A proposed experiment to search for the decay of a nucleon

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(Submitted 30 March 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **33**, 482–484 (5 May 1981)

An experiment to search for the decay of a nucleon bound in a nucleus is proposed. Detection of the neutrons evaporated from excited nuclei would make it possible to observe the decay of a nucleon with a half-life $\leq 10^{31}$ yr.

PACS numbers: 13.30.Ce, 14.20.Cg, 14.20.Ei

The stability of the nucleon has recently attracted intense interest because certain theories which agree with experimental data on electromagnetic, weak, and strong interactions predict a nucleon lifetime which may be shorter than 10^{32} yr. Experiments carried out be Reines *et al.*[1] have been interpreted as implying a lower limit of 3×10^{30} yr on the lifetime of the nucleon, if it is assumed that the decay products include muons. Preparations are reportedly[2] being made for several experiments to detect the nucleon-decay modes.

Another approach to the detection of this decay is to observe the various nuclear conversions that are caused by the decay. In the late 1950s, Flerov *et al.*[3] carried out experiments to search for the spontaneous fission of thorium. They found a lower limit of 10^{21} yr for the thorium decay half-life, and on this basis a lower limit of 2×10^{23} yr was assigned to the decay half-life of the nucleon. Techniques for detecting spontaneous fission have subsequently been improved in the course of a search for naturally occurring, superheavy elements.[4] We believe that these improved methods can be adapted to search for the decay of the nucleon, as we shall now attempt to show. Let us consider the operating principle of the neutron detectors used by Flerov *et al.* A moderator block surrounded a sensitive volume in which the sample was placed. Neutrons emitted from the sample were detected by ^{3}He-filled proportional counters in the moderator. The average lifetime of a thermal neutron (τ) was a few tens of microseconds, and an event was identified as a spontaneous-fission event if two or more neutrons were detected within a time interval of $(4\text{–}5)\tau$. The system used to seek such events was triggered when a single pulse appeared in any of the counters. The measurements were carried out at a depth of 1100 mwe (meters water equivalent), and an anticoincidence system was used to reject the background of cosmic-ray muons. Several years of measurement yielded an upper limit on the background of multiple events: less than one event per year.

This principle can be used to observe the decay of nucleons which are bound in heavy nuclei. The decay of a nucleon should be accompanied by the production of strongly interacting particles; the SU_5 model, for example, predicts[5] high probabilities for the decays $p \rightarrow e^+\pi^0$ and $n \rightarrow e^+\pi^-$. The spontaneous generation within a nucleus of a pion in a reaction of this sort should lead to an intranuclear cascade, to the emission of cascade particles, and to the formation of excited nuclei. The sum of the excitation energy of the nucleus within which the nucleon decays and the excitation energies of other nuclei, which might either capture the stopped π^- meson or undergo a secondary interaction with cascade neutrons, would range from 100 to 400 MeV. The decay of such excited nuclei would be accompanied by the evaporation of 10–20 neutrons. Other permissible nucleon-decay mechanisms would also lead to the formation of excited nuclei, and these nuclei would emit roughly the same number of neutrons. Such events could be detected by a neutron detector with a probability approaching unity.

In experiments carried out to find naturally occurring superheavy elements, the background was determined by placing samples of lead, ferrous–ferric oxide, and quartz in the sensitive volume. The total measurement time for a standard 100-kg lead sample was about 50 days. Since no multiple events have been detected, a lower limit of 5×10^{27} yr can be put on the decay half-life of the nucleon.

In order to push this lower limit up to the values predicted by the theories, it would be necessary to substantially increase the weight of the sample and the measurement time. It would be a comparatively simple matter to increase the total amount of lead in the detector to 100 metric tons. This would require, for example, a stack of 50 lead blocks $0.22 \times 0.44 \times 2$ m in size, surrounded by layers of acrylic plastic, which would hold the ^{3}He counters. In this stack it would be necessary to place about 1000 counters, each 2 m long and 3 cm in diameter and filled with ^{3}He to a pressure of 5 atm. The outside dimensions of the apparatus would be $3.1 \times 2.7 \times 2$ m, and the weight of the lead would be about 110 metric tons. The probability for detecting single neutrons emitted from the lead blocks would be about 0.4. If 10–20 neutrons were emitted simultaneously, there would be a probability >0.95 for detecting two or more neutron signals. The probability for detecting five or more would be 0.8. If the decay half-life of a nucleon bound in a nucleus were 10^{31} yr, then three events with 5–10 neutrons each would be detected per year.

Let us consider the various sources of background which would operate in such measurements. The spontaneous fission of a uranium impurity in the sample would lead to the detection of multiple-neutron events. It would apparently be a simple matter to produce lead with no more than 10^{-9} parts by mass of uranium. In this case, about 2×10^4 fission events would occur per year in a 100-metric-ton sample, and more than 3×10^3 events with a multiplicity $\geqslant 2$ would be detected. The probability for detecting events with a multiplicity $\geqslant 5$, however, is low (one event in 5–10 yr). Another source of background would be the interaction of atmospheric muons and neutrinos. In experiments at a depth of 1.5–2 km the number of nuclear interactions of muons would be 1000–1500 per year, while the number of interactions of atmospheric neutrinos would be about 20 per year. These interactions would lead to the production of hadron showers and, ultimately, the evaporation of neutrons from excited nuclei. Most such events, however, could be easily distinguished from nucleon-decay events on the basis of the number of detected neutrons (more than 10) and the topology. The muon background could be suppressed essentially completely with an anticoincidence system, which would also eliminate a substantial fraction of the neutrino background resulting from the interactions of charged currents.

The background level for this apparatus would apparently be 1–2 events per year. We do not rule out the possibility that a more thorough analysis would make it possible to reduce this background level even further. Proceeding with this estimate, however, we conclude that the decay of the nucleon could be observed in an experiment of this type if the decay half-life were $\leqslant 10^{31}$ yr. Since the result of such an experiment would apparently be as independent as possible of assumptions regarding the nucleon decay channels, it seems to be a worthwhile experiment. Such a detector might also yield new information on the flux of high-energy neutrinos.

I wish to thank G. M. Flerov for suggesting this topic and for stimulating discussions, and I also thank Yu. Ts. Oganesyan for useful discussions during the preparation of this paper.

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Translated by Dave Parsons
Edited by S. J. Amoretty