Lower limit on the proton lifetime according to data from the Baksan underground scintillation telescope

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(Submitted 12 May 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **33**, No. 12, 664–667 (20 June 1981)

Two inner layers of scintillators of the Baksan underground telescope are used to study proton decay, while six outer layers serve as an anticoincidence shield. No signal with an energy $\geq$ 500 MeV was observed over an exposure time of 0.47' yr. On this basis a lower limit of 1.25×10^{30} yr is estimated for the lifetime of the proton (or the neutron).

PACS numbers: 14.20.Ei, 13.30.Ce

According to the grand unification theory, the proton should, in principle, be unstable and should decay in a manner which does not conserve baryon number. Experimental observation of this process seems the only imaginable way to obtain direct experimental confirmation of this idea, which may prove to be the basis for a unified theory of the strong, weak, and electromagnetic interactions. In these grand unified models the energy at which the "unification" occurs is so high (10^{15} GeV) as to be completely beyond the reach of either any sort of fantastic accelerator or any astrophysical objects at the present time. This would have always been the case except during the first few moments following the Big Bang. If the temperature reached this fantastic level at that time, then fast processes which violated baryon-number conservation would have occurred and could, in principle, have led to the observed baryon–antibaryon asymmetry of the universe.

Whether it would be feasible to experimentally observe the spontaneous decay of the proton depends on its lifetime. Existing models put this time somewhere between 10^{27} and 10^{34} yr. In the SU(5) model, a lifetime of 10^{30} yr is believed to be the most probable, and this value corresponds approximately to the lower limit which has already been established experimentally. This limit was extracted from experiments which were carried out a decade ago[1] and which were not planned explicitly as a search for proton decays. In contrast, several plans involving large installations designed especially for this purpose, are currently being implemented. All call for measurements to be made as far underground as possible and involve the use of from 100 to 10 000 metric tons of some medium in which the proton or neutron[1)] decay is to be detected. Measurements are already being carried out (and have been since late 1980) in the first of these projects, which uses a 100-metric-ton apparatus in a deep KGF mine in India.[2]

Turning to the Baksan scintillation telescope, with which we are concerned in the present letter, we note that its depth is comparatively modest, 850 m.w.e. (meters water equivalent). Although the flux density of cosmic-ray muons is 5000 times lower than at the surface, the muon background still presents a serious problem in the use of this apparatus to search for proton decays. Nevertheless, in 1980 we undertook such a search, after making some structural changes to improve the anticoincidence shielding.

The telescope consists of four horizontal and four vertical layers of scintillation detectors, in the form of a rectangular parallelepiped with external dimensions of 17 × 17 × 12 m (Ref. 3). For this experiment, the top and bottom horizontal layers along with all four of the vertical layers constitute the anticoincidence shielding. Only the two inner horizontal layers are used to detect proton decays. The total mass of the telescope is 2500 metric tons, of which 330 metric tons is the liquid scintillator in the total of 3200 detectors. The mass of the two inner layers is 770 metric tons, of which 85 metric tons is liquid scintillator, and the rest is reinforced concrete. Whether the decay of a proton (or neutron) can be detected under these conditions depends on what fraction of the total decay energy of 938 MeV is evolved in a scintillator with a thickness of 23 g/cm^2. The total energy evolution in one of the two inner scintillator layers was measured under the condition that there was no signal corresponding to 5 MeV or more in one of the outer layers or in the other inner layer. A second condition was that at least two detectors of a given layer operate (these are usually adjacent detectors) at a level corresponding to at least 12.5 MeV. This requirement eliminates events resulting from spontaneous discharges in the photomultipliers.

The second row in Table I gives the integrated energy distribution of events meeting these requirements over a total measurement time of 0.47 yr. The third row shows the results of Monte Carlo calculations for 1000 nucleon decays in the 770 metric tons of material. These calculations included 500 proton decays in the mode $p \to e^+ + \pi^0$ and 500 neutron decays in the mode $n \to e^+ + \pi^-$, corresponding to $\tau = 2.2 \times 10^{29}$ yr. The ratio of the expected effect to the background improves continuously with increasing threshold energy, but the efficiency falls off, also continuously, reaching a level of only 1.3% at 500 MeV. The fourth row gives the lower limits on the proton (or neutron) lifetime for the particular threshold energy. The experimental distribution in the second row agrees well in both shape and magnitude with the background resulting from muons penetrating through the gaps in the anticoincidence

TABLE I.

E, MeV	50	100	200	300	400	500	600	700	800	900
N_{expt}	920	470	96	27	7	0	0	0	0	0
N_{calc}	215	172	72	42	25	13	8	6	2	0
$\tau \cdot 10^{-30}$	0,05	0,1	0,2	0,3	0,5	1,25	0,77	0,57	0,19	–
90% conf. lev.	1,2[1]	1,3[1]	1,2[1]	1,2[1]	1,2[1]					

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[1] After subtraction of the background, under the assumption that it is precisely equal to the measured intensity.

sheield (this background was studied in a parallel experiment). The sharp cutoff of the background energy distribution is attributed to the absence of muons moving along nearly horizontal directions (because of their absorption in the surrounding masses of rock). In principle, this background could be subtracted, but in practice the best result is obtained at a threshold of 500 MeV, at which there is no background, so that the validity of the subtraction becomes irrelevant. It should also be noted that a high threshold limits not only the effective mass in this experiment but also, in general, the sensitivity to certain decay modes. Strictly speaking, the result found here applies only to the two-particle decay modes for which the Monte Carlo calculations were carried out, but a qualitative analysis shows that the probability for the absorption of half of the decay energy in a flat scintillator layer 23 g/cm^2 thick is no lower for multiparticle decay modes, provided that no significant fraction of the energy is carried off by neutrinos. Consequently, the lower limit on the lifetime of the proton (or neutron) which emerges from this experiment is 1.25×10^{30} yr (at a 90% confidence level) for all neutrino-free decay modes.

[1)] When bound in a nucleus, the proton and the neutron have an identical lifetime, and this lifetime is the same as that of the free proton. A nucleus would of course have some effect on the kinematics of the emitted decay products when these products are hadrons.

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Translated by Dave Parsons
Edited by S. J. Amoretty