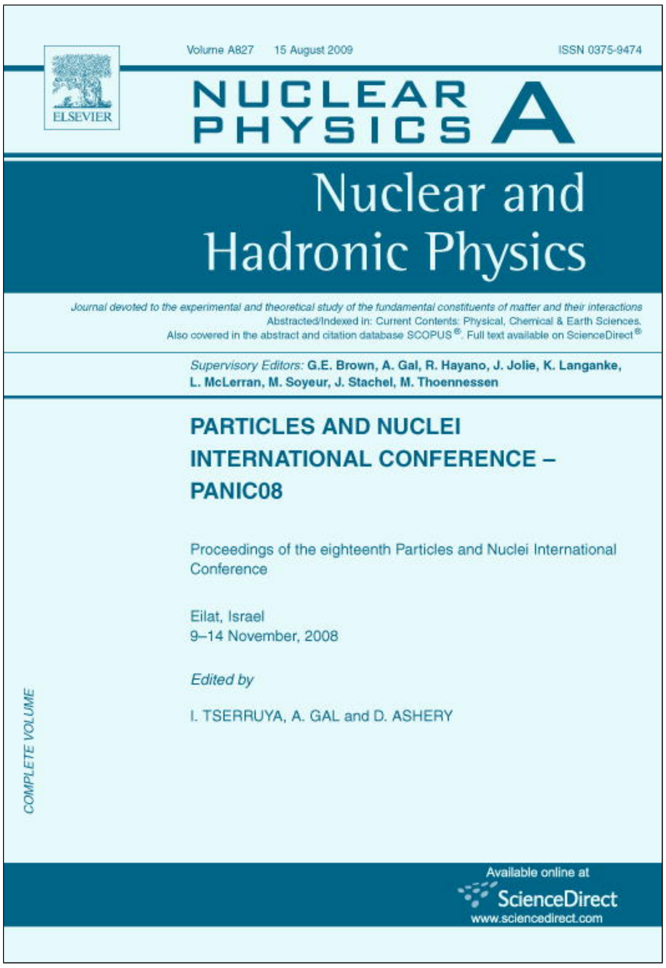

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Measurement of the parity-violating asymmetry in the reactions of cold polarized neutrons and light nuclei ^{6}Li, ^{10}B

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Abstract

We present two measurements of parity-violating secondary particle emission asymmetry in the reactions of polarized cold neutrons and light nuclei. We aim at studies of the neutral weak currents in nucleon-nucleon interaction. First, we describe the triton emission asymmetry in the $^{6}Li(n,\alpha)^{3}H$ reaction. It is equal to $\alpha_{P-odd}^{^{6}Li} = -(8.8 \pm 2.1) \cdot 10^{-8}$. Second, we present the γ-rays emission asymmetry in the nuclear reaction $^{10}B(n,\alpha)^{7}Li^{*} \rightarrow \gamma \rightarrow ^{7} Li(g.s.)$. The result is $\alpha_{P-odd}^{^{10}B} = +(0.8 \pm 3.9) \cdot 10^{-8}$. Using these values, we constrain the weak neutral current constant in framework of the cluster model $f_{\pi}^{^{6}Li} \leq 1.1 \cdot 10^{-7}$ and $f_{\pi}^{^{10}B} \leq 2.4 \cdot 10^{-7}$ (at 90% c.l.). Both these constrains contradict to "the best" DDH value of $f_{\pi}^{DDH} = 4.6 \cdot 10^{-7}$.

Key words: neutron physics, weak interaction, fundamental symmetries
PACS: 23.40.Bw, 12.15.-y, 13.75.Cs, 25.40.Hs

The main prediction of the standard model of the electroweak interactions is the weak neutral current. The parity violation in the nucleon-nucleon interaction in various processes with few-nucleon systems and nuclei has to include both charged and neutral currents. However, the weak neutral current has not yet been observed in such interactions. The nuclear reaction of light nuclei (A=6-10) with polarized slow neutrons is probably the most promising candidate to study the weak neutral current properties in nucleon-nucleon (NN) processes. Such nuclei could be described in the framework of cluster and multi-cluster models [1,2], for excitation energy $< 25 - 30\ MeV$. In [3,4], using this method and "the best DDH values" for the meson exchange constants [5], the authors calculated the P-odd asymmetry of γ-rays emission in the reaction $^{7}Li^{*} \rightarrow ^{7} Li + \gamma(M1)$, $\quad E_{\gamma} =$

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$0.478 MeV$, resulting from the reaction $^{10}B(n,\alpha)^{7}Li^{*} \rightarrow \gamma \rightarrow {}^{7}Li(g.s.)$ with polarized cold neutrons: $^{DDH}\alpha_{P-odd}^{^{10}B} \approx 0.16 f_{\pi} - 0.028 h_{\rho}^{0} = 1.1 \cdot 10^{-7}$. Two experiments [6,7] have provided a P-odd asymmetry value in the nuclear reaction with boron equal to $\alpha_{P-odd}^{^{10}B} = (2.7 \pm 3.8) \cdot 10^{-8}$.

The P-odd effect in the nuclear reaction $^{7}Li(n,\alpha)^{3}H$ has also been calculated [8] in terms of the meson exchange constants $^{DDH}\alpha_{P-odd}^{^{6}Li} \approx -0.45 f_{\pi} + 0.06 h_{\rho}^{0} = -2.8 \cdot 10^{-7}$ and measured in ref. [9]: $\alpha_{P-odd}^{^{6}Li} = (-8.6 \pm 2.0) \cdot 10^{-8}$. If the charged weak constant h_{ρ}^{0} were equal to "the best DDH value" the weak neutral constant f_{π} would be equal to $f_{\pi}^{^{6}Li} \approx (0.4 \pm 0.4) \cdot 10^{-7}$, or, at 90% confidence level, constrained as: $f_{\pi}^{^{6}Li} < 1.1 \cdot 10^{-7}$. However, this value is smaller than "the best DDH value" [5] $f_{\pi}^{DDH} = 4.6 \cdot 10^{-7}$.

