New measurement of the circular polarization of γ rays in the reaction $np \to d\gamma$

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(Submitted 16 May 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **38**, No. 3, 138–141 (10 August 1983)

A new upper limit is reported on the circular polarization of γ rays in the radiative capture of a thermal neutron by a proton: $P_\gamma \leqslant 5 \times 10^{-7}$.

PACS numbers: 25.10. + s, 25.40.Lw, 27.10. + h

Particularly noteworthy among the many studies of the effects of parity breaking in nuclear forces are the studies of few-nucleon systems, since the corresponding results can furnish reliable and comprehensive information on the amplitude of the weak neutron–neutron interaction which is currently believed to cause these effects. Unfortunately, these are also the most complicated experiments: Since the expected effects are so small ($\sim 10^{-7}$–10^{-8}), special demands are placed not only on the experimental apparatus and the measurement procedure but also on several systems of the accelerator or reactor which is serving as the particle source. It is for this reason that only a few experimental teams[1-5] have achieved the accuracy required for observation of the effect in experiments of this sort. The magnitude of the observed effects has usually exceeded the corresponding experimental errors by a factor no greater than two or three.

Only in the case of *pp* scattering[1,2] have the experimental results agreed with the theory.

In this letter we report a repetition of an experiment designed to measure the circular polarization of γ rays from the reaction $np \to d\gamma$ with unpolarized thermal neutrons. The result of the first experiment[4] furnished evidence, at the level of three standard deviations, of the occurrence of the effect $[P_\gamma = -(1.30 \pm 0.45)\times 10^{-6}]$. The magnitude of the effect was nearly two orders of magnitude higher than the theoretical predictions.[6]

The experiment was carried out at the VVR-M reactor of the Leningrad Institute of Nuclear Physics. The experimental arrangement was analogous to that in Ref. 4. The proton target was the water of one reactor loop in a water cavity formed at the center of the core, where the thermal-neutron flux density was 3×10^{14} n/(cm^2 s). The effective activity of the source in terms of the γ rays from the *np* capture reaction was $\sim 10^{16}$ s^{-1}. The γ rays from the source passed through the water in a tank in the reactor along a collimating channel to a "transmission" polarimeter. The effect (δ) was determined from the relative change in the intensity of γ rays transmitted through the absorber of the polarimeter upon a change in the magnetization direction of the polarimeter: $\delta = 2(I^+ - I^-)/(I^+ + I^-)$. The magnetization direction was changed each second. The circular polarization was taken to be $P_\gamma = \delta/\epsilon$, where ϵ, the polarization efficiency, is $\sim 5\%$ at these γ energies.

The basic difficulties in these experiments were in (1) supressing the contribution of γ radiation from the reactor core, which had a negative polarization on the order of 10^{-3} because of the bremsstrahlung γ rays from the β decay of uranium fission fragments in the fuel elements, and (2) compensating for the fluctuations in the reactor power, which were $\sim 10^{-3}$ at the polarimeter switching frequency (1 Gz). In comparison, the statistical fluctuations in the number of γ rays detected by the detector were two orders of magnitude lower. Furthermore, the observation of a relatively large circular polarization ($\sim 10^{-4}$) of the γ rays in the integrated spectrum from the $n\gamma$ reaction for several nuclei[7] imposed a requirement on this experiment which was not imposed on the experiment of Ref. 4: The structural materials of the targets and the water cavity had to be highly pure.

To resolve the first problem we shielded the water cavity with two- and three-layer lead shields with total thicknesses of 60 and 80 mm.

To compensate for the fluctuations in the reactor power, we used a polarimeter

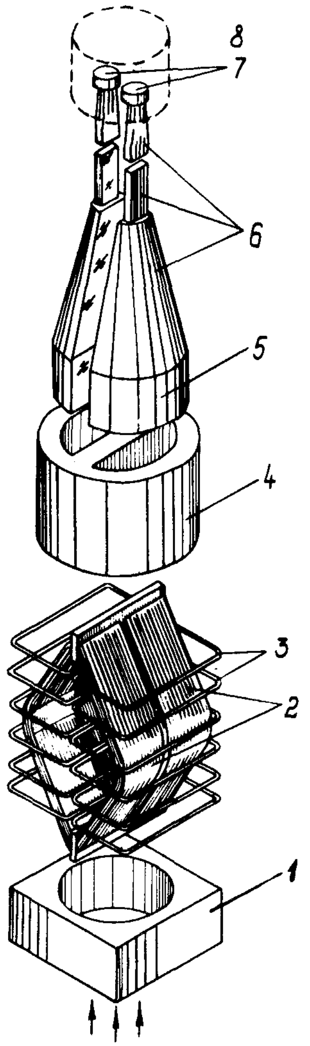

FIG. 1. 1—Collimator; 2—absorber consisting of plates of "Armco iron" in the form of a rhombus; 3—coils carrying a current of 200 A; 4—collimator which separates the beams; 5—CsI(Tl) crystals; 6—lightguides; 7—photodiodes; 8—refrigerator.

