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"Low" Energy GUTs

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Abstract: To achieve a GUT scale that is small, ≤ 200TeV, 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, $SU(2)_L \times U(2)_Y \times SU(3)^C$ 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 standard methods, for 100TeV scale physics for a dimension 6 transition, a state with the size and mass of the proton has a natural lifetime of ~ 0.01yr while the proton must be stable to ~ 10^{29-33} yrs., depending on the mode. This requires a new suppression mechanism proton decay.

In proceeding to isolate such a mechanism, we hope to keep the GUT scale in the hundreds of TeV range in contrast to the usual [48, 49] ~10^{13} TeV regime, and we hope to avoid as well as yet unseen phenomena, where here we have in mind dimensions beyond 4 [48-52], additional vector representations of the gauge group [53-61], etc.

This is our realization of the approach that is sometimes called a radically conservative approach in that one uses in a novel way well-tested ideas. Toward our end, we notice that a GUT theory has the following three fundamental sectors: a gauge sector, a family sector and a Higgs sector for spontaneous symmetry breaking. We turn first to the family and gauge sectors. Let us also note that, in effecting this discussion, we present here a different realization of the basic ideas we already introduced in ref. [62]. Only experiment can tell us which realization is used by Nature.

Specifically, given the recent experimental evidence [63, 64] of neutrino masses, we need to extend the $10+\bar{5}$ of SU(5) in ref. [12] to a sixteen dimensional representation.

We will use the 16 of SO(10) [65], which decomposes as $10+\bar{5}+1$ under an inclusion of SU(5) into SO(10). We know that in the only known and accepted unification of the SM and gravity, see for example refs. [66-72], the gauge group $E_8 \times E_8$ is singled-out when all known dualities [72] are taken into account to relate equivalent superstring theories[1].

One pattern for the attendant symmetry breakdown is the following [72]:

$$E_8 \to SU(3) \times E_6 \to SU(3) \times SO(10) \times U'(1)$$

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[1]We 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.

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$$\rightarrow SU(3) \times SU(5) \times U''(1) \times U'(1) \quad (1)$$
$$\rightarrow SU(3) \times SU(3)^C \times SU(2)_L \times U(1)_Y \times U''(1) \times U'(1)$$

Under this breaking the 248 of E_8 then splits into (8, 1) + (1, 78) + (3, 27) + $(\bar{3},\overline{27})$ under SU (3) × E_6 where each 27 under E_6 contains exactly one SM family 16-plet with 11 other states that would be expected to get GUT scale masses because they are paired with their anti-particles in helicity *via* real representations. Let us assume that, by using the heterotic string breaking scenario, we get 6 families [48,49] under the first E_8 factor, E_{8a}, in the $E_8 \times E_8$ gauge group. These families are singlets under the second $E_8 \equiv E_{8b}$. We take the first 3 families to be those with the known light leptons and the remaining 3 families to be those with the known light quarks. The quarks in the families with the known light leptons are at a scale M_{QL} that is beyond current experimental limits on new quarks; the leptons in the families with the known light quarks are at a scale M_{LL} that is beyond the current experimental limits on heavy leptons. We now repeat the same pattern of breaking for the second factor E_{8b} as well and we leave open the issue of observable families under this E_{8b}, 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* (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 $SU(3)^C \times SU(2)_L \times U(1)_Y$ 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[2]: we assume the two E_8's each break to a product group SU (3) × 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 $SU(3)^C_i \times SU(2)_{Li} \times U(1)_{Yi} \in E_{8i}$, G^a_i, a=1,…,8, $A^{i'}_i$, i'=1, …, 3, B_i, **i** = 1, 2, in a standard notation, we assume a further GUT scale breaking that leaves the following linear combinations massless at the G_{UT} scale M_{GUT} while the orthogonal linear combinations acquire masses $O(M_{GUT})$ –

$$A_f^{i'} = \sum_{i=1}^{2} \eta_{2i} A_i^{i'}$$
$$B_f = \sum_{i=1}^{2} \eta_{1i} B_i \quad (2)$$

The $\{\eta_{aj}\}$ satisfy

$$\sum_{i=1}^{2} \eta_{ai}^2,\ a = 1, 2$$

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.

