

CONCERNING THE ARTICLE BY S. M. BILEN'KII, R. M. RYNDIN, Ya. A. SMORODINSKII, AND HO TSO-HSIU, "ON THE THEORY OF NEUTRON BETA DECAY"

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WEINBERG¹ proved a theorem from which it follows that the full probability for a process of the type $\alpha \rightarrow \beta + l + \bar{\nu}$ (α and β are arbitrary strongly interacting particles and l is a lepton) does not contain V-A interferences. It is easy to see that the expression (12) for the total probability of neutron decay given in our paper² satisfies this condition, since the dependence on the first power of λ is only apparent. Indeed, in the approximation $E_0/M = \Delta/M$, which we used, expression (12) may be rewritten as follows:

$$W = \frac{G^2}{(2\pi)^3} (1 + 3\lambda^2) \left\{ m^4 \left(E_0 - \frac{m^2 + 2E_0^2}{2M} \right) \ln \frac{E_0 + \sqrt{E_0^2 - m^2}}{m} + \frac{2}{15} \sqrt{E_0^2 - m^2} \left[E_0^4 - \frac{9}{2} E_0^2 m^2 - 4m^4 + \frac{E_0}{M} (E_0^4 - 2E_0^2 m^2 + \frac{49}{4} m^4) \right] \right\}.$$

We are grateful to Prof. J. Bernstein for bringing the work of Weinberg to our attention.

¹S. Weinberg, Phys. Rev. **115**, 481 (1959).

²Bilenkii, Ryndin, Smorodinskiĭ, and Ho Tso-Hsiu, JETP **37**, 1758 (1959), Soviet Phys. JETP **10**, 1241 (1960).

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PRODUCTION OF "SUPERCOLD" POLARIZED NEUTRONS

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THE rapidly developing research on "cold" neutrons could be greatly widened if "supercold" neutrons with energies of the order of 10^{-4} to 10^{-6} °K

could be successfully obtained. However, at moderator temperatures of 1°K, the yield of neutrons with energies of the order of 10^{-5} degrees K amounts to only 10^{-11} of the total flux. To increase the yield of "supercold" neutrons, a new moderation method is proposed below, based on the interaction of the neutron's magnetic moment with a non-uniform magnetic field.

When a neutron crosses a magnetic field H , the change in the kinetic energy ϵ of the neutron will be equal to

$$\Delta\epsilon = \int_0^s \mu_{\text{eff}} \frac{\partial H}{\partial s} ds,$$

where μ_{eff} is the component of the neutron's magnetic moment in the direction of the field H , and s is the path traversed by the neutron in the field. Since the region affected by a magnetic field can be separated into two parts, in which the gradients are directed in opposite directions, then for $\mu_{\text{eff}} = \text{const}$ we have $\Delta\epsilon = 0$.

The neutron energy can be changed by a corresponding change in the sign of μ_{eff} , i.e., by a reorientation of the neutron spin at the instant when it passes through the maximum of the magnetic field. For this purpose a uniform magnetic field, falling off to zero at the ends, is applied along the neutron path. When a neutron with its moment opposed to the field enters the field, it is acted on by a retarding force $F = \mu_{\text{eff}} \partial H / \partial s$ (neutrons with spins oriented in the opposite direction will be accelerated). At the instant when it reaches the maximum field H_0 , where $\Delta\epsilon = \mu_{\text{eff}} H_0$, the change in speed will equal

$$\Delta v_1 \approx \mu_{\text{eff}} H_0 / m v_0,$$

where m is the mass and v_0 the initial velocity of the neutron.

If a field H_1 of radio frequency $\omega = \gamma H_0$ is applied in a direction perpendicular to H_0 , and if it satisfies the condition $H_1 \Delta t = \hbar / g \mu_N$ (Δt being the time of flight of the neutron through the field H_1 , g the gyromagnetic ratio, and μ_N the nuclear magneton), then the result will be a reversal of the spin of the traveling neutron, and consequently a change in the sign of μ_{eff} . This will cause retardation of the neutron during its exit from the constant-field region as well as during its entrance, and the total loss in velocity will be $2\Delta v_1$. The reorientation of neutron spins can be accomplished in a field H_0 of length 2 to 5 cm, with $H_1 \sim 1$ gauss. The velocity lost by a neutron during a single passage through the field is very small. Thus, if $H_0 = 20,000$ gauss and the initial velocity is 2×10^3 cm/sec we have $2\Delta v_1 = 100$ cm/sec.

