Possibility of observing parity nonconservation in neutron optics

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(Submitted 23 May 1980)
Pis'ma Zh. Eksp. Teor. Fiz. **32**, No. 5, 377–379 (5 September 1980)

It is shown that the odd-P effects in the interaction of a neutron with a nucleus are greatly enhanced near the p-wave compound resonances. The relative magnitude of the parity violation is $\sim 10^{-2}$.

PACS numbers: 11.30.Er, 25.40. — h

In this paper we discuss the possible experimental investigation of parity violation in the interaction of a neutron with a nucleus. We shall examine the following effect: 1) spin flip of a transversely polarized neutron around the direction of its motion. The angle of rotation along the free-path length is $\psi \sim 10^{-2}$–10^{-3}; 2) onset of longitudinal polarization in an unpolarized neutron beam. The degree of polarization along the free-path length is a $\sim 10^{-2}$–10^{-3}; 3) polarization of γ-ray quanta in the (n,γ) reaction (the neutron is not polarized). The degree of polarization is $P_\gamma \sim 10^{-1}$–10^{-2}. We should emphasize that here we are concerned with the $\mathbf{s}_\gamma \mathbf{p}_n$ correlation, rather than the $\mathbf{s}_\gamma \mathbf{p}_\gamma$ correlation usually measured.

Experimental study of the spin flip of neutrons as a result of their transmission through matter was initially proposed by Michel[1] and later by Stodolsky.[2] In those studies they discussed the nonresonance scattering of neutrons; the degree of polarization was a $\sim 10^{-8}\sqrt{E}$, eV and $\psi \sim 10^{-6}$–10^{-8} rad along the free-path length. Forte[3] (see also Refs. 4 and 5) pointed out that the effect is stronger near a single-particle, p-wave resonance. According to Forte,[5] $\psi \sim 10^{-3}$–10^{-4} rad on the resonance wing and a $\sim 10^{-5}$–10^{-6} along the free-path length. All these investigator have analyzed the effect produced as a result of interaction of a neutron with a P-odd nuclear potential, i.e., the nucleus was treated as a particle without internal degrees of freedom.

In this paper we show that another mechanism for virtual excitation of a nucleus gives a much larger magnitude of the effects under consideration. For simplicity, we shall assume that the original nucleus is spinless. We shall consider the capture of a neutron by a $p_{1/2}$ resonance. After the capture, the nucleus goes to a certain compound state with quantum numbers $|1/2^-\rangle$. In fact, because of a weak interaction between the nucleons, this state is a superposition of levels of different parity:

$$|\tfrac{1}{2}^-\rangle + i\alpha\,|\tfrac{1}{2}^+\rangle\,. \qquad (1)$$

Because of dynamic enhancement of the mixing coefficient due to a high level density of the compound nucleus, $\alpha \sim 10^{-4}$.[6-9] A capture into the state (1) proceeds via the $p_{1/2}$ state and the $s_{1/2}$ state of a neutron. Because of interference of the amplitudes of different parity, the refractive index of a neutron with a helicity $+1$ differs from the refractive index of a neutron with a helicity -1:

$$n_{\pm} = n_0 - \frac{\pi N\Gamma_p(k)}{k^3}(1 \pm P)\frac{1}{E - E_p + i\Gamma/2},$$

$$P = 2a\sqrt{\Gamma_s(k)/\Gamma_p(k)}\cos(\phi_s - \phi_p) \sim a/kR. \tag{2}$$

Here R is the nuclear radius, $\Gamma_p(k)$ and $\Gamma_s(k)$ are the neutron widths of the $1/2^-$ and $1/2^+$ states converted to the energy of an incident neutron [$\Gamma_p(k) = \Gamma_p(k/k_p)^3$, $\Gamma_s(k) = \Gamma_s k/k_s$; k_p and k_s are momenta corresponding to the resonances], ϕ_p and ϕ_s are the corresponding capture phases [in the Born approximation $\cos(\phi_s - \phi_p) = \pm 1$], N is the density of target atoms, n_0 is the nonresonance part of the refractive index, and Γ is the total width of the p resonance. We have disregarded the Doppler line broadening, which is justifiable for a cooled target. At room temperature, the Doppler broadening, which is two to three times as great as Γ, reduces the effect by approximately the same factor. The angle of rotation ψ of the neutron spin and the degree of longitudinal polarization a can be easily expressed in terms of $n_{\pm}$:

$$\psi = kl\,\mathrm{Re}(n_+ - n_-), \qquad a = -kl\,\mathrm{Im}(n_+ - n_-). \tag{3}$$

