Change in the beta-decay probability of polarized nuclei due to the action of an electromagnetic wave

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A study is made of the total and differential probabilities for the beta decay of polarized nuclei in the field of a circularly polarized electromagnetic wave in the case where the energy of the wave quantum is small compared to the rest energy of the electron.

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The effect of intense radiation on beta decay is an important problem in laser controlled fusion research (see, for example, Ref. 1). In modern lasers the parameter $\lambda = \omega/m(\hbar = c = 1)$ is a quantity of order 10^{-6}, so it is clear that a study of the beta-decay probability for $\lambda \ll 1$ is of particular interest.

Let us assume that the effect of the external wave reduces to a change in the phase volume of the decay electrons, and that the wave itself is circularly polarized. In addition, we shall ignore the Coulomb field of the nucleus, as we evidently can for light nuclei and for an intermediate decay energy. The expression for the total probability W found in this approximation[2] can be expanded in a series in powers of λ. A calculation by the authors has shown that under the condition

$$\lambda^* \ll 1, \quad \xi^* \lambda^* \ll 1, \tag{1}$$

where $\lambda^* = \lambda(\epsilon_0 - 1)^{-1}$ and $\xi^* = \xi(\epsilon_0^2 - 1)^{-1/2}$, the first terms in this series are of the form[1)]

$$W/W_0 = 1 + f_0^{-1}[\lambda^2 f_2/2! + \lambda^3 f_3/3!], \tag{2}$$

where

$$f_0 = \frac{\epsilon_0}{4}\ln(\epsilon_0 + \delta) + \delta^5/30 - \delta^3/12 - \delta/4,$$

$$f_2 = \xi^2\left[(1 + a\zeta_n)\frac{2}{3}\epsilon_0 \ln(\epsilon_0 + \delta) - \left(\frac{1}{2} + \frac{2}{3}a\zeta_n\right)\delta\right],$$

$$f_3 = g\xi^2(1 + a\zeta_n)\frac{1}{2}\ln(\epsilon_0 + \delta),$$

$$\delta = (\epsilon_0^2 - 1)^{1/2}, \quad a = \frac{2\alpha_0(1 - \alpha_0)}{1 + 3\alpha_0^2}$$

Here W_0 is the decay probability in a vacuum, $\xi = eE/(m\omega)$, E is the field amplitude of the wave, $\zeta_n = \pm 1$ is the projection of the nuclear spin onto the direction of propagation of the wave (we are considering nuclei with spin 1/2), α_0 is the ratio of the axial

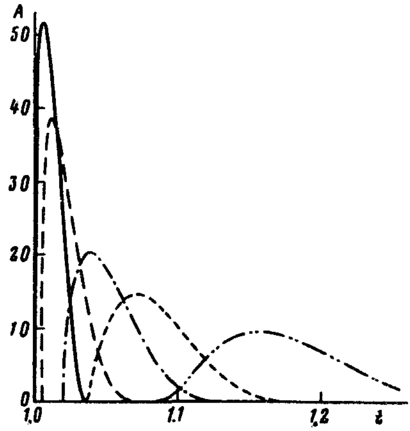

FIG. 1. Quasienergy distribution of electrons from the beta decay of unpolarized tritium nuclei. Here $t = \epsilon / m$, where ϵ is the quasienergy, and m is the electron mass $A = d(W/W_0)/dt$.——$\xi = 0$;- - - $\xi = 0.1$; -. -. - $\xi = 0.2$; - - - - - - - - - -$\xi = 0.27$;- .. - .. - $\xi = 0.4$.

and vector constants, ϵ_0 is the decay energy divided by the electron mass, and $g = \pm 1$ gives the sign of the circular polarization of the wave.

The total decay probability thus depends on the orientation of the nuclear spin. This effect is due to the nonconservation of parity in weak interactions and to the singling out of a direction by the wave. In addition, the probability depends on the polarization of the wave, although this dependence is less pronounced.

