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Gauge Coupling Evolution in an SU(8) GUT

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Although the Standard Model has achieved remarkable success, its limitations motivate physicists to continuously explore new fundamental particle theories. Among the numerous candidate theories, Grand Unified Theories (GUTs) have attracted significant attention due to their simplicity and potential to unify the three fundamental interactions.

We present a detailed study of the running of gauge couplings along several gauge symmetry breaking chains (SWW, WSW, and WWS) in the SU(8) Grand Unified Theory. By relaxing the third law of grand unification proposed by H. Georgi, we obtain the left-handed fermion representation set with the minimal fermion degrees of freedom in this GUT while ensuring anomaly cancellation. Furthermore, from the perspectives of gauge symmetry and global symmetry, we determine the representations of Higgs fields and Yukawa interactions.

The massless fermion spectrum, the two-loop renormalization group equations for gauge couplings at each stage, the CKM mixing matrix, and the relationship between gauge couplings before and after symmetry breaking are derived in detail by analyzing the breaking of the group structure. We then provide benchmark points for some parameters (especially each symmetry breaking scale) based on the measured values of the CKM matrix. Using the renormalization group equations, we calculate the coupling constants at different stages and plot the coupling running diagrams.

The results show that the minimal setup of the SU(8) GUT does not achieve the unification of gauge couplings. However, introducing numerous additional Higgs fields can strengthen the coupling strength of non-Abelian groups, leading to an unnatural unification. Moreover, the $\mathcal{N} = 1$ supersymmetric extension can modify the β coefficients and achieve the unification of coupling constants within the framework of affine Lie algebra. These results provide important references for the development of GUTs and demonstrate the potential of the SU(8) GUT in unifying gauge interactions.

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