

## Homework problems 3

### Group I

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#### Problem No 7.2

##### Abundance of neutrino species

Let us make a wrong assumption that there is no  $Z^0$  boson in Nature, while  $W^\pm$  exist. Furthermore, let us neglect loop processes and neutrino oscillations (also wrong). What are the relic abundances of neutrinos of different types?

#### Problem No 8.1

##### Nucleosynthesis

Find nucleosynthesis temperature in a hypothetical case of fast production of He-4 directly from protons and neutrons.

#### Problem No 9.4

##### Neutrino decoupling

Check that neutrino of mass  $m_\nu = 6$  GeV indeed freezes out being non-relativistic. Find the values of the neutrino mass at which this property no longer holds. Show, nevertheless, that cosmologically excluded is the entire mass range of stable neutrino

$$20\text{eV} \lesssim m_\nu \lesssim 6\text{GeV},$$

where the lower value has been obtained in Chapter 7, formula (7.10).

#### Problem No 10.3

##### Effective Higgs potential

Calculate the terms of order  $\phi^4 \log(\phi/T)$  in the high-temperature expansion of the effective potential, using the relation (10.20). Show that at  $\lambda \sim h_i^2$  (the Higgs boson mass is comparable to those of other particles) and  $h_i \ll 1$  (the couplings are small), these terms are small compared to those written in (10.29) in the entire interesting range of  $\phi$ , namely,  $0 < \phi \lesssim v$ .