High Scales masses for a model that comes from the E_6 Gauge Group.

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Introduction

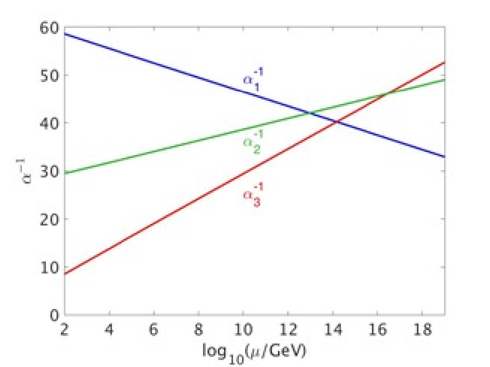
As we know, if we let the three Gauge constants couplings α_i^{-1} run with the energy, from low to high energies scales, they do not converge at the same point, that means, the three $\alpha_1^{-1}, \alpha_2^{-1}, \alpha_3^{-1}$ coupling constants of the standard model (SM), the which correspond to $U(1)_Y$, $SU(2)_L$ and $SU(3)_c$ respectively, they can not be to described as a single group. This result, claims for new physics at intermediate energy scales, or for new approaches to the unification problem.

$SU(5)$ Gauge Group

The Georgi–Glashow (Howard - Sheldon) model is a particular grand unification theory (GUT), it was proposed in 1974.

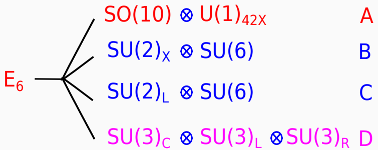
$$SU(5) \rightarrow SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$$

However, in this model the lifetime of the proton is not safe,

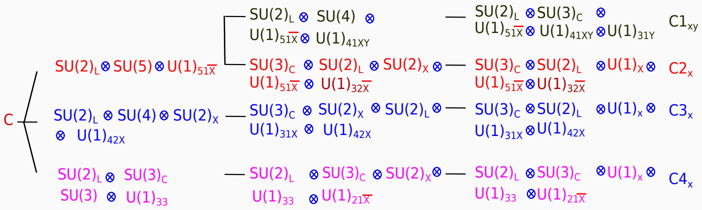


Chains of breaking of E_6 Gauge Group

There are four possible way to break E_6 to SM,



We choose the C way,



See Ref: [1] arXiv:1801.10595 [hep-ph].

One Model that works

$$E_6 \to SU(2)_L \otimes SU(6) \to SU(2)_L \otimes SU(5) \otimes U_{51\bar{l}}$$
$$\to SU(3)_c \otimes SU(2)_L \otimes SU(2)_I \otimes U_{51\bar{l}} \otimes U_{32\bar{l}} \qquad (1)$$
$$\to SU(3)_c \otimes SU(2)_L \otimes U_I \otimes U_{51\bar{l}} \otimes U_{32\bar{l}},$$

See Ref: [1], arXiv:1801.10595 [hep-ph].

As the weak hypercharge is a linear combination of the three $U(1)$ symmetries, we have

$$Y = \sqrt{\frac{5}{3}} Q_y^{E6} = k_c Q_I + k_b Q_{51\bar{l}} + k_a Q_{32\bar{l}}, \qquad (2)$$

where, Q_I, $Q_{51\bar{l}}$ and $Q_{32\bar{l}}$ are the charges to belong to U_I, $U_{51\bar{l}}$, and $U_{32\bar{l}}$, respectively.

For this string we found, $k_c = 0$, $k_b = \sqrt{3/5}$ and $k_a = -4/\sqrt{15}$

$$k_a^2 + k_b^2 + k_c^2 = 16/15 + 3/5 + 0 = 5/3,$$

Fermion Content

We begin from the fundamental representation of E_6, the 27, in this representation is possible to put all particles of the SM in the same multiplet,

$$\left[\bar{d}, q, \bar{u}, l, \bar{\nu}, e^{+}, \bar{L}, \bar{D}, L, S, D\right], \tag{3}$$

$$l = \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}, \quad q = \begin{pmatrix} u \\ d \end{pmatrix}, \quad L = \begin{pmatrix} N \\ E^- \end{pmatrix} \tag{4}$$

$$S = singlet, \quad D = quark.$$

The first step is breaking:

$E_6 \rightarrow SU(2)_L \otimes SU(6)$: that means,

$$27 \rightarrow (2, \bar{6}) \oplus (1, 15),$$

$$(L, \bar{L}, q, l) \rightarrow (2, \bar{6})_L$$

and

$$(\bar{\nu}, S, e^+, \bar{d}, \bar{u}, D, \bar{D}) \to (1, 15)_L,$$

The second step is breaking:

$SU(6) \to SU(5) \otimes U_{51\bar{l}}$:

$$15 \to 5(-4) \oplus 10(2),$$

$$(\bar{\nu}, \bar{u}, S) \to 5(-4)$$

$$(e^+, \bar{d}, D, \bar{D}) \to 10(2).$$

The third one is:

