

Cosmology II

Problem sheet 3 Thermal History II

Exercise 1:

Suppose that there were no baryon asymmetry so that the number density of baryons exactly equaled that of anti-baryons.

- (a) Determine the final relic density of baryons+anti-baryons.
- (b) At what temperature is this asymptotic value reached?

Exercise 2:

Using the fact that our universe appears to be electrically neutral, obtain that the chemical potential μ for electrons and positrons has to be practically zero. What about the neutrinos?

Hints:

1. $n_{e^-} = n_{e^+} + n_p$,
2. electrons and positrons are kept in thermal equilibrium through the process $e^+ e^- \leftrightarrow 2\gamma$,
3. $n_p \sim 10^{-10} n_\gamma$.

Exercise 3:

The epoch at which the energy density in matter ρ_m equals that in radiation ρ_r is called *matter-radiation equality*.

- (a) Find the value of the scale factor a_{eq} (in dependence on Ω_m) at which they were equal.
- (b) Express this epoch in terms of the redshift z .

Hint: Assume the neutrinos to be massless ($m_\nu = 0$), therefore $\rho_r = \rho_\gamma + \rho_\nu$.