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A Voltage Multiplier for the nEDM Experiment

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Abstract

The nEDM experiment at Oak Ridge National Laboratory is a search for the electric dipole moment of the neutron (nEDM) at the 10^{-28} level. The experiment is currently in the research and development phase. One of the variables proportional to the sensitivity of the measurement is the strength of the electric field in the measurement cell where the effect of an nEDM is to be generated. The design of the experiment calls for an electric field of 75 kV/cm in this cell. A unique voltage multiplier involving a variable capacitor has been proposed to achieve this large required electric field. Electrostatic calculations using two independent software packages, COMSOL and Field Precision, were carried out to study the feasibility of the proposed voltage multiplier. A prototype of the electrodes and the voltage multiplier whose size was 25% of full size was also built to verify the predictions of the electrostatic calculations. Results of the tests with the prototype and the electrostatic calculations, are presented.

Background

The proposed method to measure the nEDM is to measure the precessing frequency of a neutron in a magnetic field with a very large superposed electric field. When the direction of the electric field is reversed, the precession frequency will change if there is an nEDM. The figure of merit for the experiment is given by $E_o\sqrt{N\tau}$, where E_o is the electric field in the cell, N is the number of neutrons in the cell during a single measurement and τ is the duration of a measurement. An electric field of 75 kV/cm, requiring a potential difference of 650 kV, is generated by a variable capacitor system shown in Figure 1. This is achieved by applying a lower voltage across the variable capacitor and pulling the ground plate back to magnify the potential difference.

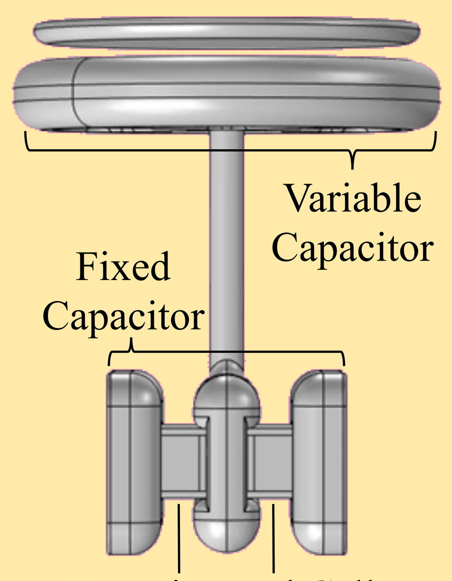

Fig. 1: The full-scale capacitor system.

Previous Work

Adam Clark, a student at Valparaiso University carried out calculations on the gain of the variable capacitor and found that the maximum possible gain achievable was around 5 (Figure 2). By adding a dielectric material between the two electrodes and optimizing the thickness of the dielectric, he was able to achieve a gain of 7.8, an increase of 50% (Figure 3).

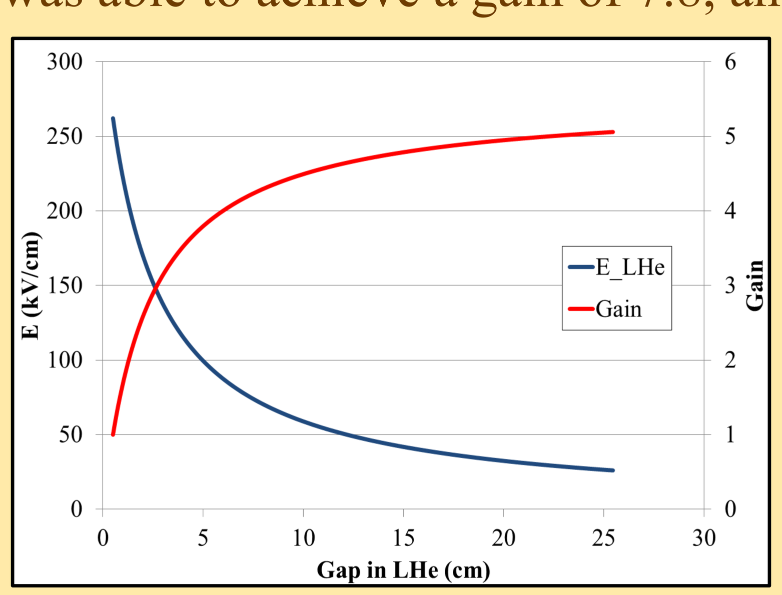

Fig. 2: Gain (magnification) of the variable capacitor as a function of the gap between the electrodes. Also shown is the electric field in the liquid helium as the gap is changed.

