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Electron electric dipole moment in mirror fermion model with electroweak scale non-sterile right-handed neutrinos

Chia-Feng Chang [a], P.Q. Hung [b,c], Chrisna Setyo Nugroho [d], Van Que Tran [d], Tzu-Chiang Yuan [e,f,*]

[a] Department of Physics, National Taiwan University, Taipei 116, Taiwan
[b] Department of Physics, University of Virginia, Charlottesville, VA 22904-4714, USA
[c] Center for Theoretical and Computational Physics, Hue University College of Education, Hue, Viet Nam
[d] Department of Physics, National Taiwan Normal University, Taipei 116, Taiwan
[e] Institute of Physics, Academia Sinica, Nangang, Taipei 11529, Taiwan
[f] Physics Division, National Center for Theoretical Sciences, Hsinchu, Taiwan

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Abstract

The electric dipole moment of the electron is studied in detail in an extended mirror fermion model with the following unique features of (a) right-handed neutrinos are non-sterile and have masses at the electroweak scale, and (b) a horizontal symmetry of the tetrahedral group is used in the lepton and scalar sectors. We study the constraint on the parameter space of the model imposed by the latest ACME experimental limit on electron electric dipole moment. Other low energy experimental observables such as the anomalous magnetic dipole moment of the muon, charged lepton flavor violating processes like muon decays into electron plus photon and muon-to-electron conversion in titanium, gold and lead are also considered in our analysis for comparison. In addition to the well-known CP violating Dirac and Majorana phases in the neutrino mixing matrix, the dependence of additional phases of the new Yukawa couplings in the model is studied in detail for all these low energy observables.

* Corresponding author.
E-mail addresses: a29788685@gmail.com (C.-F. Chang), pqh@virginia.edu (P.Q. Hung), setyo13nugros@gmail.com (C.S. Nugroho), apc.tranque@gmail.com (V.Q. Tran), tcyuan@phys.sinica.edu.tw (T.-C. Yuan).

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1. Introduction

The particle spectrum of the Standard Model (SM) has now been completed by the discovery of the 125 GeV Higgs boson at the Large Hadron Collider (LHC). Nevertheless, many questions remained unanswered within the SM. On the conceptual side, we do not understand the instability of the Higgs boson mass under quantum corrections, indicating that SM is very sensitive to new physics beyond the TeV scale; while on the phenomenological side, we have issues like the Baryon Asymmetry of the Universe (BAU), dark matter, and neutrino masses etc. The current popular view is that SM is just a low energy effective theory of a better one at a higher scale with new physics that can address some or all of the above issues. Indeed many beautiful ideas had been suggested in the literature to solve some of these issues. Current LHC constraint is already quite stringent on the scale of new physics $\Lambda_{\rm NP} \sim$ a half to a few TeV, should the new physics be supersymmetry or extra dimension or sequential fourth generation, or technicolor etc. While one should continue the direct searches for new particles at the LHC, looking for new physics indirectly from low energy observables where new particles only exist virtually at the loop level is an important alternative avenue. Historically one can recall that the charm quark was predicted long before its discovery by the GIM mechanism [1], which was engaged to suppress flavor changing neutral currents in the box diagrams of the $K\overline{K}$ kaon system.

The electric dipole moment (EDM) of an elementary particle is one such low energy observable which is sensitive to new CP violating phases from new physics. As is well known the CP violation phase in the Cabibbo–Kobayashi–Maskawa (CKM) quark mixing matrix is too minuscule to account for the BAU, characterized by the ratio of the net baryon number density to the entropy density in the Universe [2],

$$Y_B \equiv n_B/s = (8.61 \pm 0.09) \times 10^{-11} \, .$$

Moreover, the SM contribution to the electron EDM from the CKM CP violation phase must arise at least at the four-loop level [3–6]. The reasons are as follows: Due to the structure of the particle exchange symmetry in the loop integrals of the various diagrams, the W boson EDM vanishes to two-loop order in SM model, but it can be non-vanishing with one more gluon-dressed loop. By attaching the two external W boson lines of the three-loop diagrams to the electron one can generate the electron EDM in SM. Thus the resulting electron EDM (d_e) in SM is a four-loop result, estimated to be $\sim 8 \times 10^{-41} e \cdot {\rm cm}$ [6], which is twelve orders of magnitude below the current experimental limit (see below). Therefore a positive measurement of the electron EDM at the current sensitivities of various experiments or their projected improvements in the near future would definitely imply new sources of CP violation. New CP violating phases might then be helpful to solve the BAU puzzle.

The latest measurement of the electron EDM was done by the ACME Collaboration [7] using the polar molecule thorium monoxide (ThO) just a few years back,

$$d_e = (-2.1 \pm 3.7_{\rm stat} \pm 2.5_{\rm syst}) \times 10^{-29} \, e \cdot {\rm cm} \, . \tag{1}$$

This corresponds to a 90% confidence limit,