Synopsis

• Name: Joydeep Chakrabortty

• Thesis Title: Some aspects of Grand Unified Theory: gauge coupling unification with dimension-5 operators and neutrino masses in an SO(10) model.

• Supervisor: Professor Amitava Raychaudhuri

The Standard Model (SM) based on the gauge group $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ has three independent gauge couplings $g_3$, $g_2$, and $g_1$. Grand Unified Theory (GUT) aims for the unification of these couplings and also ensures the presence of quarks and leptons in a common multiplet of a single gauge group. The SM gauge couplings evolve logarithmically with energy leading to an unified coupling, $g_{GUT}$, if unification is achieved at some high scale ($M_X$). The experimental constrains on proton decay life-time set the lower bound of the GUT scale, $M_X \geq 10^{16}$ GeV.

A full theory at the Planck scale ($M_{Pl}$) is not yet known. In its absence it has been found useful to introduce higher dimensional effective operators at the GUT scale itself which will capture some of the higher scale physics implications. These operators might have significant impact on the predictions of the grand unified theory.

We focus on the corrections to the gauge kinetic term, $-\frac{1}{4\epsilon} Tr(F_{\mu\nu}F^{\mu\nu})$, through the operator, $-\frac{\eta}{M_{Pl}}[\frac{1}{4\epsilon} Tr(F_{\mu\nu}\Phi_D F^{\mu\nu})]$, where $F_{\mu\nu} = \Sigma_i \lambda_i F_{\mu\nu}^i$ is the gauge field strength tensor with $\lambda_i$ being the matrix representations of the generators normalised to $Tr(\lambda_i\lambda_j) = c \delta_{ij}$. Conventionally, for $SU(n)$ groups the $\lambda_i$ are chosen in the fundamental representation with $c = 1/2$. $\eta$ is a dimensionless parameter that determines the strength of the operator. Obviously the representations of $\Phi_D$ must appear among the representations in the symmetric product of two adjoint representations of the group.

When $\Phi_D$ develops a vacuum expectation value (vev) $v_D$, which sets the scale of grand unification $M_X$, an effective gauge kinetic term is generated and the modified gauge coupling unification condition reads as: $g_1^2(M_X)(1+\epsilon \delta_1) = g_2^2(M_X)(1+\epsilon \delta_2) = g_3^2(M_X)(1+\epsilon \delta_3)$, wherein the $\delta_i$, $i = 1, 2, 3$ are the group factors, and $\epsilon = \eta v_D/2M_{Pl} \sim O(M_X/M_{Pl})$.

We work out the consequences of these dimension-5 operators for the unified theories based on $SU(5)$, $SO(10)$, and $E(6)$. We consider all the possible choices for $\Phi_D$, namely the representations $24$, $75$, $200$ for $SU(5)$, $54$, $210$ and $770$ for $SO(10)$ and $650$, $2430$ for $E(6)$. We propose a prescription to calculate the orientations of the vevs of these Higgs fields. The orientations depend on the pattern of symmetry breaking. $SU(5)$ directly breaks to the SM. But $SO(10)$ and $E(6)$ can be broken to the SM through different intermediate gauge groups. We calculate the corrections
(δ_i’s) which arise due to the dimension-5 operator for all possible breakings with all possible choices of Φ_D’s.

We then calculate the beta coefficients and construct the renormalization group equations (RGEs) to study the evolutions of the gauge couplings upto two loop level to check whether unification is achieved or not.

We find these dimension-5 operators cannot help to achieve unification beyond 10^{16} GeV for SU(5) in non-supersymmetric (non-SUSY) scenario. But in SUSY SU(5) models unification is achieved with a high enough GUT scale. These dimension-5 operators also have impact on the prediction of sin^2 θ_W at low scale (∼ M_Z). This constrains the strength of these effective operators.

We also consider SO(10) and E(6) GUT gauge groups. We discuss no-, one-, and two-steps breakings of these gauge groups to the SM. For each cases we construct the RGEs and include the proper matching of the gauge couplings at the intermediate scales as well as at the GUT scale. In presence of one intermediate symmetry group, SU(4)_C ⊗ SU(2)_L ⊗ SU(2)_R and SU(3)_C ⊗ SU(3)_L ⊗ SU(3)_R for SO(10) and E(6) respectively, we explore D-parity (symmetry between left-right sector) conserving and broken cases. We extend our study through the inclusion of the second intermediate group, SU(3)_C ⊗ U(1)_B−L ⊗ SU(2)_L ⊗ U(1)_R and SU(3)_C ⊗ SU(2)_L ⊗ U(1)_L ⊗ SU(2)_R ⊗ U(1)_R for SO(10) and E(6) respectively. In all the above cases we determine the ranges of the intermediate scales consistent with the viable unified scenario.

It has been noted that the operator that generates the gaugino masses in a supergravity (SUGRA) model is same as the dimension-5 operator we consider. The gaugino mass non-universality is achieved through the vevs of the non-singlet Φ_D’s and the ratios of the gaugino masses are same as the ratio of the δ_i’s. We exhaustively explore all possibilities.

We also study neutrino mass generation in the context of a grand unified theory. We consider an SO(10) based model with (10+120) Higgses. It has been noted that in such a model neutrino masses cannot be generated in tree level. One can generate neutrino masses at two loop level. We aim for an alternate mechanism where all the couplings are at the tree level. To do so we extend this model by adding adjoint fermions (which transform as 45 of SO(10)) and 16 Higgs. Thus the neutrino mass matrix is extended and a double seesaw is achieved. Imposing μ − τ symmetry we consider explicit form of the Dirac-Yukawa matrices that help to generate correct light neutrino masses and tri-bimaximal (TBM) mixing angles. We also check the gauge coupling unification in this model.
List of papers that form the thesis of the candidate

• A Note on dimension-5 operators in GUTs and their impact.
  Joydeep Chakrabortty, Amitava Raychaudhuri.

• Gaugino mass non-universality in an SO(10) supersymmetric Grand Unified Theory: Low-energy spectra and collider signals.
  Subhaditya Bhattacharya, Joydeep Chakrabortty.

• GUTs with dim-5 interactions: Gauge Unification and Intermediate Scales.
  Joydeep Chakrabortty, Amitava Raychaudhuri.

• Dimension-5 operators and the unification condition in SO(10) and E(6).
  Joydeep Chakrabortty, Amitava Raychaudhuri.

• An SO(10) model with adjoint fermions for double seesaw neutrino masses.
  Joydeep Chakrabortty, Srubabati Goswami, Amitava Raychaudhuri.
List of papers of the candidate that are not included in the thesis

- Renormalization group evolution of neutrino masses and mixing in the Type-III seesaw mechanism.
  Joydeep Chakrabortty, Amol Dighe, Srubabati Goswami, Shamayita Ray.

- Maximal mixing as a ‘sum’ of small mixings.
  Joydeep Chakrabortty, Anjan S. Joshipura, Poonam Mehta, Sudhir K. Vempati

- TeV scale double seesaw in left-right symmetric theories.
  Joydeep Chakrabortty

- Type I and new seesaw in left-right symmetric theories.
  Joydeep Chakrabortty

- Multi-photon signal in supersymmetry comprising non-pointing photon(s) at the LHC.
  Sanjoy Biswas, Joydeep Chakrabortty, Sourov Roy.