Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B 791 (2008) 60–92

NUCLEAR PHYSICS B

Systematic parameter space search of extended quark–lepton complementarity

Florian Plentinger, Gerhart Seidl *, Walter Winter

Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074 Würzburg, Germany

Received 4 January 2007; received in revised form 3 August 2007; accepted 3 September 2007

Available online 26 September 2007

Abstract

We systematically investigate the parameter space of neutrino and charged lepton mass matrices for textures motivated by an extended quark–lepton complementarity. As the basic hypothesis, we postulate that all mixing angles in U_ℓ and U_ν be either maximal or described by powers of a single small quantity $\epsilon \simeq \theta_C$. All mass hierarchies are described by this ϵ as well. In this study, we do not assume specific forms for U_ℓ and U_ν, such as large mixing coming from the neutrino sector only. We perform a systematic scan of the 262 144 generated mixing matrices for being compatible with current experimental data, and find a sample of 2468 possibilities. We then analyze and classify the effective charged lepton and neutrino mass textures, where we especially focus on a subset of models getting under pressure for small θ_{13}. In addition, we predict the mixing angle distributions from our sample of all valid textures, and study the robustness of this prediction. We also demonstrate how our procedure can be extended to predictions of the Dirac and Majorana phases in U_{PMNS}. For instance, we find that CP conservation in neutrino oscillations is preferred, and we can impose a lower bound on the mixing matrix element for $0\nu\beta\beta$ decay.

PACS: 12.15.Ff; 14.60.Pq; 14.60.St

Keywords: Charged lepton and neutrino masses and mixing; Cabibbo angle; Textures; Quark–lepton complementarity

* Corresponding author.
E-mail addresses: florian.plentinger@physik.uni-wuerzburg.de (F. Plentinger), seidl@physik.uni-wuerzburg.de (G. Seidl), winter@physik.uni-wuerzburg.de (W. Winter).

0550-3213/$ – see front matter
doi:10.1016/j.nuclphysb.2007.09.016

1. Introduction

The Standard Model (SM) of elementary particle physics with three light Majorana neutrinos contains 28 free parameters. Most of them, in total 22, describe the masses and mixings of the fermions (the remaining six parameters are the three SM gauge couplings, the vacuum expectation value and quartic coupling of the Higgs, and the QCD θ parameter). This large number of parameters, especially in the fermion sector, is generally considered as an unsatisfactory feature of the SM and one therefore seeks for models in which the number of parameters can be minimized. One possibility to reduce the number of parameters is to embed the SM into a Grand Unified Theory (GUT).

By putting quarks and leptons into GUT multiplets, the masses and mixing angles in the quark and lepton sectors become related. From this point of view, it is thus reasonable to describe the observed hierarchical pattern of the masses and mixing angles of quarks and charged leptons [1] in terms of powers of a single small expansion parameter ϵ. The expansion parameter ϵ might, for example, represent a low-energy remnant of a flavor symmetry that has been broken at some high scale. In fact, the CKM mixing matrix V_{CKM} [2,3] exhibits quark mixing angles of the orders

$$|V_{us}| \sim \epsilon, \qquad |V_{cb}| \sim \epsilon^2, \qquad |V_{ub}| \sim \epsilon^3, \tag{1}$$

where the quantity ϵ is of the order of the Cabibbo angle $\theta_{\mathrm{C}} \simeq 0.2$. Similarly, for the same value $\epsilon \simeq \theta_{\mathrm{C}}$, the mass ratios of the up-type quarks, down-type quarks, and the charged leptons can be approximated, e.g., by[1]

$$\begin{aligned} &m_u : m_c : m_t = \epsilon^6 : \epsilon^4 : 1, \qquad m_d : m_s : m_b = \epsilon^4 : \epsilon^2 : 1, \\ &m_e : m_\mu : m_\tau = \epsilon^4 : \epsilon^2 : 1, \end{aligned} \tag{2}$$

where $m_b/m_t \sim \epsilon^2$, $m_\tau/m_b \sim 1$, and $m_t \simeq 175$ GeV. While the CKM angles and charged fermion masses are thus strongly hierarchical, there are striking differences in the neutrino sector. In the past few years, solar [4,5], atmospheric [6], reactor [7,8], and accelerator [9] neutrino oscillation experiments have established with increasing precision that among the leptonic mixing angles only the reactor angle θ_{13} is small whereas the solar angle θ_{12} and the atmospheric angle θ_{23} are both large. Moreover, neutrino oscillation data tells us that the neutrinos have only a mild hierarchy. To be specific, expressing the neutrino mass ratios as in Eq. (2) in terms of powers of ϵ, the neutrino mass spectrum can, e.g., be written as

$$m_1 : m_2 : m_3 = \epsilon^2 : \epsilon : 1, \qquad m_1 : m_2 : m_3 = 1 : 1 : \epsilon, \qquad m_1 : m_2 : m_3 = 1 : 1 : 1, \tag{3}$$

where m_1, m_2, and m_3 denote the 1st, 2nd, and 3rd neutrino mass eigenvalue. In Eq. (3), the first equation corresponds to a normal hierarchical, the second to an inverted hierarchical, and the third to a degenerate neutrino mass spectrum.[2] In addition, we know from cosmological observations that the absolute neutrino mass scale is of the order $\sim 10^{-2} \ldots 10^{-1}$ eV [10]. An attractive origin of the smallness of neutrino masses is provided by the seesaw mechanism [11,12]. For a summary of current values and errors for the neutrino oscillation parameters from a global analysis, see Table 1.

[1] We take here a fit compatible with an $SU(5)$ GUT.

[2] More precisely, we have in Eq. (3) for the inverse hierarchical case $m_2 > m_1$ and $(m_2 - m_1)/m_2 \sim \epsilon^2$.