“Low” Energy GUTs

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Abstract: To achieve a GUT scale that is small, \( \leq 200 \text{TeV} \), so that it is within the reach of conceivable earth-based accelerated colliding beam devices, we introduce a new approach to the subject of grand unification. Central to the approach is the abstraction of the heterotic string symmetry group physics ideas in a novel way which allows us to control baryon number violating effects to be consistent with current experimental limits.

Keywords: Grand unified theories, low energy, new chiral fermions, gauge boson mixing, running coupling constants.

INTRODUCTION

In view of its success, the structure of the Standard Model (SM) [1-10], as originally noted by the authors in refs. [11, 12], naturally suggests that the gauge interactions therein may be identified with a single unified dynamical gauge principle associated with a larger group \( G \) of which the SM gauge group, \( \text{SU}(2)_L \times \text{U}(1)_Y \times \text{SU}(3)_C \) in a by now standard notation, is a subgroup. This idea continues to be a fashionable area of investigation today. In what follows here, we also discuss the possible SM gauge forces' unification and we refer to the possibilities for such unification as GUTs as usual.

We note that recently progress [13-36] in treating the UV behavior of the Einstein-Hilbert theory for quantum gravity using resummation methods and using an underlying Planck-scale loop space suggests that, as originally discussed by Weinberg [13], the unrenormalizability of the theory is cured dynamically, either via its interactions or via modifications of the theory at short distances. In what follows, we explore the possibility, which follows from such progress, that resolving the unrenormalizability of quantum gravity is a separate issue from the unification of all other known fundamental forces.

Specifically, with an eye toward the very high energy colliding beams devices, for example we have in mind the VLHC [37-42], our objective is to formulate GUTs so that they would be accessible to such devices with 100-200TeV CMS energies. This we wish to do while satisfying the standard constraints on such theories: SM coupling constant unification, absence of anomalies, stability of baryons (this will be the most demanding requirement), naturalness [43-47] and suppression of other unwanted transitions. We want to do this in 4-dimensional Minkowski space -- this condition we take as an example of our known physical reality condition.

Baryon number stability can be seen to be the most difficult constraint on our analysis as follows. By the

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1We view here modern string theory as an extension of quantum field theory which can be used to abstract dynamical relationships which would hold in the real world even if the string theory itself is in detail only an approximate, mathematically consistent treatment of that reality, just as the old strong interaction string theory [73] could be used to abstract properties of QCD such as Regge trajectories even before QCD was discovered.
The scales \( M_{QL}, M_{LL} \) are bounded by the grand unified factor \( E_8b \) as well and we leave open the issue of observable theory beyond the current experimental limits on heavy leptons.

The \( E_6 \) contains exactly one Standard Model (SM) family \( 16 \)-plet with \( 11 \)

\[
(1, 78) + (3, 27) + \ldots
\]

Under this breaking the \( 248 \) of \( E_8 \) then splits into \( (8, 1) + (27, 3) + \ldots \) under \( E_8 \) each of the corresponding \( E_6 \)'s breaks to give two copies of \( SU(3)_C \) groups.

We take the minimal view that confinement holds for the quarks in the families with the known light quarks are at a scale \( M_{LL} \) that is beyond current experimental limits on heavy quarks; the leptons in the families with the known light quarks are at a scale \( M_{QL} \) that is beyond current experimental limits on heavy leptons.

We now repeat the same pattern of breaking for the second factor \( E_{6b} \) as well and we leave open the issue of observable families under this \( E_{6b} \), as they may exist in principle as well. The scales \( M_{QL}, M_{LL} \) are bounded by the grand unified theory (GUT) scale \( M_{GUT} \). This scenario stops baryon instability: the proton cannot decay because the leptons to which it could transform via \( (\text{leptoquark}) \) bosons are all at too high a scale. The extra heavy quarks and leptons just introduced here may of course appear already at the LHC.

The Standard Model \( SU(3) \times SU(2)_L \times U(1)_Y \) gauge bosons are now identified with a mixture of the two copies of such bosons from the two \( E_8 \)'s of the heterotic string theory:

we assume the two \( E_8 \)'s each break to a product group \( SU(3) \times E_6 \) and each of the corresponding \( E_6 \)'s breaks to give two copies of \( SU(3)^C \times SU(2)_L \times U(1)_Y \), so that for the gauge bosons for \( SU(3)^C \times SU(2)_L \times U(1)_Y \in E_{6a}, G^a_8, a=1, \ldots, 8 \)

\[
A_i^a = \sum_{i' \neq a} \eta_{i,a} A_{i'}
\]

\[
B_i = \sum_{i' \neq 1} \eta_{i,1} B_{i'}
\]

The \( \{ \eta_{i,a} \} \) satisfy

\[
\sum_{a=1}^2 \eta_{i,a}^2, a = 1, 2
\]

We take the minimal view that confinement holds for the quarks in each of the families from the two \( E_8 \)'s. We set the two strong interaction gauge couplings to be equal at the GUT scale by imposing discrete symmetry so that we have gluons \( G_1^a \) for the known quarks. We are aware that the as yet unseen color group may have to be broken, following the methods in ref. [74] for example, if experiment so dictates.

