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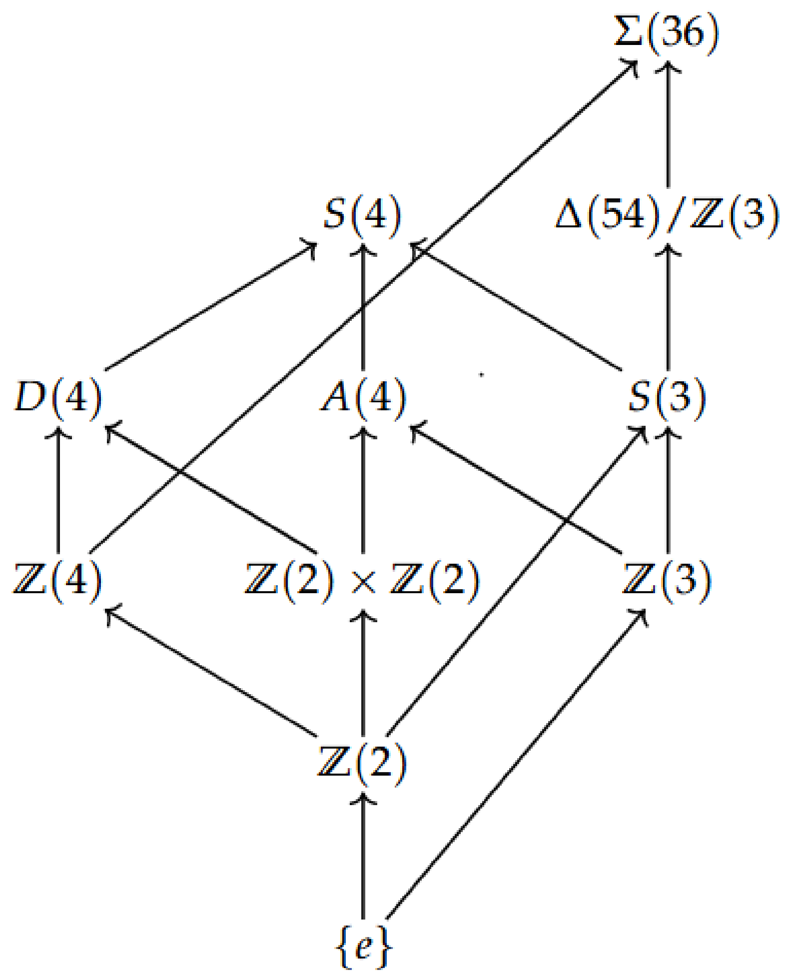
Multi-Higgs Doublet Models and Symmetries

CONTENTS

I Symmetries

Symmetries play a fundamental role in physics, serving as essential tools across all areas of the field. The mathematical framework used to understand symmetries is group theory. A group is a set equipped with a group operation that satisfies the following properties:

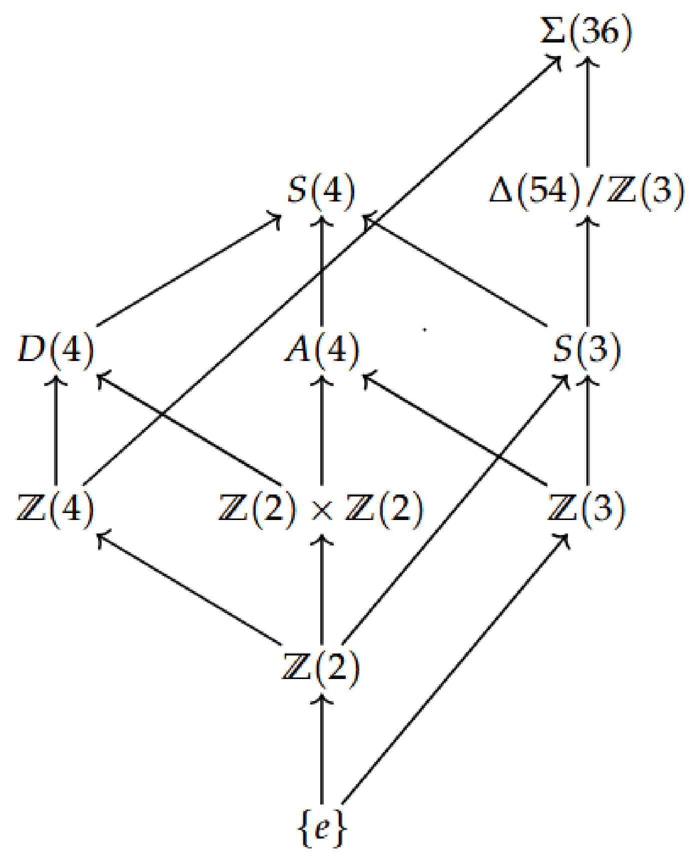
- Closure;
- Associativity;
- Identity;
- Inverse;



$\Sigma(36)$

The largest discrete symmetry group which can be imposed on the scalar sector of the 3HDM is the $\Sigma(36)$.