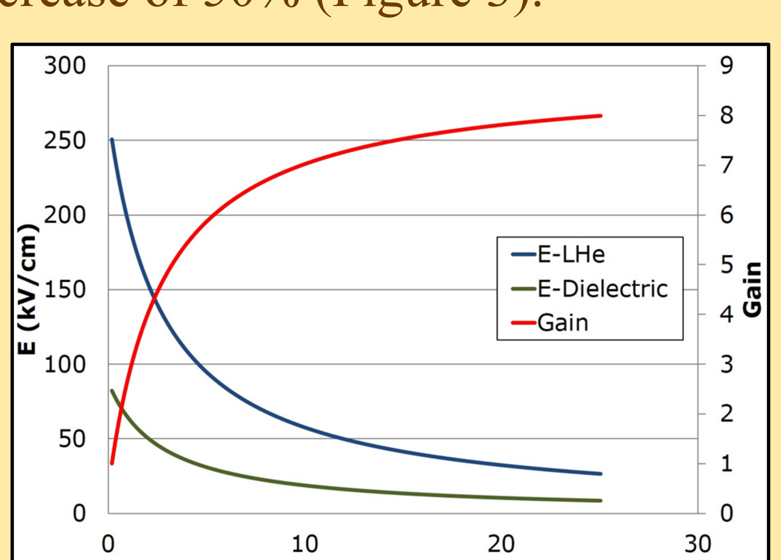

Fig. 3: Gain of the variable capacitor as a function of the gap between the electrodes with the addition of a dielectric. The electric fields inside the dielectric and the liquid helium are also shown.

Pros and Cons of using a Dielectric

Pros:

- Using a dielectric increases the gain, allowing for lower starting voltage.
- Using a dielectric prevents sparks in the system due to the breakdown of liquid helium. These sparks could damage expensive equipment and delay the experiment.

Con:

- Charges could build up on the dielectric, creating a reverse electric field, causing the net electric field in the cell to be unknown.

Charge Buildup Tests

As a proof of principle to see if we could observe charge buildup due to ionization, we carried out tests to measure the charge buildup in air. We investigated the charge buildup on the surface of 3 mil kapton foils (dielectric) attached to electrodes as shown in Figure 4. The charge was measured by touching the surface with the proof plane and inserting it into the Faraday pail (Figure 5). The deflection in the electrometer is proportional to the charge on the surface. The electrometer was calibrated by measuring the charge on the electrodes without the kapton foil. Figure 6 shows charge buildup during a fixed time (20s) as the electric field is increased. Note that the charge buildup due to ionization starts around the breakdown electric field of air, approx. 30 kV/cm. Figure 7 shows how the charge buildup increases at a fixed electric field (42 kV/cm) as a function of time. The reverse voltage shown in each figure is the potential difference due to the charge deposited on the foils.

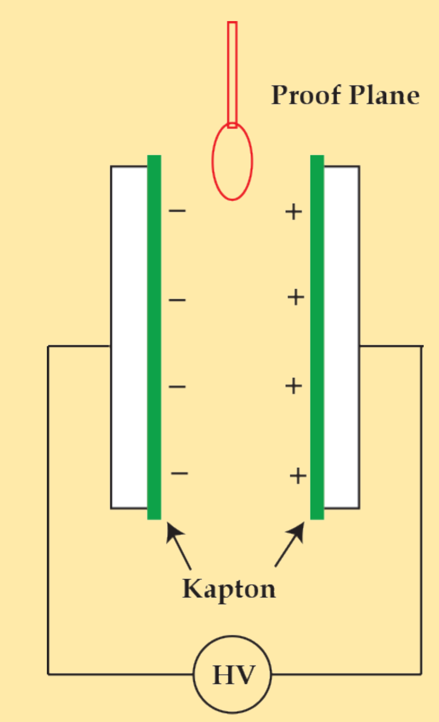

Fig. 4: Diagram of the charge buildup test apparatus (not to scale). The diameter of the stainless steel electrodes was 17 cm and the separation was 1.1 mm.