[2]If one wants to avoid any reference to superstring theory, one can just postulate our symmetry and families as needed, obviously; we leave this to the discretion of the reader.

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

$$\alpha_S(M_Z)\big|_{\overline{MS}} = 0.1184 \pm 0.0007$$
$$\alpha_W(M_Z)\big|_{\overline{MS}} = 0.033812 \pm 0.000021 \quad (3)$$
$$\alpha_{EM}(M_Z)\big|_{\overline{MS}} = 0.00781708 \pm 0.00000098$$

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 $\alpha_W(M_Z)$ and $\alpha_{EM}(M_Z)$; the latter factor is well-known [77] to necessitate $M_{GUT} \sim 10^{13} - 10^{12}$ TeV. Here, we may use the $\{\eta_{kj}\}$ 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

$$\eta_{21} \cong 1/\sqrt{2.000}$$
$$\eta_{11} \cong 1/\sqrt{3.260} \quad (4)$$

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 continuity 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].) $m_H \cong 120$ GeV and m_t = 171.2 GeV respectively, we calculate the GUT scale as $M_{GUT} \cong 136$TeV, as advertised, when one-loop beta functions [8,9] are used. We have

$$b_0^{U(1)_Y} = \frac{1}{12\pi^2}\begin{cases} 4.385, M_Z \le \mu \le m_H \cong 120GeV \\ 4.417,\ m_H < \mu \le m_t \\ 5.125, m_t < \mu \le M_{GUT} \end{cases} \quad (5)$$

from the standard formula [8,9]

$$b_0^{U(1)_Y} = \frac{1}{12\pi^2}\left(\sum_j n_j\,(Y_j/2)^2\right) \quad (6)$$

where $b_0\ U(1)_Y$ is the coefficient of g'^3 in the β function for the $U(1)_Y$ coupling constant g' in the $SU(2)_L \times U(1)_Y$ EW theory, n_j is the effective number of Dirac fermion degrees freedom, i.e. a left-handed Dirac fermion counts as ½, a complex scalar counts as ¼, and so on. For QCD and the $SU(2)_L$ theories we have

$$b_0^{SU(2)_L} = \frac{-1}{16\pi^2}\begin{cases} 3.708, M_Z \le \mu \le m_H \cong 120GeV \\ 3.667,\ m_H < \mu \le m_t \\ 3.167, m_t < \mu \le M_{GUT} \end{cases} \quad (7)$$

$$b_0^{QCD} = \frac{-1}{16\pi^2}\begin{cases} 7.667, M_Z \le \mu \le m_t \\ 7, m_t < \mu \le M_{GUT} \end{cases} \quad (8)$$

from the standard formula [8, 9]

$$b_0^{\mathcal{H}} = \frac{-1}{16\pi^2}\left(\frac{11}{3}C_2(\mathcal{H}) - \frac{4}{3}\sum_j n_j T(R_j)\right) \tag{9}$$

where $T(R_j)$ are defined *via* tr $\{\tau_a^{R_j}\ \tau_b^{R_j}\} = T(R_j)\delta_{ab}$ for the generators $\{\tau_a^{R_j}\}$ of the group $\mathcal{H}$ in the representation R_j when δ_{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]:

$$g_{\mathcal{H}}^2(\mu) = \frac{g_{\mathcal{H}}^2(\mu_0)}{1 - 2b_0^{\mathcal{H}} g_{\mathcal{H}}^2(\mu_0)\ln(\frac{\mu}{\mu_0})} \tag{10}$$

allow us to compute $M_{GUT} \cong 136$TeV when the η_{ij} are as they are given in (4). Here, the squared running coupling constant at scale μ is denoted by $g_{\mathcal{H}}^2(\mu)$ for $\mathcal{H} = U(1)_Y, SU(2)_L$, QCD $\equiv SU(3)^C$.

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 we wait for experiment to tell us what the true value is.

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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