Superheavy magnetic monopoles and decay of the proton

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(Submitted 10 May 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **33**, No. 12, 658–660 (20 June 1981)

A possible pronounced nonconservation of baryon number in interactions involving magnetic monopoles is discussed in a unified theory with SU (5) gauge group. Possible experimental consequences of this nonconservation are examined.

PACS numbers: 13.30.Ce, 12.20.Hx, 11.30.Ly, 14.80.Hv

Unified theories of the strong, weak, and electromagnetic interactions[1] predict the existence of magnetic monopoles of the 't Hooft-Polyakov type with a mass $M_{\text{mono}} \sim 10^{16}$ GeV (Ref. 2). I have recently argued[3] that an axial anomaly would lead to a pronounced nonconservation of baryon number in interactions involving magnetic monopoles. In the present letter I wish to pursue this possibility for the particular case of the simplest of monopoles in a theory with the $SU(5)$ gauge group. Possible experimental consequences of a nonconservation of baryon number will also be discussed.

The simplest monopole in the $SU(5)$ theory has a magnetic charge $g_m = 2\pi/e$ and a chromomagnetic charge $g_{\text{cm}} = 2\pi\sqrt{3}/g_c$, where g_c is the gluon coupling constant.[4] It can be shown that an axial anomaly makes the following process possible[3]:

$$p + \text{mono} \to e^+ + \text{mono} + X. \tag{1}$$

This effect is completely analogous to the violation of chirality and baryon number because of instantons,[5] but it differs in that it leads to an amplitude for reaction (1) which is not suppressed by a factor $\exp(-\text{const}/e^2)$ or by inverse powers of the leptoquark mass.[3] A model-based calculation similar to that of Ref. 3 gives

$$< M \,|\, u(r)\, u(r)\, d(r) e^-(r) \,|\, M > \,=\, C/r^6, \tag{2}$$

where $|M\rangle$ is the state of the monopole, C is a numerical constant which is independent of the coupling constants, r is the distance from the center of the monopole, and it is assumed that $r \gg M_x^{-1}$ and $r \ll M_p^{-1}$, where $M_x \sim 10^{14}$ GeV is the mass of the leptoquark. The matrix element in (2) corresponds to reaction (1). In the nonrelativistic approximation the corresponding cross section is

$$\sigma = \sigma_0 c/v, \tag{3}$$

where v is the relative velocity of the monopole and the proton. To calculate the constant σ_0, we must go beyond perturbation theory; a dimensional estimate is

$$\sigma_0 \sim M_p^{-2} \ . \tag{4}$$

In addition to reaction (1), the following may occur[3]:

$$p + \text{mono} \rightarrow e^{+} + \mu^{+} + \mu^{-} + \text{mono} + X, \qquad (5)$$

The ratio of the cross sections for reactions (5) and (1) may be a few percent (in contrast with the spontaneous decay of the proton, for which the corresponding ratio is of order $\alpha \sim 10^{-4}$).

In a theory with the group $SU(5)$ there are also monopoles with a zero chromomagnetic charge and with a magnetic charge $g_m = 6\pi/e$ (Ref. 4). It can be shown that reactions (1) and (5) with cross sections (3) and (4) would be possible for these monopoles (a study of this question by M. S. Serebryakov and the present author will be published separately).

The occurrence of reactions (1) and (5) raises the possibility of detecting superheavy, relict magnetic monopoles in an experimental search for decay of the proton. The relict monopoles have energies $E_{\text{mono}} \sim 10^{10}$–$10^{12}$ GeV (Refs. 6 and 7) and corresponding velocities $v_{\text{mono}} \sim (10^{-3}$–$10^{-2})c$. In passing through matter, relict monopoles would lose an energy of no more than 10 GeV/g (Refs. 8 and 7), so that they would lose essentially no energy in passing through the earth. For these velocities we find the cross section for reaction (1) from (3) and (4) to be[1)]

$$\sigma \sim (10^{-25} - 10^{-26})\ \text{cm}^{-2}. \qquad (6)$$

Since the energy transfer in reaction (1) is small (no greater than 1 MeV), the primary distinctions between these reactions and the spontaneous decay of the proton are (a) the relatively large fraction of events corresponding to (5) and (b) the possibility that several proton decays will be generated in a single apparatus, separated by $10^{1\pm2}$ cm in space and by $10^{-6\pm2}$ s in time (in a medium with a density of 1 g/cm^3). At $v_{mono} \sim 10^{-2}$ c, the passage of a monopole through matter is accompanied by a substantial ionization loss (1–10 GeV/cm; Refs. 7 and 8), while the loss decreases sharply at lower velocities.

To get an idea of the feasibility of experimentally searching for decay of the proton, let us find the flux density of monopoles corresponding to a proton lifetime $\tau_p = 10^{31}$ yr. Using $\sigma = 10^{-25}$ cm^2 for an estimate, we find $j_{\text{mono}} = (\sigma\tau_p)^{-1} = 10^{-13}$ cm^{-2} s^{-1}, which is not far from astrophysical limits[2)] (Refs. 7 and 9): $j_{\text{mono}} \lesssim 10^{-14}$ cm^{-2} s^{-1}.

We will conclude by examining the possibility of finding evidence of monopoles in the sun. Reactions (1) and (5) lead to the appearance of electron neutrinos through μ^+ decay.[3)] Present-day experiments are capable of detecting a flux density $j_\nu \sim 10^4$ cm^{-2} s^{-1} of these neutrinos at the earth;[4)] the corresponding total number of monopoles in the sun would be $N_{\text{mono}} \sim 10^{27}$ if the cross section for reaction (1) was given by Eqs. (3) and (4) and if a μ^+ appeared in 1% of the decay events. We note that this is the number of monopoles which would enter the sun in 10^{10} yr at a flux density $j_{\text{mono}} \sim 10^{-13}$ cm^{-2} s^{-1}.

In summary, the occurrence of reactions (1) and (5) would make it possible to detect in an experimental search for proton decay and to detect monopoles within the sun through an experimental study of solar neutrinos. The corresponding flux densities are close to the limits which have been established from astrophysical considerations.

I wish to thank G. V. Domogatskiĭ, V. A. Kuz'min, and M. E. Shaposhnikov for the discussions which led to most of the ideas regarding the observability of reactions (1) and (5). I also thank V. A. Matveev for much interest and support and I. M. Zheleznykh, N. V. Krasnikov, V. G. Lapchinskiĭ, S. P. Mikheev, A. A. Pomanskiĭ, M. S. Serebryakov, A. Yu. Smirnov, V. F. Tokarev, and M. Yu. Khlopov for interest in this work and for useful discussions.

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1)We emphasize that estimate (6) is very uncertain, because of both the rough nature of estimate (4) and the error in the determination of the monopole velocity. Thus we cannot rule out the possibility that the cross section for reaction (1) might be 10^{-23} cm^2 or 10^{-28} cm^2.

2)This limit was obtained by assuming that monopoles are carried out of the galaxy by the magnetic field. Otherwise, the limit on the flux density would be less stringent.[7]

3)As V. A. Kuz'min and M. E. Shaposhnikov have pointed out, the production of decay neutrinos is not unique to these processes: Most processes involving the release of an energy of the order of 1 GeV or more lead to the production of π^+ and, ultimately, ν_e.

4)The Davis experiment yields a limit $j_\nu < 2 \times 10^4$ cm^{-1} s^{-1}. I thank G. V. Domogatskiĭ for bringing this estimate to my attention.

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Translated by Dave Parsons
Edited by S. J. Amoretty