1. Return to the Saha equation problem on $^5\text{Li}$. The condition for the Saha equation to be valid is that the system be in equilibrium. Our clock is the Hubble time (remember the discussion in problem set one about the evolution of the early universe up until recombination, which we showed could be extrapolated from Weinberg’s table). Our other clock is the lifetime of a $^4\text{He}$ nucleus (when capturing a proton). So the problem is the following. One could argue that our previous calculation was incomplete. $^5\text{Li}$ could form later in the universe, after the time of deuterium formation, when the temperature has dropped sufficiently to favor Li formation. Explore this possibility and tell me what is the condition on the binding energy that allows Li to form at any time after nucleosynthesis. (I have never seen this worked out.)

2. Calculate the relative abundance of $^{12}\text{C}$, $^{13}\text{C}$, $^{14}\text{N}$, and $^{15}\text{N}$ in the CN cycle at equilibrium for a temperature of $T_7 = 1.583$. According to the standard model calculations of Bahcall and Pinsonneault, the temperature at the core of the sun has this value today, and the mass fractions of $^{12}\text{C}$ and $^{14}\text{N}$ are $2.42 \times 10^{-5}$ and $5.93 \times 10^{-3}$. Do these numbers seem consistent to you?

3. Determine the temperature at which the CNO cycle beta decay rates begin to be important in modifying the abundances: write down some reasonable criterion for this, then solve for T.

4. Suppose the sun produced its energy from the CNO cycle, rather from the pp chain.
Look up the solar constant, and from that deduce the neutrino fluxes that would result in the two cases. For the pp chain, it is ok to take a shortcut by using the ppI/(ppII+ppIII) and ppII/ppIII branching ratios given in class (on the pp-chain figure). It is also okay to ignore the energy loss from the sun due to neutrino emission. Had the sun been powered by the CNO cycle, do you think the counting rate in the chlorine experiment would have been higher or lower?

5. Calculate the temperature dependence of the CNO cycle. Remember that $^{14}\text{N(p,γ)}$ is the controlling reaction. You can either do this numerically, by calculating at $T_7 = 2$ and $T_7 = 2.1$, for example, or by expanding in a Taylor series around $T_7 = 2$. But $T_7 = 2$ is a good choice for the evaluation.