By passing the neutrons successively through a series of regions of uniform retarding fields H_0 , it is possible to attain a considerable reduction in the velocity of the neutrons. For instance, to retard neutrons having an initial velocity $v_0 = 2 \times 10^3$ cm/sec to a velocity $v = 40$ cm/sec with $H_0 \approx 2 \times 10^4$ gauss requires sending the neutrons successively through 15 to 20 retarding fields, and the flight path will be of the order of 200 cm. Under these circumstances the relative flux of neutrons with energies of 10^{-5} degrees K, emerging from a moderator at $T = 1^\circ$ K, will be increased more than a thousandfold, and will amount to 10^{-7} of the total current.

These neutrons can be separated from the rest of the flux by reflection from a magnetic mirror, after which the reflected neutrons will be completely polarized. In the case of a pulsed neutron source, the moderation can be effected by a traveling magnetic field.

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POSSIBLE SYMMETRY PROPERTIES FOR THE π -K SYSTEM

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THE Hamiltonian describing the π -K system has the form

$$H = H_\pi + H_K + g_{\pi\alpha\tau\alpha} K_\lambda^\dagger K_\lambda, \quad (1)$$

where H_π is the pion Hamiltonian including the $\pi\pi$ interaction, H_K is the K-meson Hamiltonian, and g is the coupling constant of the $\pi\pi KK$ interaction.¹ It is assumed in (1) that the π -meson and K-meson interactions with baryons can be neglected.

The Hamiltonian (1) is invariant under rotations of the pion field operator in isospin space with the K-meson field operator held fixed. In other words, it is possible to consider the pion as an isovector in one space and the K meson as an isospinor in another space. The Hamiltonian (1) is invariant under rotations in either space.

Let us denote pion-K-meson scattering amplitudes by $f(\pi + K \rightarrow \pi + K)$. Then from the above symmetry properties we obtain the following selection rules:

1) The following scattering amplitudes are equal to each other:

$$\begin{aligned} f(\pi^\pm + K^\pm \rightarrow \pi^\pm + K^\pm) &= f(\pi^0 + K^\pm \rightarrow \pi^0 + K^\pm) \\ &= f(\pi^\pm + K^0 \rightarrow \pi^\pm + K^0) = f(\pi^\pm + \bar{K}^0 \rightarrow \pi^\pm + \bar{K}^0) \\ &= f(\pi^0 + K^0 \rightarrow \pi^0 + K^0) = f(\pi^0 + \bar{K}^0 \rightarrow \pi^0 + \bar{K}^0). \end{aligned} \quad (2)$$

2) The charge-exchange amplitudes vanish:

$$\begin{aligned} f(\pi^+ + K^- \rightarrow \pi^0 + \bar{K}^0) &= f(\pi^- + K^+ \rightarrow \pi^0 + K^0) \\ &= f(\pi^+ + K^0 \rightarrow \pi^0 + K^+) = f(\pi^- + \bar{K}^0 \rightarrow \pi^0 + K^-) = 0. \end{aligned}$$

3) The $K + \bar{K} \rightarrow n\pi$ annihilation process proceeds only through the isoscalar state.

To obtain experimental verification of these selection rules, one can study the angular distribution of the products in the reaction $K + N \rightarrow K + N + \pi$, for which the one-meson term in the cross section is proportional to

$$\Delta^2 (\Delta^2 + \mu^2)^{-2} |f(\pi + K \rightarrow \pi + K)|^2, \quad (3)$$

where Δ^2 is the square of the nucleon momentum transfer. Expression (3) has a maximum for $\Delta^2 = \mu^2$ in the physical region.² A measurement of the form of this maximum would provide information on the amplitudes $f(\pi + K \rightarrow \pi + K)$.

According to the theory of Okun' and Pomeranchuk³ and Chew and Mandelstam⁴ the scattering phase shifts in high angular momentum states are determined by diagrams with the smallest number of exchanged π mesons. If the K^+ and K^0 have the same parity then the $K + N \rightarrow K + N$ scattering phase shifts in high angular momentum states are determined by diagrams with two mesons exchanged. Consequently a phase shift analysis of the process $K + N \rightarrow K + N$ would give certain information about the amplitudes $f(\pi + K \rightarrow \pi + K)$.

A violation of these selection rules would imply that the Hamiltonian contains terms with derivatives of the form

$$g' \pi \times \frac{\partial}{\partial x_\mu} \pi \cdot K^* \tau \frac{\partial}{\partial x_\mu} K$$

or that baryon pairs play an important role in πK interactions. Since g' is not dimensionless, a new fundamental length would appear in the Hamiltonian (in the first version).