Coupling constants of the standard model according to LEP data and scale of the left–right symmetry breaking

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The scales of the breaking of $SO(10)$ and $SU(2)_R$ symmetry are calculated in a grand unified model based on the $SO(10)$ group with intermediate left–right symmetry. New LEP data on the coupling constants of the standard model are taken into account. The results correspond to experimental data from the search for an instability of the proton.

The substantial improvement in the accuracy of the LEP data, which has made it possible, in particular, to determine $\sin^2\theta_W^{\overline{MS}}(M_Z)$ within $\pm 0.5\%$, has heightened interest in the ideas of grand unification (Ref. 1; see also Refs. 2 and 3). It turns out[1] that the foundation of these ideas—the intersection of all the constants α_i of the standard $SU(3)_C\times SU(2)_L\times U(1)_Y$ model at a common point—combined with recent data on the instability of the proton in a refinement of data on α_i, makes it possible to discard numerous phenomenological models of grand unification, starting with the minimal $SU(5)$ model with three generations and one Higgs doublet. Left as a contender for the role of a realization of the grand unification ideas is the minimal supersymmetric $SU(5)$ model, for which the renormalization-group equations, along with the LEP data, lead to a single unification scale of $10^{16\pm0.3}$ GeV, in agreement with the present lower limit on the lifetime of the proton. This analysis also suggests the mass scale of the superpartners of ordinary particles ($\sim 10^3$ GeV). These estimates have some far-reaching experimental consequences. The logic of a "supersymmetrization" of the standard model is undoubtedly attractive, and in this light it would be difficult to overestimate the importance of the increase in the accuracy of the LEP data.

In the same context, however, there is the possibility of using the accurate LEP data in a scenario in which the standard model is the end result of a breaking of the $SO(10)$ grand unification model. In this case the electroweak sector of the standard model would arise from a breaking of the left–right symmetry group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, which is a subgroup of $SO(10)$.

In the present letter we show that by working from the $SO(10)$-based renormalization-group equations for the constants of the standard model, and by using LEP data, one can achieve an intersection of the constants α_1, α_2, and α_3 at a common point. This intersection is furthermore compatible with the lifetime of the proton, τ_P. Instead of talking in terms of the mass scales of the superpartners of particles, we can require that the constants intersect at one point and use the LEP data to estimate the permissible range of scales in which parity nonconservation would arise. In other words, we will not supersymmetrize the standard model. We will instead assume that this model arises as the final step of a breaking of $SO(10)$ symmetry.

A very simple version of the $SO(10)$ model, with an intermediate left–right symmetry, was proposed in Refs. 4–6. In that case there is no problem with the lifetime of

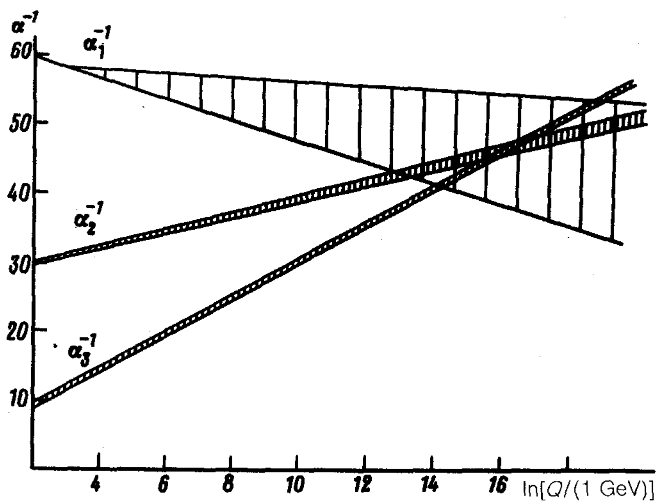

FIG. 1. Evolution of the coupling constants α_1, α_2, and α_3 as a function of the energy in the $SO(10)$ model.

the proton. The scenario for the breaking of $SO(10)$ can be outlined as follows: First, $SO(10)$ is broken by the 45-plet vacuum expectation value $\sim M_X$ to the subgroup $SU(3)_C \times U(1)_{B-L} \times SU(2)_L \times SU(2)_R$. This subgroup is then broken to $SU(3)_C \times SU(2)_L \times U(1)_Y$ at a smaller scale M_R, associated with the vacuum expectation value of the 126-plet. Actually, the results are essentially independent of the particular choice of representation for the Higgs fields.

Analysis and solution of the renormalization-group equations describing the changes in the gauge constants α_i $(i = 1,2,3)$ associated with the groups $U(12)_Y$, $SU(2)_L$, and $SU(3)_C$, respectively, with a momentum transfer Q in the two-loop approximation, for the regions $Q > M_R$ and $\mu < Q < M_R$ $(\mu = M_Z)$, lead to the results shown in Figs. 1 and 2.

Figure 1 shows the behavior of the coupling constants $\alpha_i^{-1}(Q)$ as a function of Q. In a logarithmic Q scale, these results can be described very accurately by straight lines. It follows from the renormalization-group equations that the appearance of a breaking scale M_R in one loop has absolutely no effect on the course of $\alpha_3^{-1}(Q)$ [the equations for $\alpha_3^{-1}(Q)$ are the same as those for $SU(5)$], and it has very little effect on $\alpha_2^{-1}(Q)$. The main effect of the introduction of the new scale M_R is on the behavior of $\alpha_1^{-1}(Q)$. The lower plot of $\alpha_1^{-1}(Q)$ corresponds to the case $M_R = M_X$, as for the $SU(5)$ model. The upper plot of $\alpha_1^{-1}(Q)$ corresponds to $M_R = 10^3$ GeV, since the scale of the breaking of $SU(2)_R$ is definitely above 1 TeV.

