Minimizing the Residual Field and Field Gradient in a Magnetically Shielded Room for nEDM at LANL

ABSTRACT
The LANL neutron Electric Dipole Moment (nEDM) experiment is an effort to set a sensitivity limit of $3.2 \times 10^{-27}$ e-cm on the electric dipole moment of the neutron, an order of magnitude smaller than the current upper limit. This measurement uses Ramsey’s method of oscillating magnetic fields. The magnetic field and field gradient have to be low enough to avoid the smearing of the Ramsey fringes and increase the neutron dephasing time respectively. The experiment is enclosed in a two layer Mu-metal magnetically shielded room (MSR) to null any external magnetic fields from the environment. The MSR is degaussed to sufficiently reduce its residual magnetic field and field gradient. The MSR is designed for residual fields as low as 30 nT. The experiment further requires a field gradient of 1 nT/m or smaller. Here we report on the degaussing procedure and the resulting improvement in the shielding prowess of the MSR.

BACKGROUND
Ramsey’s method of separated oscillating magnetic fields is a type of high precision interferometry. The goal is to measure the neutron precession frequency, given by (non-relativistic): $\omega = s^2 (\mu_B, g, \Delta E)$, where the spin $s = \hbar/2$ for a neutron and $\mu$ and $\Delta E$ are the magnetic and electric dipole moments respectively. Thus if the nEDM exists, there will be a change in frequency that may be measured when the polarity of the electric field is reversed.

THe $B_0$ FIELD
The uniform ‘holding’ field $B_0$ must be stable and have stringent gradient limits. The low gradient is to suppress geometric/Berry phase effects, which may give a systematic false nEDM signal.
- transverse spin relaxation effects, so that a sufficient free precession time may be obtained.

MAGNETIC SHIELDING
The current MSR will be used for the demonstration of the Ramsey method; a new MSR may be procured for the final experiment at LANL. The MSR will attempt to null ambient fields and fluctuations. A characteristic of its shielding ability is the dynamic shielding factor:

$$SF = \frac{\max(B_{msr, static} \sin(\omega t))}{\max(B_{msr, static} \sin(\omega t + \phi))}$$

where $B_{msr, static}$ is the field in the absence of the MSR, $B_{msr, static}$ is the field with the MSR in place, $\omega$ is the frequency of the field oscillation, and $\phi$ is the phase angle resolving any latency.
- The dynamic shielding factor has to be sufficiently large over a range of frequencies such that any fields inside are stable.
- The static shielding factor (for static fields) also has to be good enough so as not to affect the holding field inside and subsequently skew the interferometry data. Any such shift, however, can be corrected by magnetometry outside the measurement cell, using a fluxgate for example.

DEGAUSSING PROCESS FOR LANL nEDM
- The LANL nEDM experiment is enclosed in a two layer Mu-metal Magnetically Shielded Room (MSR) to reduce environmental noise.
- The experiment requires low magnetic fields and field gradients (of around 1 nT/m).
- At this scale, the residual field of the MSR dominates environmental effects and thus it must be sufficiently reduced by degaussing.
- Seven turns of degaussing coils were strung up both inside and outside the MSR (Fig. 1) to create fields in the three spatial directions.
- A linearly decreasing sinusoidal current was passed through the coils from a current amp.

MAPPING PROCEDURE
- The magnetic field and field gradients were measured using a triaxial fluxgate magnetometer. Data was recorded through a LabJack DAQ unit.
- The fluxgate was mounted on a rod that could be slid in and out of the MSR through openings on either side (Fig. 2). Therefore we could only obtain 1D maps.
- The field gradient was determined by sliding the rod from one wall of the MSR to the opposite, stopping at positions marked by a meter rule, and recording the readings from the fluxgate at each position.

RESULTS OF THE DEGAUSSING
- We noticed a change in the gradient and absolute field of the MSR after a preliminary degaussing (Fig. 3) using a current of only one ampere, which was not powerful enough to saturate the Mu-metal.
- The only significant change was in the $y$ direction, where the gradient decreased by a factor of 3.
- The degaussing was repeated with enough current to saturate the Mu-metal.
- With the larger current, the field gradient was greatly reduced (Fig 4) to nearing the required value of 1 nT/m, which can be met with subsequent degaussings.
- The absolute field increased after the procedure, but as mentioned before, this can be corrected for by magnetometry near the nEDM cell.

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Fig. 1 The configurations of the coils wound around the MSR to generate the degaussing field. Each of the three sets of coils are shown in a different color. Each set was made of seven turns of 10 gauge wire.

Fig. 2 Picture showing the fluxgate (orange) and the rod it was mounted on inside the MSR.

Fig. 3 Results of the preliminary degaussing. The only noticeable reduction of the gradient in the center of the room was in the $y$ direction, where it decreased by a factor of 3. We expect greater reduction with more current in the coils. Due to the intrinsic offset of the fluxgate (which was not corrected for here), only the field gradient, and not the absolute field, is meaningful here.

Fig. 4 Results of subsequent degaussing with additional current. For all three directions in the center of the room, the gradient is seen to meet the limits. As in Fig. x, the fluxgate offset is not corrected for here. This round of degaussing was done after I stopped working on the experiment.

Fig. 5 Allan deviation of the fluxgate + ADC unit used. Suitable precision may be obtained at a 1 s integration time allowing for ample offset drifts. The inset shows the corresponding absolute field drifts (each direction is offset relative to the other in order to view the drift of all three).