consisting of two separate and equivalent halves, which were positioned symmetrically with respect to the beam axis and which were magnetized in opposite direction. The γ rays transmitted through each half of the polarimeter were detected by separated scintillation detectors using CsI(Tl) crystals. The crystals were coupled by lightguides to silicon photodiodes; the integrated current signals from these diodes were converted into voltages and amplified, and their variable components were fed to the inputs of a differential amplifier, where one signal was subtracted from the other. The in-phase parts of the signals, caused by the fluctuations in the reactor power, were eliminated if the gain levels of the two amplifier channels were chosen correctely, while the useful signal, caused by the circular polarization, was summed, since the two halves of the polarimeter were magnetized in opposite directions. The difference signal was then fed to the capacitance of an analog integrator (separately for the two magnetization directions), measured by a digital voltmeter, and sent to two computer memory units. The slow drift of the channels was eliminated by means of a low-frequency correlator to whose inputs we fed the signals from one of the channels and from a differential amplifier. The output signal from the correlator controlled the adjustable amplifier of the second channel. The sensitivity of this apparatus was twice as good as that in the earlier experiment, corresponding to a polarization error of $\pm 1.3\times 10^{-6}$ per day in the measurements with water.

In control experiments, the water was displaced from the cavity by the corresponding target. To test the contribution of γ rays from the core to the effect, we used a graphite target, whose γ scattering characteristics are similar to those of water and whose $n\gamma$ cross section is small. The effect of the fast neutrons, which may acquire a polarization as a result of scattering by the targets and the shields and thereby cause a polarization of the captured γ rays, was checked with the help of a target consisting of a mixture of powdered graphite of boron-10. This target suppresses the thermal-neutron flux in the cavity, thereby causing a relative amplification of the fast-neutron effect, if it exists. This experiment doubles as a control experiment in the same sense as for the preceding experiment. For a "null" control experiment, we used a titanium target, as before. The γ rays from this target, primarily of multipolarity $E1$, were assumed to be unpolarized, although the truth of this assumption is not obvious in the light of the data of Ref. 7. The possible contribution to the effect from γ rays from the $n\gamma$ reaction in the structural materials of the cavity was checked with lead and zirconium targets; no such effect was found. Other control experiments are described in Ref. 8, where the apparatus is described in detail.

The measurements were begun with the two-layer lead shield around the water cavity, as in the earlier experiment.[4] The measurements with the water target revealed an effect (the upper part of Table I) corresponding to a circular polarization $P_\gamma = -(1.55 \pm 0.25)\times 10^{-6}$, in complete agreement with the result published in Ref. 4. The control experiments with the graphite and boron targets, however, revealed the same effect (within the experimental errors), which might have meant that the effect was due to γ rays from the core. We then installed the additional third shield around the cavity. This shield consisted of 30 aluminum tubes 36 mm in diameter in which lead had been cast. These results are shown in the lower part of Table I. We see that the effect essentially disappeared in the measurements with the graphite and boron targets, but it also disappeared in the basic measurements—with water in the cavity.

Working from all these results, we draw the following conclusions: (1) The circular polarization of γ rays in the reaction $np \rightarrow d\gamma$ does not exceed 5×10^{-7} at a confidence level of 95%. (2) The effect observed in the first experiment[4] was probably caused by a residual penetration of γ rays from the core through the shield around the water cavity and the subsequent rescattering of these γ rays toward the entrance window of the polarimeter.

As for the null result [$\delta = -(0.01 \pm 0.16)\times 10^{-7}$] of the measurements with the graphite target in the earlier experiment, we cannot offer a complete explanation. At

TABLE I.

	Experimental effect, δ, $\times 10^7$			
Target	H_2O	C	$^{10}B + C$	Ti
Two-layer Pb shield around the water cavity	− 0.71 ± 0,25			
	− 1.06 ± 0.21			− 0.085 ± 0,225
	− 0.53 ± 0.22	− 1,18 ± 0,24	− 0,32 ± 0,26	+ 0,18 ± 0,36
	− 0,63 ± 0,22	− 0.68 ± 0.24	− 0,62 ± 0.12	− 0,29 ± 0,16
	− 0.74 ± 0,11 1)	− 0.93 ± 0,17 1)	− 0,57 ± 0,11 1)	− 0,12 ± 0,12 1)
Three-layer Pb shield around the water cavity	− 0.14 ± 0,25	− 0.37 ± 0.20	− 0,29 ± 0,33	− 0,34 ± 0.16
	− 0,68 ± 0,30		+ 0,15 ± 0.28	− 0.24 ± 0,15
	+ 0.015 ± 0.27		− 0,15 ± 0,15	
	+ 0,16 ± 0.22	− 0,17 ± 0.15	− 0,21 ± 0,14	
	+ 0,05 ± 0,23			+ 0,41 ± 0,15
	+ 0.28 ± 0,26	+ 0,03 ± 0,15		+ 0.68 ± 0.18
	− 0,015 ± 0,105 1)	− 0.13 ± 0.09 1)	− 0.15 ± 0,09 1)	+ 0,09 ± 0,08 1)

1) The weighted-average effect and the rms error of the series of measurements.

best we can suggest that it might have been caused by some uncontrollable impurity (chlorine, for example), which has a large parity-breaking effect in the $n\gamma$ reaction.[7] The effects would be to compensate for the effect of the γ rays from the core.

These experiments are being continued.

We sincerely thank the operating staff of the VVR-M reactor at the Leningrad Institute of Nuclear Physics for this successful collaboration over many years.

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Translated by Dave Parsons
Edited by S. J. Amoretty