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Origins of inert Higgs doublets

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Abstract

We consider beyond the standard model embedding of inert Higgs doublet fields. We argue that inert Higgs doublets can arise naturally in grand unified theories where the necessary associated Z_2 symmetry can occur automatically. Several examples are discussed.

1. Introduction

With the discovery [1,2] of a Higgs-like boson at about 125 GeV at the Large Hadron Collider (LHC), the standard model (SM) of particle physics comes close to its completion in terms of particle spectrum. While many of the detailed Higgs properties, uncannily dictated by spontaneously symmetry breaking, still need to be pinned down at the LHC or perhaps by the International Linear Collider (ILC) from Higgs precision measurements, there are existing phenomena indicating that we must extend the SM. Among these are the neutrino masses, dark matter (DM), and baryo-leptogenesis which might be related to TeV scale physics. On the other hand, not a single clue for new physics signal has been found in existing LHC data.

Extensions of the scalar sector beyond the lone doublet in SM is quite common in the literature for various reasons. Perhaps the most studied are the two Higgs doublet models (2HDM) [3] since a second doublet is required in the popular minimal supersymmetric standard model (MSSM)

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[4], where, with a discrete symmetry imposed upon it, a scalar field component can play the role of dark matter in the inert Higgs doublet model [5,6]. Since the 125 GeV boson behaves very much like the SM Higgs, this indicates that the SM doublet is likely to play the dominant role in spontaneous electroweak symmetry breaking. In other words, if there are other Higgs multiplets present in the extended scalar sector at the TeV scale, their vacuum expectation values (VEVs) must be minuscule or even vanish. Thus an inert Higgs doublet model (IHDM), in which the second doublet has neither a VEV nor couplings with the quarks or leptons, may be a very realistic extension of the scalar sector of the SM. With the upgrade of the LHC coming this year, more data will be accumulated that could easily reveal this exciting possibility, or put stringent constraints on this simple extension. For detailed studies of phenomenological constraints on IHDM, see for example Refs. [7,8]. Here we study the rationale for the presence of an inert Higgs doublet at low energy.

The paper is organized as follows. In section 2, we discuss in general how an inert Higgs doublet can be embedded in grand unified theories (GUTs). In section 3, we classify all the inert Higgs doublet possibilities for low lying irreducible representations (irreps) of frequently studied GUT gauge groups. This is done by constructing concrete examples using $SU(5)$, $SO(10)$ and E_6 as our GUT gauge groups. In section 4, we discuss some explicit models. In section 5, some phenomenological implications are discussed.

2. Embedding the inert Higgs doublet in a GUT

It is interesting to explore how inert Higgs models are embedded in more fundamental theories. Let us consider grand unification theories and show that inert Higgses and their concomitant Z_2 symmetry can arise naturally. We note that there are other means for an inert Higgs doublet to be embedded in a higher theory, for example in a composite dark sector [9] or in a scale invariance extension of IHDM [10], but we will not discuss these possibilities here.

Before we begin, let us first be precise in our definition of what constitutes an inert Higgs model, and in our definition of natural inert Higgs models that can be embedded in a GUT theory.

Standard inert Higgs models are extensions of the SM with an extra scalar doublet, Φ, and the following properties:

(i) There is a Z_2 symmetry where Φ is odd and all SM fields are even.
(ii) The Z_2 insures that Φ does not couple to SM fermions.
(iii) The lightest component of Φ is a possible dark matter candidate.

A natural inert Higgs model embedded in GUTs extends a GUT theory with an extra scalar irrep, R_H, which contains an extra scalar doublet, Φ_n, (the need for the n subscript will become clear shortly) and has the following properties:

(i) There is an "automatic" (accidental) Z_2 symmetry where R_H is odd and all GUT fields are even.
(ii) The Z_2 insures that Φ_n does not couple to SM fermions at dimension 4 and possibly higher.
(iii) The lightest component of Φ_n is a possible dark matter candidate.