PHYS 480/581
Cosmology

Worksheet #13
Wednesday 10/12/2022

Question 1.

(a) We saw that the number density of non-relativistic particles with zero chemical potential in *thermal equilibrium* is

$$n_{\rm NR} = g\left(\frac{mT}{2\pi}\right)^{3/2} e^{-m/T}. \tag{1}$$

For $T \ll m$, this tells us that the abundance of such particle is exponentially suppressed. What is the actual physical process that is responsible for exponentially suppressing the abundance?

(b) Assuming that the process you found in part (a) is efficient, abundances will indeed get exponentially suppressed. However, the presence of a chemical potential can change that. Show that the difference in abundances between a particle (number density n) and its antiparticle (number density $\bar{n}$) is

$$n - \bar{n} = 2g\left(\frac{mT}{2\pi}\right)^{3/2} e^{-m/T} \sinh\left(\frac{\mu}{T}\right), \tag{2}$$

where μ can be a function of temperature.

(c) Near the epoch of recombination ($T \sim 1$ eV) just before neutral atoms formed, the Universe was full of non-relativistic electrons ($m_{\rm e} \sim 0.5$ MeV), apparently contradicting Eq. (1) above. How is this possible? Which eventual value of the chemical potential do you need to make this possible?