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Flavour symmetries in a renormalizable $SO(10)$ model

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Abstract

In the context of a renormalizable supersymmetric $SO(10)$ Grand Unified Theory, we consider the fermion mass matrices generated by the Yukawa couplings to a $\mathbf{10} \oplus \mathbf{120} \oplus \overline{\mathbf{126}}$ representation of scalars. We perform a complete investigation of the possibilities of imposing flavour symmetries in this scenario; the purpose is to reduce the number of Yukawa coupling constants in order to identify potentially predictive models. We have found that there are only 14 inequivalent cases of Yukawa coupling matrices, out of which 13 cases are generated by $\mathbb{Z}_n$ symmetries, with suitable n, and one case is generated by a $\mathbb{Z}_2 \times \mathbb{Z}_2$ symmetry. A numerical analysis of the 14 cases reveals that only two of them—dubbed A and B in the present paper—allow good fits to the experimentally known fermion masses and mixings.

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1. Introduction

$SO(10)$ is a popular gauge group for the construction of Grand Unified Theories (GUTs). The reason is that its 16-plet accommodates at once all the chiral fields of one fermion family. Now [1,2],

$$(\mathbf{16} \otimes \mathbf{16})_{\mathrm{S}} = \mathbf{10} \oplus \mathbf{126}, \tag{1a}$$

$$(\mathbf{16} \otimes \mathbf{16})_{\mathrm{AS}} = \mathbf{120}, \tag{1b}$$

where the subscripts "S" and "AS" stand for, respectively, the symmetric and the antisymmetric parts of the tensor product. Therefore, in a renormalizable theory the scalars occurring in the Yukawa couplings belong solely to the irreducible representations (irreps) **10**, $\overline{\mathbf{126}}$, and **120**.[1] Previously, in the so-called "minimal supersymmetric $SO(10)$ GUT" (for an incomplete list of references see Refs. [3–5]) the **120** was absent. However, inconsistencies in the fit of the experimental masses and mixings of the fermions—in particular, a tension between the seesaw and GUT scales [6]—led to the inclusion of the 120-plet; the resulting theory has been called [7] the "new minimal supersymmetric $SO(10)$ GUT" (NMSGUT)—see Ref. [8] and the references therein.[2]

It has turned out that the NMSGUT, which contains three 16-plets of fermionic fields and one multiplet of scalars for each of the irreps in the right-hand sides of equations (1), is quite a successful theory and is capable of accommodating all the available data on the fermion masses and mixings, including the recent neutrino oscillation data [11,12]; this has been demonstrated by numerical fits [13].[3] However, adding a 120-plet to the 10-plet and the 126-plet of scalars leads to a proliferation of parameters in the Yukawa couplings; one might want to restrict the number of parameters in order to obtain potentially predictive scenarios. Attempts in this direction have been made: in Ref. [15], texture zeros were placed in the mass matrices; in Ref. [16], a $\mathbb{Z}_2$ flavour symmetry has been imposed together with a *CP* symmetry; in Ref. [17], real Yukawa couplings were assumed and *CP* was broken solely by the imaginary vacuum expectation values (VEVs) of the **120**.

In the present paper we pursue the approach of Ref. [16] by investigating all the possible flavour symmetries acting on the Yukawa couplings in the NMSGUT. We firstly perform a complete discussion by using only minimal assumptions; we thereby identify all the possible cases and their symmetry groups. Thereafter, all the cases are subjected to a numerical analysis in order to identify the viable ones. Partially anticipating our results, no non-Abelian flavour symmetry groups are permitted and there are 14 inequivalent cases, out of which 13 pertain to one-generator Abelian groups and only one case has a two-generator symmetry group $\mathbb{Z}_2 \times \mathbb{Z}_2$. However, the numerical analysis rules out almost all the cases, leaving only two viable ones which are compatible with the data on the fermion masses and mixings.

In section 2 we fix the notation, display the basic formulas needed for our investigation, and set forth our assumptions. In section 3 we list all the 14 cases. The results of the numerical analysis are presented in section 4. The conclusions of our work are given in section 5. The analysis of two specific problems that arise in family symmetry-furnished GUTs is deferred to Appendix A. The

[1] The representations **10** and **120** are self-conjugate.

[2] A completely different approach is $SO(10)$ GUT models in extra dimensions—see for instance Ref. [9] and the references therein—or with a hidden sector [10].

[3] Note that skipping the $\overline{\mathbf{126}}$ of scalars does not allow for a good fit of even the charged-fermion sector alone [14].