For present-day laser sources, requirement (1) is always satisfied. This circumstance permits us to estimate the effect of high-power lasers on the decay process as a function of the decay energy. The expression obtained above imply that the effect of the external field is substantially dependent on the parameter ϵ_0, with the relative size

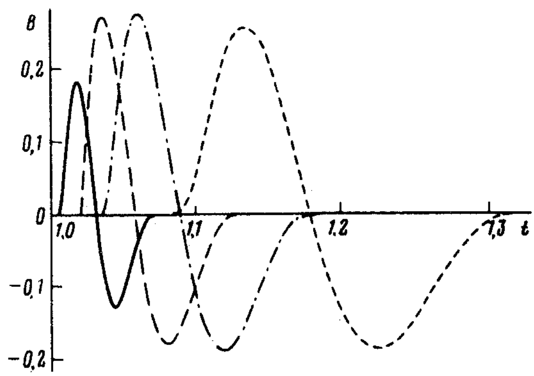

FIG. 2. Quasienergy difference spectrum of beta-decay electrons from polarized tritium nuclei, $B = (1/2a)\{d(W/W_0)/dt|_{\zeta_n = -1} - d(W/W_0)/dt|_{\zeta_n = +1}\}$ ——$\xi = 0.1$;- - - - $\xi = 0.2$;- . - . $\xi = 0.27$; - - - - - - - - $\xi = 0.4$.

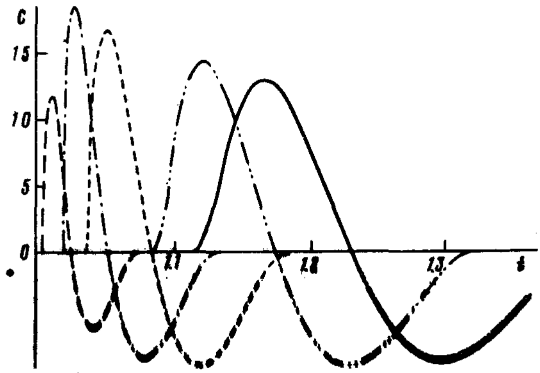

FIG. 3. Influence of the polarization of the external wave on the quasienergy spectrum of the beta-decay electrons from tritium nuclei. $C=(1/2\lambda)\{d(W/W_0)/dt|_{g=+1}-d(W/W_0)/dt|_{g=-1}\}$. $---\xi=0.1$; $-.-.-\xi=0.2$; $------\xi=0.27$; $-..-..-\xi=0.4$; ———— $\xi=0.5$.

of the corrections to the probability growing as the decay energy decreases. For example, for a free neutron one has $\epsilon_0=2.53$, and

$$W/W_0 = 1 + (0.408 + a\zeta_n\, 0.305)\xi^2\lambda^2 , \tag{3}$$

whereas for tritium one has $\epsilon_0=1.036$, and

$$W/W_0 = 1 + 10^4(1.28 + a\zeta_n 0.11)\,\xi^2\lambda^2, \tag{4}$$

i.e., the relative size of the corrections is of order 10^4. In spite of this, a laser beam does not have much effect on the total decay probability.[2)] It can be stated with assurance that Becker *et al.*[1,5] are mistaken in asserting that a sharp growth of the total beta-decay probability is possible in the region $\xi \simeq 1$.

At present, it is extremely doubtful that the change in the total decay probability (2) can be observed experimentally. A completely different picture arises, however, in a study of the energy spectrum of the electrons. The effect of the wave on the shape of the spectrum is rather appreciable, as was pointed out in Ref. 6. A dependence on the orientation of the nuclear spin is already present in zeroth order of the expansion in λ, and a dependence on the polarization of the wave appears in first order. The effect is largest at $\xi^* \sim 1$, as is illustrated by the accompanying figures.

In summary, it is possible in principle to observe the effect of an electromagnetic field on beta decay. It should be noted that in experiments with polarized nuclei it can also be established whether the external field affects the ratio of the axial and vector constants, an important question in refining the theory of weak interactions.

[1)]The asymptotic expansion of the total probability in the parameter λ was obtained in the form of a series with coefficients that are generalized functions of ϵ_0. This circumstance has prevented us as yet from studying the terms which oscillate rapidly with changing λ, but it can be stated that these terms are of order λ^3.

[2)]For weak decays in a static field the field corrections to the total probability are also small, as was noted in Refs. 2–4.

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