This contradiction could be clarified if the asymmetry $\alpha_{P-odd}^{^{10}B}$ measured more precisely.

In the light of the above, we have carried out another experiment on the PF1B beam of polarized cold neutrons [10] at the Institut Laue-Langevin (ILL), Grenoble, France.

The neutron spin $\vec{\sigma_{n}}$, the γ-ray momentum $\vec{p_{\gamma}}$ and the neutron momentum $\vec{p_{n}}$ were set as follows: $\vec{\sigma_{n}} \parallel \vec{p_{\gamma}} \perp \vec{p_{n}}$. The P-odd effect could be observed in the asymmetry of the angular distribution of the γ-rays emission. The magnetic field guiding the neutron spin and the γ-ray momentum were set parallel to each other with an accuracy of 10^{-2} sr. This is sufficiently precise, as the left-right asymmetry in the γ-rays emission is zero [11]; it does not therefore contribute to the P-odd effect.

We used two detectors in the electric current mode and a method to compensate for any possible false effects described in refs. [12]. The sample was produced from an amorphous powder ^{10}B; its isotopic enrichment was 85%. The sample was installed in the centre of the neutron beam; the angle between the neutron beam axis and the sample surface was 45°. Most of the neutrons were absorbed by the sample; an absorption event results in the emission of an α-particle and γ-ray. The distance between the sample centre and the centre of each detector is 75 mm. Each γ-rays detector consists of a $NaI(Tl)$ crystal with a diameter of 200 mm and thickness of 100 mm. "Hamamatsu" S3204-03 photodiodes sized 18×18 mm^{2} were used to detect scintillation photons. The polarizer and the spin-flippers were protected by boron collimators. The detectors were protected with boron rubber. We used boron for the protection, but avoided ^{6}Li, as it contains 10% ^{7}Li and the 12-14 MeV beta-decay of ^{8}Li has up to 3% asymmentry [13]. This could compromise the results with a false P-odd effect. Neutron absorption in other-than-sample materials does not produce P-odd asymmetry of γ-rays emission as the neutron scattering is nearly completely incoherent.

A new version of the integral measuring method was first used to measure P-odd asymmetry in ref. [14]: the frequency of neutron spin flip was higher than the typical frequency of the reactor power noise. The spectral noise density decreases sharply at high frequency; so the corresponding systematic error could generally be suppressed. New electronic system is adapted to the neutron spin-flip frequency of $0.01 - 50$ Hz.

In order to reduce the effects of apparatus asymmetry and radio noise, we reversed the direction of the guiding magnetic field at the sample in every series. We measured an equal number of series for two field directions in analogy to ref. [9]. The subtracted signal thus contains double asymmetry; in contrast, apparatus-related false asymmetries are subtracted. As the spin-flip frequency was equal to 5 Hz (in the last cycle) and was not high enough to minimize the measurement uncertainty, we also used the scheme of compensation for reactor power fluctuations.

We performed two other kinds of test experiment. One test consisted in performing measurements with no sample in the neutron beam. In these circumstances the neutron beam penetrates the material behind the sample position and produces γ-rays (the neutrons are otherwise absorbed by the sample in the main experiment). The second test involves replacing the ^{10}B sample with a different target sample; the target scatters neutrons but does not emit γ-rays in (n,γ) nuclear reactions. The scattered neutrons can be absorbed by the apparatus materials and emit γ-rays. If γ-rays emission in impurities in the apparatus materials is P-odd asymmetric, the corresponding false P-odd asymmetry is greatly enhanced (thanks to the highly enhanced flux of the scattered neutrons). Graphite is such an "ideal" scatterer.

The final estimation resulting from the "zero" experiments is $\alpha_0^{total} = (2.1 \pm 2.8) \cdot 10^{-8}$. Taking into account this "zero" value the coefficient of P-odd asymmetry for all carried out experiments is equal to: $\alpha_{P-odd}^{^{10}B} = (0.8 \pm 3.9) \cdot 10^{-8}$.

Thus, we could estimate the weak neutral current constant in a fashion similar to our estimations in ref. [15]. $f_\pi^{^{10}B} = -(1.5 \pm 2.4) \cdot 10^{-7}$, or, at 90% confidence level: $f_\pi^{^{10}B} < 2.4 \cdot 10^{-7}$.

The existing data is sufficiently precise to be able to state that the weak neutral current constant in the reaction $^{10}B(n,\alpha)^7Li^* \to \gamma \to ^7 Li(g.s.)$ is smaller than the "best DDH value". As mentioned above, the constraint for the weak neutral constant obtained in the reaction with ^6Li [9] in the framework of the cluster model [8] $f_\pi^{^6Li} < 1.1 \cdot 10^{-7}$ is also smaller than the "best DDH value". Finally, we conclude that the two measured constraints (with ^{10}B and ^6Li) for the weak neutral constant agree with each other but contradict the "best DDH value" $f_\pi^{DDH} = 4.6 \cdot 10^{-7}$. We would like to underline that recent progress in the experimental methods and facilities allows us to measure reliably non-zero asymmetry values of the order of $10^{-8} - 10^{-7}$ in reactions of polarized cold neutrons with light nuclei, thus giving access to studies of the weak neutral currents. However, we understand limitations of the theoretical models used and invite specialists in the field to contribute to theoretical analysis of the problem.

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