$SU(5) \to SU(3)_c \otimes SU(2)_l \otimes U_{32\bar{l}}$:

$$5 \to (2, 1)(3) \oplus (1, 3)(-2),$$

$$10 \to (1,1)6 \oplus (1,\bar{3})(-4) \oplus (2,3)(1),$$

i.e.,

$$(\bar{\nu}, S) \to (2,1)(3), \quad \bar{u} \to (1,3)(-2)$$

$$(\bar{d}, \bar{D}) \to (2,3)(1), \quad e^+ \to (1,1)(6), \quad D \to (1,\bar{3})(-4).$$

Finally, to the model, $SU(3)_c \otimes SU(2)_L \otimes U_l \otimes U_{51\bar{l}} \otimes U_{32\bar{l}}$, the fermion content is:

$$(L, \bar{L}, q, l) \to (2,6); \quad (\bar{\nu}, S) \to (2,1)(3); \quad (\bar{d}, \bar{D}) \to (2,3)(1);$$

$$\bar{u} \to (1,3)(-2); \quad D \to (1,\bar{3})(-4); \quad e^+ \to (1,1)(6).$$

Energy unification scale and value of α_u^{-1}

According to one-loop Renormalization Group Equations (RGE) [2]

$$\mu\frac{d\alpha_i}{d\mu} = -b_i\alpha_i^2, \tag{5}$$

where, μ is the energy mass scale, and $\alpha_i = g_i^2/4\pi$, $i = 1, 2, 3$ are the running constants couplings,

$$\beta_o^i = \frac{11}{3}C_2(G_i) - \frac{4}{3}T(R_i) - \frac{1}{3}H. \tag{6}$$

where, $\delta_{ab}C_2(G_i) = f^i_{acd}f^i_{bcd}$, $\delta_{ab}T(R_i) = Tr(t^i_a t^i_b)$, [2, 3].

Then

$$\alpha_i^{-1}(Q^2) = \alpha_i^{-1}(\mu^2) + \frac{\beta_0^i}{4\pi}\ln\left(\frac{Q^2}{\mu^2}\right). \tag{7}$$

The breaking scheme is showed in this picture

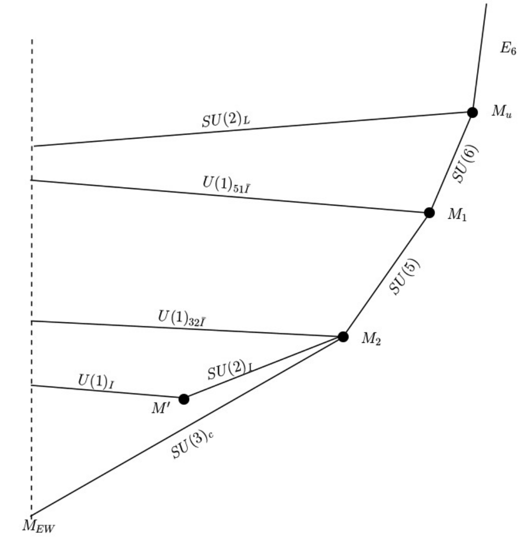


Figure 1: Scheme of breaking to E_6

Without Scalars, H=0

The running couplings constants α^{-1}, for this scheme are:

$$\alpha_{32\bar{1}}^{-1} = \alpha_u^{-1} + 2\left(\frac{1}{\pi}\right)\log\frac{M_2}{M_{ew}} - 2\left(\frac{11(5)-2(6)}{12\pi}\right)\log\frac{M_1}{M_2} - 2\left(\frac{11(6)-2(6)}{12\pi}\right)\log\frac{M_u}{M_1}, \quad (8)$$

$$\alpha_{51\bar{1}}^{-1} = \alpha_u^{-1} + 2\left(\frac{1}{\pi}\right)\log\frac{M_1}{M_{ew}} - 2\left(\frac{11(6)-2(6)}{12\pi}\right)\log\frac{M_u}{M_1}, \quad (9)$$

$$\alpha_2^{-1} = \alpha_u^{-1} - 2\left(\frac{11(2)-2(6)}{12\pi}\right)\log\frac{M_u}{M_{ew}}, \quad (10)$$

$$\alpha_3^{-1} = \alpha_u^{-1} - 2\left(\frac{11(3)-2(6)}{12\pi}\right)\log\frac{M_2}{M_{ew}} - 2\left(\frac{11(5)-2(6)}{12\pi}\right)\log\frac{M_1}{M_2} - 2\left(\frac{11(6)-2(6)}{12\pi}\right)\log\frac{M_u}{M_1}, \quad (11)$$

With convenient combinations between them, we find that

$$M_u = e^{\frac{3\pi}{22}\left(\alpha^{-1}-\frac{8}{3}\alpha_3^{-1}\right)} M_{ew}^{3/2} M_1^{-1/2}. \tag{12}$$

and also,

$$M_1 = e^{\frac{-6\pi}{11}\left(\alpha^{-1}\sin\theta_w-\alpha_3^{-1}\right)} M_u^4 M_2^{-2} M_{ew}^{-1}, \tag{13}$$