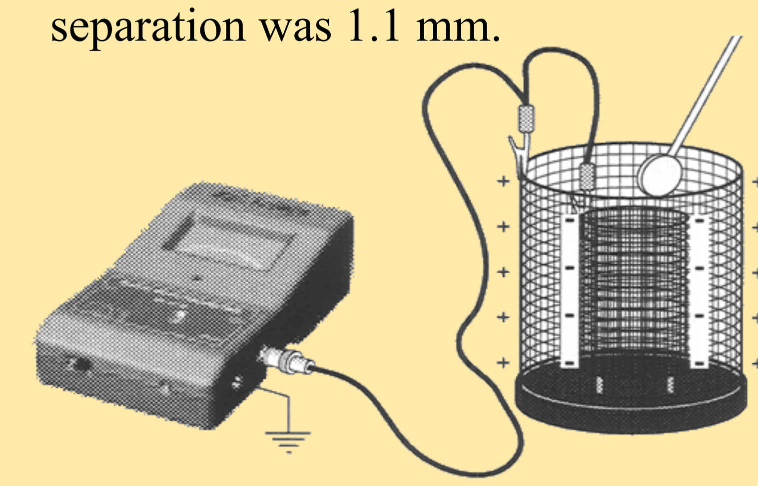

Fig. 5: Faraday ice pick and pail and electrometer.

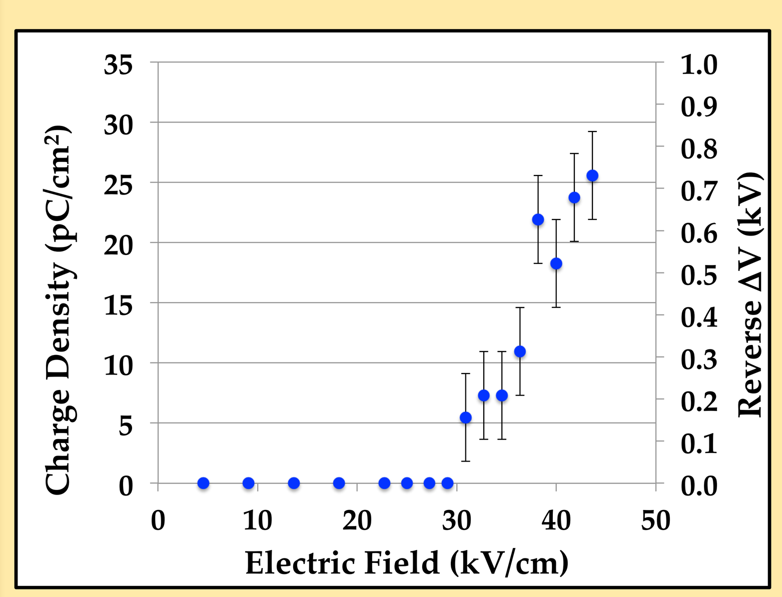

Fig. 6: Charge density on the dielectric foil after 20 s as a function of the electric field.

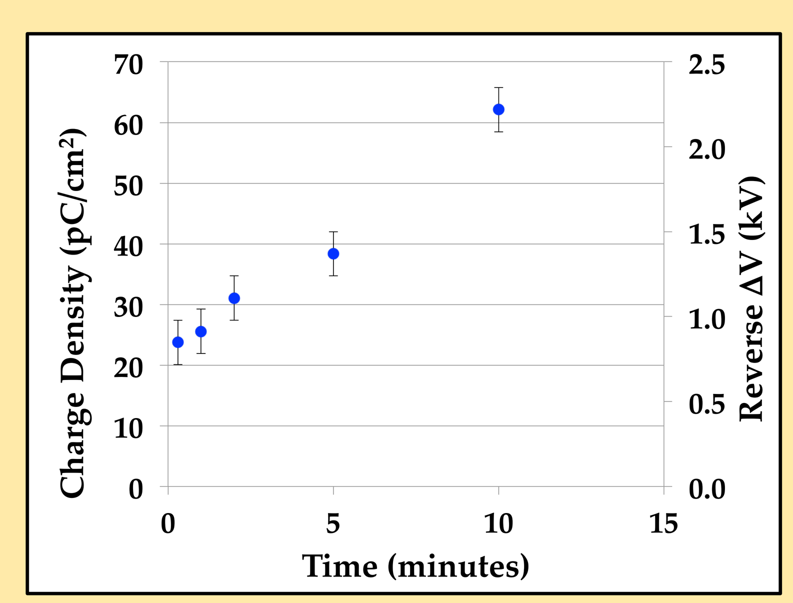

Fig. 7: Charge density on the dielectric foil in 42 kV/cm electric field as a function of time.

