# Intermediate symmetry in the SO(10) model and the masses of heavy quarks

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A violation of SO(10) through a left–right symmetry group causes the masses of heavy quarks with charges $Q = -1/3$ and $Q = 2/3$ to be equal if there exists only a single light Higgs boson. The possibility of such a violation is ruled out for three generations by the condition $m_b \neq m_t$. For a larger number of generations, a strong limitation arises on the scale of the violation of $L$-$R$ symmetry.

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The popular SO(10) grand unified model[1] differs from the simple SO(5) model in that it allows various types of symmetry breaking. Effects related to an intermediate symmetry have been studied in several papers.[2–5] The possibility of obtaining large values of $\sin^2\theta_W$, the lifetime of the proton, neutrino masses, etc. has been pointed out. In the present letter we show that a violation of SO(10) through the $L$–$R$ symmetry subgroup gives rise to relations between the masses of heavy quarks.

Our conclusions are based on the hypothesis that there exists only a single light Higgs boson[6] (with a mass $\sim M_W$). This hypothesis is defended on the basis of a natural suppression of the off-diagonal neutral currents and the absence of anomalous cancellations between the parameters of the scalar potential for fields that do not violate $SU_L(2)$. The schemes in the literature with several light scalars (of which the simplest is discussed in Ref. 6) generally contain an additional symmetry, which relates the actual Higgs boson to other scalar fields. We will not pursue this possibility here.

Let us assume that in the first step the SO(10) symmetry is broken to one of the subgroups $SU_L(2)\times SU_R(2)\times SU(4)$ or $SU_L(2)\times SU_R(2)\times SU(3)\times U(1)$. The masses of the light fermions arise from the vacuum expectation values of the scalars $\phi_j$ ($j = 1, 2,\ldots,N$), which form the (2,2) representation in $SU_L(2)\times SU_R(2)$ with zero values of $B$-$L$. The mass part of the Langrangian of the neutral components of these scalars is

$$\mathcal{L}_{\mathcal{M}} = M^2 \sum_{i,j} (\xi_i^*,\ \eta_i) \begin{pmatrix} a_{ij} & b_{ij} \\ b_{ij} & a_{ij} \end{pmatrix} \begin{pmatrix} \xi_j \\ \eta_j^* \end{pmatrix}, \qquad (1)$$

where $a_{ij}$ and $b_{ij}$ are real parameters which are symmetric with respect to their indices, $M$ is the scale of the breaking of SO(10), and $\xi_j$ and $\eta_j$ are the neutral components of $\phi_j$. This structure of $\mathcal{L}_{\mathcal{M}}$ follows from $SU_L(2)\times SU_R(2)$ invariance. Reality of the elements of the mass matrix is guaranteed by the Hermitian nature and by the $L\leftrightarrow R$ interchange symmetry, under which we have $\phi_j \leftrightarrow \phi_j^+$. In the basis $(\xi_j + \eta_j^*)/\sqrt{2}$, $(\xi_j - \eta_j^*)/\sqrt{2}$ the mass matrix is block-diagonal, and a mixing of blocks is possible only after a breaking of the $L$–$R$ symmetry (at the level $M_R \ll M$), so that the mixing angles are $\sim M_R/M$. By virtue of our assumption, only the true Higgs boson, whose vacuum expectation value completes the symmetry breaking, has a small mass ($\sim M_W$). This boson belongs to one of the blocks; e.g., it is a certain linear combination of $(\xi_j + \eta_j^*)/\sqrt{2}$ with a small ($\sim M_R/M$) admixture of $(\xi_j - \eta_j^*)/\sqrt{2}$ states, so that we have

$$\frac{1}{\sqrt{2}}\left(\langle \xi_j \rangle + \langle \eta_j^* \rangle\right) \sim \lambda \equiv (\sqrt{2}G_F)^{-1/2}, \qquad (2)$$

$$\frac{1}{\sqrt{2}}\left(\langle \xi_j \rangle - \langle \eta_j^* \rangle\right) \sim \lambda(M_R/M). \qquad (3)$$

It follows from (3) that the mass matrices of the $u$ and $d$ quarks are equal[1]:

$$M_u = M_d, \qquad (4)$$

within the accuracy $m_f(M_R/M)$, where $m_f$ is the scale fermion mass. The violation of this equality is important only for the light quarks, and the masses of the heaviest quarks turn out to be equal. A situation of this type was discussed in Ref. 7 in connection with the $m_d = m_e$ problem.

If only three generations of fermions exist in nature, then (4) gives us $m_b \approx m_t$, in explicit contradiction of experiment. This problem can be avoided only in the case $M_R \sim M$, i.e., only if there is no intermediate left-right symmetry. Let us assume that there are more than three generations; then the difference between the masses of the $b$ and $t$ quarks must be due entirely to effects that break the $L$–$R$ symmetry. This result means that

$$m_t - m_b \lesssim m_{t'}(M_R/M), \qquad (5)$$

where $m_{t'} \approx m_{b'}$ is the mass of the heaviest quarks. Assuming, for example, $m_{t'} \lesssim 100$ GeV, as is required for stability of the scalar potential in strong fields[8] in the effective SU(3)×SU(2)×U(1) theory, we find $M_R/M \gtrsim 1/7$ for $m_t > 18$ GeV (Ref. 9). Even at larger values of $m_{t'}$ relation (5) imposes a strong restriction on $M_R$. We note that the baryon symmetry of the universe also implies a limitation[10] on $M_R$, but weaker: $M_R > 10^9$ GeV.

There can be an important increase in the proton lifetime ($\tau_p$) in the SO(10) model only for $L$–$R$ symmetry intermediate groups, due to an increase in the unification mass.[2,3] In all other cases this mass remains the same as in the SU(5) model, and the changes in $\tau_p$ due to the auxiliary bosons $X'$ and $Y'$ are small.[11] In summary, for three-fermion generations we expect $\tau_p$ to be the same as in the SU(5) model. The prediction of the SU(5) model, on the other hand, is at the experimental boundary,[12] even when we take the large uncertainty in $\tau_p$ into account.

We note in conclusion that our results remain in force for certain other models, e.g., for the $E_6$ model.[13]

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[1)] It should be noted that the $\langle \xi_j \rangle$ and $\langle \eta_j \rangle$ phases also arise only after the breaking of the $L$–$R$ symmetry and thus are $\sim M_R/M$.


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