The path length l cannot noticeably exceed the free-path length of the neutrons $l_0 = 1/k\ \mathrm{Im}\ (n_+ - n_-) \sim 1\text{–}2$ cm. The numerical estimates (for $l = l_0$) for the lower four resonances of ^{238}U (Refs. 10 and 11), under the assumption that $J = 1/2$ for all these resonances, are given in Table I. The cross sections for the peaks are given without taking the substrate into account, $\sigma_0 = 10$ b. Of course, since these are only order-of-magnitude estimates, the significant figures for P, a, and ψ in Table I have a certain meaning only when they are compared with each other.

In principle, experiments can also be performed with thermal neutrons. The resonances are usually located at a distance of $\Delta E \sim 1\text{–}10$ eV from the thermal region, and $\Gamma \sim 0.03$ eV. Thus, for the thermal neutrons $\psi \sim 10^{-2}\ \Gamma/2\Delta E \sim 10^{-4}\text{–}10^{-5}$, $a \sim 10^{-2}(\Gamma/2\Delta E)^2 \sim 10^{-6}\text{–}10^{-8}$.

The polarization of γ-ray quanta in the (n,γ) reaction produced as a result of capture of unpolarized neutrons in the $p_{1/2}$ resonance can be measured in addition to

TABLE I.

E, eV	σ_{peak}, bH	P	$-a(E_p)$	$\psi(E_p + \Gamma/2) - \psi(E_p - \Gamma/2)$
4.41	2.6	0.04	0.008	0.009
10.25	15.8	0.01	0.007	0.011
11.32	3.3	0.03	0.006	0.008
16.30	0.3	0.07	0.002	0.002

experiments involving the measurement of neutron polarization. Because of the difference between the σ_+ and σ_- cross sections, the intermediate compound nucleus is longitudinally polarized. As a result of decay, this polarization is transferred to the γ-ray quantum. For this reason we are considering the $\mathbf{s}_\gamma \mathbf{p}_n$ correlation, i.e., the sign of circular polarization, $P_\gamma \sim \cos\theta$, for photons emitted in the direction of the neutron momentum is different from that for photons emitted in the opposite direction, $P_\gamma \sim P \sim 10^{-1}$–$10^{-2}$. For example, $P_\gamma = P$ for the transition $J_i = 1/2 \rightarrow J_f = 1/2$. Of course, an analogous effect exists in the single-particle, p-wave resonances, but these resonances have no dynamic enhancement and hence P_γ is a factor of 10^3 smaller.

In conclusion, we should emphasize that the large effects analyzed in this investigation can be attributed to two factors. First, the kinematic enhacement due to the fact that the impurity s amplitude is a factor of $1/kR$ greater than the main p amplitude. Second, the dynamic enhancement of the odd-P mixing in the compound nucleus.

The authors thank I. B. Khriplov for stimulating discussions and interest in this work.

[1]F. C. Michel, Phys. Rev. **329B**, 133 (1964).
[2]L. Stodolsky, Phys. Lett. **50B**, 352 (1974).
[3]M. Forte, ILL Research proposal 03-03-002, 1976.
[4]G. Karl and D. Tadic, Phys. Rev. **16C**, 1726 (1977).
[5]M. Forte, Inst. Phys. Conf. Ser., 1978, No. 42, Chapter 2, p. 86.
[6]R. Haas, L. B. Leipuner, R. K. Adair, Phys. Rev. **116**, 1221 (1959).
[7]R. J. Blin-Stoyle, Phys. Rev. **120**, 181 (1960).
[8]I. S. Shapiro, Usp. Fiz. Nauk **95**, 647 (1968). [Sov. Fiz. Uspekhi **11**, 582 (1969)]
[9]O. P. Sushkov and V. V. Flambaum, Preprint Inst. Nucl. Phys. 80-18 (1980).
[10]D. J. Hughes and R. B. Schwartz, Neutron Cross Sections, BNL-325, Second Ed., 1958.
[11]L. M. Bollinger and G. E. Thomas, Phys. Rev. **171**, 1293 (1968).

Translated by S. J. Amoretty
Edited by R. T. Beyer