International Journal of Modern Physics A


# A NEW SEARCH FOR A NEUTRON ELECTRIC DIPOLE MOMENT

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The possible existence of a non-zero neutron electric dipole moment directly impacts our understanding of the nature of the electroweak and strong interactions. Experimental efforts over the past fifty years have increased the sensitivity to this very small quantity by eight orders of magnitude. An overview of a proposed experiment with the goal of a further two orders of magnitude increase in sensitivity to the level of $10^{-28}$ $e$-cm is presented. Progress towards the solution of various technical challenges associated with the experiment is discussed, and a timeline for the experiment is outlined.

## 1. Introduction

The existence of a non-zero neutron electric dipole moment (EDM) requires the violation of both the parity (P) and time-reversal (T) symmetries[1,2]. Assuming the validity of the CPT theorem, the discovery of a non-zero neutron EDM would provide the first evidence for CP violation in a light quark system. The Standard Model (SM) prediction[3] for the neutron EDM, as embodied within the complex phase of the CKM matrix, is a miniscule $10^{-31}$ to $10^{-33}$ $e$-cm, while the best experimental limit[4] is $< 6.3 \times 10^{-26}$ $e$-cm. Although the experimental sensitivity still stands approximately five orders of magnitude above the SM prediction, a number of proposed extensions to the SM, such as left-right symmetric models, supersymmetry, etc., predict values for the neutron EDM that lie one to two orders of magnitude below the current experimental limit (see, e.g., Ref. 5 for a compilation).

The goal of the proposed experiment[6,7] discussed in the remainder of this article is a further two orders of magnitude increase in sensitivity to $10^{-28}$ $e$-cm. At this level of sensitivity, the experiment has the potential to either discover a non-zero neutron EDM or to severely constrain proposed SM extensions. Results from complementary leptonic and atomic EDM searches would be needed in order to interpret a positive or null signal for the neutron EDM in terms of CP violation in the QCD sector or the possibility of new physics, and the synthesis of all these experimental results could possibly shed light on the puzzle of the baryon asymmetry of the universe (see Ref. 8 for a recent theoretical overview of EDM implications).

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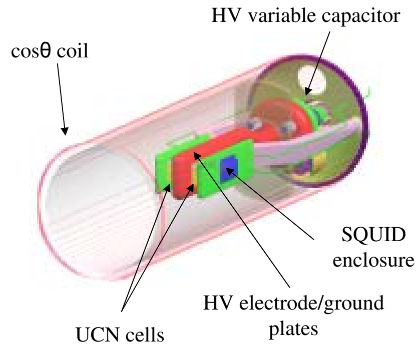


Fig. 1. Simplified schematic diagram of the proposed experiment.

## 2. Overview of Proposed Experiment

The experiment is based on the traditional magnetic resonance technique of measuring the neutron precession frequency, $\nu_n$, under the influence of (weak) magnetic, $\vec{B}$, and (strong) electric, $\vec{E}$, fields. In external electromagnetic fields, the Hamiltonian for the neutron ground state is $\mathcal{H} = h\nu_n = -2(\vec{\mu}_n \cdot \vec{B} + \vec{d}_n \cdot \vec{E})$ , where $\vec{\mu}_n$ ($\vec{d}_n$) denotes the neutron magnetic (electric) dipole moment. A value for or a limit on $|\vec{d}_n|$ can be extracted from a comparison of measurements of $\nu_n$ with the $\vec{E}$ field aligned parallel and anti-parallel to the $\vec{B}$ field.

An up-to-date simplified schematic diagram of the proposed experiment is shown in Fig. 1. The entire appartus shown in this figure will be immersed in a bath of superfluid $^4$He maintained at 300 mK. Ultra-cold neutrons (UCNs) will be locally produced and subsequently trapped in specially coated UCN cells via the downscattering of an incoming 8.9 Å cold neutron beam in the superfluid $^4$He[9]. As indicated in the figure, two identical storage cells will sit in between a high-voltage electrode and two ground plates. The strong electric fields (nominal 50 kV/cm) will be generated by charging a variable capacitor to some smaller voltage and then increasing the plate separation distance, thereby increasing the voltage. The weak magnetic fields (nominal 1–10 mGauss) will be generated by an iron-free cos $\theta$ coil.

Knowledge of the $\vec{B}$ field is of crucial importance and will be measured *in situ* in real time via the introduction of a small amount ($10^{-10}$) of polarized $^3$He into the superfluid $^4$He. An rf field will rotate the neutron and $^3$He spins into a plane perpendicular to the $\vec{B}$ field, and SQUID coils will be used to determine the $^3$He precession frequency. Analysis of the SQUID signals will provide a direct measure of the volume-averaged magnetic field. The neutron precession frequency will then be determined via measurements of the spin dependence of the $n$-$^3$He capture reaction. As the neutron and $^3$He magnetic moments differ slightly, they will precess at slightly different rates, leading to a sinusoidal dependence (on the neutron and $^3$He precession frequency difference) in the scintillation light generated in the superfluid $^4$He by the $n$-$^3$He capture reaction products (protons and tritons).

## 3. Technical Achievements and Experiment Timeline

The collaboration has now demonstrated the technical feasibility of the experiment, and a partial listing of some of the technical achievements includes the following.

First, a full-scale mockup of the high-voltage multiplier has been constructed and operated successfully at 4 K (superfluid tests expected soon). The $\vec{E}$ field will be monitored over time via the electro-optical Kerr effect (such measurements will be used to monitor leakage currents), and our collaborators have observed for the first time the Kerr effect in liquid helium[10]. Second, work on the magnetic fields and requisite magnetic shielding has commenced. A successful prototype $\cos\theta$ coil has been constructed, and studies of the impact of mirror currents in the magnetic shielding on the field uniformity at cryogenic temperatures are underway. Third, relaxation times for polarized $^3$He have been measured at 4 K and 2.5 K, and efforts are currently underway to observe a $^3$He spin signal using SQUIDs. Fourth, particle identification studies have begun at a reactor in order to discriminate between recoil protons/tritons and $\beta$-decay electrons. Finally, the collaboration has begun efforts to measure neutron storage times in UCN bottles using an already existing UCN beamline constructed at LANL.

Research and development efforts will continue through 2006, and the collaboration is eager to begin the construction phase of the experiment in 2007. The experiment will ultimately be mounted at the Oak Ridge National Laboratory Spallation Neutron Source with a projected data-taking run commencing sometime during 2010-2012. The final projected sensitivity for the neutron EDM from this experiment is at the level of $10^{-28}$ $e$-cm in $\sim$100 days of running.

## Acknowledgments

This work was supported in part by funds from the National Science Foundation and the U.S. Department of Energy.

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