**Problem 1.** (1 point) chapter 4. Qian Sun, et al., *(Journal of Chemical Engineering Data, 2015, 60, 2057-2061)* used bomb calorimetry to measure the energy of combustion of the high-energy-density material "FOX-7" (1,1-diamino-2,2-dinitroethylene, C\(_2\)H\(_4\)O\(_4\)N\(_4\)). \(\Delta_c U^0= -7831\) J/g. In combustion, FOX-7 reacts with oxygen gas; products are nitrogen gas, carbon dioxide gas, and liquid water. T = 298.15K. P=101325 Pa.

a) Write the balanced combustion reaction. Convert \(\Delta_c U^0\) to kJ/mol, then to \(\Delta_c H^0\) using \(\Delta_n\)gas.

b) Using tabulated values of the formation enthalpies of water and carbon dioxide, calculate the standard enthalpy of formation of FOX-7, in kJ/mol.

---

**Problem 2.** (4 points) chapter 5.

**Background:** This problem is based on data given in the paper, "A single-atom heat engine," *Science*, 352(6283, pages 325-329, 2016, by Johannes Rossnagel, et al. The authors placed a single Ca\(^+\) ion in a "Paul trap," which uses special-shaped electrodes to confine the atom. A laser beam cools the atom. Electrical noise in the outer electrodes heats the ion. Work done on the atom pushes it toward the narrower end of the electrodes. Temperature is measured from Doppler broadening, a CHEM 4644 spectroscopy topic. When operating at steady state, temperature and position of the ion follow a closed cycle. We can suppose that heat and work are reversible.

**Data and actions:** T(S) is plotted at right. Circles are experimental points. Dashed curves are quadratic polynomial fits. On the hot side of the cycle,

\[
T = -121577.16203 + 1319.30843 S -3.55907676 S^2
\]

where S is in units of \(10^{-24}\) J/K and T is in units of mK. (mK stands for milli-Kelvin) Likewise on the cold side of the cycle,

\[
T = 418827.26298 - 4698.56612 S +13.19446244 S^2
\]

Using all of the digits displayed above is recommended.

The minimum entropy is \(S_{\text{min}} = 179.343\times10^{-24}\) J/K.

The maximum entropy is \(S_{\text{max}} = 179.842\times10^{-24}\) J/K.

a) Calculate the minimum and maximum temperature from the minimum and maximum entropy. Within uncertainty, either the hot-T or the cold-T polynomial can be used.

b) Calculate \(d_{\text{hot}}\) the heat along the high-temperature side of the cycle. S is increasing.

Note that \(dq=TdS\), so \(q = \int T dS\).

c) Calculate \(d_{\text{cold}}\) the heat along the low-temperature side of the cycle. S is decreasing.

d) Calculate q, the heat around the entire cycle.

e) What is \(\Delta U\) for the cycle?

f) Calculate w, the work for the entire cycle.

g) Calculate the efficiency of the cycle, \(|w|/q_{\text{hot}}\).