Nuclear Proton Decay

Horwitz and Katznelson recently suggested that nuclear collisions might lower the rate for the decay of nucleons inside nuclei so far below the decay rate for free baryons "that nucleon decay could be completely quenched and would not be observed at all in heavy nuclei."[1]

Essentially, their argument[1,2] goes as follows: Nuclear collisions effectively constitute "measurements" of the state of a nucleon. If the nuclear collisions occur rapidly enough, then each measurement takes place in the period during which the probability of a decay is proportional to the square of the elapsed time. After each measurement, the state vector representing the nucleon must be reduced so as to incorporate the result of the measurement. The probability of the nucleon's not decaying then takes the form, after N measurements separated by the time interval τ,

$$[1-(a\tau)^2]^N \approx \exp[-(aT)^2/N]$$

in which $T = N\tau$ is the total time of observation. Thus if the interval between measurements τ is sufficiently short, the probability of the nucleon's not decaying is essentially unity, even for very long observation times T.

However, one of the basic principles of quantum mechanics is that probability amplitudes are to be added unless the systems to which they refer are physically removed from the experiment, as by a baffle or a barrier. When systems are so removed, then it is appropriate to reduce the state vector accordingly. But nuclear collisions do not remove anything from the experiment. Thus a reduction of the state vector after each nuclear collision, or after many collisions, is inappropriate.

Let us recall how nuclear collisions are treated in the usual formalism. The nucleus is in a stationary ground state, $|0\rangle$, of the nuclear Hamiltonian H_0, if we neglect interactions that change baryon number. The nuclear Hamiltonian H_0 describes all nuclear many-body effects, including nuclear collisions. The total Hamiltonian H is the sum of H_0 and the term V that changes baryon number. The nuclear Hamiltonian H_0 possesses a complete set of eigenstates $|n\rangle$ with energies E_n. These states describe A interacting nucleons, $A-1$ nucleons plus $\pi^0 + e^+$, etc. The nucleus $|t\rangle$ at $t=0$ has baryon number $B=A$ and is in the ground state $|0\rangle$. The nucleus $|t\rangle$ at time t may be expanded in terms of the eigenstates $|n\rangle$ of H_0 as

$$|t\rangle = \sum_n a_n(t)\,|n\rangle \exp(-iE_n t).$$

The baryon decay rate may be determined from the formula

$$i\dot{a}_n = \sum_m a_m(t)\langle n|V|m\rangle \exp[i(E_n - E_m)t].$$

The nuclear Hamiltonian H_0, which describes the effects of nuclear collisions, does not appear in this formula; consequently neither it nor they affect the phase coherence of any $B \neq A$ states, $|m\rangle$, in $|t\rangle$. That phase coherence can only be affected by adding to H *other* pieces of the world Hamiltonian, describing, e.g., an external boundary or an observer. Many-body effects do enter the last formula through the matrix elements of V; they alter the nucleon decay rate by 5% to 50%.[3]

The present interpretation is supported by data on nuclear beta decay. In some nuclei, beta decay does not take place or is hindered because of Pauli blocking of the final proton. The approximately 20% quenching of Gamow-Teller transitions is due to medium effects. The rate of nuclear beta decay is about 10^{23} times slower than the rate of nuclear collisions. No quenching of the type suggested by Horwitz and Katznelson is observed.

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