Comment on "Is Proton Decay Measurable?"

In a recent Letter, Horwitz and Katznelson[1] suggest that proton decay might be significantly inhibited in a nucleus. They argue that the proton's existence is constantly being monitored through collisions with other nucleons in the nucleus, and that this approximates a continuous series of quantum mechanical measurements which invalidates the usual analysis of a decaying state. An examination of decaying-state theory shows their analysis to be faulty and their conclusions incorrect. Since the decay interaction is very weak, it is perfectly adequate to treat it in lowest-order perturbation theory. This involves simply the matrix element of the decay interaction between eigenstates of the exact Hamiltonian for all strong, electromagnetic, and weak interactions except the proton decay interaction. Nucleon collisions are not and should not be regarded as measurements; rather, the nucleus as a whole is initially described by a pure quantum state.

After very short times ($\sim 10^{-23}$ sec), the rate for a nucleus N to decay into a new nuclear state N' plus debris D from a proton decay becomes constant. To first order in the (ultraweak) decay interaction H_D, this rate is just

$$\Gamma = 2\pi \sum_{N'D} \delta(E_{N'} + E_D - E_N) \,|\langle N'D|H_D|N\rangle|^2.$$

All nuclear interactions, both before and after the decay, are treated *exactly* in this formula; such effects enter through the states $|N\rangle$ and $|N'D\rangle$. We have approximated H_D by a local interaction. The nonlocality due to exchange of the X boson occurs over time scales $\sim 10^{-15}\ \mathrm{GeV}^{-1}$, much shorter than typical nuclear time scales. Consequently, for all practical purposes, Γ is the exact decay rate of nucleus N.

The question remains as to the validity of approximating Γ by the decay rate Γ_0 for a free nucleon multiplied by the number of nucleons in N. This result follows directly from closure over the nuclear states provided we neglect (a) the excitation energy of the final nuclear state relative to the kinetic energy of the decay products; (b) time dilation due to the decaying nucleon's Fermi motion; (c) energy shifts due to the fact that the decaying nucleon is off the mass shell; and (d) strong interactions between the nucleon's decay products and the remaining nucleons. Most of these effects are indeed negligible since the decay products D have very large kinetic energies (~ 500 MeV) relative to the nucleons (~ 20 MeV). The most important corrections are probably due to final-state interactions between mesons in D and nucleons in N'. These interactions are unlikely to alter the rate by more than (30–50)% although they may affect the "signature" for nucleon decay.[2]

Contrary to the impression given by Ref. 1, one need not go beyond the standard analysis for decaying states to include effects due to the nucleon-nucleon interactions in a nucleus. All such effects are included in the standard (Fermi's golden rule) expression for the nucleus' decay rate, given above. Standard techniques exist that relate this rate to the free nucleon rate Γ_0, and we find no corrections to the naive result (= No. of nucleons $\times\, \Gamma_0$) that are particularly significant, especially given the large uncertainties in calculations of Γ_0. Our analysis does not involve quantum mechanical measurement theory, and indeed we see nothing in this problem that resembles the rather exotic physics described in Ref. 1.

Our understanding of the physics of this problem benefited from discussions with our colleagues, particularly Kurt Gottfried and Henry Tye. This work was supported in part by the National Science Foundation.

G. Peter Lepage
Tung-Mow Yan
Donald R. Yennie
Laboratory of Nuclear Studies
Cornell University
Ithaca, New York 14853

Received 2 May 1983
PACS numbers: 14.20.Dh, 12.90.+b, 13.30.Ce

[1] L. P. Horwitz and E. Katznelson, Phys. Rev. Lett. 50, 1184 (1983).

[2] See, for example, C. Dover, M. Goldhaber, T. Trueman, and L. Chau, Phys. Rev. D 24, 2886 (1981).

