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MeV-scale reheating temperature and thermalization of three active neutrinos by radiative and hadronic decays of massive particles

We determine the minimum value of the reheating temperature set by Big-Bang Nucleosynthesis by considering both radiative and hadronic decays of long-lived massive particles. In the current study, effects of neutrino oscillation and neutrino self-interaction are taken into account in the calculation of the neutrino thermalization. We adopt updated observational bounds on the primordial abundance of light elements. An obtained lower bound on the reheating temperature is $T_{\rm RH}\ > 2.6$ MeV in the case of the 100% radiative decay, and $T_{\rm RH}\ > 3$ MeV $-$ 5 MeV in the case with hadronic decays depending on the mass of the massive particles and the hadronic branching ratio of the decay. Also, we find that the effects of neutrino oscillation and neutrino self-interaction increase the lower bound at the level of $O(10)$% in the case of the 100% radiative decay and $O(1)$% in the case with hadronic decays.

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