Search for Realistic Orbifold Models*

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We have studied Z_N (N=3,4,6,7,8,12) orbifold models realized by only shift embeddings (without Wilson lines) in order to get realistic models. We have systematically classified that which gauge groups and matter contents are realized by these models[1] . A important result is that these models cannot produce $SU_3 \times SU_2 \times U_1^n$ gauge groups but can produce GUT groups. From this result we can choose two ways as follows.

1.Flipped SU_5 in Z_{12} orbifold.

Many models have GUT gauge groups, SU_5, SO_{10} and E_8. Z_N orbifold models (and other constructions) have no adjoint higgses which break GUT gauge groups to $SU_3 \times SU_2 \times U_1$ at GUT scale. This lead to the flipped GUT models. We concentrate on the most promising one, flipped SU_5[2] . We would like to get the same superpotential as flipped SU_5 so that we can use the phenomenological scheme of that approach. $SU_5 \times U_1^n$ gauge group is a charactaristic feature contained in Z_{12} obifold. There are only three candidates for three generation models in this approach, which are realized by the shifts

$$\begin{aligned} 12V &= (4,3,3,3,3,3,2,-1;4,4,4,4,4,4,0,0), \\ 12V &= (5,4,3,3,3,3,-2;4,4,4,4,4,4,0,0), \\ 12V &= (5,4,3,3,3,3,2,-1;4,4,4,4,4,4,4,-4), \end{aligned} \tag{1}$$

where first two are probably equivalent. Matter contents are found in Table 1. Now we want to identify which matters correspond to quarks, leptons and higgses so as to allow the flipped SU_5 superpotential. Even order orbifolds are more complex than

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prime order ones (Z_3,Z_7 orbifold models), since twisted strings are often not on a fixed point but a combination of them. We are seeking a hypercharge assignment which realizes the flipped SU_5 superpotential.

2.Wilson line mechanism.

If we would like to get $SU_3 \times SU_2 \times U_1^n$ gauge group, Wilson line mechanism (or other scheme which breaks the gauge groups further) is nessecally. We can realize $SU_3 \times SU_2 \times U_1^n$ with three generation in Z_7 orbifold by

$$\begin{aligned}
7V &= (2,2,2,0,0,0,0,0;1,1,0,0,0,0,0,0), \\
7A &= (3,2,-1,5,2,1,1,1;4,2,2,0,0,0,0,0),
\end{aligned} \tag{2}$$

where A is a Wilson line. There exists only one freedom of Wilson line which is a characteristic of Z_7 orbifold. The simple roots are given by

$$\begin{aligned}
\alpha_1 &= (0,0,0,1,1,0,0,0;0,0,0,0,0,0,0,0), \\
\alpha_2 &= (0,0,0,0,0,1,-1,0;0,0,0,0,0,0,0,0), \\
\alpha_3 &= (0,0,0,0,0,0,1,-1;0,0,0,0,0,0,0,0), \\
\alpha_4 &= (0,0,0,0,0,0,0,0;0,0,0,1,-1,0,0,0), \\
\alpha_5 &= (0,0,0,0,0,0,0,0;0,0,0,0,1,-1,0,0), \\
\alpha_6 &= (0,0,0,0,0,0,0,0;0,0,0,0,0,1,-1,0), \\
\alpha_7 &= (0,0,0,0,0,0,0,0;0,0,0,0,0,0,1,-1), \\
\alpha_8 &= (0,0,0,0,0,0,0,0;0,0,0,0,0,0,1,1), \\
\alpha_9 &= (0,0,0,0,0,0,0,0;1,-1,-1,-1,-1,-1,-1,1)/2,
\end{aligned} \tag{3}$$

and U_1 basis as

$$\begin{aligned}
Q_1 &= (1,0,0,0,0,0,0,0;0,0,0,0,0,0,0,0), \\
Q_2 &= (0,1,0,0,0,0,0,1,0;0,0,0,0,0,0,0,0), \\
Q_3 &= (0,0,1,0,0,0,0,0;0,0,0,0,0,0,0,0), \\
Q_4 &= (0,0,0,1,-1,0,0,0;0,0,0,0,0,0,0,0),
\end{aligned} \tag{4}$$

$$Q_5 = (0,0,0,0,0,1,1,1;0,0,0,0,0,0,0,0),$$
$$Q_6 = (0,0,0,0,0,0,0,0;1,1,0,0,0,0,0,0),$$
$$Q_7 = (0,0,0,0,0,0,0,0;1,-1,2,0,0,0,0,0).$$

