Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B 904 (2016) 86–105

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Evaluation of the Majorana phases of a general Majorana neutrino mass matrix: Testability of hierarchical flavour models

Rome Samanta, Mainak Chakraborty, Ambar Ghosal *

Saha Institute of Nuclear Physics, 1/AF Bidhannagar, Kolkata 700064, India

Received 23 September 2015; received in revised form 8 December 2015; accepted 2 January 2016

Available online 6 January 2016

Editor: Hong-Jian He

Abstract

We evaluate the Majorana phases for a general 3×3 complex symmetric neutrino mass matrix on the basis of Mohapatra–Rodejohann's phase convention using the three rephasing invariant quantities I_{12}, I_{13} and I_{23} proposed by Sarkar and Singh. We find them interesting as they allow us to evaluate each Majorana phase in a model independent way even if one eigenvalue is zero. Utilizing the solution of a general complex symmetric mass matrix for eigenvalues and mixing angles we determine the Majorana phases for both the hierarchies, normal and inverted, taking into account the constraints from neutrino oscillation global fit data as well as bound on the sum of the three light neutrino masses ($\Sigma_i m_i$) and the neutrinoless double beta decay ($\beta\beta_{0\nu}$) parameter $|m_{11}|$. This methodology of finding the Majorana phases is applied thereafter in some predictive models for both the hierarchical cases (normal and inverted) to evaluate the corresponding Majorana phases and it is shown that all the sub cases presented in inverted hierarchy section can be realized in a model with texture zeros and scaling ansatz within the framework of inverse seesaw although one of the sub cases following the normal hierarchy is yet to be established. Except the case of quasi degenerate neutrinos, the methodology obtained in this work is able to evaluate the corresponding Majorana phases, given any model of neutrino masses.

* Corresponding author.

E-mail addresses: rome.samanta@saha.ac.in (R. Samanta), mainak.chakraborty@saha.ac.in (M. Chakraborty), ambar.ghosal@saha.ac.in (A. Ghosal).

http://dx.doi.org/10.1016/j.nuclphysb.2016.01.001

1. Introduction

Apart from hierarchical structure of massive neutrinos a fundamental qualitative nature of these elusive particles whether they are Dirac or Majorana type is yet unknown. Neutrinoless double beta decay ($\beta\beta_{0\nu}$) mode [1–12] is able to discriminate between the two different types. Positive evidence of the above experimental search will be able to determine the Majorana nature of neutrinos assuming the above decay is mediated due to light neutrino. Several $\beta\beta_{0\nu}$ experiments are ongoing and planned. In Ref. [13] a brief discussion about some of the important experiments is presented. Among them, EXO-200 [14] experiment puts an upper limit on the relevant neutrino mass matrix element $|m_{11}|$ within a range as $|m_{11}| < (0.14–0.35\ \text{eV})$. Further, NEXT-100 [15] experiment will be able to bring down the above value of the order of 0.1 eV. Thus in an optimistic point of view such property of neutrino could be testified by the next generation experiments. However, even if it is possible to pin down the value of $|m_{11}|$, it is still difficult to predict the values of the Majorana phases until we can fix the absolute neutrino mass scale. It is shown in Ref. [16] that in addition to the $\beta\beta_{0\nu}$ decay experiments, lepton number violating processes in which the Majorana phases show up are also corroborative to determine the individual Majorana phases. Another interesting physical aspect such as contribution of the Majorana phases to the generation of θ_{13} within the present 3σ range of neutrino oscillation global fit data is also studied in the literature [17]. Ref. [18] discusses how to constrain the Majorana phases using the results from cosmology and double beta decay. Thus it is worthwhile to study the calculability of the Majorana phases in terms of a general neutrino mass matrix (m_ν) parameters. In the present work we evaluate individual Majorana phases in terms of the parameters of a general m_ν using three rephasing invariants I_{12}, I_{13} and I_{23} presented in Ref. [19] on the basis of Mohapatra–Rodejohann's phase convention [20]. Although there are several papers which discuss the general procedure for calculating the Majorana phases, motivation behind taking the rephasing invariants is that the methodology we present here is capable of calculating the Majorana phase in a model independent way even if one of the eigenvalues is zero which is still allowed as far as the present neutrino oscillation global fit data is concerned. Moreover as one of the rephasing invariant (I_{23}) is directly proportional to m_3, therefore it vanishes if $m_3 = 0$ and hence shows a strong dependency of the Majorana phases with the light neutrino masses. In the present work we evaluate the Majorana phases for a general complex symmetric neutrino mass matrix (m_ν) taking into account the global fit oscillation data and the upper bound on the sum of the three light neutrino masses ($\Sigma_i m_i$) along with the $\beta\beta_{0\nu}$ decay parameter for both the hierarchical cases. We then conclude except the case of quasi degeneracy,[1] the methodology presented in this work is able to calculate the Majorana phases, given any model of neutrino masses and for convenience, we further numerically estimate the ranges of each Majorana phase for both types of hierarchies, in the context of a cyclic symmetric model as well as a model with scaling ansatz property. It is also shown that all the sub cases we present in inverted hierarchy section of the general discussion can be realized through the choice of a model with scaling ansatz with texture zeros within the framework of inverse seesaw while one of the phenomenologically viable sub case of the normal hierarchy section is yet to be identified. The plan of the paper is as follows.

In Section 2 we briefly discuss the basic formalism to set the convention of the Majorana phase representation within the framework of neutrino oscillation phenomena. CP violating rephasing invariants are presented in Section 3. Section 4 contains explicit calculation of the

[1] For the quasi-degenerate case the procedures of calculating the Majorana phases are stated in Sec. 4.3.