Physics 880A20 COSMOLOGY Problem Set 8 November 13, 2006

Note: The numbers in [ ] are the point totals for each part of each problem.

Problem 1 :

a) If the ratio of nucleons to photons in the Universe today is 6×10^{-10}, find the number density (fm^{-3}) of nucleons in the early Universe when $kT_\gamma = 1$ MeV. Using this density, estimate the internucleon separation (in fm). [10]

b) BBN ends when the temperature drops below ≈ 30 keV. How old is the Universe at this time and how many nucleons are there within the (particle) horizon? (Find R_H, V_H, and N_H). For $m_{\mathrm{N}} \approx 0.94$ GeV, how many solar masses of causally connected nucleons (*i.e.* within the horizon) are there at this time? [10]

c) Suppose at BBN Newton's gravitational constant were smaller than its present value by 10% ($G'/G = 0.9$). How would this effect the predicted primordial abundance of ^{4}He (compared to SBBN)? Using the notes, make a rough quantitative estimate of the magnitude of the change in $\mathrm{Y_P}$. [10]

Problem 2 :

When a ^{4}He nucleus is created, 28 MeV of energy is released. In contrast to the standard cosmology, suppose there was no relic radiation from the early Universe and imagine that helium-4 was synthesized instantaneously and uniformly throughout the Universe much more recently. Suppose the ^{4}He mass fraction is $\mathrm{Y} = 0.25$ and the present baryon to photon ratio is 6.0×10^{-10}.

a) Suppose all the energy released in making this abundance of helium-4 were instantaneously thermalized, creating a black body spectrum at a temperature T_γ. If this synthesis occurs today (t_0), find the value of this temperature, $T_{\gamma 0}$. [10]

b) At what redshift should this synthesis (and instantaneous conversion to radiation) occur, if the present temperature is $T_{\gamma 0} = 2.725$ K? [10]

Problem 3 :

a) A recent experiment suggests that the neutron lifetime is smaller than the currently accepted (Particle Data Group) value. Describe qualitatively the effect this would have, if correct, on the predicted primordial abundances of the elements produced in BBN. [10]

b) Suppose there were an unstable, massive particle, X, which was present at the time of BBN but which decayed afterwards, long after BBN has ended. Assume that the decay products are harmless and do not modify the BBN abundances. If the X particle was non-relativistic at BBN and if it dominated the energy density at that time ($\rho_X >> \rho_R$), describe the effect this would have had on BBN. In particular, for $\eta_{10} \approx 6$, would the predicted primordial abundances of D, ^{4}He, ^{7}Li, be higher, lower, or unchanged (from SBBN)? [10]