Exercise Sheet 5: Thermal Universe & Baryogenesis

Exercise 1

Consider the Boltzmann equations for the right-handed neutrino number density and the $B - L$ number density in the limit of negligible wash-out and way-out of equilibrium condition, i.e.

$$\frac{dn_N}{dt} + 3Hn_N = -\langle\Gamma\rangle(n_N - n_{N,eq})$$

$$\frac{dn_{B-L}}{dt} + 3Hn_{B-L} = +\epsilon\langle\Gamma\rangle(n_N - n_{N,eq}) \tag{1}$$

with $n_N \gg n_{N,eq}$.

a) Rewrite the equations for the quantities Y_N, Y_{B-L}, where as before $Y_X = n_X/s$, using as time variable the rescaled temperature $x = T/m_N$, assuming again a period of adiabatic expansion of the universe, i.e.

$$H(T) = \frac{\pi}{3}\left(\frac{g_\rho}{10}\right)^{1/2}\frac{T^2}{M_P}$$

with $g_\rho = g_S$ constant. The entropy density is given as $s(T) = \frac{2\pi^2}{45}g_S T^3$.

b) Solve the Boltzmann equation for Y_N assuming constant $\langle\Gamma\rangle$ and a non-relativistic RH neutrino with $n_{N,eq}(x) = \frac{g}{\pi^2}m_N^3 x^{-3/2}e^{-x}$, for $x = m_N/T$.

c) Use this solution in to the equation for Y_{B-L} to obtain the present value of $B - L$, again assuming a constant $\langle\Gamma\rangle$ and a non-relativistic RH neutrino with $n_{N,eq}(x) = \frac{g}{\pi^2}m_N^3 x^{-3/2}e^{-x}$, for $x = m_N/T$.

d) Discuss now the effect of the wash-out processes. Draw a couple of diagrams for such 2-to-2 scatterings and find out how they depend on the temperature. Which is the dominant process ?

e) What happens if $n_N = 0$ initially ?