Measuring the Electric Dipole Moment of the Neutron

Hena Kachroo

June 2022

1 Introduction

The search for a separation of positive and negative charge, called the electric dipole moment (EDM), within the neutron is one of the most pressing issues in nuclear/particle physics. The discovery of charge separation in the neutron would be a major step forward in explaining the imbalance between matter and antimatter in our universe. According to the Big Bang theory, equal parts of matter and antimatter should have been created in our universe, but now it is predominantly matter. A non-zero EDM in the neutron would be evidence of processes required to convert antimatter into matter during the formation of the Universe. According to Sakharov, these baryon number (B) violating processes require parity (P) violation and charge-parity (CP) violation, equivalent to temporal (T) symmetry violation, which are both present under the standard model of physics, but with not nearly enough strength to explain the asymmetry. Thus detection of a finite nEDM would help to explain the Baryon Asymmetry of the Universe (BAU) [1].

In testing the EDM of the neutron, physicists have exposed neutrons to magnetic fields and measured the precision frequency of the particles. The precision frequency is measured through a nuclear reaction with polarized He-3 atoms. If the neutron had an EDM, its spin axis would also precess when exposed to an electric field, albeit on a much slower scale. After measuring the precision frequency, the large electric field is reversed, and the frequency is measured again to see the difference from background effects. Were an electric dipole moment to be present in the neutron, the precision frequency would shift according to the strength of the applied electric field. The precision frequency can be calculated using the following formula: $\omega_L \hbar/2 = \pm\vec{d} \cdot \vec{E} + \vec{\mu} \cdot \vec{B}$. In this equation, ω_L is the precision frequency, $\hbar/2$ is the spin angular momentum of the neutron, $\pm\vec{d} \cdot \vec{E}$ is the electric dipole moment, and $\vec{\mu} \cdot \vec{B}$ is the magnetic moment dot the B field [1][3].

Due to neutrons being hypersensitive to magnetic fields, a slight change in the magnetic field could produce results mimicking the presence of an EDM, causing a systematic error in the experiment. Therefore, the design of a uniform magnetic field is crucial in testing for EDMs. A double cosine theta coil will be used in this project. This is a unique coil containing two cylindrical layers which produces a uniform magnetic field on the inside of the coil. This design prevents a fringe field from being formed which blocks interference with nearby devices. Through Nuclear Magnetic Resonance, the electric dipole moment of the neutron can then be measured [2].

2 Procedure

1. We will use Autodesk Inventor to develop a skin for a pre − existing skeleton. This skeleton is the decided shape of the magnetic field. The skin will be made of resin from 3-D printing and will contain small clips to hold the wires in place.
2. We will wrap wire around the skins precisely where the clips are placed to create a uniform magnetic field.
3. The robotic magnetic field mapper will be used to measure the magnetic field. Then, computer programs will be used to compare what was measured with what was expected for the magnetic field.

This project is important in the manipulation of neutrons. These neutrons will then be used in nuclear physics experiments including determining the electric dipole moment of the neutron.

3 References

[1] Cartlidge, E. “Physicists place stringent limits on the neutron electric dipole moment”. In: Physics World (2020).

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

[3] Nico, J. “Neutron beta decay”. In: Journal of Physics G: Nuclear and Particle Physics (2009).