass of ice can be produced in one day by a 0.50 hp motor that is running continuously? Assume that the refrigerator is perfectly insulated and operates at the maximum theoretical efficiency.

Problem 3, 10 marks – ideal gas expansion

Find ΔU, ΔH, ΔS, ΔA and ΔG for the isothermal expansion of an ideal gas, initially occupying one liter at 1 atm and 25 °C, to a final volume of 100 liters.

Problem 4, 10 marks – phase transition in solids

In the transition $CaCO_3$(aragonite) → $CaCO_3$(calcite), $\Delta G^\circ = -790$ J/mol and ΔV = 2.75 mL/mol at 25 °C. At what pressure would aragonite become the stable form at 25 °C? (assume ΔV is independent of pressure). The notation ° means 1 atm pressure.

Problem 5, 10 marks – chemical reaction

Using tabulated $\Delta_f H^\circ_{298}$ (Table 19.2) and standard molar entropies given in Table 21.2, calculate $\Delta_{rxn} G^\circ_{298}$ for the reaction $H_2O(\ell) \rightarrow H_2(g) + \frac{1}{2}O_2(g)$

a) At what temperature would the reaction become favorable assuming $\Delta_{rxn} H^\circ_{298}$ and $\Delta_{rxn} S^\circ_{298}$ are independent of temperature?

b) Using the temperature you found in part (a), and assuming constant pressure, calculate the entropy increase for one mole of a diatomic ideal gas from 298 K. Compare this value (as a percent) to $\Delta_{rxn} S^\circ_{298}$. You can refer back to homework 2 for a diatomic gas.