Testing the Gain Predictions of the Software

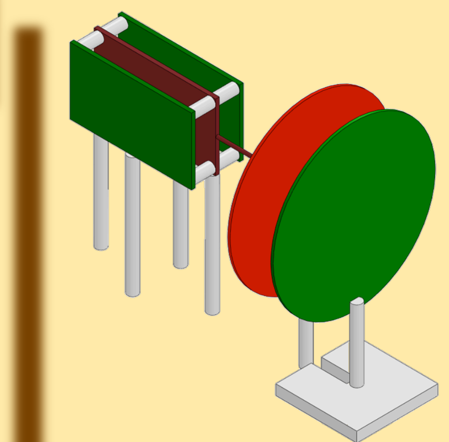

Fig. 8: The simplified scale model.

SolidWorks was used to design a 25% scale model of the full apparatus (Figure 8), and we used it in two software packages (COMSOL and Field Precision) to calculate the capacitances and the voltage gains. The software uses a finite element method to perform calculations.

We built a scale model of the system using stainless steel for the conducting parts and acrylic rods to position and support the components. We electrically isolated the system by mounting it to a box with inner walls covered in grounded aluminum foil. We measured voltages across the plates with a PASCO ES-9078 Electrometer, which had an impedance of approximately 10^{14} Ω.

Agreement Among Gain Predictions and Experimental Data

Figure 9 shows the voltage gain predicted by each software program and the data from the scale model tests. There is good agreement between the two software programs and both agree rather well with the measured data, indicating that the programs can be used to make reliable predictions for the scale model system.

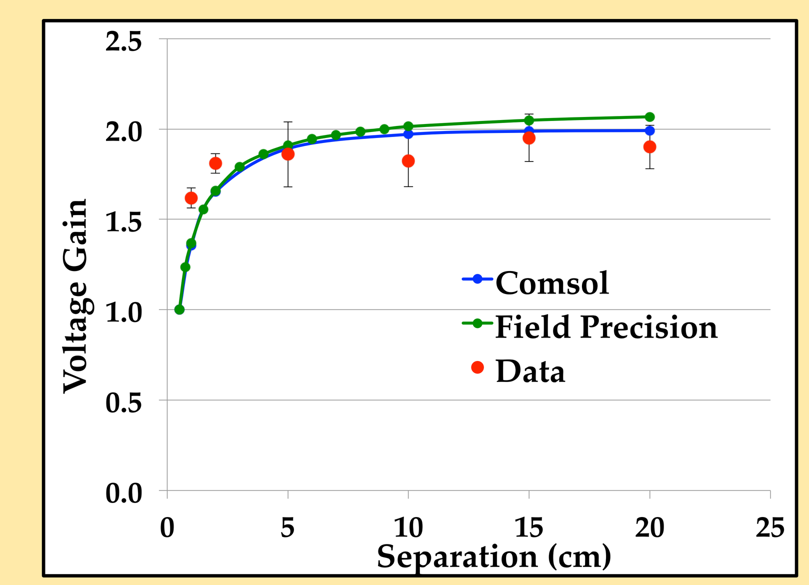

Fig. 9: Voltage gain as a function of the separation between the electrodes. The software predictions and the experimental measurements are shown.

Summary

The charge buildup tests were successful in demonstrating a method for finding breakdown electric fields and measuring the charge buildup on the dielectric. The good agreement among the gains predicted by the software programs and those measured with the scale model demonstrate the viability of and increase confidence in the predictions made by the software for the full scale apparatus.

Future Work

While the current tests were carried out in air, the experiment to measure the nEDM will take place in liquid helium. Future plans for research therefore include repeating the tests in liquid helium to determine the charge buildup and the breakdown voltage. An intermediate step is planned by first carrying out the tests in liquid nitrogen.