# MEASUREMENT OF THE P-ODD EFFECT IN RADIATIVE CROSS SECTION ON NATURAL LEAD

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## Abstract

The measurements of the P-odd asymmetry in radiative cross section on natural lead have been performed at the PF1B instrument of the ILL reactor (Grenoble, France). The integral flux of cold (mean wave length is 4.7 Å) neutrons was ~ $10^{10}$ 1/c. The neutron polarization was not worse than 92 %. Polarization was been switching by an adiabatic flipper. The sample was placed into a box of lithium rubber opened from a side of beam entrance. Two crystals of NaI (Tl) served as the detectors. The integral method of P-odd effect measurement was applied. Measurements, including the "0"-experiment, lasted 17 days. Taking into account the result of "0-test", an effect of asymmetry is $a_\gamma(^{nat}Pb) = (2.3 \pm 3.5)\cdot 10^{-7}$ or $a_\gamma \leq 8.1\cdot 10^{-7}$ at 90% c. l.

## Introduction

Natural lead is a mixture of four isotopes: 204(1.43%), 206(24.15%), 207(22.4%), and 208(52.4%). None of the isotopes contains any suitable pairs of s- and p-resonances that may be responsible for P-odd effects in reactions with neutrons.

Nevertheless, in two measurements of the spin rotation angle for neutrons polarised transversely to their momentum vector in a sample of natural lead there was obtained the rotation angle $\Delta\phi = (2.24 \pm 0.33)\cdot 10^{-6}$ rad/cm [1] and $\Delta\phi = (3.53 \pm 0.79)\cdot 10^{-6}$ rad/cm [2]. Moreover, the measurement of the effect in a sample enriched with the isotope $^{207}$Pb to 87% gave the spin rotation angle $\Delta\phi < 4.3\cdot 10^{-6}$ at 90% c. l. [2]. This establishes the grounds for making the conclusion that the isotope $^{204}$Pb is a source of the effect.

The mechanism responsible for the observed spin rotation angle of neutrons traversing a lead sample is mixing of the compound-nucleus states of the spin having opposite parities. Paper [3] suggests the existence of a "negative" *p*- wave resonance in $^{204}$Pb to explain the P-odd effect in the spin rotation angle. Another measurement of $\Delta\phi$ was done with a Pb sample enriched with $^{204}$Pb to 36.6 %. [4]. The obtained result for the neutron spin rotation angle in the lead sample is $\Delta\phi = (8 \pm 2)\cdot 10^{-5}$ rad/cm for the lead with 100% content of $^{204}$Pb. It is shown [5] that the traditionally being measured effect includes two components, namely truly spin rotation when transmitting through the sample and some addition explained by instrumental error of the method. Recently, a search for the p-resonance in the measurement of the radiative neutron capture cross section at resonance energy was undertaken in Dubna [6]. The group used a sample of natural Pb and a sample enriched with $^{204}$Pb to 36.6 %. The conclusion of paper [6] is that the isotope $^{207}$Pb has a strong “negative” *p*- resonance, which may explain the parity-violation effect in natural lead. Therefore, in comparison with the conclusion of papers [1,2,4] and [6] there appears some contradiction concerning $^{204}$Pb.

From our point of view there are the possibilities to obtain additional information which may help to solve this problem. According to the optical theorem the P-odd effect in neutron spin rotation must be accompanied with P-odd effects in the total cross section

$$a_n = \frac{\sigma_{tot}^{+} - \sigma_{tot}^{-}}{\sigma_{tot}^{+} + \sigma_{tot}^{-}} = \frac{\Delta\sigma_{tot}}{2\sigma_{tot}} \qquad (1)$$

and in the radiative capture cross section

$$a_\gamma = \frac{\sigma_{\gamma}^{+} - \sigma_{\gamma}^{-}}{\sigma_{\gamma}^{+} + \sigma_{\gamma}^{-}} = \frac{\Delta\sigma_{\gamma}}{2\sigma_{\gamma}} \qquad (2)$$

for longitudinally polarized neutrons. Here, $\sigma^{+}_{tot}$, $\sigma^{-}_{tot}$ and $\sigma^{+}_{\gamma}$, $\sigma^{-}_{\gamma}$ are the total cross sections and radiative capture cross sections for the neutrons having opposite polarizations with respect to the momentum. Although these effects are much weaker than that in the $\Delta\phi$ measurement, the realization of these experiments is much easier methodologically. As it was shown by numerous experiments $\Delta\sigma_{tot} \cong \Delta\sigma_{\gamma}$ for slow neutrons. As far as the radiative neutron capture cross section for natural lead at thermal energy (0.17 b) is much less than the total cross section (11 b), we decided to carry out an experiment on the measurement of parity violation effect namely in radiative cross section.

