V. A. Rubakov. *Structure of the vacuum in gauge theories and monopole catalysis of proton decay.* The problem of the structure of the ground state is one of the key problems of contemporary quantum field theory. The properties of the vacuum determine to a significant degree both the spectrum of particles and the characteristic features of their interactions. Special interest in presented by study of the structure of the ground theories, which form the basis for the construction of models of the strong, weak, and electro-magnetic interactions. Recently it has been shown[1,2] that the requirement of conservation of such quantum numbers as fermion number or chirality is in conflict with the requirement of gauge invariance, which is fundamental in gauge theories. The unitary operators $U[\alpha]$ which perform gauge transformations with gauge parameters $\alpha(x)$ which do not vanish at infinity, generally speaking, carry the fermion number or chirality; as a result of this the vacuum of perturbation theory $|0\rangle$ is not gauge-invariant, and the physical ground state is a linear superposition of the form

$$|\theta\rangle = \sum_{n=-\infty}^{\infty} e^{-in\theta} (U[\alpha])^n \,|\, 0\rangle.$$

The physical vacuum $|\theta\rangle$ does not have a definite fermion number or chirality, and excitations above it cannot be characterized by these quantum numbers; fermion number and chirality, generally speaking, are not required to be conserved. Arguments[1] favoring the θ structure of the vacuum in four-dimensional theories have been based on investigation of the contribution of instantons[3] to the functional integral. In the exactly solvable two-dimensional model (quantum electrodynamics with massless fermions) the gauge transformation operators were constructed explicitly[2] and the ground state of the model actually does have undetermined fermion number and chirality.

In quantum chromodynamics the vacuum structure involves nonconservation of chirality[1] (but not of fermion number), which may form the basis for solution of the well known $U(1)$ problem (the absence of the ninth light pseudoscalar boson). In addition a number of new problems arise such as the problem of *CP* conservation in strong interactions.[1,4] In models of weak and electromagnetic interactions there is nonconservation of fermion and baryon number due to the complex structure of the ground state, but the corresponding amplitudes are suppressed by a factor $\exp(-\mathrm{const}/\alpha)$ and by inverse powers of the mass of the W boson.[1]

It has recently been discovered[5–9] that similar suppression factors do not arise if one considers processes involving magnetic monopoles. Monopoles[10] appear in unified models of strong, weak, and electromagnetic interactions as static solutions of the classical field equations; in quantization they correspond to particles whose mass is estimated to be of the order 10^{16}–10^{17} GeV. Like the vacuum state, the monopole state does not have a definite fermion number, but in contrast to the vacuum sector, transitions between monopole states with different fermion numbers are described by gauge field configurations having an action which differs arbitrarily little from the action of the monopole itself. This leads to disappearance of the exponential suppression of the amplitudes of processes with fermion number nonconservation. The absence of suppression by inverse powers of the heavy vector boson mass is due to the fact that the corresponding configurations can have a purely electromagnetic nature. In spite of the fact that investigation of processes with nonconservation of fermion number in the presence of monopoles cannot be carried out either in the framework of perturbation theory or by means of the standard saddle-point method, it has been possible to calculate some matrix elements.[6] We shall give as an example the expression for the density of fermion condensate which violates the baryon number in the presence of a monopole in the SU(5) model of grand unification:

$$\langle uude^-(x)\rangle^{\mathrm{mon}} = \frac{1}{(4\pi)^4 r^6},$$

where r is the distance to the monopole. This expression is valid with accuracy to quantum corrections of order α_s and α in the region $r \lesssim 10^{-13}$ cm. Matrix elements of this type describe processes of proton decay in the presence of a monopole, i.e., the processes

$$\mathrm{p} + \mathrm{monopole} \to \mathrm{e}^+ + \mathrm{monopole} + \mathrm{pions}.$$

An estimate of the cross sections for these processes has the form[9]

$$\sigma \sim \left(\frac{c}{v}\right)^2 \sigma_0,$$

where $\sigma_0 \sim 10^{-28}$ cm^2; it is assumed that $v/c \ll 1$. Other modes of "decay" of the proton with the same characteristic cross section also exist.[5,7–9]

The best experimental restrictions on the flux of relic superheavy magnetic monopoles have been obtained at the Baksan Neutrino Observatory of the Nuclear Research Institute, USSR Academy of Sciences[11]: $j < 5 \cdot 10^{-15}$ cm^{-2} sec^{-1} sr^{-1}. The possibility of monopole catalysis of proton decay permits one to search for monopoles in underground[5] and underwater[12] Cherenkov detectors. Here one can hope to achieve a flux value $j \sim 10^{-17}$ cm^{-2} sec^{-1} sr.$^{-1}$ Monopole catalysis inside the Sun and inside neutron stars could appear respectively in the appearance of a flux of neutrinos from μ^+ decay[5] and a flux of thermal radiation in the x-ray region.[7,13]

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