Asymmetry of charged-particle emission in the capture of polarized thermal neutrons by ^{3}He and ^{10}B nuclei

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Measurements by an integrating method yield an upper limit on the magnitude of the P-odd asymmetry in the reactions ^{3}He$(n,p)^3$H and ^{10}B$(n,\alpha)^7$Li. There is a left–right asymmetry in the reaction ^{10}B$(n,\alpha_0)^7$Li with a coefficient $a_{RL} = (0.77 \pm 0.06) \cdot 10^{-4}$.

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In this letter we report the results of an ongoing study of parity violation in nuclear reactions.[1,2] In addition to the reactions with ^{6}Li and ^{10}B, which were proposed by Lobov and Danilyan,[3] we included the reaction ^{3}He$(n,p)^3$H, since it involves a few-nucleon system for which detailed theoretical calculations are possible (in contrast with heavy nuclei). In addition to the P-odd correlation $\vec{\sigma} \times \mathbf{p}$, we studied the left–right asymmetry in the direction perpendicular to the spin and momentum of the captured neutron, $\vec{\sigma} \times (\mathbf{p}_n \times \mathbf{p})$, where $\vec{\sigma}$, $\mathbf{p}_n$, and $\mathbf{p}$ are unit vectors along the directions of the spin and momentum of the neutron and the momentum of the light fragment, respectively.

Measurements were carried out in a beam of polarized thermal neutrons from the VVR-M reactor of the Leningrad Institute of Nuclear Physics; the beam intensity was 6×10^7 n/s.

In the measurements, the neutron polarization direction with respect to the guiding magnetic field was reversed with an adiabatic rf flipper. The detectors, which were multiwire porportional counters operated in an integrating mode, detected the corresponding current change caused by the light reaction products emitted along the axis with respect to which the asymmetry was studied. The detector arrangement is shown in Fig. 1. The neutron beam was incident perpendicular to the plane of the figure, polarized along the horizontal axis in the study of the P-odd asymmetry or along the vertical axis in a study of the left–right asymmetry. The ionization produced in a volume defined by high-voltage electrodes was measured. The heavy reaction products were not detected, because of their comparatively short range in the gas at the pressure used. For the experiments on the ^{10}B$+n$ reaction the sensitive volume was further divided into two parts–inner and outer–so that only the α particles corresponding to the α_0 line would be detected in the outer part. A differential method was used to cancel out the fluctuations in the intensity of the neutron beam: In the difference between the currents from detectors at opposite ends, the asymmetry signals were added, while the intensity fluctuations were subtracted. The asym-

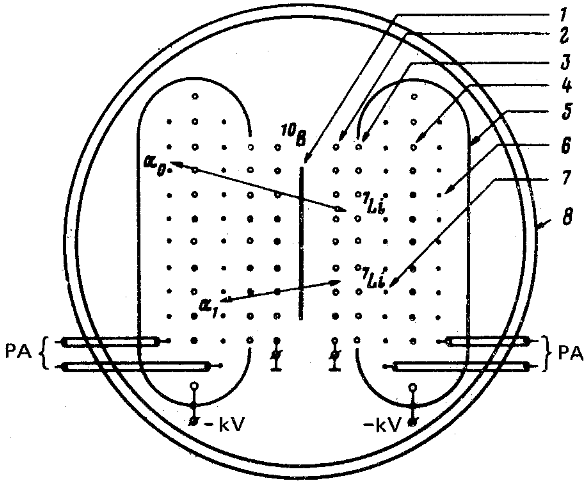

FIG. 1. Chamber arrangement. 1—^{10}B target; 2—grounded grid; 3-5—high-voltage grids and solid electrodes; 6,7—signal grids of the outer detector (which detected only the α_0 line) and of the inner detector (which detected a mixture of α_0 and α_1), with leads to preamplifiers; 8—chamber wall.

metry A in an individual measurement is

$$A = [(Q_L - Q_R)_1 - (Q_L - Q_R)_0] / [(Q_L + Q_R)_1 + (Q_L + Q_R)_0], \qquad (1)$$

where Q_L and Q_R are the charges induced at the left and right signal electrodes during the measurement, and the subscripts 1 and 0 correspond to the state of the on—off rf field of the flipper.

