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Flipped $SU(5)$ from $\mathbf{Z}_{12-\mathrm{I}}$ orbifold with Wilson line

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Abstract

We construct a three family flipped $SU(5)$ model from the heterotic string theory compactified on the $\mathbf{Z}_{12-\mathrm{I}}$ orbifold with one Wilson line. The gauge group is $SU(5) \times U(1)_X \times U(1)^3 \times [SU(2) \times SO(10) \times U(1)^2]'$. This model does not derive any non-Abelian group except $SU(5)$ from E_8, which is possible only for two cases in case of one shift V, one in $\mathbf{Z}_{12-\mathrm{I}}$ and the other in $\mathbf{Z}_{12-\mathrm{II}}$. We present all possible Yukawa couplings. We place the third quark family in the twisted sectors and two light quark families in the untwisted sector. From the Yukawa couplings, the model provides the R-parity, the doublet–triplet splitting, and one pair of Higgs doublets. It is also shown that quark and lepton mixings are possible. So far we have not encountered a serious phenomenological problem. There exist vector-like flavor $SU(5)$ exotics (including $Q_{\mathrm{em}} = \pm\frac{1}{6}$ color exotics and $Q_{\mathrm{em}} = \pm\frac{1}{2}$ electromagnetic exotics) and $SU(5)$ vector-like singlet exotics with $Q_{\mathrm{em}} = \pm\frac{1}{2}$ which can be removed near the GUT scale. In this model, $\sin^2\theta_W^0 = \frac{3}{8}$ at the full unification scale.

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Keywords: Orbifold; Three families; Yukawa couplings; Flipped $SU(5)$

1. Introduction

At present, it is of utmost importance to connect the high energy string theory with the low energy standard model, in particular with the minimal supersymmetric standard model (MSSM).

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The initial attempt of the Calabi–Yau space compactification, which is geometrical, has been very attractive [1]. But the orbifold compactification, also being a geometrical device, got more interest due to its simplicity in model buildings [2,3]. Initially, the standard-like models were looked for [4], in an attempt to obtain minimal supersymmetric standard models (MSSMs), but it became clear that the standard-like models have a serious problem on $\sin^2\theta_W$ to arrive at MSSMs [5]. All $\mathbf{Z}_N$ models without Wilson lines were tabulated a long time ago [6] and recently all $\mathbf{Z}_3$ models with Wilson lines are tabulated in a book [7].

The $\sin^2\theta_W$ problem is that it is better for the bare value of $\sin^2\theta_W^0$ at the unification or string scale to be close to $\frac{3}{8}$ [5] so that it reproduces the fact of the convergence of three gauge couplings at one point near the unification scale [8]. The so-called flipped $SU(5)$ does not fulfill this requirement automatically due to the leakage of $U(1)_Y$ beyond $SU(5)$.[1] Thus, the $\sin^2\theta_W$ problem directs toward grand unified theories (GUTs) from superstring without the electroweak hypercharge Y leaking outside the GUT group. In this regard, one may consider simple GUT groups $SU(5)$ [12], $SO(10)$ [13], E_6 [14] and trinification $SU(3)^3$ [15]. The simplest orbifold without matter representations beyond the fundamentals require the Kac–Moody level $K = 1$. With $K = 1$, one cannot obtain adjoint representations [7]; thus among the above GUT groups the trinification group is the allowed one. Also, the Pati–Salam $SU(4) \times SU(2) \times SU(2)$ [16] can be broken to the standard model without an adjoint matter representation; above the GUT scale however three gauge couplings of the Pati–Salam model diverge rather than evolving in unison. Thus, trinification GUT seems to be the most attractive solution regarding the $\sin^2\theta_W$ problem. The trinification is possible only in $\mathbf{Z}_3$ orbifolds [17].

Another interesting GUT group, though not giving $\sin^2\theta_W = \frac{3}{8}$ necessarily, is the flipped $SU(5)$ [9,10] where the exchanges $d^c \leftrightarrow u^c$ and $e^c \leftrightarrow$ (neutral singlet ν^c) in the representations of $SU(5)$ are adopted. The matter representation of the flipped $SU(5)$ is, under $SU(5) \times U(1)_X$,[2]

$$\mathbf{16}_{\text{flip}} \equiv \mathbf{10}_{\mathbf{1}} + \bar{\mathbf{5}}_{-\mathbf{3}} + \mathbf{1}_{\mathbf{5}}. \tag{1}$$

The electroweak hypercharge is given by

$$Y = \tfrac{1}{5}(X + Y_5) \tag{2}$$

where $Y_5 = \mathrm{diag}(\frac{1}{3}\ \frac{1}{3}\ \frac{1}{3}\ -\frac{1}{2}\ -\frac{1}{2})$ and $X = \mathrm{diag}(x\ x\ x\ x\ x)$. Then, the electroweak hypercharges of $\mathbf{1}_{\mathbf{5}}$ and $\bar{\mathbf{5}}_{-\mathbf{3}}$ are $+1$, $-\frac{2}{3}$, and $-\frac{1}{2}$, which are e^c, u^c, and electron doublet. There are some nice features of flipped $SU(5)$ [18].

From the string context, flipped $SU(5)$ was considered before in the fermionic construction scheme [11] and recently in orbifold construction also [19], Calabi–Yau compactification [20], and intersecting D-brane models [21]. Let us call flipped $SU(5)$ from string construction 'string flipped' $SU(5)$. In string flipped $SU(5)$, it does not necessarily predict $\sin^2\theta_W = \frac{3}{8}$ at the unification scale [5]. However, if we introduce more parameters intrinsic in flipped $SU(5)$, we may fit parameters so that the gauge couplings meet at one point at the string scale M_s, the unification scale of $SU(5)$ and $U(1)_X$ couplings. These parameters include the symmetry breaking scale M_{GUT} for $SU(5) \times U(1)_X \to$ SM breaking and *intermediate scales of vector-like representations*. Above M_{GUT} the RG evolutions of $SU(5)$ and $U(1)_X$ couplings are different, and we do not expect a string scale around 0.7×10^{18} GeV [22] but can be determined by the unification

[1] The terminology flipped $SU(5)$ was used as an $SU(5) \times U(1)_X$ subgroup of $SO(10)$ [9–11]. In this paper, we still use the same terminology if there appear **16**s having the same quantum numbers as in the flipped $SU(5)$.

[2] The quantum number X of $U(1)_X$ in the flipped $SU(5)$ is highlighted.