\( Eq. (2) \) allows us some choices in realizing the known E6 bosons. We recall the values [75, 76] of the known gauge couplings at scale \( M_Z \) as follows:

\[
\alpha_S(M_Z) \bigg|_{MS} = 0.1184 \pm 0.0007
\]

\[
\alpha_W(M_Z) \bigg|_{MS} = 0.033812 \pm 0.000021
\]

\[
\alpha_{EM}(M_Z) \bigg|_{MS} = 0.00781708 \pm 0.0000098
\]

Although the respective unified coupling ratio values are 1 and 2.67, there is a factor of almost 4 between \( \alpha_S(M_Z) \) and \( \alpha_W(M_Z) \) and between \( \alpha_{EM}(M_Z) \); the latter factor is well-known [77] to necessitate \( M_{GUT} \approx 10^{13} \text{ to } 10^{12} \text{ TeV} \).

We may use the \( \{ \eta_{i,a} \} \) to realize most of the discrepancy between the observed values of the coupling ratios and the unification coupling ratios of 1 and 2.67.

This will allow GUT scales within the reach of foreseeable accelerated colliding beam devices.

Specifically, one may set

\[
\eta_{21} = 1/\sqrt{2.000}
\]

\[
\eta_{11} = 1/\sqrt{3.260}
\]

and this will leave a “small” amount of evolution to be done between the scale \( M_Z \) and \( M_{GUT} \).

Specifically, from the choices in (4), taken together with continuum of gauge coupling constants at the thresholds (There is now a candidate for the Englert-Brout-Higgs [78-81] boson \( H \) in the mass regime which we indicate here, see refs. [82,83].) \( m_H \approx 120 \text{ GeV} \) and \( m_t = 171.2 \text{ GeV} \) respectively, we calculate the GUT scale as \( M_{GUT} \approx 136 \text{ TeV} \), as advertised, when one-loop beta functions [8,9] are used.

We have

\[
b_0^{U(1)_Y} = \frac{1}{12\pi^2} \left( 4.358, M_Z \leq \mu \leq m_t \approx 120 \text{ GeV} \right)
\]

\[
4.417, m_H < \mu \leq m_t
\]

\[
5.125, m_t < \mu \leq M_{GUT}
\]

from the standard formula [8,9]

\[
b_0^{U(1)_Y} = \frac{1}{12\pi^2} \left( \sum_{j} (Y_j / 2)^2 \right)
\]

where \( b_0 U(1)_Y \) is the coefficient of \( g^2 \) in the \( \beta \) function for the \( U(1)_Y \) coupling constant \( g' \) in the SU(2)_L × U(1)_Y EW theory, \( n_i \) is the effective number of Dirac fermion degrees freedom, i.e. a left-handed Dirac fermion counts as \( 1/2 \), a complex scalar counts as \( 1/4 \), and so on. For QCD and the SU(2)_L theories we have

\[
b_0^{SU(2)_L} = \frac{-1}{16\pi^2} \left( 3.708, M_Z \leq \mu \leq m_t \approx 120 \text{ GeV} \right)
\]

\[
3.667, m_t < \mu \leq m_t
\]

\[
3.167, m_t < \mu \leq M_{GUT}
\]

\[
b_0^{QCD} = \frac{-1}{16\pi^2} \left( 7.667, M_Z \leq \mu \leq m_t \right)
\]

\[
7, m_t < \mu \leq M_{GUT}
\]
from the standard formula [8, 9]

\[ b^\mu_0 = \frac{-1}{16\pi^2} \left( \frac{11}{3} C_2(\mathcal{H}) - \frac{4}{3} \sum_j \eta_j T(R_j) \right) \]

(9)

where \( T(R_j) \) are defined via \( \tau \) \( R^0_j = T(R_j) \delta_{ab} \) for the generators \( \{ \tau^R_j \} \) of the group \( \mathcal{H} \) in the representation \( R_j \) when \( \delta_{ab} \) is the Kronecker delta and the quadratic Casimir invariant eigenvalue for the adjoined representation of \( \mathcal{H} \) has been denoted by \( C_2(\mathcal{H}) \).

These results (5,6,7,8,9) together with the standard one-loop solution [8,9]:

\[ g^2_{\mu} (\mu) = \frac{g^2_{\mu} (\mu_0)}{1 - 2b^\mu_0 g^2_{\mu} (\mu_0) \ln(\frac{\mu}{\mu_0})} \]

(10)

allow us to compute \( M_{\text{GUT}} \approx 136 \text{TeV} \) when the \( \eta_{a,j} \) are as they are given in (4). Here, the squared running coupling constant at scale \( \mu \) is denoted by \( g^2_{\mu} (\mu) \) for \( \mathcal{H} = U(1)_Y \cdot SU(2)_L \cdot SU(3)_C \).

For illustration we have chosen the value of 136TeV for the unification scale. In principle any value between the TeV scale and the Planck scale is allowed in our approach so that the unification scale. In principle any value between the TeV scale and the Planck scale is allowed in our approach so that the

We sum up with the following observation, already made in ref. [62]: we propose here a “green pasture” between the TeV scale and the GUT scale instead of the traditional “desert” [12, 77].

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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