Because of this cancellation of the intensity fluctuations of the beam, the rms error of the measured asymmetry in the experiment with ^3He was only one-third that corresponding to a simple averaging of the measurements by the two detectors. The flipper was prevented from affecting the detector sensitivity in the following way: After passage through the flipper, the neutron polarization was put in two mutually opposite directions twice a day by switching a constant magnetic field ("+ field" and "– field"). The effect under study changed sign, while that of a possible false effect did not. The asymmetry coefficient was determined from

$$a = [A(+\text{field}) - A(-\text{field})] / 2P\overline{\cos\theta}, \qquad (2)$$

where $P = 0.97$ is the beam polarization, and $\overline{\cos\theta}$ is a factor reflecting the finite size of the detectors.

In the experiments with ^3He the target was that part of the volume of the working mixture ($^3He + 2\% CO_2$) in the chamber which was intersected by the beam. The ^{10}B targets were of a sandwich design, consisting of 100 $\mu g/cm^2$ of Ti, 300–400 $\mu g/cm^2$ of B, and 100 $\mu g/cm^2$ of Ti (the boron was enriched to 83% in the ^{10}B isotope). In the experiments on the reaction $^{10}B(n,\alpha)^7Li$, in contrast to Ref. 1, the effect which was measured was actually the combined effect of two α lines, associated

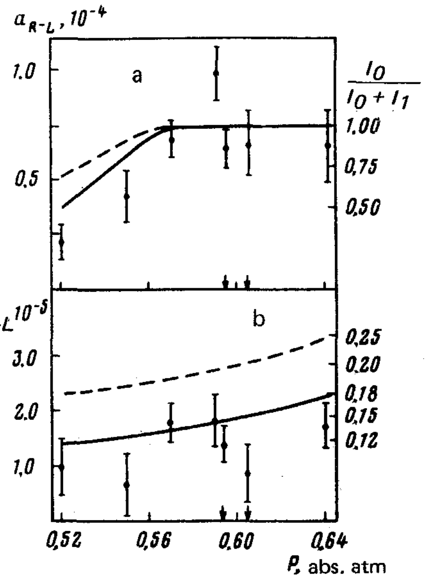

FIG. 2. Left–right asymmetry in the reaction $n + {}^{10}B$ as a function of the pressure in the chamber. (a) As detected by the outer detectors. At $P > 0.57$ abs. atm, this asymmetry is caused solely by the α_0 line. (b) As detected by the inner detectors. This asymmetry is determined by an $\alpha_0 + \alpha_1$ mixture. Solid curves represent the effect at the α_0 line calculated for an infinitesimally thin target; dashed curves represent the same effect for an infinitely thick target. The fraction of the current corresponding to the α_1 line is shown on the ordinate scale at the right. The arrows show the pressures at which the P-odd asymmetry was determined.

with the production of the ^{7}Li recoil nucleus in the ground state (the α_0 line) and in the first excited state (α_1). It must be noted, however, that the different final states are apparently related to different capture states: the α_1 line to the $7/2^+$ state and the α_0 line primarily to the $5/2^+$ state.[4] The parity violation may be different for the two lines; in particular, it may be much more pronounced for the weaker (6.7%) α_0 line.[3)] In our experiments the α_0 line was isolated because of the larger (≈20%) range of the corresponding α particles, and the asymmetry was determined separately for the α_0 line and for the mixture of α_0 and α_1. The asymmetry at the α_0 line was determined in the outer detectors. Figure 2a shows the degree of separation of the α_0 line; as the pressure is reduced, only at $p = 0.57$ abs. atm does the left–right asymmetry associated with the α_0 line begin to decrease because of the admixture of the more intense α_1 line. The magnitude of the left–right asymmetry was determined at the α_0 line at $p > 0.58$ abs. atm, and the P-odd asymmetry was determined at 0.60 abs. atm. The inner detectors detected a mixture of α_0 and α_1. The calculated contribution of both these lines to the detector current depends on the α range in the target, since the target thickness in mass units is comparable to the thickness of the gas-filled gap between the target and the detector. Since the ^{10}B target was inhomogeneous in thickness, the current ratio was calculated for two extreme cases: infinitely thick and infinitesimally thin targets (Fig. 2b). As a result, the data obtained for the α_1 line can be taken as no more than an indication of the

TABLE I.

