Search For The Electric Dipole Moment Of The Neutron

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Abstract. We report on the nEDM experiment at the Institut Laue Langevin (ILL), based on a precision measurement of the Larmor precession frequency of polarised ultra-cold neutrons stored in a cell in a magnetic field. An EDM would reveal itself by a response of the Larmor precession frequency of the neutron to an electric field applied over the storage volume. The experiment has been taking data over a period of six years and has subsequently been running for one year devoted to systematic studies related to the experiment. These systematic studies have now been completed. This experiment will result in an EDM measurement with a sensitivity of the order of 10^{-26} *e* cm. The experimental techniques used in the experiment are presented as well as the systematic studies and results of the data analysis of the experiment.

Keywords: Electric dipole moment, CP violation, Ultra-cold neutron
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INTRODUCTION

For particles to have electric dipole moments, the forces concerned in their structure must be asymmetric with regard to space-parity (P) and time reversal (T) [1, 2]. CP violation is believed to be responsible for the baryon asymmetry of the Universe but the CP violation found in the Standard Model is many orders of magnitude too small to account for the observed baryon asymmetry. Extensions to the Standard Model of the electroweak interaction, such as additional Higgs fields, right-handed currents or supersymmetric partners typically give rise to dipole contributions which are of order 10^{-26} to 10^{-28} *e* cm. Experimental measurements of particle EDMs, and in particular that of the neutron, are providing some of the strongest additional constraints on these theories. The current experimental limit on the neutron EDM is set by our collaboration to $|d_n| < 6.3 \times 10^{-26}$ *e* cm (90% CL) [3].

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EXPERIMENTAL TECHNIQUES

The Ramsey resonance technique is used to measure, with very high precision, the Larmor precession frequency of spin polarised ultracold neutrons (UCN) in a weak magnetic field. The precession frequency will change in the presence of an electric field if the neutron has an EDM. The EDM experiment incorporates a magnetometer based on atomic ^{199}Hg stored simultaneously in the same cell as the neutrons [4]. This system provides us with a magnetometer probing the UCN storage cell with an accuracy of 1nG. The measurement is made with UCN stored in a cell permeated by **E**- and **B**-fields. The terms $-\boldsymbol{\mu}_\mathbf{n}.\mathbf{B}$ and $-\mathbf{d}_\mathbf{n}.\mathbf{E}$ are added to the Hamiltonian determining the states of the neutron. The difference in Larmor frequencies between parallel and antiparallel **E** and **B** fields relate to d_n via $h(\nu_{\uparrow\uparrow}-\nu_{\uparrow\downarrow}) = 4\mathbf{d}_n.\mathbf{E}$. Thus, the goal is to measure any shift in the transition frequency ν when a strong **E** field is reversed relative to **B**. With a polarisation of the neutrons of 0.85, an electric field strength of E = 11 kV/cm, a storage time T = 130 and N = 18000 neutrons counted per batch we obtained a precision $\sigma(d_n)$ from one day of data of about 15×10^{-26} e cm.

ACQUIRED DATA

The experiment has been acquiring data for a total of six years. Figure 1 shows the statistical precision that we have accumulated over this period. The precision with which the EDM measurements have been made has improved steadily over the years. As the experiment was carried out techniques have been developed and incorporated in the experiment that allowed e.g. to increase the electric field strength and the storage potential of the cell. As shown in Figure 1, the resulting final statistical sensitivity that we obtained in our measurement is 1.5×10^{-26} e cm.

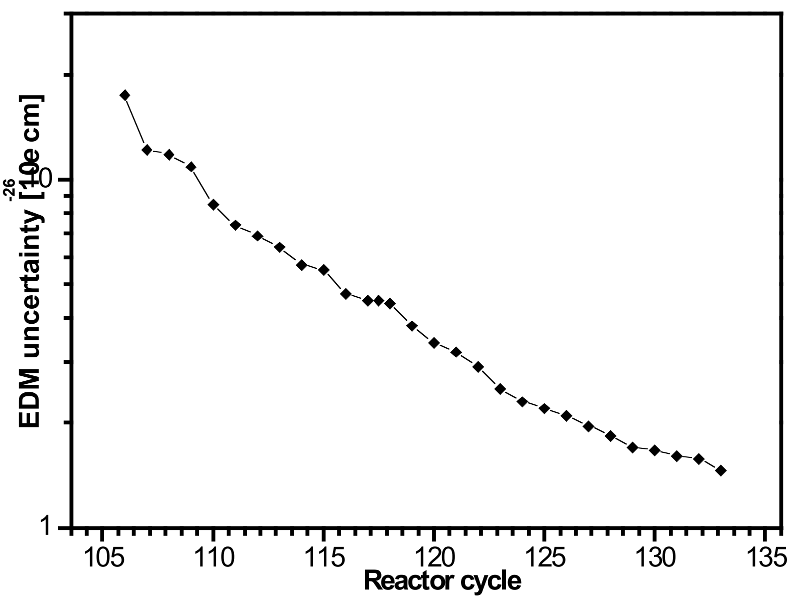

FIGURE 1. The statistical precision on the neutron EDM accumulated per reactor cycle. The period covers the full six years of the experiments running time.

SYSTEMATIC EFFECTS IN THE EXPERIMENT

There are a number of effects that can alter the precession frequency of the neutron and generate a false EDM signal or shift any measured EDM signal. Most of these effects are suppressed by the configuration of the experiment to a level well below 10^{-26} e cm, *i.e.* a level well below the obtained statistical precision. However there is one mechanism, the geometric phase effect described in [5], that can generate EDM signals big enough to affect our result. This will, through the Ramsey-Bloch-Siegert mechanism, shift the precession frequency of the neutron in response to an applied electric field and thus generate a false EDM signal. We have indeed found this effect by analysing the data as function of the vertical magnetic field gradients present in the experiment. The effect introduces a possible systematic error that is of the same order as the statistical uncertainty and presents our leading systematic error.

CONCLUSIONS

We have made a measurement of the nEDM by making a precision measurement of the Larmor precession of a neutron stored in a magnetic field aligned to an external electric field. The data taking is completed and studies have been carried out to identify and quantify the systematic effects present in the experiment. The final statistical uncertainty that is obtained is 1.5×10^{-26} e cm. The leading systematic effect is well understood and gives rise to a possible systematic error that is of the same order in size as the statistical uncertainty.

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