PH3930 (Particle Astrophysics)
Problem sheet 5
Due date to be announced.

1: Consider the time period relevant for Big Bang Nucleosynthesis when the temperature is in the MeV range.

(a) What is the effective number of degrees of freedom g_* at a temperature of several MeV? Briefly justify your answer.

(b) The reaction $\mathrm{n}\nu \leftrightarrow \mathrm{pe}^-$ has a rate

$$\Gamma(\mathrm{n}\nu \leftrightarrow \mathrm{pe}^-) \approx G_{\mathrm{F}}^2 T^5 \ . \tag{1}$$

Plot or sketch this reaction rate versus T along with the expansion rate H in the temperature range relevant for big bang nucleosynthesis and indicate roughly the freeze-out temperature T_{f} and the regions where thermal equilibrium does and does not hold.

(c) Show that the freeze-out temperature T_{f} depends on g_* as $T_{\mathrm{f}} \propto g_*^{1/6}$.

(d) Show that if the number of neutrino families N_ν were 4 rather than 3, the freeze-out temperature would be larger by a factor of about 1.025.

(e) By what factor would the ratio of neutrons to protons at freeze-out be different for $N_\nu = 4$? (Use $T_{\mathrm{f}} = 0.7$ MeV for $N_\nu = 3$ and recall the neutron-proton mass difference is $\Delta m = 1.3$ MeV.)

(f) Using the results of (d) and (e), Find the mass fraction of ^{4}He for the case $N_\nu = 4$ and compare this to the result you would obtain for $N_\nu = 3$.

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