Matter contents of this model is exoressed by

$$3(3,2;1) + 17(3,1;1) + 23(\overline{3},1;1) + 31(1,2;1) + 145(1,1;1) \tag{5}$$

under $(SU_3, SU_2; E_6')$ representation. Anomalous U_1 does not exist in this model. The weak hypercharge is assigned as

$$14Y = 6Q_1 - 6Q_2 + 3Q_4 + 2Q_5 = (6,-6,0,3,-3,2,2,2;0,0,0,0,0,0,0,0) \tag{6}$$

so that the correct hypercharges are assigned for the three (3,2;1), at least six (3,1;1) and so on in eq.(6), as three generations of quarks, leptons and a pair of higgs doublets. If some of singlets acquire vaccum expectation values so as to preserve N=1 supersymmetry, from which one may be able to obtain $SU_3 \times SU_2 \times U_{1Y}$ with fewer extra matters which decouple from hidden sector[3] [4] .

Another $SU_3 \times SU_2 \times U_1^n$ with three generation in Z_7 is realized by choosing

$$7V = (2,2,2,0,0,0,0,0;1,1,0,0,0,0,0,0),$$
$$7A = (3,2,1,2,2,2,1,1;3,-1,2,0,0,0,0,0). \tag{7}$$

We have discussed Z_N orbifold models with and without a Wilson line. We have found $SU_5 \times U_1^n$ and $SU_3 \times SU_2 \times U_1^n$ with three generations in Z_{12} and Z_7 orbifold model, respectivelly. Since our examples are only a part of enoumous possibilities, one can get similar models through the similar procedures.

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Table 1. Three-generation flipped SU_5 models in Z_{12}

Charges with respect to four $U(1)$'s are omitted. Only positive helicity particles are shown explicitly. Negative helicity particles of k-twisted sectors are in $(12-k)$-twisted sectors.

No.	Gauge	Shift	U-Sector	T-Sector						
	Group	$12\ V_J$	$k=0$	$k=1$	$k=2$	$k=3$	$k=4$	$k=6$	$k=7$	$k=9$
1	$(SU_5;$	(4333332-1;				(10;1,1)		2(10;1,1)		(10;1,1)
	$E_6, SU_3)$	44444400)	$2(\overline{10};1,1)$			$+(\overline{10};1,1)$		$+2(\overline{10};1,1)$		$+2(\overline{10};1,1)$
			+5(5;1,1)			+5(5;1,1)		+8(5;1,1)		+4(5;1,1)
			$+2(\overline{5};1,1)$			$+4(\overline{5};1,1)$		$+9(\overline{5};1,1)$		$+4(\overline{5};1,1)$
			+4(1;1,1)			+19(1;1,1)		+39(1;1,1)		+18(1;1,1)
			$+(1;\overline{27},3)$	$6(1;1,\overline{3})$	6(1;1,3)		$21(1;1,\overline{3})$		$6(1;1,\overline{3})$	
2	$(SU_5;$	(5433333-2;	2(10;1,1)			2(10;1,1)		2(10;1,1)		(10;1,1)
	$E_6, SU_3)$	44444400)				$+(\overline{10};1,1)$		$+2(\overline{10};1,1)$		$+(\overline{10};1,1)$
			+2(5;1,1)			+4(5;1,1)		+9(5;1,1)		+4(5;1,1)
			$+5(\overline{5};1,1)$			$+4(\overline{5};1,1)$		$+8(\overline{5};1,1)$		$+5(\overline{5};1,1)$
			+4(1;1,1)			+18(1;1,1)		+39(1;1,1)		+19(1;1,1)
			$+(1;\overline{27},3)$	$6(1;1,\overline{3})$	6(1;1,3)		$21(1;1,\overline{3})$		$6(1;1,\overline{3})$	
3	$(SU_5;$	(5433332-1;	(10;1)			(10;1)		2(10;1)		(10;1)
	$SU_9)$	4444444-4)	$+2(\overline{10};1)$			$+2(\overline{10};1)$		$+2(\overline{10};1)$		$+2(\overline{10};1)$
			+2(5;1)			+4(5;1)		+9(5;1)		+4(5;1)
			$+2(\overline{5};1)$			$+3(\overline{5};1)$		$+8(\overline{5};1)$		$+3(\overline{5};1)$
			+7(1;1)			+20(1;1)		+40(1;1)		+20(1;1)
			+(1;84)	$3(1;\overline{9})$	3(1;9)		$6(1;\overline{9})$		$3(1;\overline{9})$	