We analyzed two options:

1. When $M_1 = M_2$

$$M_u = 2.00967 \times 10^{15} \ \text{GeV}, \tag{14}$$

and

$$M_1 = 3.08814 \times 10^{14} \ \text{GeV}, \tag{15}$$

2. when $M_u = M_1$,

$$M_u = 1.07622 \times 10^{15} \ \text{GeV}, \tag{16}$$

and

$$M_2 = 4.7434 \times 10^{13} \ \text{GeV}. \tag{17}$$

$$\alpha_u^{-1} = 45.77, \tag{18}$$

to the first case, and,

$$\alpha_u^{-1} = 45.44, \tag{19}$$

for the second one.

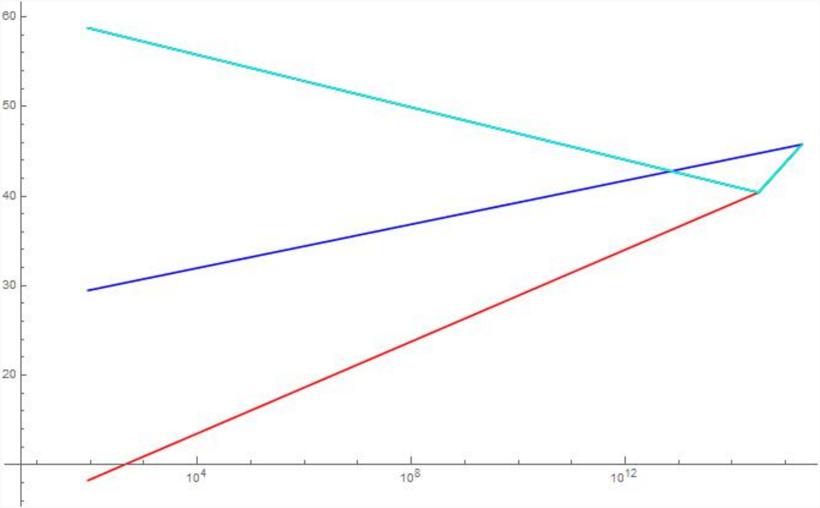


Figure 2: Running couplings $\alpha_i^{-1} = (g_i^2/4\pi)^{-1}$, versus $\ln Q^2/\mu^2$, in one-loop approximation, for $U(1)$, $SU(2)$, and $SU(3)$ respectively.

With scalars fields

In this case,

$$\beta_o^i = \frac{11}{3}C_2(G_i) - \frac{4}{3}T(R_i) - \frac{1}{3}H. \tag{20}$$

using $H = 2$ and making the same steps that before, we find that

$$M_u = 3.97 \times 10^{16} GeV$$

$$M_1 = M_2 = 1.65 \times 10^{16} GeV$$

$$\alpha_u^{-1} = 43.78$$

and now:

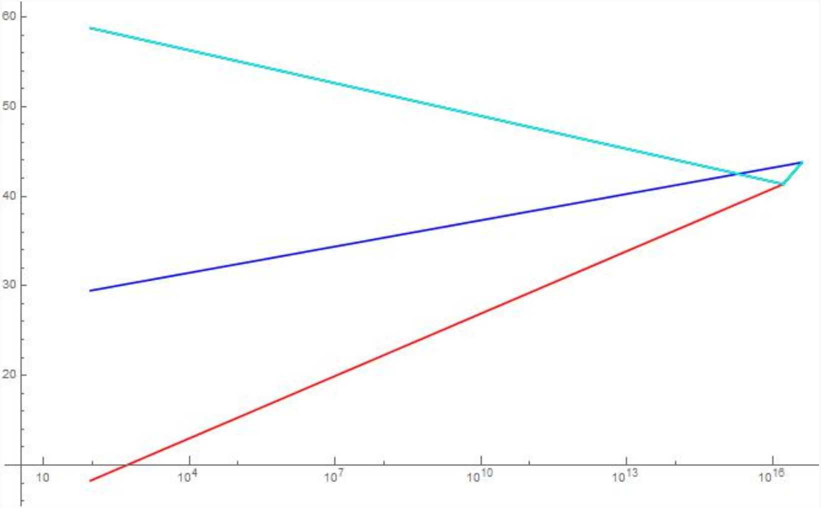


Figure 3: Running couplings $\alpha_i^{-1} = (g_i^2/4\pi)^{-1}$, versus $\ln Q^2/\mu^2$, in one-loop approximation, for $U(1)$, $SU(2)$, and $SU(3)$ respectively.

Conclussions

To conclude, we emphasize that is possible to get unification of the three running constants couplings without and with scalars into the model analyzed, in the first case the mass unification scale could be low, however, when we introduce two higgses doublets in the model, the unification scale has a good value.

The model showed is free of the Gauge anomalies, because, this model comes from E_6 gauge symmetry group. As far know as, this model has not been analyzed in the literature, it could be a good option to study physics beyond standard model.

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Thanks a lot!