Electroweak nonconservation of the baryon number in the decay of heavy particles

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A technicolor model is used to show that an electroweak nonconservation of the baryon number due to the θ structure of the vacuum and the triangular anomaly may be considerable in the decay of particles with a mass greater than or comparable to $M'_W/\alpha_W(\sim 10$ TeV). Experiments have shown that such a decay is marked by the production of a large number of quarks (jets) and leptons in the final state.

Anomalous nonconservation of fermion quantum numbers such as the axial $U(1)$ charge in four-dimensional quantum chromodynamics[1] and two-dimensional quantum electrodynamics[3] or the baryon number in the standard electroweak theory[1] is an intriguing effect of the θ structure of vacuum in the gauge theories.[1–3] In four-dimensional theories with a small coupling constant, the nonconservation of fermion quantum numbers is usually associated with instantons[4] that describe tunnel transitions between the vacuums with different quantum numbers, so that the corresponding amplitudes are assumed to be exponentially small. In particular, the electroweak nonconservation of baryon number is assumed to be suppressed by a factor $\exp(-\text{const}/\alpha_W)$.

In the present letter we show that in models containing heavy paticles (with a mass greater than or equal to $M_W/\alpha_W \sim 10$ TeV) the anomalous electroweak nonconservation of baryon number in the decay of these particles may be fairly large (the reader is referred to Ref. 5 for more details). As an example, we consider the decay of a technibaryon in the technicolor model.[6] We will describe the technibaryon using Skyrme's model.[7,8] We can write the Lagrangian of Skyrme's model (within the context of technicolor) with the $SU(2)_L$ gauge group (the weak-hypercharge group is un-

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important in our discussion) as

$$L = \frac{1}{2g_W^2}\,\mathrm{Tr}\,A_{\mu\nu}^2 - F_\Pi^2\,\mathrm{Tr}(U^{-1}D_\mu U)^2 + \frac{1}{32e^2}\mathrm{Tr}\,[\,U^{-1}D_\mu U, U^{-1}D_\nu U\,]^2\,, \quad (1)$$

where $U=\exp(i\tau^a P^a/2F_P)$, P^a are the technipion fields, F_P is the technipion coupling constant, e is Skyrme's constant, and $D_\mu = \partial_\mu + A_\mu$. If the technicolor number (N_{TC}) is large, we have

$$F_P^2 \propto N_{TC} \text{ and } e^2 \propto N_{TC}^{-1}\,. \quad (2)$$

In the case of a gauge transformation of ω from $\mathrm{SU}(2)_L$, the field $U(x)$ transforms in the following way: $U \to \omega U$, so that we can choose a unitary gauge $U=1$. In this gauge $D_\mu U = A_\mu$. We see from (1), therefore, that the vector bosons acquire a mass $M_W = g_W F_P$ but the technipions vanish from the spectrum.

Let us consider the static solitons (technibaryons) in model (1). These solitons are the local minima of the energy functional. It is useful to replace the variables $x^i = y^i/F_P e$, $A^i = F_P e B^i$ (it may be assumed that $A_0 = 0$ for a static soliton) and to write the energy functional in the unitary gauge as $H=(F_P/e)\widetilde{H}$, where

$$\widetilde{H} = -\frac{e^2}{2g_W^2}\int \mathrm{Tr}\,B_{ij}^2\,d^3y - \int \mathrm{Tr}\,B_i^2 d^3y - \frac{1}{32}\int \mathrm{Tr}[B_i, B_j]^2\,d^3y\,. \quad (3)$$

In the limit $g_W^2/e^2 \to 0$ (weak interactions are switched off), the first term in (3) is the dominant term if it is nonvanishing. The requirement that the first term be zero means that B_i is of a "purely gauge" form, $B_i = V\partial_i V^{-1}, V(\mathbf{x})\in\mathrm{SU}(2)$. A minimization of the remaining terms with a B_i of this type leads to Skyrme's equations that have a soliton solution with a topologically nontrivial V. The mass of a soliton (technibaryon) is on the order of F_P/e; a soliton is classically stable and can decay only through tunneling, i.e., as a result of an instanton transition.[9]

On the other hand, the first term in (3) may be omitted when the values of g_W^2/e^2 are fairly large. The energy functional does not have a local minimum. The second and third terms in (3) are positive and, after a scale transformation $B_i \to \lambda B_i$, behave as λ^2 and λ^4, respectively, demonstrating that there is no local minimum (this is the standard Derrik argument; see Ref. 8). There is accordingly no metastable technibaryon in this case (in Skyrme's model, at any rate). Since the technibaryon number is not conserved only because of electroweak triangular anomaly, we conclude that the nonconservation of this number is appreciable if g_W^2/e^2 is larger than a certain critical value of about unity or, in other words, if the technibaryon mass, $M_{TB} \sim F_P/e$, is larger than a certain critical value of about $F_P/g_W \sim M_W/\alpha_W$ (the calculation of this critical value will be published elsewhere[10]). According to (2), this argument holds at least when the values of N_{TC} are fairly large.

In models in which a technibaryon has such a large mass, a perturbative production of a technibaryon (in combination with an anti-technibaryon) leads to its rapid anomalous decay (it may be assumed[5] that its lifetime is on the order of M_W^{-1}). This decay produces $\mathrm{SU}(2)_L$-group gauge fields with a unitary value $q \equiv (32\pi^2)^{-1}\int \mathrm{Tr}\,A_{\mu\nu}\widetilde{A}_{\mu\nu}\,d^4x$, since a change in the technibaryon number is equal to q.

In Skyrme's model, for example, the technibaryon state (in unitary gauge) is described by a configuration of the type $A_i(\mathbf{x},t=0) = V\partial_i V^{-1}$ with a topologically nontrivial $V(\mathbf{x})$; its decay is a classical transition of this configuration to a vacuum $A_i(\mathbf{x},t=\infty) = 0$; for such $A_i(\mathbf{x},t)$ we have $q=1$. The electroweak gauge fields with $q=1$ produce ordinary quarks and leptons. Here the standard baryon and lepton numbers are not conserved and the fermion number of each doublet changes by unity.[11] The anomalous decay of a technibaryon is thus accompanied by the production of at least nine quarks (jets) and three leptons, a characteristic which can be observed experimentally.

We note in conclusion that unsuppressed anomalous nonconservation of the baryon and lepton numbers in the decay of heavy particles may be a characteristic feature of not only the technicolor models. There are arguments[5] supporting the fact that baryon and lepton numbers are not conserved in the standard electroweak model with a Higgs mechanism if this model contains elementary fermion doublets whose mass exceeds a certain critical value of about M_W/α_W. These arguments, however, compound the difficulty of analyzing this problem quantitatively, since the Yukawa coupling constant for heavy fermions with a Higgs field is large (on the order of g_W^{-1}).

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