Frustrated symmetries in Multi-Higgs-doublet models

Venus Ebrahimi

IFPA, University of Liège
In colaboration with Igor Ivanov
Based on the paper arXiv:1007.5305

PhD Student's day, 23/09/2010

1. Standard Model
2. Higgs Mechanism
3. NHDM and properties
4. Examples in 3HDM
5. Conclusions

Standard Model

- A gauge theory of Electroweak interactions

- Very well consistant with experiment

- Though there are aspects that SM doesn't explain $\Rightarrow$ BSM

- The last key ingredient of SM, the Higgs boson(s) is not discovered yet.

- There is a freedom in theorizing BSM models

Higgs Mechanism

It explains how gauge bosons acquire their masses by coupling to the Higgs field:

Consider the lagrangian:
$L = \frac{-1}{4} F_{\mu\nu} F^{\mu\nu} + |D_\mu \phi|^2 - V(\phi)$
Where:
$V(\phi) = \mu^2 |\phi|^2 + \lambda (|\phi|^2)^2$, $D_\mu = \partial_\mu - ieA_\mu$
which is gauge invariant

Though minimizing the potential shows that there is a non-zero vacuum expectation value, and the symmetry is broken: Spontaneous symmetry breaking
$\mu^2 > 0$ v.e.v is zero and symmetry is explicit
$\mu^2 < 0$ v.e.v is non-zero and the symmetry is broken

Higgs doublets

Since we have some freedom in theorizing a model, we start with minimal extension of the SM: 2HDM

Two Higgs doublets: $\phi_a = \begin{pmatrix} \phi_a^+ \\ \phi_a^0 \end{pmatrix}$, $\phi_b = \begin{pmatrix} \phi_b^+ \\ \phi_b^0 \end{pmatrix}$

The general potential, a gauge-invariant combinations of ϕ_1 and ϕ_2 would have 14 free parameters.

At this level special symmetries can still be imposed and it is possible to minimize the potential and solve the problem analitycaly

Minimizing the potential gives: $\phi_1 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_1 \end{pmatrix}$, $\phi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} u \\ v_2 e^{i\varepsilon} \end{pmatrix}$

$u = 0$: neutral vacuum , $u \neq 0$: charge breaking vacuum

Introducing the orbit space $r^{\mu} : (r^0, r^i)$ would make it easier to see these symmetries, specially in multi-doublet-Higgs models.

$r^0 = \phi_a^{\dagger}\phi_a$, $r^i = \phi_a^{\dagger}\sigma^i_{ab}\phi_b$, $i = 1, 2, 3$

σ^i are Pauli matrices

The potential could be written as $V = -M_{\mu} r^{\mu} + \frac{1}{2}\Lambda_{\mu\nu} r^{\mu} r^{\nu}$

NHDM

- In NHDM we introduce N Higgs doublets ϕ_a, a=1,...,N.
- The general potential would be a gauge-invariant combination of $\phi_a^\dagger \phi_b$'s.
- The number of free parameters would be $\frac{N^2(N^2+3)}{2}$
- There is no hope to explicitly study and minimize the potential, and in particular to find the possible symmetries in such a model. However, we have found certain symmetries that are always broken aftre the EWSB.

The orbit space would be represented as:

$$r_0 = \sqrt{\frac{N-1}{2N}} \sum_a \phi_a^\dagger \phi_a$$

$$r_i = \sum_{a,b} \phi_a^\dagger \lambda_{a,b}^i \phi_b$$

where λ_i are generators of $SU(N)$.
The potential has the same form as before:
$V = -M_\mu r^\mu + \frac{1}{2}\Lambda_{\mu\nu} r^\mu r^\nu$
but the goemetry of orbit space is more complicated.

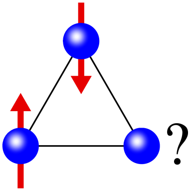
We can devise such symmetries where the only point that could conserve the symmetry would be:
$\vec{r} = 0, r_0 \neq 0$

Such point is not physically realizable in the case of $N > 2$

Therefore such symmetries are always broken aftre EWSB in NHDM with $N > 2$

Having $\vec{r} = 0$, $r_0 \neq 0$ means that all products $(\phi_i^\dagger \phi_j)$ should be zero while keeping $(|\phi_i|)^2$ non-zero and equal.
This not possible to achive with more than two doublets:
$$\begin{pmatrix} 0 \\ u \end{pmatrix}, \begin{pmatrix} u \\ 0 \end{pmatrix}, \begin{pmatrix} ? \\ ? \end{pmatrix}$$

The situation is similar to the case of geometrical frustration in Condensed matter where:



We have found two such symmetries in three-Higgs-doublet models:

Tetrahedral symmetry in 3HDM:

$$V = -M_0 r_0 + \Lambda_0 r_0^2 + \Lambda_1 (r_1^2 + r_4^2 + r_6^2) + \Lambda_2 (r_2^2 + r_5^2 + r_7^2) + \Lambda_3 (r_3^2 + r_8^2) + \Lambda_4 (r_1 r_2 - r_4 r_5 + r_6 r_7)$$

Octahedral symmetry in 3HDM:

$$V = -M_0 r_0 + \Lambda_0 r_0^2 + \Lambda_1 (r_1^2 + r_4^2 + r_6^2) + \Lambda_2 (r_2^2 + r_5^2 + r_7^2) + \Lambda_3 (r_3^2 + r_8^2)$$

The properties of these models are being studied.

Conclusions

• In 2HDM any symmetry imposed on the potential can be conserved in the vacuum state
• Whereas in NHDM there are certain symmetries that aren't conserved in the vacuum state
• We call such symmetries "Frustrated symmetries", because of their symmilarity to "Geometrical frustration" in Condensed matter physics.