

Change in Primordial Abundances Due to a Change in the Primordial Plasma Energy Density

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Abstract. We recently showed that the energy density of a plasma is appreciably different than previously thought when high frequency plasma fluctuations, $\omega \geq k_B T / \hbar$, are taken into account (M. Opher & R. Opher, 1999). A change in the primordial plasma energy density changes the primordial expansion rate of the universe, the neutron temperature freeze-out, and the primordial nucleosynthesis abundances. The change in the primordial abundances due to the change in the primordial plasma energy density is evaluated, taking into account the high frequency, as well as the low frequency fluctuations of the plasma.

The universe at the epoch of primordial nucleosynthesis was an electron positron plasma at the beginning and, after the electron positron annihilation, an electron-proton-helium plasma. The energy estimated in the primordial nucleosynthesis epoch is the sum of the energies of all of the particles present in the primordial soup. In the standard calculation, the energy density of the particles is obtained by treating the particles as non-interacting, as in an ideal gas. The photon energy density is estimated to be the energy density of the blackbody in vacuum (Kolb & Turner 1990).

Recently, we showed that the correction to an ideal gas is greater than the Debye-Hückel correction, in the low temperature classical limit (Opher & Opher 1999). This investigation was made by studying the electromagnetic fluctuations present in a plasma, where all of the frequencies were included. The Debye-Hückel theory is recovered when only fluctuations with frequencies $\omega < T$ are included ($\hbar = k_B = 1$). We studied plasmas with temperatures $T = 10^3 - 10^5$ K and densities $n = 10^{13} - 10^{19}$ cm⁻³, obtaining corrections on the order of $10^2 - 10^{10}$ times greater than those given by the Debye-Hückel theory. We may, therefore, expect that in the epoch of primordial nucleosynthesis, a similar important correction exists to the energy, as that found for classical low temperature plasmas (Opher & Opher 1999).

By integrating the spectra in wave number and frequency, we obtain the energy densities of the magnetic field, ρ_B , and of the transverse and longitudinal electric fields, ρ_{E_T} and ρ_L . We perform the integration of the spectra over frequency and wave number, without assuming that $\omega < T$. For details of the calculation, see our previous investigation (Opher & Opher 1999).

To obtain the interaction energy, ρ_{int} , we subtract the energy of the particles due to their own fields from the longitudinal energy density, ρ_L . We previously found that the transverse energy (summing the transverse electric and magnetic field energies, ρ_{E_T} and ρ_B) has an additional energy, compared to the blackbody energy density in vacuum. The additional transverse energy is $\Delta\rho_\gamma = \rho_B + \rho_{E_T} - \rho_\gamma$, where ρ_γ is the photon energy density, estimated to be the blackbody energy density in vacuum.

Adding the interaction energy ρ_{int} to $\Delta\rho_\gamma$, we obtain the total change in the energy density due to the transverse and longitudinal components, $\rho_{new} = \Delta\rho_\gamma + \rho_{int}$. We calculate ρ_{new} for the primordial electron-positron plasma for $3 \times 10^9 K < T < 1.3 \times 10^{10} K$. ρ_{new} is also calculated for low temperatures, after the electron-positron annihilation, when we have an electron-proton-helium plasma. After annihilation, the density drops by a factor of 10^{10} . Therefore, ρ_{new} will be negligible for low temperatures. We find that $\rho_{new} \sim -10\%\rho_\gamma$ and goes to zero at lower temperatures. This is consistent with our previous analysis at low temperatures (Opher & Opher 1999), where we found that ρ_{new} is positive.

It is interesting to note that the ratio ρ_{new}/ρ_{part} over this range of temperatures and densities (i.e., between $T = 3.5 \times 10^9 K$ and $T = 1.3 \times 10^{10} K$) is approximately constant (~ -0.33), where ρ_{part} is the energy density of the particles, $\rho_{part} = (3/2)nT$. The maximum variation is $\sim 2\%$. Thus, we can write $\rho_{new} \cong -0.33((3/2)nT)$, valid for all temperatures.

We found that the energy content is $\sim -10\%$ less than previously thought. A decrease of ρ_γ by 10% acts like a decrease in the number of relativistic neutrinos from $N_\nu = 3.0$ to $N_\nu = 2.6$, which predicts a decrease in the theoretical abundance of helium Y (Theor.). This is in agreement with the results presented at this meeting. Whereas the standard model (with low deuterium abundance) predicts Y (Theor.)=0.245, Viegas and Gruenwald (2000) report at this meeting that observations of HII extragalactic regions (taking into account their inhomogeneity) indicate that Y (Observ.)=0.241 and Peimbert (2000) reports at this meeting, as well, that observations of the Magellanic Clouds indicate that Y(Observ.)=0.236

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