Continuation of the search for T-invariance violation in β decay of a free neutron

B. G. Erozolimskiĭ, Yu. A. Mostovoĭ, V. P. Fedunin, A. I. Frank, and O. V. Khakhan

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A new facility with a high-power beam of polarized neutrons was used to continue the measurements of the three-vector correlation that violates time parity. A value $D = -0.0027 \pm 0.0033$ is obtained for the constant. The measurements are being continued.

Several recent investigations of β decay of polarized neutrons were devoted to a search for the dependence of the decay probability on the direction of the neutron spin σ relative to the decay plane $(\mathbf{p}_e \cdot \mathbf{p}_{\bar{\nu}})$.[1,2,5] It is known that the presence of such a correlation, characterized by a coefficient D, would violate time parity in this process. There are still no experimental indications of the existence of such an effect. The first study of the Chicago group[1] yielded $D = 0.04 \pm 0.05$. An investigation at the I.V. Kurchatov Institute in 1968 has shown that $D = -0.01 \pm 0.01$.[3-6 1)]

In view of their fundamental significance, these searches were continued. To increase the statistical accuracy of the measurements, a new high-power beam of polarized neutrons was developed in 1970—1973 with the IRT-M reactor of the Kurchatov Atomic Energy Institute, with a total flux 1.5×10^9 neut/sec at a reactor power 7 MW, and with a polarization ~70%. To this end, a beryllium-water "trap" was installed at the center of the active zone of the reactor, to ensure a "flash" of thermal neutrons, thus initiating a vertical channel passing through the entire thickness of the water shield of the reactor. In the central part of the channel, at a depth of 3 meters under the water, are located cobalt mirrors with total area 4500 cm^2, and the longitudinal field that magnetized the cobalt layers was produced by a solenoid wound on top of the channel and cooled directly with the water of the reactor pool. The upper part of the channel is filled when necessary with water, producing a "water damper" for the channel.[2)] The measurement system itself was fundamentally modified in comparison with that described in[5]. The electrons were registered with type FÉU-52 counters with plastic scintillators of 70 mm diameter and 3 mm thickness, based on vinyl xylol (5 such counters in each of the two β detectors). The recoil protons were registered with the same electrostatic-focusing system as before, with a field-free transit cylinder, with the aid of which, as shown in[3,4,6], the proton time of flight is used to separate the events of neutron decay accompanied by emission of antineutrinos, with momenta lying in a definite angle cone. The recoil protons accelerated to 25 keV were counted with two photomultipliers having thin CsI(Tl) layers.

The main feature of the measuring system first employed in[3] was the use of two symmetrically disposed pairs of electron counters and recoil protons. This, as shown in[5], suppressed appreciably the methodological errors due to the presence of electron-spin and antineutrino-spin correlations, which otherwise were capable of imitating the sought effect as a result of the inaccuracy in the setting of the entire measurement system relative to the spin direction. It was shown that the overall methodological error due to such a tilt of the apparatus of[5] did not exceed 10^{-3}.

A subsequent analysis undertaken in connection with attempts to measure the constant D with higher accuracy has shown, however, that there exists an entire class of effects capable, in final analysis, of imitating the sought T-odd asymmetry, and which are quite difficult to reveal in any individual control experiment. The point is that since the initial momentum of the recoil proton is determined by the total momentum of the antineutrino and the electron, it follows that the proton trajectories inside the measuring chamber are different for cases when the electron is registered by different β detectors, and furthermore, they vary (on the average) when the neutron-spin direction is changed by the strong correlation between the neutron spin and the antineutrino momentum. It can be shown that if there are some inhomogeneous proton losses (in grids, diaphragms, and also in the scintillation layer of the counter), with the asymmetry axis making an average angle of 45° with the neutron-spin direction, then the result is a false effect of the sought type, which is not suppressed by the overall symmetry of the apparatus. We have performed a crude control experiment in which two quadrants of the proton detector (at 45° to the symmetry axis of the installation) were covered with aluminum foil, and this produced a false effect corresponding to a constant $D = 0.2$! It is therefore extremely important to minimize the proton losses and to make them symmetrical relative to the axis of the installation. Thus, for example, in investigations where no system is used for proton focusing, the false effect can be the result of inaccuracies in the manufacture of the diaphragms that separate the protons, or because of the diaphragms are tilted.

In our first investigation, the proton counter diameter was 70 mm, which agrees only in the limit with the dimension of the focus of the gathered recoil protons. Therefore in the new investigation, a brief preliminary report of which is presented here, the diameter of the proton detectors was increased (FÉU-94 with a photocathode of 100 mm diameter and a CsI(Tl) layer 0.5 μ thick). In addition, to average out any possible inhomogeneities in the sensitivity of the scintillating layer and of the photomultiplier cathode, the two proton detectors were periodically rotated 90° about their axes.

By now we have registered approximately 1.5×10^6 decay events, and the three-vector correlation coefficient was found to be $D = -0.0027 \pm 0.0035$. The error indicated here is statistical, but according to our estimate the measures employed will ensure even smaller methodological errors. The accumulation of the statistics is being continued.

[1)] Recent work at Grenoble yielded for the constant a value $D = -(1.1 \pm 1.7) \times 10^{-3}$ [Phys. Rev. Lett. 33, 41 (1974)].

[2)] Participating in the development of the new vertical channel, undertaken at the initiative of Academician A. P. Aleksandrov and V. V. Goncharov, were in addition to the present authors also the operating crew of the IRT-M reactor headed by V. N. Chernyshevich, and also B. A. Obinyakov, A. E. Kurkov, and S. A. Petushkov of the Atomic Energy Institute.

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