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Families and Irreducible Anomaly-Free Sets for 3–3–3–1 Gauge Theories

We present a model-agnostic scheme to assemble \textbf{quark–lepton families} within flipped trinification, $SU(3)_C \times SU(3)_L \times SU(3)_R \times U(1)_X$, allowing for arbitrary charge embeddings. The core of our construction is the identification and taxonomy of \textbf{Irreducible Anomaly-Free Sets (IAFS)}: minimal fermion multiplet combinations that, on their own, cancel all gauge and mixed anomalies—$[SU(3)_{L,R}]^3$, $[SU(3)_{L,R}]^2 U(1)_X$, $[SU(3)_C]^2 U(1)_X$, $U(1)_X^3$, and grav$^2 U(1)_X$. We show that Standard-Model families can be realized as unions of only a few IAFS, deriving general relations between color and family replication and recovering the familiar 331-like non-universality as a limiting case. For each IAFS we supply charge assignments consistent with the electroweak sector, delineate the scalar content required for the staged breaking $SU(3)_L \times SU(3)_R \times U(1)_X \to SU(2)_L \times U(1)_Y$, and exhibit renormalizable Yukawa structures that yield realistic quark and lepton masses—including right-handed neutrinos—while keeping exotic states under control. The classification feeds directly into phenomenology, implying characteristic patterns for extra neutral currents (Z'/Z''), exotic quark/lepton charges, residual discrete symmetries, and flavor textures. Altogether, we provide a modular set of "building blocks" to engineer flipped-trinification models from \textbf{quark–lepton families} and their \textbf{irreducible anomaly-free} combinations, and we delineate which embeddings remain compatible with current collider and flavor constraints.

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