## Experiment

The measurements were performed on the PF1B beam of polarized cold neutrons [7] at the Institut Laue-Langevin (ILL) in Grenoble, France. The average neutron wavelength at the PF1B was $<\lambda_n>$ =4.7 Å. The neutron beam at the sample position was 80 mm by 50 mm. The total neutron flux at the sample was equal to $\sim\cdot 10^{10}$ $c^{-1}$. The neutron polarization was not worse than 92 %. A scheme of experiment is shown in Fig. 1. The guiding magnetic field was produced by Helmholtz coils (not shown in figure); it was reversed periodically during measurements. The strength of guiding magnetic field was equal to several Oersteds. The neutron polarization was reversed via switching high-frequency flipper. A sample was placed between two detectors. The sample represented 2 cylinders of natural lead (99.95% purity) in diameter of 80 mm and height 100 mm located one after another on the neutron beam axe. Necessary condition of measurement of P-odd asymmetry in γ-quanta is full absorption of the neutrons scattered by the sample. Therefore the target was located in a box of lithium rubber ($^{6}$LiF) with the thickness of ~1.9 mm opened from an neutron entrace side.

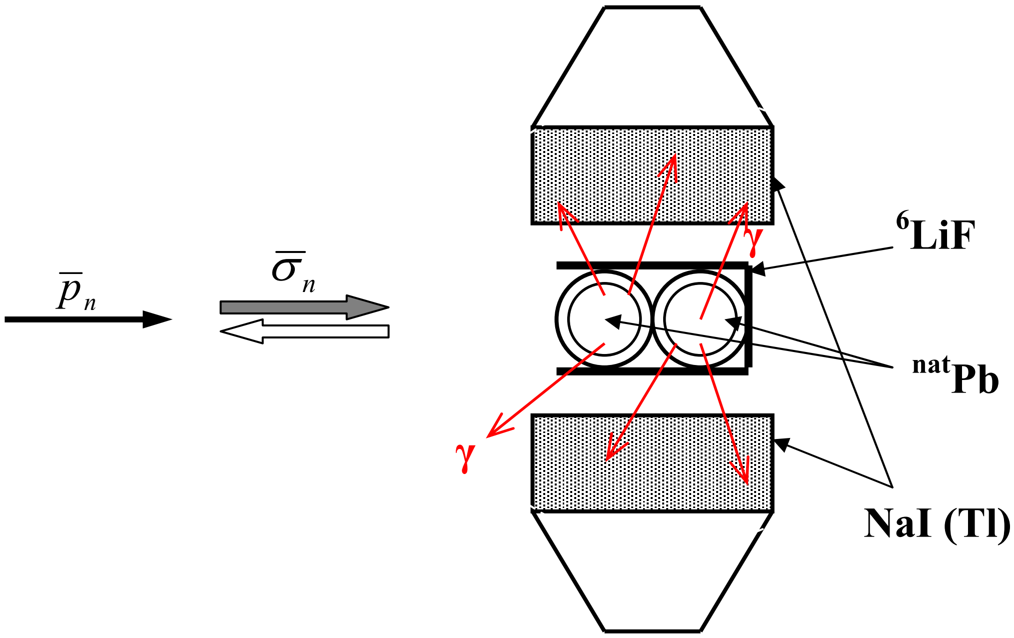


Fig. 1. A scheme of experiment.

Each γ-quanta detector consists of an NaI (Tl) crystal with a diameter of 200 mm and a thickness of 100 mm. "Hamamatsu" S3204-03 photodiodes with a size of 18×18 mm$^2$ were used to detect scintillation photons. The photodiodes are connected to the NaI(Tl) crystals via Plexiglas light-guides. The detectors were inserted into aluminium-alloy cases. A current method for the event detection was used (for more details see, for example, [8, 9]). The current preamplifiers used in our experiment converted the detector current into the output voltage. The output signal was digitized by a digital signal processor [10]. In experiment a quantity was measured:

$$\delta_\gamma = \frac{I_\gamma^+ - I_\gamma^-}{I_\gamma^+ + I_\gamma^-} \qquad (3),$$

where $I_\gamma^+$, $I_\gamma^-$ - are the intensities of detected γ-quanta corresponding to the different neutron helicities. This quantity is connected with the asimmetry in radiative capture cross section as $a_\gamma \approx - \delta_\gamma/P_n$, where $P_n$ is polarization of neutron beam. For reducing influence of the reactor power fluctuations, the frequency of neutron polarization switching was higher than main frequencies of reactor noise spectrum [10]. Frequency of switching of polarization in experiment was equal to 8.3 Hz. To compensate false asymmetries the direction of the guiding magnetic field was reversed every series (every 4 min). For the averaged values we took into account the direction reverse of actual P-odd effect due to reverse of the guiding magnetic field. The P-odd effects are added in this case, because they have opposite signs.

