# Designing a Uniform Magnetic to Help Detect the Electric Dipole Moment of a Neutron

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## 1 Introduction

The breaking of time symmetry in particle systems is essential in uncovering the secrets of the early universe. Evidence of breaking time (T) invariance may help explain the abundance of matter over antimatter, or the Baryonic Asymmetry, of the Universe. If the T symmetry was truly invariant, theoretically, there should exist equal amounts of both types of matter (as Andrei Sakharov realized), contrary to what modern measurements are telling us. Physicists are searching for more evidence of T violations that could lead to an explanation to the aforementioned phenomena [1].

A promising piece of evidence, if can be proven with the development of an extremely uniform magnetic field, would be the electric dipole moment of a neutron (nEDM).The dipole moment results from a subtle separation of the quarks in a neutron, similar to the way a molecule is polarized with partial positive and negative charges. Evidence of a non-zero nEDM violates both Parity and Time symmetries [1]. The separation of these quarks behaves differently in a mirror-reflected world, or Parity symmetry, as well as in one where time is reversed. As my teammate Stephanie Betancourt denotes, this is evident in the equation $d_n = \vec{d} \cdot \vec{\sigma} = q\vec{r} \cdot \vec{r} \times m\frac{d\vec{r}}{dt}$. Parity symmetry is violated when $P : \vec{r} \to -\vec{r}$, so $d_n$ is also reversed. Time invariance is violated because $T : t \to -t$, so $d_n$, the observable EDM range of frequency, becomes reversed as well. $\vec{d}$ is the EDM vector that is not measured. $\vec{\sigma}$ represents the spin or angular momentum of the neutron. In $q\vec{r}$ q is the charge of quarks and $\vec{r}$ presents the level of separation in respect to the center. Lastly, $m\frac{d\vec{r}}{dt} = P$ where P is momentum. These inconsistencies make the nEDM a potential piece of insight to the antimatter-matter imbalance in the universe.

Because the nEDM would be magnitudes of times smaller than the tiny neutron itself, a uniform magnetic field is imperative to highlight any possible resulting disturbances in the field. Even an extremely minuscule difference of 1 fT in a less uniform field can imitate the signal for a non zero nEDM [1]. Therefore, the design of these types of magnetic fields is one of the most important aspects in the search for an electric dipole moment in a neutron. However, this type of testing would be severely limited with the electromagnet currently designed [3]. Our project seeks to improve upon this electromagnet and test the magnetic fields associated with our designs so that they can be effective in future nEDM detection experiments.

# 2 Procedure

Our research is composed of two main parts. The first is to develop a design through computer-aided design (CAD) to improve upon a faulty design of the electromagnetic coils. The second part is testing, mapping, and comparing the strengths of the magnetic fields of multiple coils.

## 2.1 CAD Implementations

The electromagnet has an sturdy, aluminum skeleton, which a resin-printed ”skin” will envelop. The current model, which uses only grooves to hold the wire in place, does not do its job ably [3]. This results in a much less uniform magnetic field compared to when the wires are tightly secured in a confined space. A coil clip design has been provided to us, and it is our goal to implement this design with the preferred blueprint of the magnet that will be used in the nEDM experiments [3]. We will use either Fusion 360 or Inventor Pro to produce testable prints for the aluminum skeleton.

## 2.2 Testing and Mapping the Magnetic Field

In a nutshell, to detect a nEDM of $10^-23$ cm we would need a magnet with a level of uniformity of

$$\frac{\Delta B}{|B|} = \frac{10^-7}{cm}$$

where B is the magnitude of the magnetic field [2] This will be taken into account in our testing and mapping. To mimic the geometry of the double cos theta coil that will be used for measuring the nEDM, we will wind copper wire around non-conducting skeletons of various sizes. Each point at which the coil sharply curves upwards or downwards along the cylinder will be mapped as a coordinate point using trigonometry (the “circle” of the cylinder acting as a unit circle). Since all designs will be cylindrical, the points can be mapped in respect to the center of the cross-section at the very bottom of the shape (x = 0, y = 0, z = 0). Given a previously developed program in MATLAB, we can then input these points as arguments in a function to find the strength of the B field at a given point on the cos theta coil. The coils should be wound along the equipotential lines of the magnetic field to produce the expected B field in the equation, which can be calculated with a magnetic scalar potential equation [2]. The theoretical values are to be compared with the experimental value measured using a magnetometer. By constantly testing and comparing, we can determine an optimal structure for the winding of the coils around the final magnet.

# 3 References

[1] Crawford, C. ”Robotic Mapping of Magnetic Fields in a Magnetically Shielded Environment”. In: KY NSF EPSCoR PROJECT DESCRIPTION.

[2] Hunter, B. Spencer, L. K. and Crawford, C. “Drilling a double cosine – theta coil”. In: University of Kentucky poster presentation.

[3] Ziemyte, G. ”Designing and Winding an Electromagnetic Coil”. In: REU Project Proposal