Where $w = e^{i2\pi/3}$. It is straightforward to verify that $a^3 = b^3 = d^4 = 1$



$$\Sigma(36) \simeq (Z(3) \times Z(3)) \rtimes Z(4)$$

$$a = \begin{pmatrix} 1 & 0 & 0 \\ 0 & w & 0 \\ 0 & 0 & w^2 \end{pmatrix} \qquad b = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix} \qquad d = \frac{i}{\sqrt{3}} \begin{pmatrix} 1 & 1 & 1 \\ 1 & w^2 & w \\ 1 & w & w^2 \end{pmatrix}$$

II Minimization of the Potential

$\Sigma(36)$ Potential

$$\begin{aligned}
V_0 = &- m^2(\phi_1^\dagger\phi_1 + \phi_2^\dagger\phi_2 + \phi_3^\dagger\phi_3) + \lambda_1(\phi_1^\dagger\phi_1 + \phi_2^\dagger\phi_2 + \phi_3^\dagger\phi_3)^2 \\
&- \lambda_2(|\phi_1^\dagger\phi_2|^2 + |\phi_2^\dagger\phi_3|^2 + |\phi_3^\dagger\phi_1|^2 - (\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) - (\phi_2^\dagger\phi_2)(\phi_3^\dagger\phi_3) - (\phi_3^\dagger\phi_3)(\phi_1^\dagger\phi_1)) \\
&+ \lambda_3(|\phi_1^\dagger\phi_2 - \phi_2^\dagger\phi_3|^2 + |\phi_2^\dagger\phi_3 - \phi_3^\dagger\phi_1|^2 + |\phi_3^\dagger\phi_1 - \phi_1^\dagger\phi_2|^2)
\end{aligned}$$

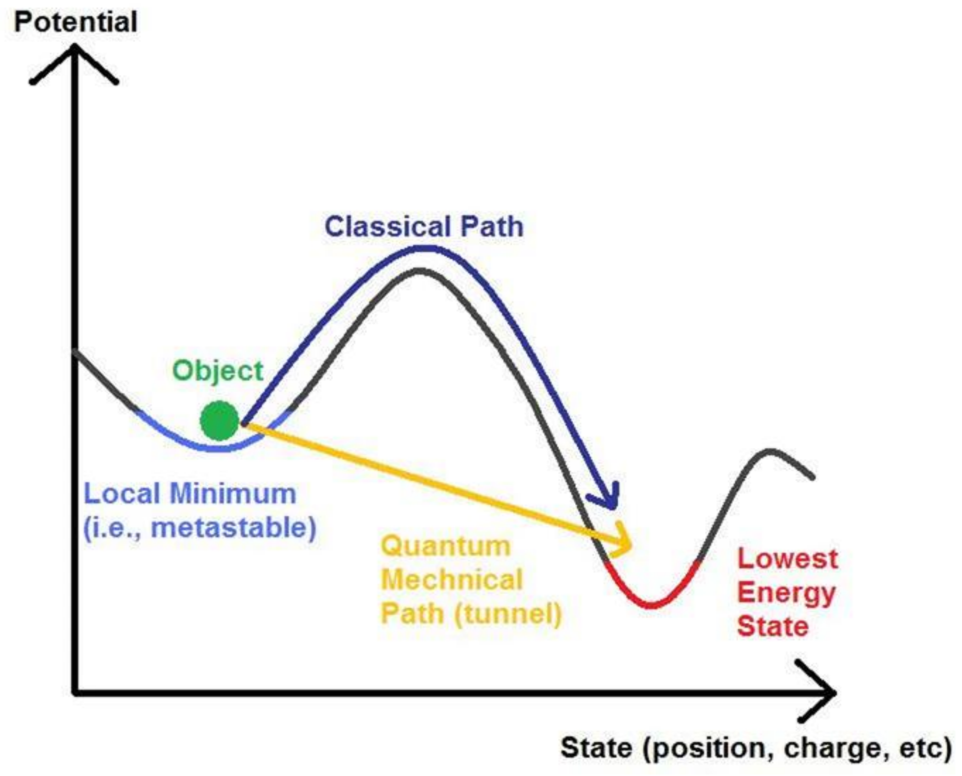
For a 3HDM with a finite symmetry group, the primary method used is geometric minimization. This process was explicitly calculated for the $\Sigma(36)$ potential, leading to the following VEV alignments

$$\begin{aligned}
A &= (w,1,1), (1,w,1), (1,1,w) \\
A' &= (w^2,1,1), (1,w^2,1), (1,1,w^2) \\
B &= (1,0,0), (0,1,0), (0,0,1) \\
C &= (1,1,1), (1,w,w^2), (1,w^2,w)
\end{aligned}$$

III Soft Symmetry Breaking

Adding soft breaking parameters introduces additional flexibility to the model. Soft breaking parameters are quadratic terms that are not invariant under all group actions. When these parameters are activated, they can either preserve or disrupt the alignment of a specific VEV.

This can lead to the formation of unstable domain walls. Through quantum tunneling, these unstable domain walls may generate gravitational waves.



IV Objectives

The objective of this project are:

- Select a specific VEV;
- Activate one of the soft-breaking parameters that does not preserve the VEV alignment;
- Develop a method to minimize the potential;
- Calculate the mass matrix of the Higgs sector;
- Determine the masses of the physical scalars;
- Check the possible decays into non-standard Higgs particles;

This project also aims to provide an introduction to research in particle physic.

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Thank you