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# Recent developments in nonsupersymmetric $SO(10)$ unification

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**Summary.** — I review the recent efforts in the search for a minimal and predictive nonsupersymmetric $SO(10)$ theory. The outcome is the revival of a minimal scenario in which an old result, claiming the incompatibility between unification constraints and symmetry-breaking dynamics, is now confuted by the implementation of the one-loop effective potential.

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## 1. – The vacuum of the minimal nonsupersymmetric $SO(10)$ GUT

During the last twenty years the high-energy community focussed mainly on the supersymmetric version of $SO(10)$, due to the success of weak scale supersymmetry in predicting gauge unification. However, supersymmetry might be broken at scales much higher than the TeV and one should consider seriously also the ordinary version of $SO(10)$, which predicts the existence of intermediate scales in the ideal range for the generation of neutrino masses [1-4]. The discussion of fermion masses and mixings, in the context of ordinary $SO(10)$, has been recently reconsidered in [3].

Devising a realistic and simple enough $SO(10)$ Grand Unified Theory (GUT) is a rather non-trivial task. The main reason has to do with the structure of the minimal Higgs sector of nonsupersymmetric $SO(10)$ models. A full breaking of the GUT symmetry down to the Standard Model (SM) can be achieved via a pair of Higgs multiplets: an adjoint, $45_H$, and a spinor, $16_H$. A SM preserving breaking pattern is controlled by two $45_H$ vacuum expectation values (VEVs) and one $16_H$ VEV. Different configurations of the two adjoint VEVs preserve different $SO(10)$ subalgebras, namely, $4_C\, 2_L\, 1_R$ (short-hand notation for $SU(4)_C \otimes SU(2)_L \otimes U(1)_R$), $3_c\, 2_L\, 2_R\, 1_{B-L}$, $3_c\, 2_L\, 1_R\, 1_{B-L}$, and the flipped

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or standard $SU(5) \otimes U(1)$. Except for the last case, the subsequent breaking to the SM is obtained via the standard $SU(5)$ conserving $16_H$ VEV.

The phenomenologically favored scenarios allowed by gauge coupling unification correspond minimally to a two-step breaking along one of the following directions [4]:

$$SO(10) \xrightarrow{M_G} 3_c\, 2_L\, 2_R\, 1_{B-L} \xrightarrow{M_I} \text{SM}, \qquad SO(10) \xrightarrow{M_G} 4_C\, 2_L\, 1_R \xrightarrow{M_I} \text{SM}, \tag{1}$$

where the first breaking stage is driven by the $45_H$ VEVs, while the breaking to the SM at the intermediate scale $M_I$, several orders of magnitude below the unification scale $M_G$, is controlled by the $16_H$ VEV.

Gauge unification, even without proton decay limits, excludes any intermediate $SU(5)$-symmetric stages. On the other hand, a series of studies in the early 1980's of the $45_H \oplus 16_H$ model [5-8] indicated that the only intermediate stages allowed by the scalar sector dynamics were the flipped $SU(5) \otimes U(1)$ for leading $45_H$ VEVs or the standard $SU(5)$ GUT for dominant $16_H$ VEV. This observation excluded the simplest $SO(10)$ Higgs sector from realistic consideration.

In [9] we show that the exclusion of the breaking patterns in eq. (1) is an artifact of the tree level potential. As a matter of fact, some entries of the scalar Hessian are accidentally over-constrained at the tree level. A number of scalar interactions that, by a simple inspection of the relevant global symmetries and their explicit breaking, are expected to contribute to these critical states, are not effective at the tree level.

On the other hand, once quantum corrections are taken into account, contributions of $O(M_G^2/16\pi^2)$ induced on these entries open in a natural way all group-theoretically allowed vacuum configurations. Remarkably enough, the study of the one-loop effective potential can be consistently carried out just for the critical tree level Hessian entries. For all other states in the scalar spectrum, quantum corrections remain perturbations of the tree level results and do not affect the discussion of the vacuum pattern.

Our conclusions apply to any Higgs setting where the first step of the $SO(10)$ gauge symmetry breaking is driven by the $45_H$ VEVs, while the other Higgs representations control the intermediate and weak scale stages.

The results presented in ref. [9] open the option of reconsidering the minimal nonsupersymmetric $SO(10)$ model as a reference framework for unified model building. Extending the Higgs sector to include one $10_H$ (together with either one $16_H$ or one $126_H$) provides the playground for exploring the possibility of a realistic and predictive GUT, along the lines of the recent efforts in the supersymmetric context.

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