We also note that the contribution of the second loop is insignificant, as are the contributions of the Higgs fields. Even less important is the contribution of the Higgs sector in the second loop, and we will ignore it.

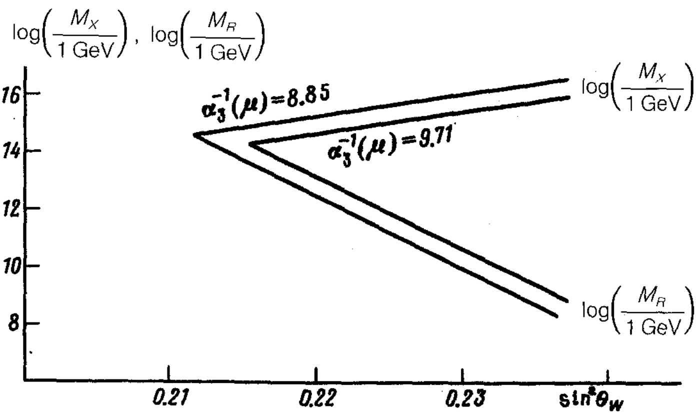

FIG. 2. Scale of the breaking of $SO(10)(M_X)$ and of the intermediate symmetry $SU(3)_C \times U(1)_{B-L} \times SU(2)_R \times SU(2)_L (M_R)$ versus the Weinberg angle $\sin^2 \theta_W$ for various values of $\alpha_3^{-1}\mu$.

It can be seen from this figure that the three curves intersect at values of M_R which lie between M_X and 10^3 GeV.

To determine the region corresponding to these values of M_R, we note that the behavior of M_X and M_R as a function of the Weinberg angle can be determined from the renormalization-group equations, by requiring that the three curves $\alpha_i^{-1}(Q)$ $(i = 1,2,3)$ intersect at a common point. Figure 2 shows these curves. Using recent data on the Weinberg angle, $\sin^2\theta_W^{\overline{MS}}(\mu) = 0.2336 \pm 0.0018$, and on the strong-coupling constants of $SU(3)_C$, $\alpha_3(\mu) = 0.108 \pm 0.005$, we find the following values for the scale of the breaking of $SO(10)$, M_X, and for that of the breaking of the left–right symmetry, M_R:

$$M_X = 10^{16.0\pm0.4}\ \text{GeV},$$
$$M_R = 10^{9.4\pm0.8}\ \text{GeV}. \tag{4}$$

We see that the proton lifetime determined by the value of M_X can be vastly longer than the values predicted in the ordinary $SU(5)$ model, and it does not contradict experiments carried out to search for proton decay.[1]

We also note that an important prediction of the $SU(5)$ model, regarding the mass of the b quark,[7] remains in force in the case at hand. The reason is that in the relation $m_b \approx 3m_\tau$ the relative renormalization of the masses of the b quark and the τ lepton is dominated by the strong-interaction constant α_3, whose energy dependence is the same in $SU(5)$ and $SO(10)$, as was pointed out above. This relation in the $SO(10)$ model is thus the same, within the errors, as in $SU(5)$.

One should bear in mind that the breaking $SU(2)_R \times U(1)_{B-L} \to U(1)_Y$ discussed above might occur in two steps: First, the vacuum expectation value of the 45-plet, $\sim M_R$, breaks this group to $U(1)_R \times U(1)_{B-L}$, and then the vacuum expectation value of the 126-plet breaks the symmetry to $U(1)_Y$. The overall breaking scheme is[6]

$$\begin{aligned} SO(10) &\xrightarrow{M_X} SU(3)_C \times U(1)_{B-L} \times SU(2)_L \times SU(2)_R \\ &\xrightarrow{M_R} SU(3)_C \times U(1)_{B-L} \times SU(2)_L \times U(1)_R \\ &\xrightarrow{M_R^0} SU(3)_C \times SU(2)_L \times U(1)_Y. \end{aligned}$$

The introduction of the new scale M_R^0 has essentially no effect on the predictions of the proton lifetime. The scale M_R^0, on the other hand, might be fairly small[6,8] ($\gtrsim 1$ TeV). In this case we would expect effects which could be observed in the not too distant future (a new neutral boson, Z', with a mass > 1 TeV).

The two cases discussed here do not exhaust all possible scenarios for the breaking of $SO(10)$ to the standard model. These scenarios are discussed in detail in Refs. 4, 6, 8, and 9. Analysis shows, however, that either the other scenarios do not lead to acceptable values of τ_P or they depend very strongly on the multiplet composition of the Higgs sector.

In summary, the analysis above shows that the $SO(10)$ model proposed here is in complete correspondence with the recent LEP data and also with experiments carried out to search for an instability of the proton. We do not believe that these estimates of the scales of the $SU(2)_R$ and $U(1)_R$ breaking found in light of the new LEP data are totally devoid of interest.

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