Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B 797 (2008) 93–116
NUCLEAR PHYSICS B
www.elsevier.com/locate/nuclphysb

Effects of lightest neutrino mass in leptogenesis

E. Molinaro, S.T. Petcov [1], T. Shindou [2], Y. Takanishi [*]

SISSA and INFN-Sezione di Trieste, Trieste I-34014, Italy

Received 12 September 2007; accepted 20 December 2007

Available online 15 January 2008

Abstract

The effects of the lightest neutrino mass in "flavoured" leptogenesis are investigated in the case when the CP-violation necessary for the generation of the baryon asymmetry of the Universe is due exclusively to the Dirac and/or Majorana phases in the neutrino mixing matrix U. The type I see-saw scenario with three heavy right-handed Majorana neutrinos having hierarchical spectrum is considered. The "orthogonal" parametrisation of the matrix of neutrino Yukawa couplings, which involves a complex orthogonal matrix R, is employed. Results for light neutrino mass spectrum with normal and inverted ordering (hierarchy) are obtained. It is shown, in particular, that if the matrix R is real and CP-conserving and the lightest neutrino mass m_3 in the case of inverted hierarchical spectrum lies the interval $5 \times 10^{-4}\ \text{eV} \lesssim m_3 \lesssim 7 \times 10^{-3}\ \text{eV}$, the predicted baryon asymmetry can be larger by a factor of ~ 100 than the asymmetry corresponding to negligible $m_3 \cong 0$. As consequence, we can have successful thermal leptogenesis for $5 \times 10^{-6}\ \text{eV} \lesssim m_3 \lesssim 5 \times 10^{-2}\ \text{eV}$ even if R is real and the only source of CP-violation in leptogenesis is the Majorana and/or Dirac phase(s) in U.

PACS: 98.80.Cq; 14.60.Pq; 14.60.St

Keywords: Thermal leptogenesis; Seesaw mechanism; Lepton flavour effects

[*] Corresponding author.
E-mail addresses: molinaro@sissa.it (E. Molinaro), testuo.shindou@desy.de (T. Shindou), yasutaka@sissa.it (Y. Takanishi).
[1] Also at: Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, 1784 Sofia, Bulgaria.
[2] Current address: Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22603 Hamburg, Germany.

0550-3213/$ – see front matter
doi:10.1016/j.nuclphysb.2007.12.033

1. Introduction

In the present article we continue to investigate the possible connection between leptogenesis [1,2] (see also, e.g., [3,4]) and the low energy CP-violation in the lepton (neutrino) sector (for earlier discussions see, e.g., [5–8] and the references quoted therein). It was shown recently [9] that the CP-violation necessary for the generation of the observed baryon asymmetry of the Universe in the thermal leptogenesis scenario can be due exclusively to the Dirac and/or Majorana CP-violating phases in the Pontecorvo–Maki–Nakagawa–Sakata (PMNS) [10] neutrino mixing matrix, and thus can be directly related to the low energy CP-violation in the lepton sector (e.g., in neutrino oscillations, etc.). The analysis performed in [9] (see also [11,12]) was stimulated by the progress made in the understanding of the importance of lepton flavour effects in leptogenesis [13–18]. It led to the realisation that these effects can play crucial role in the leptogenesis scenario of baryon asymmetry generation [15–17]. It was noticed in [16], in particular, that "Scenarios in which $\epsilon_1 = 0$ while $\epsilon_1^j \neq 0$ entail the possibility that the phases in the light neutrino mixing matrix U are the only source of CP violation", ϵ_1^j and ϵ_1 being respectively the individual lepton number and the total lepton number CP violating asymmetries.

As is well-known, the leptogenesis theory [1] is based on the see-saw mechanism of neutrino mass generation [19]. The latter provides a natural explanation of the observed smallness of neutrino masses (see, e.g., [20–22]). An additional appealing feature of the see-saw scenario is that through the leptogenesis theory it allows to relate the generation and the smallness of neutrino masses with the generation of the baryon (matter–antimatter) asymmetry of the Universe, Y_B.

The non-supersymmetric version of the type I see-saw model with two or three heavy right-handed (RH) Majorana neutrinos is the minimal scheme in which leptogenesis can be implemented. In [9] the analysis was performed within the simplest type I see-saw mechanism of neutrino mass generation with three heavy RH Majorana neutrinos, N_j, $j = 1, 2, 3$. Taking into account the lepton flavour effects in leptogenesis it was shown [9], in particular, that if the heavy Majorana neutrinos have a hierarchical spectrum, i.e., if $M_1 \ll M_{2,3}$, M_j being the mass of N_j, the observed baryon asymmetry Y_B can be produced even if the only source of CP-violation is the Majorana and/or Dirac phase(s) in the PMNS matrix[3] $U_{\rm PMNS} \equiv U$. Let us recall that in the case of hierarchical spectrum of the heavy Majorana neutrinos, the lepton flavour effects can be significant in leptogenesis provided the mass of the lightest one M_1 satisfies the constraint [15–17] (see also [23]): $M_1 \lesssim 10^{12}$ GeV. In this case the predicted value of the baryon asymmetry depends explicitly (i.e., directly) on U and on the CP-violating phases in U. The results quoted above were demonstrated to hold both for normal hierarchical (NH) and inverted hierarchical (IH) spectrum of masses of the light Majorana neutrinos (see, e.g., [20]). In both these cases they were obtained for negligible lightest neutrino mass and CP-conserving elements of the orthogonal matrix R, present in the "orthogonal" parametrisation [24] of the matrix of neutrino Yukawa couplings. The CP-invariance constraints imply [9] that the matrix R could conserve the CP-symmetry if its elements are real or purely imaginary. As was demonstrated in [9], for NH spectrum and negligible lightest neutrino mass m_1 one can have successful thermal leptogenesis with real R. In contrast, in the case of IH spectrum and negligible lightest neutrino mass (m_3), the requisite baryon asymmetry was found to be produced for CP-conserving matrix R only if certain elements of R are purely imaginary: for real R the baryon asymmetry Y_B is strongly suppressed [8] and leptogenesis cannot be successful for $M_1 \lesssim 10^{12}$ GeV (i.e., in the regime in

[3] The same result was shown to hold also for quasi-degenerate in mass heavy RH Majorana neutrinos [9].