Before main experiment the working ability of the setup was tested in the measurement of the radiative capture asymmetry for natural Br. We used a 30 g sample of the KBr powder. For 4 hours of measurement we obtained P-odd effect in radiative cross section $a_\gamma(\text{Br}) = (11.0 \pm 1.3)\cdot 10^{-6}$, that coincides with the earlier result of Ref. [11] $a_\gamma(\text{Br}) = (10.5 \pm 1.4)\cdot 10^{-6}$.

Measurements on lead were performed during ~ 10 days. The corrected for the neutron polarization result is $a_\gamma^m = (3.3 \pm 2.9)\cdot 10^{-7}$. For the "zero" experiment a box of lithium rubber without lead was located to the place of a target between detectors. Measurement time cotsisted of 6.5 days. The result of measurement is $a_0 = (1.0 \pm 2.0)\cdot 10^{-7}$. The value is normalized to the γ-intensity in measurement with lead (see, for example, [8]) and corrected for the neutron polarization.

Taking into account "zero" experiment the asymmetry of radiative capture cross section on natural lead is $a_\gamma(^{nat}Pb) = (2.3 \pm 3.5)\cdot 10^{-7}$ or $a_\gamma \leq 8.1\cdot 10^{-7}$ at 90% c. l.

## Discussion

Unique measurement of the P-odd asymmetry in total cross section at passage of the longitudinaly polarized neutrons trough natural lead has been performed in [12]. Result of this experiment (an integral neutron flux was $2\cdot 10^7$ $c^{-1}$, polarization was 85 %) at thermal neutron energy is $a_n = -(7 \pm 8)\cdot 10^{-7}$. Using Exp. (1) and (2) and taking in to account that $\Delta\sigma_{tot} \cong \Delta\sigma_\gamma$, one can calculat the size of $a_\gamma$ from $a_n$ for thermal neutrons ($\lambda$ = 1.8 Å): $a_\gamma = (3.1 \pm 3.5)\cdot 10^{-6}$. It is seen, that an experimental accuracy received by us is 100 times better the accuracy of the previous experiment.

In Ref [3] G. Lobov performed the calculation of the P-odd asymmetry in total cross section for natural lead under assumption of existence of negative p-wave resonance in $^{204}Pb$ with $E_p$ = - 16 eV. He used the typical parameters for p-wave resonances: a neutron width is $\Gamma^n{}_P = 3\cdot 10^{-3}$ eV, a radiation width is $\Gamma^\gamma{}_P = 0.1$ eV. For s-wave resonances he took experimentally known resonances with $E_S$ = -2.98 keV, $\Gamma^n{}_S$ = 72 eV [13]. Using experimental values for the neutron spin rotation [1, 2] and relation between $\Delta\phi$ and $a_n$

$$\Delta\varphi = n\,\Delta\sigma\frac{E - E_P}{\Gamma_P} \qquad (4)$$

$$\Delta\sigma = 2\,a_n(E)\,\sigma \qquad (5)$$

the author has calculated size of P-odd effect in total cross section for $^{nat}Pb$ at neutron energies corresponding to the wave lengths of $\lambda$ = 6.8 Å and $\lambda$ = 1.8 Å: $a_n^{calc} = 2\cdot 10^{-7}$ and $a_n^{calc} = 1\cdot 10^{-9}$ respectively. As the total cross section in (4) and (5) he used the values of σ (6.8 Å) = 2.25 b and σ (1.8 Å) = 0.65 b. However, as one can see from [13], this size corresponds to the radiative cross section with the 1/v behavior. Thus, from our point of view, he actually calculated P-odd effect in radiative cross section, instead of total cross section where it is necessary to consider potential scattering. Therefore, if we are right, his calculation can be compared directly with our experimental result.

According to the same work [3], $a_n \sim 1/\sqrt{E_n}$ , where $E_n$ is the energy of neutrons. Then, for neutron energy in our experiment (λ = 4.7Å), the Lobov's estimation gives $a_\gamma^{calc} = 1.4\cdot 10^{-7}$.

As one can see, the accuracy reached in our experiment is insufficient for certain conclusions about presence or absence a negative p-wave resonances. It is necessary to increase for increasing, at least, in 3-4 times. There is a possibility to reduce significantly the background coming from the interaction of neutrons with air and construction materials of installation [10] and to increase the measurement time. According our estimation the accuracy of experiment can be increased in factor of 2-5, that can be sufficient for unequivocal conclusions.

This work is supported by the Russian Foundation for Basic Research, Grant No. 10-02-00174-a.

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