Comment on "Tests of the Exponential Decay Law at Short and Long Times"

In a recent Letter by Norman *et al.*,[1] the results of a series of clever experiments to search for proposed deviations from the exponential decay law at short and long times were presented. The search for long-time deviations was extended to 45 half-lives with use of the β decay of ^{56}Mn, and in itself is very interesting. It was stated, however, that their measurements with ^{60}Co constituted "the first search for deviations from the exponential decay law at short times compared with the lifetime. . . ." They measured down to $10^{-10}t_{1/2}$, which is $\sim 1.7\times 10^{-2}$ sec. It is interesting to ask if one should have expected any deviation in this regime.

A number of authors point out that the time scale to reach exponentiality is dictated by the energy scale and independent of the decay constant.[2-4] We have performed calculations, analogous to Weisskopf or Moskowski estimates, to demonstrate this principle, and to estimate the time scale for a γ-unstable nucleus to achieve exponentiality.

A nonrelativistic treatment cannot give an accurate description of the time evolution of the decay constant $\lambda(t)$ at very early times when the system is far off the mass shell. It will give a good estimate of when exponentiality is reached.

The general solution to Schrödinger's equation is written:

$$\lambda(t)=\frac{4t}{\hbar^2}\int |\langle\psi_f|H'|\psi_i\rangle|^2(\omega t)^{-2} \times\sin^2(\tfrac{1}{2}\omega t)\rho(E_f)\,dE_f\,, \quad (1)$$

where $\omega=[E_\gamma-(E_i^0-E_f^0)]/\hbar$, and $E_{i,f}^0$ are the nuclear eigenstate energies, $\rho(E_f)$ is the usual density of final states, and ψ_i and ψ_f are the initial and final states of the total system of nucleus and radiation field. In the approach to Fermi's "golden rule," the function $(\omega t)^{-2}\times\sin^2(\frac{1}{2}\omega t)$ rapidly becomes a δ function, yielding the Fermi "golden rule."

In the present calculation, the nuclear matrix elements were evaluated in the single-particle harmonic-oscillator basis,[5] with $\hbar\omega_0=6$ MeV, and $E_\gamma=0.6$ MeV when $\omega=0$. The γ-ray matrix element was evaluated numerically as a function of ω, and no short- or long-wavelength approximations were used. The result of the evaluation of Eq. (1) at 50 different times is shown in Fig. 1. Other choices of the parameters, consistent with nuclear phenomenology in this region of the nuclide chart, do not affect the results drastically.

It is clear from Fig. 1 that all deviations from $\lambda=$const (exponentiality condition) are damped out before 5×10^{-22} sec. It is also easily demonstrated that the effect of using nonrelativistic quantum mechanics vanishes long before that time. In addition, it is easy to show that the emission of more particles, as in β decay, will not change this picture dramatically.

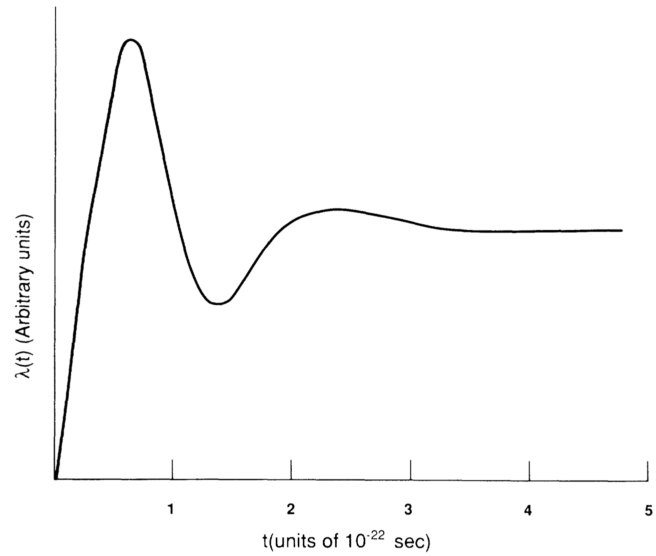

FIG. 1. Numerically calculated decay constant, $\lambda(t)$, as a function of time.

In conclusion, nuclear-decay experiments are roughly 18 to 20 orders of magnitude less time sensitive than required to constitute a meaningful search for preexponential behavior.

This treatment in no way is intended to replace rigorous work, such as that of Chiu, Sudarshan, and Misra,[6] for example.

The author is grateful to Laura Ellen Wood for assistance with the computations and to Yakir Aharonov and David Albert for extensive discussions on this general topic.

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Received 11 July 1988
PACS numbers: 23.90.+w, 03.65.Bz, 23.20.−g

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