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$SU(3)_F$ gauge family model and new symmetry breaking scale from FCNC processes

Shou-Shan Bao [a,c,*], Zhuo Liu [a,b], Yue-Liang Wu [a,b]

[a] *State Key Laboratory of Theoretical Physics (SKLTP), Kavli Institute for Theoretical Physics China (KITPC), Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing, 100190, PR China*

[b] *University of Chinese Academy of Sciences (UCAS), Beijing, 100190, PR China*

[c] *School of Physics, Shandong University, Jinan, 250100, PR China*

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Abstract

Based on the $SU(3)_F$ gauge family symmetry model which was proposed to explain the observed mass and mixing pattern of neutrinos, we investigate the symmetry breaking, the mixing pattern in quark and lepton sectors, and the contribution of the new gauge bosons to some flavour changing neutral currents (FCNC) processes at low energy. With the current data of the mass differences in the neutral pseudo-scalar P^0–$\bar{P}^0$ systems, we find that the $SU(3)_F$ symmetry breaking scale can be as low as 300 TeV and the mass of the lightest gauge boson be about 100 TeV. Other FCNC processes, such as the lepton flavour number violation process $\mu^- \to e^- e^+ e^-$ and the semi-leptonic rare decay $K \to \pi \bar{\nu} \nu$, contain contributions via the new gauge bosons exchanging. With the constrains obtained from P^0–$\bar{P}^0$ system, we estimate that the contribution of the new physics is around 10^{-16}, far below the current experimental bounds.

1. Introduction

The last five decades have witnessed the great triumph of the standard model (SM). Especially the Higgs boson was finally discovered at the Large Hadron Collider (LHC) [1,2]. However, there

* Corresponding author at: School of Physics, Shandong University, Jinan, 250100, PR China.
E-mail addresses: ssbao@sdu.edu.cn (S.-S. Bao), liuzhuo@itp.ac.cn (Z. Liu), ylwu@itp.ac.cn (Y.-L. Wu).

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are some solid experimental evidences hinting new physics beyond SM. These evidences include neutrino oscillations [3,4], dark matter (DM) [5,6] and baryon asymmetry of the universe (BAU) [7,8]. Neutrino oscillations can be explained by nonzero but tiny masses of neutrinos. And the observed nearly tri–bimaximal mixing pattern [9–14] strongly indicates new symmetries, discrete or continuous, in the neutrino flavour sector. In general, models [15–23] inhabited by these new flavour symmetries contain new heavy particles and new CP violation (CPV) phases. As a bonus, these models may provide candidates of the DM, and new CPV sources accounting for BAU. So the flavour symmetry can be a possible solution to the puzzles mentioned above.

In SM, before electroweak symmetry is spontaneously broken, quarks and leptons are all massless. Due to the universality of gauge interactions, no quantum number can distinguish the three families. Only the Yukawa interactions can tell them apart. Thus a simple extension to SM is to introduce a new flavour symmetry among the three families, which is then broken spontaneously. In this work we take the $SU(3)$ as the flavour symmetry group, denoted as $SU(3)_F$. The flavour structure of Minimal Flavour Violation in quark and lepton sectors based on family symmetries have been discussed in [24–28]. Models based on other family symmetry, such as $SO(3)_F$ symmetry, have been discussed in [16,17,29–32].

In the $SU(3)_F$ gauged family symmetry model [18], there are new interactions among the three families. The extended gauge symmetry group becomes $SU(3)_F \otimes SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$. As the SM Higgs field being singlet under this new family symmetry transformation, new Higgs fields are needed to break the $SU(3)_F$ symmetry. A Hermitian field $\Phi = \Phi^\dagger$ which is adjoint representation of the $SU(3)_F$ can do this job. Actually, to explain the mass and the mixing pattern both in quark and lepton sectors, we need two Hermitian fields $\Phi_{1,2} = \Phi^\dagger_{1,2}$. In the lepton sector, we also need right handed neutrinos N_R and seesaw mechanism [33–35] to explain the tiny neutrino masses. So there should be a complex symmetric Higgs $\Phi_\nu = \Phi_\nu^T$ to generate Majorana mass terms for N_R. The new Higgs fields transform under the $SU(3)_F$ gauge transformation as

$$\Phi_{1,2} \to g\Phi_{1,2}g^\dagger,\ \Phi_\nu \to g\Phi_\nu g^T, \quad g(x) \in SU(3)_F. \tag{1}$$

For the representation of $SU(3)$, one has $\underline{3} \otimes \underline{3} = \underline{6} \oplus \bar{3}$ where the $\underline{6}$ representation denoted as $(2,0)$ in $p-q$ notation is symmetric while $\bar{3}$ is anti-symmetric. Here the Φ_ν is the symmetric $\underline{6}$ representation of $SU(3)_F$. Seesaw mechanism can also be used to explain the mass hierarchy structures in quark and charged lepton sectors. There could also be new heavy charged fermion fields as cousins of N_R, and a new $SU(3)_F$ singlet Higgs ϕ_s to couple these new heavy fields with SM fields together. We can write down the general particle contents based on $SU(3)_F$ gauge family symmetry with features mentioned above, as listed in Table 1. For the new gauge transformation acting in the same way on the left handed and right handed parts of all fermions, no chiral anomaly occurs here.

The general form of the Lagrangian is

$$\mathcal{L} = \mathcal{L}_G + \mathcal{L}_k + \mathcal{L}_H + \mathcal{L}_Y + \mathcal{L}_n, \tag{2}$$

where $\mathcal{L}_G$ contains the kinetic and self-interaction terms of gauge bosons, including the new gauge bosons. $\mathcal{L}_k$ is the covariant kinetic term of the SM fermions, and contains the new gauge interactions among the three families's fermions mediated by the eight new gauge bosons. And $\mathcal{L}_H = \mathcal{L}_{DH} - V$, with $\mathcal{L}_{DH}$ the Higgs fields' covariant kinetic terms, and V the Higgs potential. $\mathcal{L}_{DH}$ gives masses to all the gauge bosons after spontaneously symmetry breaking (SSB). V undergoes the SSB and gives mass terms of Higgs bosons. $\mathcal{L}_Y$ is the Yukawa interactions among all the fermions and Higgs fields. It generates masses for SM fermions and the new heavy fermions.