Reaction	Asymmetry	A(+ field), × 10^{-6}	A(− field), × 10^{-6}	$\overline{\cos\theta}$	a, × 10^{-6}
$^3He(n, p)\,^3H$	*P*-odd	0,46 ± 0,47	− 0.06 ± 0.46	0,70	0.38 ± 0.49
$^3He(n, p)\,^3H$	Left–right	−0,75 ± 0,76	0,08 ± 0,79	0,70	− 0.34 ± 0.57
$^{10}B(n, \alpha_0)\,^7Li$	*P*-odd	0,6 ± 7,5	11.4 ± 7.4	0,96	5.8 ± 6,1
$^{10}B(n, \alpha_0)\,^7Li$	Left–right	See Fig. 2a	–	0,95 ÷ 0.97	77 ± 6
$^{10}B(n, \alpha_1)\,^7Li^*$	*P*-odd	−0,66 ± 1.35[1)]	− 1,05 ± 1,34[1)]	0,90	1.1 ± 1,6[2)]
$^{10}B(n, \alpha_1)\,^7Li^*$	*P*-odd	− 0,66 ± 1,35[1)]	− 1,05 ± 1,34[1)]	0,88	0.8 ± 1,4[3)]
$^{10}B(n, \alpha_1)\,^7Li^*$	Left–right	See Fig. 2b	–	0.88 ÷ 0.92	− 10,0 ± 1.5[2)]
$^{10}B(n, \alpha_1)\,^7Li^*$	Left–right	See Fig. 2b	–	0.84 ÷ 0,90	− 2,8 ± 1.4[3)]

[1)]Mixture of the α_0 and α_1 lines.

[2)]The effect of the α_0 line was calculated for an infinitely thick target.

[3)]The effect of the α_0 line was calculated for an infinitesimally thin target.

existence of a left–right asymmetry of the other sign at this line, at the level of 10^{-5}. The experimental results are listed in Table I. The magnitude of the left–right asymmetry coefficient measured for the reaction $^6Li(n,t)^4He$ in Ref. 1 and the corresponding results for the reaction $^{10}B(n,\alpha_0)^7Li$ from the present experiments are proportional to the imaginary part of the ratio A_p/A_s, where $A_{s,p}$ are the *s*- and *p*-wave reaction amplitudes. The real part of this ratio, determined from the forward–backward asymmetry in these reactions, was measured in Ref. 5 at neutron energies of 2 keV and 24 keV. Comparing these results, and noting that the relative importance of the interference term is proportional to the momentum of the captured neutron because of the corresponding change in the neutron widths, we find that the imaginary part of A_p/A_s is comparable in magnitude to the real part in these reactions. The limits found on the magnitude of the *P*-odd asymmetry in the reactions $^{10}B(n,\alpha_{0,1})^7Li$, $|\alpha_0| < 1.6 \times 10^{-5}$ and $|\alpha_1| < 3.8 \times 10^{-6}$ (90% confidence level) are approximately equal to the simple estimates made by Lobov and Danilyan.[3] The experimental accuracy can improved further by eliminating false effects associated with the left–right asymmetry, by reducing the neutron energy or by using a beam of longitudinally polarized neutrons. The upper limit on the *P*-odd asymmetry in the reaction $^3He(n,p)^3H$ is quite low, $|\alpha| < 1.2 \times 10^{-6}$ (90% confidence level), but there is a suppression here by a least an order of magnitude, because the capture into the 1^+ state is so slight (the 0^+ ground capture state does not contribute to a polarization of the compound nucleus).

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3)G. A. Lobov brought this possibility to our attention.

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