Search for electric dipole moment of the neutron

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The result of measuring the electric dipole moment (EDM) of the neutron by using ultracold neutrons is presented. The results of the measurements give the value of the EDM: $d_n = (4 \pm 7.5)\times 10^{-25}$ e·cm. Hence, it can be concluded that $|d| < 1.6\times 10^{-24}$ e·cm at the 90% confidence level.

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A research for the electric dipole moment of the neutron is of great interest because of the violation of *CP* invariance. A number of experiments, the last of which[1] was performed in Grenoble in 1976, made it possible to establish the upper limit for the electric dipole moment (EDM) ($|d_n| < 3\times 10^{-24}$ e·cm). These experiments fully tested the potentialities of the flight-path measurements. The accuracy of the experiment involving the serach for the EDM of the neutron can be further increased by using ultracold neutrons.[2,3]

In this paper we give the results of an experiment which was carried out by using the ultracold neutrons. The experimental setup includes an ultracold neutron source with a mirror neutron guide[4,6] and a magnetic resonance spectrometer.[7,8]

The ultracold neutron source is a beryllium converter cooled to 30 K by using helium gas that removes 1.3 kW of heat. The converter is situated at the center of the reactor core in a thermal neutron flux of 1×10^{14} neutrons/sec·cm^2. The density of the ultracold neutron flux is increased 10 to 12 fold by cooling the converter. A stainless-steel mirror neutron guide transmits the neutrons to the magnetic resonance spectrometer. The ultracold neutron flux ($v < 6.8$ m/sec) is 1.2×10^4 neutrons/sec at the entrance to the spectrometer.

The search for the EDM using the magnetic resonance method is based on the fact that a change in direction of the electric field relative to the magnetic field shifts the resonance frequency if the neutron has an electric dipole moment ($H = -\mu\vec{\sigma}\mathbf{H} - d_n\vec{\sigma}\mathbf{E}$). The ultracold neutron gas, which was held in the traps for ~ 5 sec, was used as the working material in theis spectrometer. This made it possible to obtain a very narrow magnetic resonance line ($\Delta\nu \approx 8\times 10^{-2}$ Hz). The required stability of the magnetic field (10^{-6}–10^{-7} Oe) was maintained by means of a three-layer induction screen, by magnetic-field stabilization outside the induction screens and by magnetic-field stabilization inside the induction screens, which was established by using an optically pumped quantum magnetometer. Moreover, the resonance stability was maintained by varying the neutron count by automatic frequency tuning. The homogeneity of the magnetic field in the active volume of the spectrometer was $(1-2)\times 10^{-5}$ Oe, the operating frequency was 83 Hz, and the electric field strength was ~ 25 kV/cm.

TABLE I. Results of individual series of measurements (in units of 10^{-24} e·cm).

№	EDM	Statistical error	RMS error
1	– 1.29	2.41	2.71
2	– 2.1	2.93	3.03
3	1.15	1.12	1.11
4	– 2.80	2.50	2.62
5	– 0.43	1.76	1.72
6	2.08	1.99	1.95

The spectrometer has three main characteristic features. It has two chambers, it has a system for double analysis of the polarization,[9,10] and it uses the adiabatic method of separate oscillating fields.[8]

The measurements and the experiment were automatically controlled by a M-400 computer. The polarity of the voltage was changed at intervals of time during the measurements and a possible shift of the resonance frequency was determined.

We carried out several sets of measurements from which we determined the distribution of the deviation of the results from the average value. This analysis showed that the deviation is normal and its half width is only 3% higher than the statistical. The weighted mean of the final results, which is within the limits of one standard deviation, is

$$d_n = (4.0 \pm 7.5) \times 10^{-25} \text{ e·cm}.$$

We also conducted a control analysis of the results, which enabled us to determine the contribution of the systematic errors to the results of the measurements. This analysis was possible because of the special, two-chamber design of the spectrometer. We discovered no systematic errors in the control analysis of the results, which indicates that our results are reliable.

Thus, at the 90% confidence level $|d_n| < 1.6 \times 10^{-24}$e·cm.

The results of the individual measurements are given in Table I and the results of the control analysis are given in Table II.

TABLE II. Control analysis of the results (in units of 10^{-24} e·cm).

	EDM	Statistical error	RMS error
Upper chamber	0.72	1.02	1.21
Lower chamber	0.19	1.06	1.26

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