November 16, 2014

Cornell University, Department of Physics

PHYS 7646, Elementary particle II, HW # 6, due: 11/25/14

Question 1: BBN

In class we discuss the ^{4}He abundant, Y. The very basic picture is that at freeze out the neutron to proton ratio is $x(T_{f.o.}) \approx 1/6$. The neutron are free until Deuterium can be produced at much lower temperature, $T_D \ll T_{f.o.}$. Once Deuterium can be produced, almost all of it is converted into ^{4}He very fast and basically all of the neutrons end up in ^{4}He. Yet, in the time from freeze out until t_D some of the neutrons decay, and thus $x(T_{f.o.}) \approx 1/7$. This leads to $Y \approx 0.25$.

Here you are asked to evaluate how variations of some parameters would affect Y. You should assume that all the parameters that are not mentioned are not modified.

1. g_* is slightly larger.
2. G_F is slightly larger.
3. The neutron is slightly heavier.
4. The deuterium binding energy is slightly higher.

Question 2: Leptogenesis

Consider a model where we add two right handed neutrinos $N_i(1,1)_0$ $(i = 1, 2)$. We assume that $M_2 \gg M_1$.

1. Write the couplings of N_i to the SM fermions.
2. What of the following accidental symmetries of the SM is broken by N_i?

$$L, \qquad B, \qquad B - L, \qquad B + L. \tag{1}$$

3. Plot the diagrams that lead to leptogenesis in the model. You can assume that only N_1 is generated. You do not have to evaluate all the loop integrals, but make sure you identify the CP violating invariant.