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Neutrino mass and mixing in the seesaw playground ☆

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Abstract

We discuss neutrino mass and mixing in the framework of the classic seesaw mechanism, involving right-handed neutrinos with large Majorana masses, which provides an appealing way to understand the smallness of neutrino masses. However, with many input parameters, the seesaw mechanism is in general not predictive. We focus on natural implementations of the seesaw mechanism, in which large cancellations do not occur, where one of the right-handed neutrinos is dominantly responsible for the atmospheric neutrino mass, while a second right-handed neutrino accounts for the solar neutrino mass, leading to an effective two right-handed neutrino model. We discuss recent attempts to predict lepton mixing and CP violation within such natural frameworks, focusing on the Littlest Seesaw and its distinctive predictions.

1. Introduction

Although the discovery of neutrino oscillations implying mass and mixing can be regarded as one of the greatest discoveries in physics in the last two decades, not least because it provides the only laboratory evidence for physics beyond the Standard Model (SM), it remains a sobering fact that we still do not know the origin of neutrino mass and mixing (for reviews see e.g. [1]). However, at least there seems to be a leading candidate for neutrino mass and mixing, namely the seesaw mechanism involving additional right-handed neutrinos with heavy Majorana masses [2].

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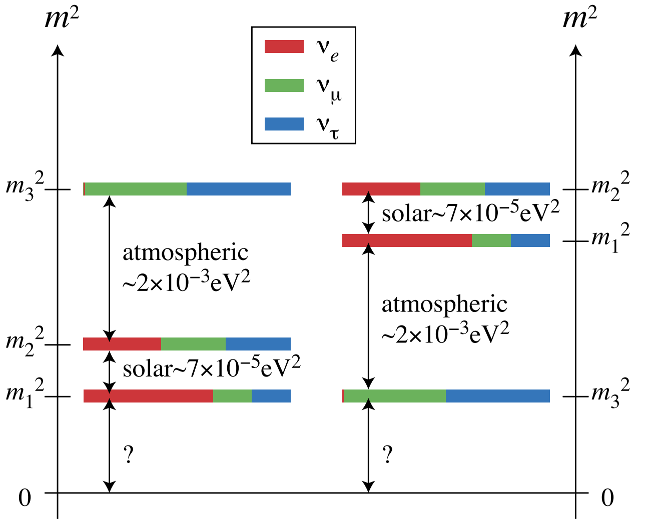

Fig. 1. The probability that a particular neutrino mass state ν_i with mass m_i contains a particular charged lepton mass basis state $(\nu_e, \nu_\mu, \nu_\tau)$ is represented by colours. The left and right panels of the figure are referred to as normal or inverted mass squared ordering, respectively, referred to as NO or IO. The value of the lightest neutrino mass is presently unknown. The current best fit values of the mass squared differences are given in [5–7]. For example, the best fit mass squareds for a normal neutrino mass ordering are [5] are: $m_3^2 - m_1^2 = (2.547 \pm 0.047) \times 10^{-3}$ eV^2 and $m_2^2 - m_1^2 = (7.50 \pm 0.18) \times 10^{-5}$ eV^2.

Although the seesaw mechanism represents an astonishingly elegant explanation of the smallness of neutrino mass, it involves many parameters making quantitative predictions of neutrino mass and mixing challenging, but not impossible, as we shall discuss.

In this paper we focus on natural implementations of the seesaw mechanism in which large cancellations do not occur, where typically one of the right-handed neutrinos is dominantly responsible for the atmospheric neutrino mass [3], while a second right-handed neutrino accounts for the solar neutrino mass [4]. After reviewing the unanswered questions, and lepton mixing, we enter the seesaw playground and discuss recent attempts to try to understand lepton mixing and CP violation within such natural frameworks, focusing on the Littlest Seesaw with its distinctive predictions.

2. Unanswered questions

The present status of neutrino physics is summarised in Figs. 1, 2. Despite the great pace of progress in neutrino physics, there are still several unanswered experimental questions, as follows:

- Is the atmospheric neutrino angle θ_{23} in the first or second octant?
- Do neutrino mass squared eigenvalues have a normal ordering (NO) or inverted ordering (IO)?
- What is the value of the lightest neutrino mass?
- Are neutrinos Dirac or Majorana?
- Is $\mathcal{CP}$ violated in the leptonic sector and if so by how much?