INVESTIGATIONS BEYOND THE STANDARD MODEL

ABSTRACT

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The investigations carried out under this thesis can be broadly classified into two categories: (A) The impact of certain higher-dimensional operators on the predictions of SU(5) and SO(10) grand unified theories, (B) Natural seesaw mechanism for neutrino masses in a new class of models with identical parity (P)-and $SU(2)_R$-breaking scales. While the Chapters II-V have been devoted to the analysis of the type (A), Chapter VI is devoted to obtain results of the type (B). Chapter I provides a general introduction while the summary and conclusions are stated in Chapter VII.

Although superstring theories offer an exciting possibility of unification of all interactions, the extension of the original Kaluza-Klein type of unification with gravity by the introduction of extra spatial dimensions is also a very attractive one. The impact of such a unification scheme on grand unified theories (GUT's) need special attention in the context of direct and indirect experimental signatures at low or accelerator energies. When extra dimensions are compactified, besides the usual GUT Lagrangian of the effective four-dimensional theory, nonrenormalizable terms involving certain higher-dimensional operator(s) and scaled by suitable powers of the compactification mass (M_G) usually occur as residual effects of compactification. Although the presence of such terms makes the GUT Lagrangian nonrenormalizable, a very attractive feature is that they are absorbed as renormalizable terms of the Lagrangian of the effective theory at the lower scale ($\mu \ll M_U$), once the GUT

symmetry breaks spontaneously. For example, the effective theory below the unification mass in SU(5) is the standard theory $G_{st}=SU(2)_L \times U(1)_Y \times SU(3)_C$. The effect of such five-dimensional operators on SU(5) and certain SO(10) predictions have been investigated by a number of authors who have noted that such an operator might also originate from effects of quantam gravity in four dimensions especially with $M_G \simeq M_{pl}=10^{19}$GeV. We have examined the modifications caused by the five- and six-dimensional operators on SU(5) and the relevant five-dimensional operators in the effective chains of SO(10) leading to very attractive predictions for low-energy experiments not obtained earlier.

In Chapter II we show that the combined effects of the five-and six-dimensional operators lead to large enhancement of proton lifetime (τ_p) in SU(5) with $\tau_p \geq 10^{38}$yr for the $p \longrightarrow e^+\pi^0$ mode and $\sin^2\theta_W \simeq 0.22$-$0.24$.

In Chapter III we found that even with a single intermediate symmetry in the chain $SO(10) \xrightarrow{M_U} SU(2)_L \times U(1)_R \times SU(4)_C \xrightarrow{M_C} G_{st}$, the quark-lepton unification scale is allowed to be as low as 10^5-10^6GeV, when the effect of the relevant five-dimensional operator is included in the renormalization-group equations (RGE's). Such a scale leads to the observable rare-kaon decay ($K_L \longrightarrow \bar{\mu}\, e$) and small neutrino masses.

In contrast to the chain made by Rizzo few years earlier that the low-mass $W_R^{\pm}$ -gauge bosons are predicted in the scenario, $SO(10) \xrightarrow{M_U} SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C \times P\ (\equiv G_{2213P}) \xrightarrow{M_R} G_{st}$, where P stands for parity, leading to $M_R \simeq 100$GeV, we find that the modifications to the boundary conditions of the RGE's have not

been calculated correctly. When this is done, the lowest permissible value turns out to be $M_R \simeq 10^8$GeV, invalidating the earlier claim. Interestingly enough, when we adopt the method of decoupling P- and $SU(2)_R$-breakings with the same intermediate symmetry, but excluding P ($g_{2L} \neq g_{2R}$), the effect of the five-dimensional operator permits $M_R \simeq$ 500GeV - few TeV. Thus a very interesting and new result of Chapter IV is the demonstration of the existence of low-mass $W_R^{\pm}$ and Z_R-gauge bosons in SO(10) without observable parity restoration.

In Chapter V we investigate the effect of the revelant five-dimensional operator on SO(10) predictions with the single $SU(2)_L \times SU(2)_R \times SU(4)_C (\equiv G_{224})$ intermediate symmetry with and without (P). In the case of G_{224P} intermediate symmetry, the quark-lepton unification mass M_C and grand unification scale M_U are found to be as large as $M_C \simeq 10^{14}$GeV and $M_U \simeq 10^{18}$GeV, respectively leading to a very stable proton and no cosmologically problematic domain walls. With G_{224} intermediate symmetry, it yields $M_C = M_{W_R} \simeq 10^5 - 10^6$GeV leading to observable predictions of $n-\bar{n}$ oscillation, and $K_L \longrightarrow \bar{\mu} e$ decay and small Majorana neutrino masses.

All investigations in Chapter VI are made without introducing any higher-dimensional operator. We find that in models of the following class,

$$SO(10) \xrightarrow{M_U} G_{2213P} \xrightarrow{M_P = M_R^+} SU(2)_L \times U(1)_R \times U(1)_{B-L} \times SU(3)_C (\equiv G_{2113})$$
$$\xrightarrow{M_R^0} G_{st'}$$

$$SO(10) \xrightarrow{M_U = M_R^+} G_{214} \xrightarrow{M_C} G_{2113} \xrightarrow{M_R^0} G_{st'}$$

the seesaw mechanism for generating small Majorana neutrino masses can be implemented in a very natural manner in that the induced contributions are negligible for certain large value of the ratio M_R^+/M_R^0, permissible by the solutions to RGE's. In these models the low-energy gauge group could be a minimally extension of the standard group predicting the existence of a low-mass Z_R boson. At several stages of the thesis, other predictions of different model have been noted and the method of circumventing the cosmological bound on neutrino masses has been discussed.

The following papers have been produced under this thesis,

1. "Gravity-induced large grand-unification mass in SU(5) with higher-dimensional operators."
   M.K.Parida, P.K.Patra, and A.K.Mohanty, Phys.Rev.D 39, 316(1989).
2. "Spontaneous compactification effects, low-energy signatures of quark-lepton unification, and small neutrino masses in SO(10)."
   M.K.Parida and P.K.Patra, Phys.Rev.D39, 2000(1989).
3. "Spontaneous compactification effects in SO(10) with low-mass $W_R^{\pm}$-gauge bosons without observable parity restoration".
   M.K.Parida and P.K.Patra, Phys.Lett.234B, 45(1990).
4. "Spontaneous compactification effects on SO(10) grand unification with $SU(2)_L \times SU(2)_R \times SU(4)_C$ intermediate symmetry"
   P.K.Patra and M.K.Parida, submitted to Phys.Rev.D.
5. "Models with natural seesaw mechanism for neutrino masses with identical parity-and $SU(2)_R$-breaking scales."
   M.K.Parida, P.K.Patra, and C.C.Hazra, Phys.Rev.D 43, (1991).